The Urban Landscape Mosaic, Assessing Barriers and their Impact on the Quality of Urban Form:

A Montreal Case Study

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Abstract

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This thesis discusses the adaptation of landscape fragmentation analytical methods to the study of urban form. It posits that together, the natural and human-made barriers create a network that delineates the inhabitable spaces that accommodate residential and other associated urban functions, thus creating an "urban landscape mosaic" composed of threads and meshes. A taxonomy of urban barriers is proposed that distinguishes first order quasi-impermeable barriers (rivers, escarpments, railroads, highways, etc.) and second order boundaries such as thoroughfares and large parks. A case study in Montréal illustrates how first order barriers and second order boundaries together form a morphological matrix that orders the space. It sheds light on how urban landscape fragmentation analyses could reveal the existence of recognizable patterns and dimensional thresholds and allow for the empirical exploration of spatial relationships between the barriers and boundaries matrix and some of the characters of the form at the scales of the urban organism and of the urban tissue.

Key Words: Urban Form, Barriers, Fragmentation, Urban Landscape Mosaic.

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1. Introduction | Chapter One

1.1 Problem Definition

Back in 1958, Lewis Mumford pointed to the end of a way of life with the massive intrusion of highways on existing inner-cities and downtowns. According to Mumford, highway engineers were "repeating, with the audacity of confident ignorance, all the mistakes in urban planning of those who designed our railroads" (Mumford, 1963: 238).

> "The wide swathes of land devoted to cloverleaves, and even more complicated multi-level interchanges, to expressways, parking lots and parking garages, in the very heart of the city, butcher up precious urban space in exactly the same way that freight yards and marshalling yards did when the railroads dumped their passengers and freight inside the city" (1963: 238).

Many others have echoed this sentiment on the impacts of transport infrastructure and it is argued that, while important contributors to economic development at the regional scale for instance, they can constitute barriers at the local scale (Jacobs, 1961), "disrupting the physical and social fabrics of the neighborhoods they traverse" (Tatom, 2006: 181). These barriers create strips of dead space through their impediment of pedestrian traffic flows and, in many cases, greatly impact a neighbourhoods' ability to act as a service provider (Talen, 2003), which is defined on the basis of access to facilities and can be evaluated in terms of spatial proximities between residents and the facilities that are important to their daily life needs. Over the course of the twentieth century, infrastructural systems, such as highways and rail lines, have become increasingly standardized and built towards ever increasing levels of technical efficiency. Unfortunately, these ubiquitous components of our contemporary built landscapes have gradually been considered and evaluated solely on technical criteria and somehow exempted from having to function socially, aesthetically and ecologically (Mossop, 2006: 171).

Looking more specifically at the case of highways, the roads-and-traffic driven approach towards this type of infrastructure has proven ‘disastrous’. This, largely because the impact of highway engineering in urban areas is not limited to the physical intrusion, severance demolition and blight that can collectively be referred to as *urban destruction*. The “record” also includes the negative effects of highway engineering as a formative influence on urban layout (Marshall, 2005: 9). Marshall’s argument on *disurban creation* refers directly to the tendency of highway-led approaches to result in dull or dysfunctional layouts, where new development ends up lacking identity, vitality and/or urbanity. A key difference between urban destruction and disurban creation is that while the cost of urban destruction is tangible, disurban creation is more of an opportunity cost; the opportunity lost for creating good urban places (2005: 9). These concepts of urban destruction and disurban creation are not unique to highway infrastructure and have also resulted from the implementation of various other infrastructures within the urban environment.

In conjunction with pre-existing natural barriers (such as rivers and escarpments), the human-made barriers such as transportation infrastructures and ground-level technical networks constitute a morphological framework (or matrix[i]) which informs the initial urbanization patterns or, in the case of later additions, impact the evolution of built forms

[i] Matrix here refers to a surrounding medium or structure.

of existing neighbourhoods (Larochelle and Gauthier, 2002). In Montreal's Saint-Henri for instance, the urbanization was determined in part by the barriers that the Saint-Jacques natural escarpment and the human-made Lachine Canal constitute, as well as by the presence of railroads intended to serve the nascent industrial activity (Bliek and Gauthier, 2006). More recently, the construction of urban highways in this neighbourhood and the adjacent neighbourhood Notre-Dame-de-Grace, constitute an example of the introduction of a physical barrier in pre-existing urban settlements. The overlapping networks of physical barriers over time leads to the fragmentation of the urban landscape; resulting in the creation of what can be described as a landscape mosaic (a term borrowed from Forman, 1995). This mosaic is composed of a system of 'patches' of varying shapes and sizes delineated by urban barriers. It is the goal of this research to analyze these patches in both qualitative and quantitative terms based on their inherent spatial qualities and as a key element of landscape fragmentation. Leaving aside their contrasted internal morphological characteristics, it is argued for instance that the size, and in some cases the shape, of these patches as well as the nature of their connections with surrounding patches inform their ability to provide hospitable settling environments.

This research posits that the livability, or social and economic viability of neighbourhoods, is to a large extent, a function of *the critical mass* of population required to justify the provision of services. Talen (2003) defines the *provision of services* in terms of "spatial proximities between residents and the facilities that are important to their daily life needs." Acknowledging this, the research argues that the livability of a neighborhood may be determined or compromised, to a significant extent, by the patch size and shape.

1.2 Structure and Organization

This work is organized around a series of chapters; it begins by building a theoretical framework situating this work within the literature pertaining to the idea of urban barriers, transportation, urban morphology and landscape fragmentation both globally and in respect to Montreal. Key concepts into the nature of urban barriers rooted in both their physical characteristics and impacts are presented and discussed in detail.

Chapter three presents a detailed methodology outlining the specific data used as well as the specific methods adopted from urban morphology and landscape fragmentation analysis. These methods include explanations regarding the qualification and quantification of size, shape and fragmentation. In addition, the theoretical applicability of these methods to studying fragmentation in an urban environment are discussed. The methodology section discusses as well, the applicability of a landscape analysis approach in identifying and assessing internal factors which may have impacts on the overall quality of urban form; specifically with regards to street network connectivity. Various means of quantifying street network connectivity will be presented and discussed.

Chapter four aims at establishing and building upon a definition of urban barriers. The result will be a taxonomy of urban barriers, based on morphological criteria, which will be applicable to any urban environment not only the study area of Montreal. This taxonomy includes different types of barriers that combine to create a network which produces an urban landscape “mosaic” i.e. a system of patches of mainly residential space which represent hospitable settling environments. The fifth chapter explores further the idea of urban barriers, by discussing the nature of urban thoroughfares both historically and in a contemporary context as urban boundaries which also serve to physically delineate urban tissues. The resulting boundary network creates a second level mosaic.

Chapter six deals with the exploration urban landscape mosaic in detail by exploring two different geometries assembled from the urban barriers and boundaries. These geometries will demonstrate patterns within the landscape based on size, shape and relative position. The issue of landscape fragmentation comes to the forefront here as more precarious patch configurations will be identified and discussed. As well, the quantification of fragmentation as a means of inquiry within the urban landscape will be presented.

The final chapter of analysis, chapter seven, will deal with the mosaic structure defined by both urban barriers and boundaries in order to measure some of the impacts at the ‘neighbourhood’ level. This mosaic structure allows for instance, for the the selection and classification of patches according to some of their morphological characters (e.g. area, configuration), as well as for comparative analysis aiming at determining the impact of patch morphology on other characters of the form: in an attempt to determine the level at which patch size and shape impact street network connectivity and subsequently the quality of urban form.

2. Theoretical Framework | Chapter Two

2.1 Introduction

This theoretical framework developed to study the impacts of various urban infrastructures that act as urban barriers. This study posits that when combined, urban barriers form a network of 'meshes', that defines inhabitable patches of land. It is argued that the meshing constitutes a morphological framework that informs the formation and later transformations of the urban spatial system. The research is rooted mainly within the discipline of urban morphology; i.e. the study of spatial forms and artifacts but also draws from other disciplines as well, such as transportation studies and landscape ecology, more specifically the sub-discipline of landscape fragmentation. This sub-discipline focuses largely on the impacts of transportation infrastructure on natural landscapes and wildlife habitats, but many principles will be shown to relate and be applicable to the urban built environment. With regards to transportation studies, this research will draw upon work which focuses on street network hierarchies/configurations and theories pertaining to barrier and severance effects. In order to properly frame the analysis and to understand its implications, it is important to highlight the theories which are both influential in directing this research as well as those which are fundamental to urban morphology which are integral to the analysis. We will begin by discussing the existence of urban barriers, followed by a discussion of morphological theory which is fundamental to the definition of the problem at hand.

2.2 Urban Barriers

The idea of an 'urban barrier' is not new. The concept has been put forward in previous prominent works, although often in a superficial or general way or from a fairly abstract theoretical perspective. 'The Image of the City' by Kevin Lynch is one such famous work. Within his study on the legibility of the city, Lynch includes a definition for the concept of *edges* described as:

> "the linear elements not considered as paths: they are usually but not quite always, the boundaries between two kinds of areas. They act as lateral references... Those edges seem strongest which are not only visually prominent, but also continuous in form and impenetrable to cross movement" (Lynch, 1960: 62).

This work also points to the idea that edges can be both fragmentary or unifying, stating that "while continuity and visibility are crucial, strong edges are not necessarily impenetrable. Many edges are uniting seams rather than isolating barriers ..." (Lynch, 1960: 65). The idea that an edge can be a unifying seam is assimilable to the 'anti-nodal dividing axis' that constitute urban thoroughfares that are located at the periphery of "neighbourhood units" while being connected to their respective arterial systems. "Generally speaking, we take the centralizing nodal axis of a portion of the urban organism to be a commercial route, generally equipped with distinct facilities and anti-nodal dividing axis, on the contrary, to be marginal routes mainly intended for traffic [*sic!*]" (Caniggia and Maffei, 2001: 184).

Lynch's notion of 'edges' shares similarities with work from the same era by Jane Jacobs (1960) who recognized a similar phenomenon which she dubbed 'border vacuums'. Some of these borders "halt cross-use from both sides… such is the case with railroad tracks or expressways or water barriers (i.e. canals, rivers, lakes, etc.) are common examples" (1960: 261). Jacobs also points to the fact that not all borders or edges are necessarily linear, as "some barriers have cross-use from both directions, but it is limited, in appreciable amounts, to daylight or it falls off drastically at certain times of year. Large parks are common examples" (1960: 261). This study makes good note off Jacobs' point that non-linear elements can constitute edges as well. This research posits that this idea goes further than just large parks but also includes mono-functional zones within cities, which resulted from modernist principles advocating the separation of land uses. These mono-functional areas (other than residential) share a quality in common with each other and with linear urban barriers in the way in that they form borders; borders which "usually make destructive neighbors" (Jacobs, 1960: 257). "The root trouble with borders, as city neighbours, is that they are apt to form dead ends for most users of city streets. They represent, for most people, most of the time, barriers" (Jacobs, 1960: 259).

Lynch and Jacobs provide different views on the concept of urban barriers. Lynch posits their existence in the mind of the inhabitants of the city and discusses the cognitive effects of barriers on the mental maps that the former build mentally. Jacobs on the other hand deals with border vacuums and their negative effects on the quality of urban form and of urban life. Even the name urban barrier denotes some sort of negative impact but this is not necessarily so. These barriers can also have positive impacts as boundaries that correspond to social geographies. Alexander et al. point to the existence of a 'mosaic of subcultures' (1977: 44) within the city. "In a city made of a large number of subcultures relatively small in size, each occupying an identifiable place and separated from other subcultures by a boundary of non-residential land, new ways of life can develop" (Alexander et al., 1977: 44). Barriers that act as physical separators of subcultures are playing a positive role, on the grounds that "distinct subcultures will only survive, [as such], if they are physically separated in space" (1977: 49).

> "people from different subcultures actually require different things of their environment… people of different ages groups, different interests, different emphasis on family, different national background, need different kinds of houses, they need different outdoor environment round the houses, and above all, they need different kinds of community services" (1977: 49).

This sentiment is echoed by more recent work by Barton et al. (2003), *Shaping Neighbourhoods*, a community planning and urban design manual. The authors state that:

> "different uses will have different catchments of users who are likely to bring their custom, given the use is visible, accessible and conveniently located. Each use requires sufficient density of population within the visibility/location/ convenience criteria. Thus there are critical supporting populations for health centres, libraries, restaurants, florists, takeaways, launderette and primary schools" (2003: 196).

While Barton et al.'s view is complementary to what Alexander et al. are describing, as it stresses that the provision of services and amenities - especially of the specialized kind catering to a particular subculture - is dependent upon a solid customer base. These services and amenities can only subsist "if customers of the same subculture live in strong concentrations" (Alexander et al., 1977: 49). Such a concentration is not only a requirement for the provision of services but is also a requirement "so that one subculture does not dilute the next: indeed, from this point of view they not only need to be internally concentrated – but also physically separated from one another …" (1977: 49).

Alexander et al.'s work goes even further, establishing the existence of another level of boundaries, a neighborhood boundary.

> "The physical boundary needed to protect subcultures from one another, and to allow their ways of life to be unique and idiosyncratic, is guaranteed, for a community of 7000 by the pattern of subculture boundary. But a second, smaller kind of boundary is needed to create the smaller identifiable neighborhood" (1977: 87).

People "want to be able to identify the part of the city where they live as distinct from all others. Available evidence suggests, first, that the neighborhoods which people identify with have extremely small populations; second, that they are small in area; and third, that a major road through a neighborhood destroys it" (Alexander et al., 1977: 81). The neighborhood boundary functions similarly to the subculture boundary but where the subculture boundary "requires wide swaths of land and commercial and industrial activity, the neighborhood boundaries can be much more modest" (1977: 88). From observations of neighborhoods that are well-defined, both physically and in the minds of the townspeople, Alexander et al. point out that the "single most important feature of a neighborhood's boundary is restricted access into the neighborhood: neighborhoods that are successfully defined have definite and relatively few paths and roads leading into them" (1977: 88).

Finishing off the somewhat historical discussion of how urban barriers/ boundaries have been defined by highly regarded authors such as Lynch, Jacobs and Alexander, we must look at the work of Caniggia and Maffei (2001) who put forth the idea of 'relatively impassable barriers'. These barriers, that exist at different levels of spatial resolution, are defined as

> "systems of natural or artificial obstacles, which are accepted or laid in place to assert boundary barriers for any territorial dimension, for example, the natural ditch bounding two sides of a protomony, a ridge separating two nations, field enclosures, or stones marking a farm boundary" (2001: 227).

Here, relatively impassable barriers are not limited to the territorial scale. The concept of the 'urban barrier' was recently discussed in the work of Larochelle and Gauthier (2002), in which a definition of what constitutes an urban barrier was more thoroughly defined as follows:

> "*les zones du territoire urbain affectées par des lignes de discontinuité produites par des éléments naturels – cours d'eau, fortes dénivellations, escarpements, etc. – ou par des œuvres humaines – murs de fortification, et autres travaux de défense, canaux, autoroutes ou voies ferrées – dont la traversée a pied s'avère fatigante, difficile ou impossible, dangereuse ou interdite*" (Larochelle & Gauthier, 2002 : 6).

This definition is quite profound in some respects as it allows for the classification of many elements as an urban barrier through their interaction with the pedestrian, and a pedestrians ability to move through or across these elements. As the definition points out, barriers are either natural features or artifacts although "*dans la ville contemporaine, les barrières urbaines présentent généralement un caractère artificiel. Les barrières naturelles sont normalement franchies par des ouvrages de génie – ponts, tunnels, escaliers, funiculaires, etc. – édifiés au cours des siècles*" (2002). While Larochelle and Gauthier's definition encompasses a significant amount, it still lacks a certain level of specificity, which this thesis will aim to address. One omission from the definition is that it does not necessarily account for the border vacuum or barrier effect associated with large-mono-functional-zones such as parks, or any other large specialized zones, such as industrial parks and/or airports for instance. The impacts of these types of zones are dependent on their size and the scale at which we are exploring. An airport, for example, occupies a tract of land which is larger than multiple neighborhoods, and therefore would easily constitute a barrier to the adjacent neighborhoods which border it. This logic also applies to large regional parks. Smaller mono-functional-zones also exist and may not be evident at a territorial scale (that is the scale of the entire island of Montreal and surroundings) but at a more intermediate scale such as that of a city scale or urban tissue scale (neighborhood) they display similar impacts to that of the airport described above. Also, other linear elements could be added to the list of barriers such as high power lines which while somewhat permeable for pedestrians, do represent lines of discontinuity in the built form of the urban fabric.

> *"Il faut comprendre que chacun des réseaux techniques contemporains crée, à l'égard de la genèse de la forme territoriale, des conditions analogues à celles qui sont engendrées par le réseau hydrographique ou par certaines conditions topographiques : l'implantation d'un réseau technique de surface produit des limites relativement infranchissables qui ont un effet analogue à celui d'une barrière naturelle. À première vue, il n'y a rien de comparable entre une ligne de transport d'électricité à haute tension et une rivière, mais dans les faits, leur impact est le même aux plans morphologiques et, à certains égards, sociaux."* (Larochelle and Gauthier, 2002: 20).

Larochelle and Gauthier's definition of what constitutes an urban barrier is the jumping off point for the development of a typology of barriers. The impacts of urban barriers are acknowledged in contemporary urban design guides, such as the *Urban Design Compendium* (English Partnerships, 2000) . Barriers are not inherently bad per se, but it is the location of these barriers and the spatial relationship with other barriers that is a cause of concern. "Linear elements that define boundaries of a place – the edges – may be used to define the limits of a development site or regeneration area. Rivers, canals, parklands, busy roads or viaducts, may provide the definition that contributes to a sense of place" (English Partnerships, 2000: 36). Many artificial barriers, associated with transportation innovations, today sever communities and subordinate the livability of neighborhoods to such considerations as the speed and efficiency of traffic flows. "But sometimes punching through or spanning these edges will create an enhanced spatial dynamic, by forging links with surrounding areas and reducing severance" (2000: 36). Up to this point, there have been many studies dealing with urban barriers, mainly based on a case study approach, where a smaller area is selected and barriers are pointed to in a specific context. What is generally missing is the recognition that barriers are part of a larger system, which implies that focusing on one level of spatial resolution and on looking at one specific case can leave out a lot of pertinent information that can only stem from an enquiry that embraces the varied nature and the contrasted impacts of barriers deployed at different spatial scales. It is the goal of this research to show the pertinence of considering the entire urban organism[ii] when looking at urban barriers. Moving forward now, I will take a look at the relationship between transportation and urban form as this is central to the impacts of various barrier types.

2.3 Transportation and Urban Form

The evolution of urban form appears to be clearly linked with transportation technology (Giuliano, 2004: 237) and there has been much research into the relationship

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[ii] The urban organism is defined as "a system of residential building and manufactory, craftsman and commercial activity, closely related to a territorial domain wider than that necessary to the built area. This system is internally organized, with its own center, peripheric boundaries, axes etc..[*sic*!]" (Caniggia and Maffei, 2001: 249).

between the two. For instance, there exists a large body of literature which stresses the overall importance of transportation technology and its associated settlement configurations and land-use patterns on the overall environmental footprints of our cities (Newman and Kenworthy, 1999; Muller, 2004). Most often, this literature discusses the problem from a regional scale's perspective, focusing on the problems associated with urban sprawl. This literature stesses that a distinctive spatial structure corresponds to each stage of transportation innovation and development and that a geographical reorganization tends to follow breakthroughs in movement technology. Work done in Montreal by Lewis (2001) and Marsan (1981) for instance has showed that "industrial suburbanization" in the late 19th century was a result of transportation innovation which subsequently shaped the development of adjacent residential neighbourhoods.

While transportation infrastructures have a definite impact on the overall spatial form of the city, they also have more localized impacts. In an article surveying the study of urban form in Canada, Gilliland and Gauthier, (2006) identify numerous articles which look at the dynamic relationship between transportation and urban form at different levels of spatial resolution. Works of particular interest include studies regarding changes to the street network (Gilliland, 2002) and waterfront redevelopment (Gilliland, 2004; Gordon, 2000). Other studies that stress the role of transportation infrastructure in the evolution of urban form in Montreal include Lewis' (2000) work concerning manufacturing districts in Montreal and industrial suburbanization and Bliek and Gauthier's (2006) work which points to the impact of rail infrastructure on the industrialization of the Lachine Canal. The central role of rail infrastructure in Montreal's industrial history is fairly well documented. From the 1850s, manufacturing firms often led the urbanisation, which pushed the urban frontier further out. Accordingly, Greenfield sites in rural areas and existing 'satellite' towns became part of a network of manufacturing districts extending out of the built-up city. In nearly all cases, suburban manufacturing located along transportation corridors that radiated out from or encircled the city centre (Lewis, 2001). Lewis contends that, even in the late 20th century "new railway facilities encourage industrial suburbanization" (2001: 30).

At a higher level of spatial resolution, Canadian studies, echoing similar studies conducted in Australia, the United States and Europe, have been conducted on the emergence of a 'dispersed city form' (Bunting and Filion, 1999) or on the evolution of neighborhood morphology over the 20th century (Filion and Hammond, 2003). Filion and Hammond (2003) situate their work in the broader context, according to which, at the turn of the 21st century, planning models reacted against the nefarious consequences of an automobile dependent society. The planning movements of New Urbanism and Pedestrian Oriented Development illustrate how planners began to rethink the regional and neighborhood spatial development models. Other studies by Senecal et al. (2000) for instance have discussed the impacts of urban highways in Montreal on adjacent land values that are said to have destabilized the associated urban tissues.

So the links between transportation infrastructures and the urbanization and industrialization spatial patterns are discussed quite extensively in the literature, including in the literature on Montreal's historical urban development. But this study wishes to look more specifically at the impact of urban infrastructures, including transportation, on the quality of urban form, in particular with respect to the residential areas that were or still are impacted by their presence. Such an objective calls for a discussion of the theme of 'quality of urban form' in the present context.

2.4 Quality of Urban Form

According to Kevin Lynch, urban form is the "spatial pattern of the large, inert, permanent physical objects in the city" (1981: 47). While the 'quality' of urban form is difficult to define (Jabareen, 2006), and considering that such a definition arguably has changed over time, the definitions of good city form that have emerged over the second half of the 20th century are largely informed by planning models and norms which address the deleterious impact of the automobile based planning paradigm. The relationship between urban form, land-use, and sustainability are central in the discourses of new urban planning and design approaches such as New Urbanism and Pedestrian Oriented Development (P.O.D.) for instance (Calthorpe, 1993; Wheeler, 2003). In reference to the most prevalent themes in the planning literature, Larochelle and Gauthier (2002) distinguish three criteria believed to be critical for the quality of urban form: intelligibility; permeability and the mix of uses.

2.4.1 Intelligibility

Intelligibility refers to the quality of the built environment that allows the users of the collective public space to 'absorb', or internalize, the form and structure of their environment in a manner that allows them to create a cognitive map. Widespread research on the legibility of the city has built upon the work initiated by Kevin Lynch (1960; 1981). Based on extensive empirical work, Lynch identified five criteria of legibility of the urban form that allow for the mental construction of "the image of the city". These criteria are the pathways, edges, nodes, districts and landmarks (often represented by the acronym PENDL). Lynch, his collaborators and his followers have developed fairly complex and resource intensive methods to reconstruct the mental maps of the population inhabiting the urban areas under their scrutiny. Such methods are beyond the scope of this research. Another method, strictly quantitative this time, which allows for the measurement of the legibility (if not the intelligibility) of the city was developed by Bill Hillier and his team (1996). This method is based on the production of 'axial lines and isovists' which allow for the quantification of the spatial enclosure and permeability of space, two central variables of the intelligibility of the urban form.

2.4.2 Accessibility & Permeability

The notion of 'permeability', touched upon briefly in the precedent section, refers to the ability to travel within a street network, notably by foot, and is defined as the "extent to which an environment allows a choice of routes both through and within it" (Carmona et al., 2003: 64). Permeability, also referred to as 'connectivity', essentially constitutes a measure for the opportunity for movement. It is not only a key component of good urban form, but a significant contributor to quality of life (Larochelle & Gauthier, 2002). A critical morphological factor which impacts on the permeability of an area is naturally the presence of (urban) barriers, either natural or artificial. As mentioned earlier urban barriers are defined as continuous lines consisting of natural and human-made elements in the urban landscape, where pedestrian crossing becomes difficult or impossible, even dangerous or forbidden (Larochelle and Gauthier, 2002).

At the neighbourhood scale, permeability can be measured based on the mesh size of the pathway network, or size of blocks. Several small blocks (fine grain) would provide more movement choices and opportunities than large-sized blocks (coarse grain) (Lewis, 2005; Jacobs, 1961). An example of the measurement of neighbourhood connectivity consists in measuring the distance between street intersections.

Talen (2002) discusses methods to assess the quality of the urban environment both qualitatively and quantitatively. She suggests that pedestrian access is an important urban quality indicator, and defines it as "the quality of having interaction with, or passage to, a particular good, service, or facility" (Talen, 2002: 259). Many studies have been conducted concerning neighborhood accessibility and connectivity, hence contributing to the debates on permeability. One influential work which was rooted in morphological analysis was that of Hess (1997), which largely focused on comparing pre-war suburban neighborhoods with their post-war counterparts in terms of walkability. It was found that pre-war suburbs averaged more than three times the number of pedestrians walking to retail districts. Randall and Baetz (2001) subsequently borrowed measures of connectivity from Hess and developed a methodology for retrofitting existing suburban neighborhood designs to increase pedestrian connectivity. Doing so, they argued would increase urban sustainability by providing shorter distances and more direct routes to destinations, hence decreasing automobile dependence. According to

Handy (1996), urban form was also found to play a role in the choice to walk to a destination, with the distance from home to destination being one of the most important factors. Krizek (2003) stated that many land use-transportation planning proposals were aiming to create neighborhoods with higher neighbourhood accessibility and arguably increasing the quality of the pedestrian environment. Other studies have considered neighborhood connectivity and accessibility and its effect on housing price using hedonic price modeling and found that residents were willing to pay a premium for higher connectivity, more streets, smaller blocks, better pedestrian accessibility to commercial land uses, mixed land uses and proximity to transport (Song & Knaap, 2003) all deemed critical features for pedestrian oriented neighborhoods. Zegras and Napolitan (2007: 2) point to the fact that "some cities have made the decision to remove [barriers such as] urban freeways, or at least segments of them, and replace them with at grade boulevards, reclaiming the resulting land for housing, recreational space and commercial development as to re-knit the urban fabric that was destroyed." This removal of barriers is one of the conditions for a good pedestrian environment, according to Leung (2003).

2.4.3 Mixed Use

Mixed land use "indicates the diversity of functional land uses such as residential, commercial, industrial, institutional and those related to transportation" (Jabareen, 2006: 41). Mixed-uses has been referred to as the "thrust of sustainable development" (Leung, 2003: 133) and, in conjunction with pedestrian accessibility, it is a major determining factor of the quality of urban form and is key in creating vibrant and successful neighbourhoods (Jacobs, 1961). Mixing uses thus “forms part of a strategy for sustainable development as a theory of good urban form, with the objectives of economic vitality, social equity, and environmental quality” (Grant, 2002: 73). It is also argued that “mixing land uses can improve the use of infrastructure, exploit economies of scale, and enhance a site’s development potential” (Leung, 2003: 133). For these reasons mixing land uses has been widely adopted in the theory of today’s contemporary urban design and planning movements such as New Urbanism and Smart Growth. Although this may seem relatively straight forward, there are inherent complexities associated with mixed uses, particularly regarding its implementation. One such complexity is pointed out by Leung (2003) who states that the size and shape of the site are key site characteristics of successful mixed use developments. As well, Barton et al. (2003) mention that various commercial and social uses will have different catchments of users, but that they all have in common that “each of these uses requires sufficient density of population within the visibility/location/convenience criteria” (2003: 196). The authors offer as a “very rough guide” the figures of “a population of 8,000 – 10,000 people within 400-500 m of a high street center at an average density of 50 dwellings per hectare” (2003: 196). The latter discussion of a specific set of criteria as with the previous arguments stemming from a variety of contributions ranging from explanatory theories to applied research, are all pointing to the intertwined spatial and morphological realities of building and population densities; settlements configurations and network patterns, and finally; land-use distribution. This research aims precisely at revealing the variety of the spatial articulations between these instances, as these articulations are informed by the overarching morphological framework that constitutes the system of urban barriers (in particular the barriers of the “transportation” variety). The following sections will discuss how the theories and methods of *urban morphology* and *landscape pattern analysis* in particular could serve such a purpose.

2.5 Urban Morphology

The discipline of urban morphology is a systematic approach to the built environment, which studies the process of city building and its products (Moudon, 1995). It focuses “on the tangible results of social and economic forces: [morphologists] study the outcomes of ideas and intentions as they take shape on the ground and mould our cities” (Moudon, 1997: 3). Morphological analysis is based on three analytical instances: form, level of spatial resolution (i.e. scale) and time.

2.5.1 Form

At the city district level for instance, the form is assimilated to the system of the *urban tissue,* “which is the superimposition of several structures acting at different scales, but which appears as a system with linkages in each part of the city” (Panerai et al., 2004: 158), and is comprised of three interrelated sub-systems:

- the street and road network, in their double roles of movement and distribution;
- the land division matrix based on the smallest increment of property, the parcel, forming what can be referred to as the parcel matrix (or the allotment system), and;

- the building fabric, consisting of the buildings that occupy the parcel and their related open spaces. (see Caniggia and Maffei, 2001; Moudon, 1997; Panerai et al., 2004; Tatom, 2006).

These same elements and sub-systems make up what Conzen (1960) termed a 'plan unit', which is the "individualized combinations in different areas of the town of the three element complexes of streets, plots and buildings" (1960: 5). These three sub-systems clearly "persist beyond the life cycle of humans and their concerns" (Tatom, 2004: 79), and are therefore the central object of study for urban morphology (Malfroy, 1995). Of these three sub-systems, "street patterns are probably the most important single element of urban form, since these networks determine so much else about neighborhood design and are difficult to change once they become established" (Wheeler, 2003: 318). Extensive work on street patterns has been conducted for instance by Moudon (1992) in her work on the evolution of 20th century residential forms in Seattle. According to a common procedure in morphological studies, Moudon identified typical categories in order to build a typology. She pointed to the existence of three basic types of street networks (Figure 2.2): 1) the small gridiron which prevailed until the 1930s; 2) a network of continuous curvilinear streets which

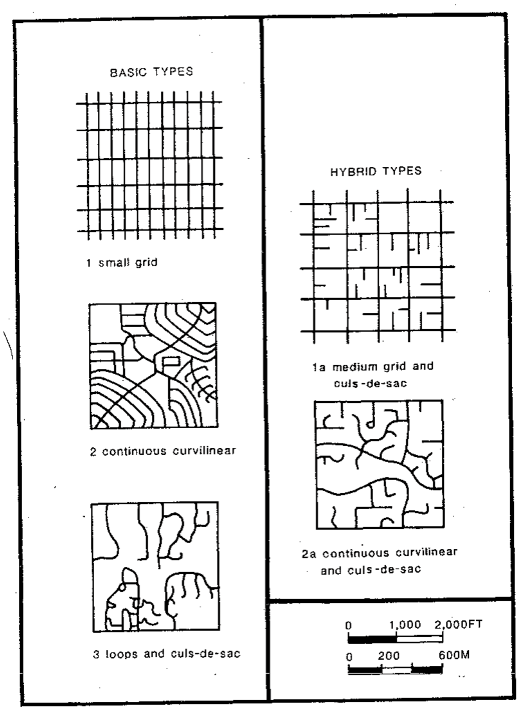

Figure 2.1: Basic street network types (Moudon, 1992).

emerged in the 1930s; and 3) the loop road feeding the subdivision which has prevailed since the 1970s. Moudon noted as well that these basic types could be found in varying combinations forming hybrid street types. In 2005, a more thorough analysis of patterns was undertaken by Stephen Marshall entitled '*Streets and Patterns*'. This book takes a quantitative and qualitative approach to the topic of urban design and transport. Marshall's aim is to address "the street as an urban place as well as a movement channel, and how to make this conception of the street work – not just as an isolated architectural set piece, but as a contribution to wider urban structure" (Marshall, 2005: 15). Marshall's work addresses two main issues. The first issue is grounded within professional debates and pertains to the role of the street and how various street patterns may be designed to create desirable functional urban layouts. The second issue, more theoretical in nature, is related to "how various structures underpin the urban and street patterns built out on the ground. The work looks at types of streets and the basis for their arrangement in 'hierarchies', types of pattern, and how they may be classified, the idea of streets as routes and their inherent structure" (2005: 16).

2.5.2 Levels of Spatial Resolution

Morphological readings of the built environment generally operate at four levels of spatial resolution, or scales[iii]: the buildings; the urban tissue, the settlements (the city as a whole) and the territorial scale, or region (Larochelle and Gauthier, 2002). The elements present at various scales are interlocked, so that a complex system at one level

[iii] The term "scale" assumes different meanings in urban studies literature; the expression "level of spatial resolution," is preferred. If a bit verbose, the latter expression is certainly less loaded and potentially ambiguous than the former.

of spatial resolution becomes a simple component at another level. For example, at the building scale, the architectural objects are seen as complex systems, made of sub-systems pertaining to the spatial distribution of rooms or the construction system, etc. At the scale of the urban tissue, as mentioned earlier, the architectural objects are seen as a basic component of the *building fabric* system, and are spatially articulated to the other spatial components that are the *parcel* (part of the allotment system) and the *street segment* (part of the street network). The spatial articulations between the elements are described in syntactic terms (i.e. as sets of spatial relations). This study focuses on an intermediary scale between the urban tissues and the scale of the city as a whole. Accordingly, it will look at objects and sub-systems that play a role at such levels of spatial resolution. Such objects of enquiry include: 1) geomorphological elements (i.e. escarpments, hydrological features, etc.), the ground-level technical networks as well as large scale transportation networks (all components belonging to the territorial scale); 2) the plan-units (or urban tissues displaying a particular spatial syntax and confined within the meshing system of the city) and specialized streets such as the local high-streets and thoroughfares (all components belonging to the settlement scale); 3) the street network (cf. Moudon study), the distinction between residential and specialized tissues (components belonging to the urban tissue scale).

2.5.3 Time

Urban space can only be understood as a temporal phenomenon (Caniggia and Maffei, 2001; Moudon, 1995), since the elements of which it is comprised undergo continuous transformation and replacement (Moudon, 1997). This is fundamental to the thinking of Caniggia, as to that of Conzen, as the intelligibility of the city depends on its history (Whitehand, 1992). This process of morphological change, i.e. morphogenesis (Vance, 1990), has been extensively studied. Acknowledging that time is an important component to morphological analysis as all morphological elements change over time, it must also be pointed out that "the different elements that make up the urban landscape change at different speeds" (Whitehand, 1992: 625). Malfroy (1998) posits that elements also coincide to different levels of historical category, which help to distinguish that which "evolves according to a continuous process, that which emerges as a result of a partial break and that which remains essentially 'out of time'" (Malfroy, 1998: 27). He offers as an example, the landscape as a whole "with its built armature and networks of infrastructure that remain relatively inert, individual buildings show great adaptability, monuments remain as permanent features, while urban tissue in peripheral locations show an intermediate degree of changeability" (1998: 27). An example of theorization of the nature of the change with regards to the parcel matrix, is offered by the work of Tatom (2006), who proposed a categorization in terms of persistence, subdivision or assembly. Tatom also suggests characterizing change pertaining to roadways and buildings in manners of, creation, persistence or replacement (Tatom, 2006). The fundamental idea behind the efforts to analyze the landscape in spatio-temporal terms is that the dynamic system of the built environment displays a structural character, as 'forms' are generated in accordance to constraints and a potential for change imbedded in the system itself, as the resilience of sometimes very old inherited settlement configurations for instance will inform the morphological changes made today to respond to current social necessities. It is the collective character of the enterprise on the one hand, as well as its temporal and incremental nature on the other, which confers structural qualities to the built landscape (Gauthier, 2005).

2.6 Landscape Pattern Analysis

According to McGarigal et al. (2002) landscapes, both natural and built, contain complex spatial patterns that vary over time and the quantification of these patterns and their dynamics is the purview of landscape pattern analysis. These patterns can be quantified in a variety of ways depending on the objectives of the investigation and the data available. Considering the objectives of this research, the most suitable pattern analysis method are thematic-categorical map patterns, which represent data in a way in which the system of interest is represented as a 'mosaic of discrete patches' (2002). Within this category the patch boundaries are distinguished by 'abrupt discontinuities' (boundaries) in environmental character from their surroundings. Using categorical pattern analysis, patches maybe classified and delineated qualitatively through visual interpretation of the data (2002) which lends itself nicely to morphological analysis involving the qualification of the built environment via visual interpretation of historic and/or contemporary maps. There are various approaches towards identifying patches in the landscape, including the most common method of aggregating all adjacent (touching) areas that have the same (or similar) value on the variable of interest. Alternatively, one can define the patches by outlining them; that is by finding the edges around the patch.

These edges constitute areas where a measured value changes abruptly. An edge in our case would be either a static barrier such as a highway or rail line, or a major thoroughfare falling under the barrier classification via the barrier effect which will be discussed hereafter. A divisive approach may be used as well, commencing with a single patch (the landscape) and then successively breaking it up into regions that would be statistically homogeneous patches. The overall goal of the categorical map pattern analysis is to characterize the composition and spatial configuration of the patch mosaic, and a plethora of metrics has been developed for this purpose (see McGarigal et al., 2002).

2.6.1 Categorical Map Patterns

There are two different perspectives on categorical map patterns which have greatly influenced the development of various metrics with which one can analyze various landscapes. These are the Island Biogeographic Model and the Landscape Mosaic Model.

Island Biogeographic Model

Under this perspective, patch fragments, constituting the landscape mosaic, are viewed as islands in a neutral, or hostile, background (matrix). Here the emphasis is on the extent, spatial character, and distribution of the focal patch type without explicitly considering the role of the matrix. The major advantage and disadvantage of this model is its simplicity as it becomes easier to comprehend, though it arguably does not constitute a 'real' representation of the interaction between patches (McGarigal et al., 2002).

Landscape Mosaic Model

In this model landscapes are viewed as spatially complex, heterogeneous assemblages of patch types, which cannot be simply categorized into discrete elements such as patches, matrix and corridors. A major advantage of this model is that it provides a more realistic representation of how organisms perceive and interact with landscape patterns. However, the disadvantage of the model is that it requires a detailed understanding of how organisms interact with landscape pattern, and therefore is quite difficult to implement (McGarigal et al. 2002).

Due to the requirements of the landscape mosaic model described above, this study will be employing metrics developed based on the Island Biogeographic model which allow for 'islands' of distinct areas, or 'patches' to be isolated within the built landscape.

2.6.2 Landscape Fragmentation

The notion of the urban or built landscape, also referred to as a 'townscape' (Conzen, 1960: 3), has clear roots within the notion of a landscape in the study of the natural environment. According to Forman (1995), a landscape is formed by "a mix of local ecosystems or land use types that is repeated over the land" (1995: 134). A landscape is "not necessarily defined by size; rather it is defined by an interacting mosaic of patches relevant to the phenomenon under consideration" (McGarigal et al., 2002). The phenomenon under consideration can range from elements in the natural or built environment and can also vary based on the scale of resolution considered. Mosaics are evident at all scales, from the submicroscopic to the planet and universe, and are all "composed of spatial elements" (Forman, 1995: 134). Landscapes are subject to change and are therefore transformed by several spatial processes including fragmentation. Fragmentation refers to "the destruction of established ecological connections between adjoining areas of the landscape" (Jaeger et al., 2007: 10), breaking the landscape into pieces that are often "widely and unevenly separated" (Forman, 1995: 138). This breaking up of the landscape into smaller pieces or 'patches' of habitat contributes to the further complexity of the 'mosaic' and results in a decrease in habitat connectivity (Forman, 1995). The causes of fragmentation in the natural environment include human-made transportation infrastructure, urban development as well as natural elements such as rivers and escarpments. Such natural breaks are defined as geogenic fragmentation (Jaeger, 2000). The resulting impact of the fragmentation is both short-term and long-term as discussed notably by De Santo (1993) in his work pertaining to the impact of the construction of a high-speed rail line. Over the short-term, the impacts relate directly to construction activities and the presence of workers and large machinery etc., which disrupt animal habitats. In the long-term though, the impacts in the natural environment can be directly translated to those that may be seen in urban context. These impacts pertain directly to "habitat loss as a function of the width and length of the corridor" (1993: 112).

Work has been conducted on the application of ecological principles to the urban landscape (Zipperer et al., 2000). They put forth that one approach to studying urban landscapes is the spatially focused approach of patch dynamics. As such, they acknowledge that the urban landscape "can be divided into different urban contexts: city, inner suburbs, suburbs, exurban. Each of these contexts can be divided further into land-use types, neighbourhoods, blocks and so on" (2000: 686). It is possible to consider that the urban landscape changes in a similar fashion, as a result of spatial processes, some of which are quite similar to those experienced in the natural environment. In this research, the phenomenon or organism under consideration is urban, which consists of an interacting mosaic of 'patches' of urban tissues or plan-units (Conzen, 1960). Larochelle and Gauthier (2002) bring our attention to the problem of urban tissue 'meshing' ("maillage tissulaire") and stress in particular how assessing the impacts of the systems of human-made and natural barriers is critical to better understand the reasons behind the poor quality of the regional and urban form in post second-world-war suburbs of Quebec City. It is my contention here that studying such mosaics which, in the urban context, could also be referred to as a 'townscape mosaic', is of equal importance for both Montreal's inner-city and more recently built neighbourhoods. An effort is required though, to assess how concepts of landscape fragmentation, combined with the methods of urban morphology, can be applied to the urban landscape. This research aims at taking up such a challenge. The theoretical and methodological apparatus hence developed and tested in Montreal should then shed light on an urban landscape that is fragmented by both natural and human-made physical elements, which in some cases disrupt urban tissues leading to 'malformations' and a degradation of the overall quality of urban form.

2.7 Barrier Effect and Severance

Before concluding the theoretical discussion, it is useful to provide an introduction to the pertinent transportation literature on social severance, defined as the "cost of dividing communities with infrastructure" (Levinson, 2002: 180). Such a cost, or externality related to transportation is first and foremost a result of the presence of a physical barrier (e.g. highway, rail line, canal) which impedes pedestrian movement and social interactions in a way that is somewhat similar to impacts on fauna in natural landscapes. That particular condition is referred to as static severance (Guo et al. 2001). Social severance can also result from a difficulty in crossing certain streets, a difficulty associated and influenced by such factors as the width of the roadway, the volume, speed and composition of the traffic, and street environment adjustments (e.g. traffic lights, pedestrian crossings, pedestrian traffic islands). Increased traffic causes the roadway to appear more and more like a barrier, restricting pedestrian flows (Soguel, 1995) and is referred to as the "barrier effect" (Victoria Transport Policy Institute, 2006) or "dynamic severance" (Guo et al., 2001). This barrier effect is associated with road construction and automobile dependency, resulting in reduced access to local amenities and disruption of social networks, is similar in its impacts to static barriers (highway infrastructure) running through the community (Egan et al., 2003). Heavy traffic roads undermine both the movement function and the social (playing and strolling) function of the pedestrian network, provoking psychological effects (stress, insecurity, discomfort), which can result in behavioral adaptations such as changes in route. Overall, these adaptations imply an additional loss of social welfare (Soguel, 1995). This phenomenon is widely acknowledged but could be quite difficult to quantify, although in qualitative terms it shows clear links to the notion of 'barrier or edge' described by Lynch (1961) where the limits of a district could be clearly delineated by residents regardless of an actual static structural element. The notion of severance allows for the integration of environmental factors associated with highways and railroads into the equation. This research aims at measuring the spatial and material impacts of highways and railroads in different sets of morphological conditions. Some such impacts will inevitably be related to the environmental conditions created by the infrastructures rather than by their mere physical presence. A comparative analysis would allow to distinguish between morphological and severance factors.

3. Methodology | Chapter Three

3.1 Introduction

Some of the aims of this study include developing tools to both qualify and quantify the impacts of natural and human-made barriers on urban form. This study proposes to do so by relying largely upon morphological analysis combined with the methods borrowed from natural landscape fragmentation analysis and transportation severance studies. More specifically, this study will focus first on the entire island of Montreal, a distinct morphological area bounded by the St.Lawrence River. Urban barriers and boundaries will be defined based on their inherent morphological qualities and will subsequently be mapped and the resulting spaces will be analyzed. We will begin by outlining the databases and data sets used.

3.2 GIS database

The database of GIS layers that was used to create/outline the fragmenting elements and planning units included the DMTI Spatial Inc. (2008) data which consists of GIS layers for highways, railways, and local street network information as well as high-tension power lines for both the Island of Montreal and the surrounding areas. This database also includes hydrological features, the land mass as well as other topographical and administrative features. Land use information (2007, McGill TRAM) was acquired through the Community University Research Alliance (CURA) research database at McGill University also, a partial data set for the buildings of the Montreal CMA was procured from the Transportation Research at McGill (TRAM) group as well via the CURA research database. Modifications were made to certain GIS files within the data sets available to account for recent changes in infrastructure networks, as well as to increase the accuracy of any layers which were deemed to require more accuracy than provided; such was the case with the information provided for the Lachine Canal for instance which was manually digitized from land mass data available from the CANMAP (2008) data set. Elevation data was attained from the same set of data and subsequently transformed into a Digital Elevation Model (DEM) for the area. This DEM was used to isolate areas of extreme slope based on the parameters which will be outlined in the next chapter. Once all modifications were made to the required fragmenting elements, they were combined together using GIS overlay techniques to create a suite of two fragmentation geometries. These fragmentation geometries provide information related to patch size and shape.

3.3 Fragmentation Geometries

The mapping of various elements followed similar methodology as that presented in the work of Girvetz et al. (2008: 207-208). Using the GIS data sets mentioned above, various infrastructures require a buffer to best represent footprints within the system. Therefore, highways were buffered at a distance of 10m on either side, railways were buffered at 3m, and major roads were buffered to 5m (see Girvetz et al., 2008). From this the buffering of other barriers was inferred and high tension power-lines were buffered to the same extent as a major road at 5m. In the case of the Canal and aqueduct, these elements were not buffered but were digitally traced in as two-dimensional objects and added to the map, therefore their footprint is precisely represented. The reason for buffering of various road types and the power-lines is one of necessity as this infrastructure is depicted in the GIS data as centre lines depicting rights of way and their specific path. They do not possess volumetric data which would convey their specific size. The logic is that when these elements are buffered, some elements are larger or smaller than the given buffer size and on average this cancels any discrepancy out. This is possible only at a very low scale of resolution as the difference of a meter at this scale is negligible for this analysis. When looking more closely at specific conditions these same assumptions could not be made and the actual width would be used. Once all the elements were buffered they were added to each other systematically in order to create a final geometry. The two fragmentation geometries used in this analysis pertain to the elements which will be established as first order (Chapter 4) and second order barriers (Chapter 5). A fragmentation geometry was produced for each scenario and a comparative analysis was conducted based on each.

Elimination of Noise

The fragmentation geometries created contain an abundance of small patches, where a clover-leaf interchange found in highway networks or small gaps between railways running in parallel for instance would record as patches. This is compounded by the GIS requirement to buffer infrastructure data, which are centre lines, to approximate road widths. While these buffers have been established in previous research (Girvetz et al., 2008), in many cases there remain gaps in between the buffered roads which by definition become patches as well. We can justifiably classify these patches as ‘noise’ within the model and can neglect them from the analysis. The criteria used here to establish the limit for what constitutes ‘noise’ is based on anything smaller than a typical Montreal block (2.5 ha or 0.025km^2). Any area smaller than this figure would not constitute as a “hospitable” settling environment that could accommodate housing and complimentary functions (at least not in the Montreal context). For comparisons sake, what exactly does 0.025km^2 translate to in terms of building densities? Considering a patch of this area if it were to be used for single-detached homes it would translate to approximately 30 units (Leung, 2003: 113). On the opposite end, if we were looking at high-density development, a 13-storey apartment building for instance, this would translate to some 250 units. While this is significant development, 250 units would be located on a physically isolated area of land where its connections to outside amenities would be hindered and this unit density does not necessarily translate into a significant population which could support essential services of proximity leading to the creation of a sustainable functional neighborhood.

3.4 Comparative Analysis

The fragmentation geometries resulted in two different scenarios of a landscape mosaic model. Each model was analyzed based on a qualitative assessment of patch size and shape based on categories and patterns determined from a visual assessment. Some examples were discussed in more detail. This analysis cannot possibly discuss everything that may be pertinent but will attempt to cover intriguing patch patterns and identify patches which may be at risk due to prevailing physical conditions. This assessment also included the quantification and comparison of fragmentation. This was done for the island of Montreal as a whole and also using a reporting area based on the administrative boundaries of the Montreal boroughs.

3.5 Quantifying Fragmentation: Effective Mesh Size and Density

Effective mesh size is a landscape metric developed by Jaeger (2000) which "expresses the likelihood that any two randomly chosen points in the region under observation may or may not be connected" (Girvetz et al., 2008: 207), that is, "not separated by barriers such as transport routes or developed land" (Jaeger et al., 2007). The more barriers present within a given landscape the less chance that two given points will be connected and the lower the effective mesh size (Jaeger, 2000; Jaeger et al., 2007; Girvetz et al. 2008). "Accordingly, the likelihood also decreases that animals or people will be able to move freely in a landscape without encountering such barriers" (Jaeger et al. 2007: 13). The effective mesh size is calculated for a given planning unit *j* using the following formula developed by Jaeger (2000):

Figure 3.1: Barriers in the landscape (left) and the corresponding effective mesh size represented in the form of a regular grid (right) (Source: Jaeger et al. 2007: 13).

$$\mathrm{m_{eff}}(j) = \frac{1}{A_{tj}} \sum_{i=1}^{n} A_{ij}^2$$

where n is the number of unfragmented patches in planning unit j, A_{ij} is the size of patch i within planning unit j, and A_{tj} is the total area of planning unit j.

An additional measure used is the effective mesh density (S_{eff}), which is essentially a measure of the effective number of meshes in a given area. This is therefore expressed as:

$$S_{eff} = \frac{1000\ km^2}{m_{eff}} * \frac{1}{1000 km^2} = \frac{1}{m_{eff}}$$

It is worth noting, that the mesh density increases if fragmentation increases, and by that logic both measures contain similar information about the landscape, but the mesh density is more suitable for spotting trends (Jaeger et al. 2007). An important strength to both these measures "lies in the fact that the spatial structure of complex networks, comprising transport infrastructure and urban zones, can be meaningfully described using one simple, understandable value. Unlike the traffic line density and average patch area, effective mesh size and density express changes in the spatial arrangement of transport routes" (Jaeger et al., 2007).

Recently, an ArcGIS tool was developed by Girvetz (2009) which calculates the effective mesh size landscape fragmentation metric. The tool uses two different procedures: the originally proposed cutting-out procedure (CUT) (Jaeger, 2000), and the more recent cross-boundary connection (CBC) procedure (Moser et al., 2007). One problem with the original effective mesh size definition, as pointed out by Moser et al. (2007), is that it assumes the patches of land stop at the boundary of the planning unit (i.e., a county, a borough, or watershed),when in fact, a patch may extend far beyond the boundary of the planning unit. Accordingly, the cutting-out (CUT) procedure cuts patches at the edge of a given planning unit (like a cookie cutter), and ignores contiguous parts of patches located outside the unit boundary. If these patch parts are large, this approach can generate considerable negative bias in the results, constituting the so-called boundary problem (Moser et al., 2007). An alternative implementation of the effective mesh size calculation is the cross-boundary connection (CBC) procedure, which accounts for connected unfragmented areas that extend beyond the boundaries of a given planning unit that the effective mesh size is being calculated for. Therefore, this tool calculates effective mesh size using both the CUT and CBC procedures, with the CBC method being the recommended for use in virtually all instances, and therefore the method that is used in the calculation of effective mesh size in this research.

3.6 Measuring Shape

The first and one of the most important characters of the form is its dimensions or more specifically the area.

> "Area metrics quantify landscape composition, not landscape configuration. The *area* of each patch is perhaps the single most important and useful piece of information contained in the landscape. Not only is this information the basis for many of the patch, class and landscape indices, but patch area has a great deal of ecological utility in its own right" (McGarigal and Marks, 1995: 25).

As one of the goals of morphological analysis is finding patterns in urban development, we must look to pattern analysis when dealing with the aspect of shape. "Pattern analysis in a broader sense involves calculating indices to describe the spatial distribution, arrangement, and structure of geographic objects (typically points, lines, areas, or grids and/or their attributes)" (Williams & Wentz, 2008: 100). As such we can say that, shape is a key component to understanding the urban landscape;

> "Shape matters. The shape of urban footprints matters. The shape of forest patches matters. The shape of election districts matters. The shape of spreading epidemics matters. Some shapes may be more or less efficient, more or less equitable and more or less sustainable than other shapes with the same area. And to understand why that may be so, we need to measure their spatial properties" (Angel et al. 2010: 2).

Just why size and configuration are so important in our context is in direct relationship to the idea of the 'neighbourhood' unit. Where the idea of an area of a certain size, population and arguably compactness (density) is optimal to promote certain living conditions, such as promoting the live-work lifestyle, and non-motorized transport through the promotion of mixed-use development, as a patch displaying a capricious shape inevitably reduces the possibility to circulate within, without encountering an outer limit (i.e. a barrier). The usual method for assessing shape is via a perimeter-area ratio, which works fine for regular geometric shapes but in landscape analysis, one will likely encounter the boundary problem. This issue pertains to cerated edges and other type shapes which may appear and their perimeter-area ratio being misleading. Figure 3.2 demonstrates two different shapes, where most would agree that the one the left is more

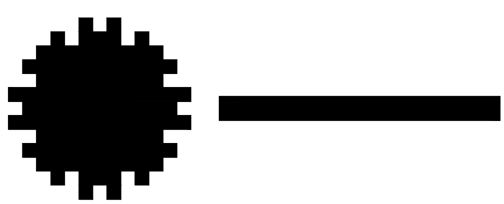

Figure 3.2: Two figures with the same perimter-area relationship (Angel & Parent. 2010: 46)

compact, which have the same perimeter-area relationship. Acknowledging that shape, more specifically the “measurement of compactness, [is] arguably the most important spatial property of geographic shapes” (Angel et al., 2010: 2), Angel et al. (2010) propose ten compactness properties of the circle which are in fact, unique and independent geometrical properties. The authors have identified that some of these properties are highly correlated. In this research we will focus on the *Area Exchange* property as an indicator of shape.

3.6.1 Area Exchange

The Area Exchange property of any given shape is the share of the area of the shape in an Equal-Area Circle about the center of the shape. The efficiency of this measure is demonstrated in Figure 3.3 showing the Equal-Area Circle about the center of a U.S. Congressional district in this case. The larger the area of the district inside the circle, the more compact the district.

Figure 3.3: Area Exchange Compactness in U.S. Congressional Districts in 2004; Left-Texas Dist. 25 (0.34, low); Middle-Ohio Dist. 13 (0.49); and Right-Arizona Dist. 4 (0.91, High). (Source: Angel & Parent, 2010: 54).

Area Exchange is calculated using a computer script for ArcGIS 9.3 for calculating shape by Jason Parent (2009) which was updated and obtained using the ArcScript website in direct collaboration with the author. The script calculates the values for each aspect of shape for the individual shapes as well as a normalized value (from 0 to 1) which aids comparison between elements in the landscape mosaic.

3.7 *Measuring Street Networks*

One possible outcome of this analysis is showing that the patch size and configuration have a relationship with the performance of the internal street network of a given area. In other words, if we take a look at a theoretical model (Figure 3.4) which employs a theoretical street grid similar for both, the more compact the shape, as compared to a more capricious shape, the better performance one could find in the more compact shape.

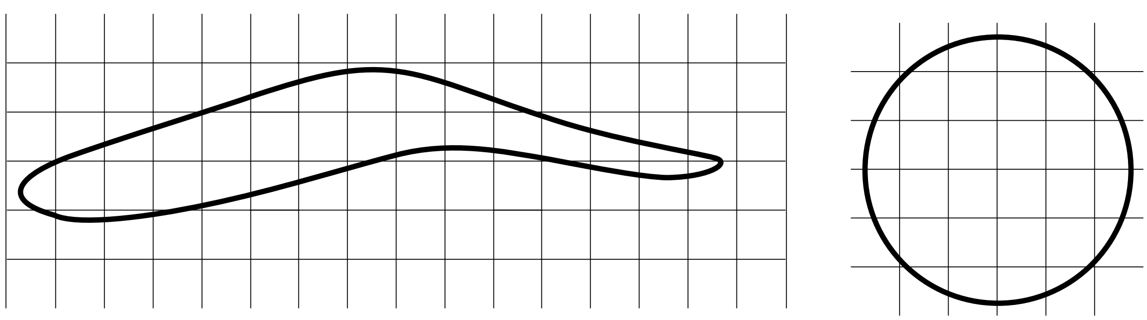

Figure 3.4: Theoretical Patches displaying same area but varying shape. Patches may display varying internal conditions based on their shape and proximity to an edge.

That said, in order to measure and compare such a relationship, appropriate measures need to be chosen which are not directly linked to the area of the 'patch'. This implies that measures which simply count elements such as total street length for a given area are not appropriate as the varying size of the patches would imply a varying amount of street length in a given area. Therefore measures associated with densities or overall network connectivity are more appropriate. Measures chosen for this analysis include Street density, the link-node ratio, the density and percentage of 4-way intersections, and the Gamma and alpha network connectivity indexes.

3.7.1 Street Density

Street density (see Handy, 1996; Mately et al., 2001) is measured as the number of linear kilometers of street present per square kilometer. A higher number would indicate more streets and, presumably, higher connectivity. Street density, intersection density, as well as block density are likely highly and positively correlated with each other (Dil, 2004).

3.7.2 Percentage and Density of Four-way Intersections

Assessing intersection density, without distinguishing intersection type, can be misleading as areas which are characterized by the presence of three-way and two-way intersections may return calculated results as areas with four-way intersections, masking effective differences in network permeability. That said, identifying and measuring the presence of four-way intersections in terms of their percentage within the network or density is a good indication of areas which are more permeable than others as there would be more route choices present.

3.7.3 *Link-Node Ratio*

The Link-Node Ratio (LNR) (see Ewing, 1996) is an index of connectivity equal to the number of links divided by the number of nodes within in an indicated area. Links are defined as roadway or pathway segments between two nodes. Nodes on the other hand, are intersections or the end of a cul-de-sac. A perfect grid has a ratio of 2.5. Ewing (1996) suggests that a link-node ratio of 1.4 is a good target for network planning purposes. It is the contention of this research that this is possibly too low and that through the use of a theoretical model maximums and minimums may be established for individual cities, in this case: Montreal. Figure 3.5 demonstrates how increasing the link-node ratio increases connectivity. Intuitively, this represents increased connectivity. The link-node ratio does not reflect the length of the links in any way. Therefore, a perfect grid of 1,000-foot blocks will have the same link-node ratio as a grid with 200-foot blocks. The latter would result in shorter network trip distances. For this reason, at least one city has combined link-node ratio with an intersection spacing standard (Handy et al., 2003).

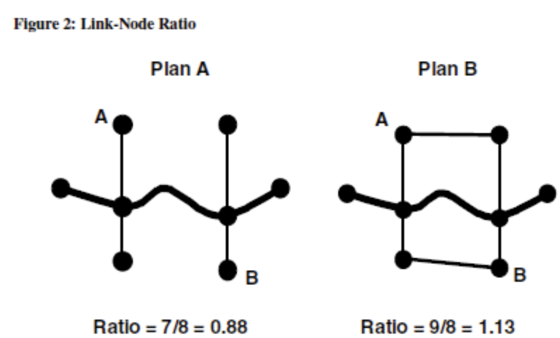

Figure 3.5: Example of the Link-Node Ratio (Dill, 2004).

3.7.4 Alpha Index

Planning is not the only profession concerned with connectivity. Searching for work regarding connectivity reveals papers from numerous fields, including medicine, geology, geography, ecology, computer science, and urban studies. More specifically, geographers have developed the gamma index and alpha index as measures of connectivity. The alpha index uses the concept of a circuit – a finite, closed path starting and ending at a single node. The alpha index is the ratio of the number of actual circuits to the maximum number of circuits (Xie and Levinson, 2007: 340) and is equal to:

$$\text{Alpha index} = \frac{\#\text{ links} - \#\text{ nodes} + 1}{2(\#\text{ nodes}) - 5}$$

The values for the alpha index range from 0 to 1, with higher values representing a more connected network. This index has been described as an applicable measure of connectivity for urban environments, can estimate the multiplicity of links in a road network and can also form some useful common yardsticks for comparison between networks (Xie and Levinson, 2007: 341). It should be noted that while these descriptive measures are useful, they are incomplete as they disregard the distance and orientation of links. But for the purpose of this research where we will be comparing patches of varying size and shape the orientation and distance of the networks are not of concern to us as they would be impacted by varying size. It could become a point of concern when one ‘zooms’ in and focuses on particular cases where the distance and orientation would matter. This would be a by-product of the scale of resolution and the specific query at hand. It has been pointed out that “although, streets and patterns have been an intriguing research topic (see Marshall, 2005), little quantitative evidence is provided as to how urban streets are hierarchically organized” (Jiang, 2009: 1033).

3.8 Patterns

Finally, the data resulting from measuring both the patch size and shape in the second fragmentation geometry, which is delineated by urban barriers and boundaries, was compared with the resulting data pertaining to the individually defined street networks. The comparison explored whether there is a visible relationship between shape and/or size with internal street network connectivity (an indicator of quality of urban form). These results were discussed in detail.

4. Urban Barriers | Chapter Four

4.1 Introduction

Within the built landscape, a variety of elements can be classified by type: buildings, open spaces, parcels, routes and infrastructure. This chapter is aimed at distinguishing the different elements which would constitute types of urban barriers within the urban landscape. This includes certain types of urban infrastructure, as well as other urban and/or natural elements, which impede pedestrian movement and disrupt urban tissue patterns within the built landscape. This exploration led to the building of a taxonomy, which is essentially a classification of types of elements "that cannot be further reduced, [such as] elements of a city as well as of an architecture" (Rossi, 1982: 41). For clarification, according to Marshall, a typology is "a practically useful sub-set of all possible types (that may be regarded as a 'slice' extracted from a fuller taxonomy), organized in pragmatic structure, e.g. a simple listing" (Marshall 2005: 294). A taxonomy, on the other hand, constitutes a "system of classification in which sets of possible and actual types are organized in a systematic structure of classes and sub-classes" (2005: 294). Considering this, I will begin by introducing the morphological criteria that will be used to categorize various elements within the taxonomy. This taxonomy is essentially based on elements found within the case study of the Island of Montreal, but also includes occasional elements which either once existed or exist within other urban environments thereby placing the case study within a larger taxonomy of urban barriers [iv], applicable to any urban environment. This exercise is relevant for a

[iv] A concise table of the taxonomy of urban barriers can be found in Appendix A

variety of reasons. First, it allows to establish categories of barriers - often alluded to, and loosely defined sometimes, in the planning literature - based on consistent morphological criteria. Secondly, a thorough survey of barriers of different categories allows for their mapping in order to establish the network of barriers that criss-cross in the urban landscape. When combined, these urban barriers create a mesh which defines the tracts or 'patches' of land that can accommodate urban development. To use an analogy borrowed from photography, the network of urban barriers represents the 'negative' image of the urban built environment: akin to a morphological matrix within which, the inhabited spaces of the city are spatially deployed. This network hence defines the livable or developable spaces of the city. This study posits that the size and shape of the meshes is a determining factor in the success or quality of the urban environments which are found within, as the "inhabitability" will be largely conditioned by the dimensions, configuration and interconnectivity of the patches that house them.

4.2 Morphological Criteria

Before identifying the specific types which will make up the taxonomy, the criteria by which urban barriers are evaluated and categorized must be established. These are based largely on morphological criteria, which focus on three main physical characteristics: *dimension*, *configuration*, and *relative position*. Yet, these three criteria are crucial but not exclusive, as there are other characteristics which are also quite important which distinguish urban barriers from each other.

4.2.1 Nature

A first distinction can be made between natural and human-made barriers. Looking at the inherent nature of the barriers considered, one can distinguish if they are naturally occurring, such as elements associated with the topography of an area (i.e. rivers, lakes, mountains, ravines, etc.). The former will be termed 'natural' barriers. The opposite category will therefore include 'artificial/human-made' elements. This distinction is quite important for reasons pointed to by Larochelle and Gauthier, as they state that "*en effet, la configuration et la position relative des composantes du territoire : les villes, les réseaux et les aires productives sont essentiellement déterminées par les principales caractéristiques orographiques et hydrographiques originelles du terrain*" (2002: 5). This holds true for all settlements and in the case of Montreal, the site for the original settlement was chosen "at the very limits of navigable waters, at the foot of the Lachine rapids" (Marsan, 1994: 17) illustrating the effect that the natural conditions have had on the selection of Montreal's original location. Similarly, natural features will inform the settlement patterns within the urban organism.

4.2.2 Level of Spatial Resolution

A second distinction considers the level of spatial resolution at which the urban barrier exists. Previously, I identified the four levels considered by morphologists to conduct their analysis: that of the 1) territory/region; 2) city/settlement; 3) urban tissue; and finally, 4) the building scale. In the initial assessment of urban barrier status, these categories may seem overly simplistic but as I move forward the level of spatial resolution will prove an important factor not only in establishing the existence of an urban barrier, but also in determining the influence exerted by said barrier at various scales. In other words, what is constituting a barrier at a lower level of spatial resolution might not record as a barrier at a higher level. This analysis will begin with barriers at the territorial/regional scale, a scale at which morphological analysis looks to explain "*la relation entre la forme des structures anthropiques et la structure naturelle — la géomorphologie — du lieu*" (Larochelle and Gauthier, 2002: 5). This is important because the topography of a given area informs the spatial logic not only of original settlement patterns, but in many ways informs the direction that development takes later on as well. This holds true also for all urban barriers, as those which are artificial/human-made would also be informed by the topography of the area in question and would coincide with technological advancements in construction and transportation for instance leading to the introduction of elements such as bridges which would allow certain natural barriers to be crossed.

4.2.3 Configuration

Moving on, we consider the configuration of the barrier. The simplest way to define configuration is to contrast it with composition. These are two types of formation "those relating to absolute physical geometry, as opposed to those referring to abstract topology. These may be referred to respectively as composition and configuration" (Marshall, 2005: 87). In the simplest terms, we will distinguish urban barriers as either linear or non-linear (i.e. puncture the landscape). Linear (including curvilinear) elements can still vary in size as there are varying sizes of rivers just as there are highways of differing number of lanes but they are still linear as they usually follow a certain pathway. Non-linear elements that puncture the landscape such as with a lake, a mountain, or a rail yard also vary in size and shape. In this respect, these elements share a similar configuration but varying compositions.

4.2.4 Permeability

Next, we consider permeability, which we previously pointed to as being defined as the “extent to which an environment allows a choice of routes both through and within it” (Carmona et al., 2003: 64). Larochelle and Gauthier (2002) pointed to ease of pedestrian movement as a defining factor in their definition of what constitutes an urban barrier. Therefore, I continue along the lines of route choice and pedestrian movement as defining factors in our assessment of levels of permeability. Carmona et al. defined permeability within the context of a given environment (i.e. a neighborhood), but in the case of urban barriers I am discussing a singular element rather than an environment. That said, permeability, as previously defined, still applies to both linear and non-linear barriers as what is being considered is the extent to which an urban barrier allows a choice of routes through it, and the frequency at which these through routes are found. Routes in this context would constitute pathways which allow a pedestrian to cross a barrier, essentially creating points of connection between two distinct ‘patches’. Realizing there are a multitude of levels that could be ranked for permeability, we have decided to establish four levels of permeability; defined here as 1) highly permeable; 2) permeable; 3) moderately permeable; and 4) impermeable. Highly permeable would constitute a distance between crossings of no greater than 200m. This distance being based on the highly permeable block structure found in Montreal's Central Business District (CBD). 'Permeable' would then possess crossings at a distance between 200m to 350m. This distance is roughly the distance between intersections in older Montreal neighborhoods which pre-date the introduction of the automobile. These neighborhoods would be either 'pedestrian' or 'streetcar' suburbs of Montreal, such as the Plateau Mont-Royal for instance. The crossing distance is based on block size and intersection frequency that was planned into the design of these neighborhoods and is a good measure of a permeable environment. Moderately permeable is then a situation where the crossings are found at a separation distance of 350m to 500m, which is the typical distance between railroad crossings in central Montreal. Finally, impermeable is defined by crossings which are more than 500m apart.

4.2.5 Connection Type

Directly related to permeability is the type of connections that a certain barrier has with other infrastructures as well as adjacent tissues. This is important as some elements will have direct connection via a formal intersection where two infrastructures may cross each other or where infrastructure crosses the local street network. Otherwise there are other forms of connections such as formal crossing points such as the case of crossing a highway via a tunnel or overpass. As well, the connections with the local street network may be such that an infrastructure such as a highway connects but does not intersect nor does it cross as is the case with interchanges/viaducts. These connections also have drastic impacts on the surrounding urban environment through the creation of high volume streets where previously there may have been none. This high volume of traffic that would come with a highway connection could arguably change the livability of a street. This is obviously more of an issue for infrastructure associated with private automobile traffic and a topic of discussion at the level of resolution of the city or urban tissue.

4.2.6 Relative Position

The final criterion for distinction and categorization, is that of relative position, which denotes an element's location within the urban organism (i.e. at the periphery or edge of the territorial module) but also its relative position within the system; that is in the case of urban barriers, the position relative to other barriers is the question I will focus on most. This is a key concept to point out, as through the process of morphogenesis, a peripheral element such as a river, rail line or canal, may later become central as the city grows and evolves around it. This absorption, for lack of a better term, of peripheral elements within the urban landscape leads to the creation of internal peripheries within the system, and the barrier effect is magnified. Relative position is therefore more than just a descriptor of boundaries but is also a descriptor of position and constitution within the system; for instance, whether or not an element would be a dividing axis, as opposed to a centralizing nodal axis. The scale of spatial resolution would determine just what would be divided, (i.e. territorial modules, or urban tissues).

It is worth noting that, as a general rule, the inertia of forms is proportional to their spatial magnitude: buildings are transformed routinely, but elements of the hydrographic system or of the agricultural allotment system are far more resilient. The original agricultural subdivision of Montreal, for instance, is still 'visible' as it informs the street pattern of the contemporary city.

4.3 Taxonomy of Urban Barriers

We begin the building of a taxonomy of urban barriers with 'natural' barriers, looking first at rivers, given their significance in the settling of Montreal.

4.3.1 Natural Barriers

Rivers

Rivers are defined as "a natural stream of water of fairly large size flowing in a definite course or channel or series of diverging and converging channels" ("River", Collins English Dictionary). These hydrographic elements fall within the territorial/ regional scale and in the case of Montreal they provide the boundaries or limits for my study area; the island of Montreal. Rivers possess a curvilinear configuration but, as they vary in size along their course as well as when compared to other rivers, they possess an extensively varying composition. Rivers are highly impermeable, as they require bridges or marine transportation such as a barge or boat to cross. In the case of Montreal, the crossing points are quite infrequent and are reserved crossings by either railways or

Figure 4.1. Rivers defining the Island of Montreal.

highways and other major routes. This low crossing frequency is linked to the size of the river in question which can create a more difficult crossing which increases both economic and construction constraints. That said, there are examples of cities which have developed around smaller rivers such as La Seine in Paris, France (Figure 4.2). This river runs through the city centre and is crossed quite frequently by bridges allowing for an overall higher level of permeability. As well, although somewhat of a rare occurrence, there are cases where there are direct connections between the local street network and public transportation systems where a ferry system is an integrated part of

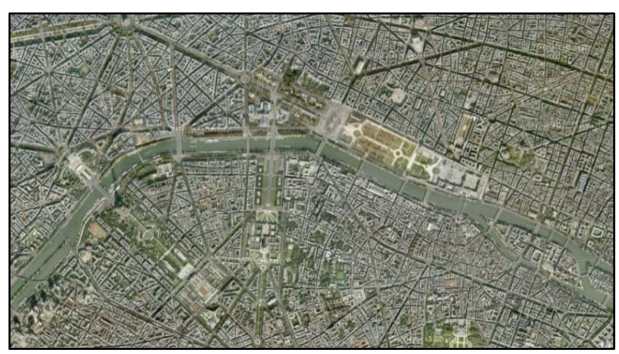

Figure 4.2. La Seine in Paris, France. Note the frequency of crossings denoting a higher level of permeability. (Source: Google Maps, 2009).

the public transportation system. Finally, we can describe this type of barrier as not necessarily intersected but crossed. It is worth noting that, in the past, rivers would have been relatively nodal as the first settlements would have sprung up along them allowing for easier access to water sources for irrigation and daily life. As time has moved forward the proximity to large sources of water have become less and less important with advances in transportation and irrigation technologies.

Steep Slopes

The next natural element we will consider is that of steep slopes (Figure 4.3). These elements are interesting in that their is great variance in their composition as they

Figure 4.3. Slope gradients greater than 10% on the island of Montreal.

can occur as both linear and perforating elements[v]. This is seen in the case of an escarpment which is a linear element versus a mountain or large hill which punctures the landscape. While steep slopes are visually identifiable it is still necessary to define them, as the gradient or steepness has varying impacts on urban form. According to Leung, "land which has a slope over 5% is still acceptable for residential uses but would not be good for industrial uses" (1999: 135). While this criterion is not exactly what we are looking for, it gives us a starting point towards understanding the gradients and their effects on development. Leung further elaborates by way of a table which was adapted from the work of Lynch and Hack (1984).

Activity Type	**Gradient**
Roads	0.5-8%
Paved Area	min. 1%
Planted Areas	min. 1%
Drainage Swales and Ditches	2-10%
General Purpose	max. 4%
Informal	max. 10%
Grass Banks	max. 25%
Unknown Planted Banks	max. 50-60%

Table 4.1 Slope gradients (in %) and their associated acceptable uses (Leung, 1999: 135).

The significant elements within the table include the slope gradient for roads at 0.5-8%, which implies that roads on sloped gradients greater than 8% require some form of modifications to the landscape for their construction, implying that they are conditioned by the topography. Informal uses, usually in the form of low-density residential development, are placed at a maximum of 10%. Based on this information, as well as some morphological testing, areas which possess a slope gradient greater than 10%

[v] These are barriers which are polygonal in shape and perforate the landscape resulting in what can be described as a donut hole effect.

would constitute a barrier for which development and road construction would have to be adapted and therefore conditioned by the natural environment (Figure 4.4). This is the case with some road and residential development found in areas with extreme slopes where the road system adopts a curvilinear configuration which allows it to 'snake' up the slope and development can proceed along altered (flattened) sites along the roads path. On the island of Montreal, the City of Westmount at Bellevue Avenue and its surroundings or Montreal's Redpath Crescent are physical examples of this.

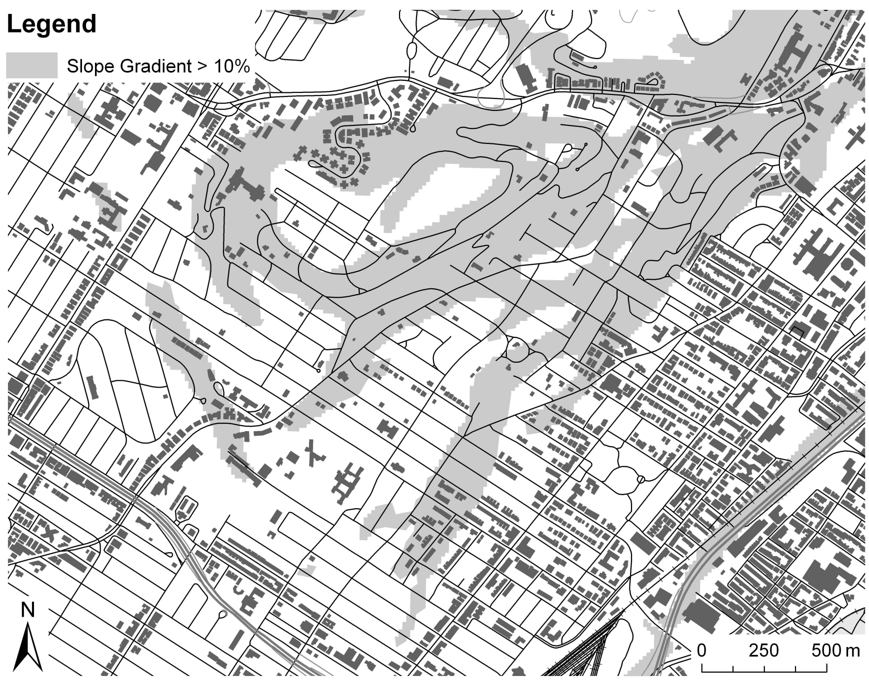

Figure 4.4. A 10% slope gradient (in red) conditioning local street network in Montreal.

Essentially, areas of severe slope could be defined as areas where steep slopes or a drastic change in slope impedes development or comfortable pedestrian movement. This could constitute a natural barrier at either the territorial/regional, or city/settlement level of spatial resolution. A linear element such as the falaise St. Jacques, which is quite

Figure 4.5. The St. Jacques escarpment (on the left) and adjacent turcot yards (source: www.arch.mcgill.ca, 2010).

steep, possesses a high level of impermeability as there are few crossing points (Figure 4.5). But, similar to the case of the river, there are varying compositions of escarpments which are perhaps less steep, for instance, and have been modified for development. Such is the case along the Sherbrooke escarpment. Here the escarpment could be classified as permeable as the grid street pattern has been overlaid on the slope and the street network is more or less continuous. Even in this state, the escarpment still exerts a certain influence as the location itself becomes a dividing axis as it constitutes the limits of the surrounding urban tissues. This is a much more recent development as the escarpment in its original state would have been a territorial/regional barrier defining the limits of the city of Montreal at a certain point in time. Also, it may have been a dividing axis in the early planning of the agricultural allotment system, which influenced the urbanization of Montreal. That said, escarpments as a whole can be said to range from impermeable to more or less permeable depending on the size and composition of the escarpment in question. As major morphological features, they are deployed at the regional/territorial scale. It is only through advances in construction technology and under certain circumstances where the slopes are moderate enough and the location of the barrier is central enough to the city as a whole that the street network will spread more or less uninterrupted by the escarpment. An extreme and exceptional example can be found in San Francisco for instance. Similar to the example above of La Seine in Paris, in central areas of cities exceptional measures can be taken in order to instill some permeability in a capricious landscape (steps, elevators, funiculair and tramways in a city such as Lisbon for example). In terms of its relative position, a major escarpment would generally constitute a boundary of the territorial module and act as a dividing axis.

Another barrier which falls under steep slopes, but is non-linear and can be described as puncturing the landscape includes mountains or hills. The slopes fall under the same gradient categories previously described but the effect is much more pronounced obviously, and the barrier is polygonal in shape. In Montreal's case the so-called "mountain" or Mount Royal, is highly impermeable with the exception of a tunnel which was created to allow for a train to pass through it, and the curvilinear streets both for pedestrians and another for automobiles which allow access and crossing opportunities along indirect routes.

Lakes

Lakes constitute the last natural barrier in this discussion. Defined as an "inland body of water, generally large and too deep to have rooted vegetation completely covering the surface" ('Lake', World Encyclopedia), lakes punctuate the landscape. Such a barrier is deployed at either the territorial/regional or city/settlement scale depending on the size of the lake in question. They generally are non-linear and highly impermeable. Lakes can be crossed using various means of marine transportation, or perhaps be crossed via a bridge in some circumstances. Since lakes come in all sorts of shapes and sizes, it is possible that lakes can exert their influence at various levels of spatial resolution. A lake could take the form of a human-made element or just be such a size that it has been incorporated into the urban fabric , it could delineate tissue modules as well, or when large enough, it could constitute a territorial boundary and therefore define the territorial module.

4.3.2 Artificial Barriers

'Natural' barriers are all elements which pre-date initial settlement and therefore inform and influence the humanization and urbanization patterns of a given area. That said, in the context of urban barriers, it has been established that, "*dans la ville contemporaine, les barrières urbaines présentent généralement un caractère artificiel. Les barrières naturelles sont normalement franchies par des ouvrages de génie – ponts, tunnels, escaliers, funiculaires, etc. – édifiés au cours des siècles*" (Larochelle and Gauthier, 2002: 6). Given that the majority of barriers come in the form of artificial/ human-made infrastructures such as canals, railroads, highways, etc., I will now look at this category. Artificial barriers are introduced in a loose chronological order, that is to say the order in which they were introduced to the landscape. As their significance has changed over time, it also makes the most sense to discuss them in this order.

Fortifications

While no longer in existence in Montreal, in the spirit of being thorough, it is necessary to begin our discussion with a former barrier, as it shares similar characteristics to barriers which are still present in the Montreal today, such as the Lachine Canal. This former barrier in the Montreal landscape is fortification walls. In cities in which they still exist, fortification systems constitute urban barriers, but in the case of Montreal, the fortification walls, completed in 1739, were since removed in the early 19th century (Marsan, 1984). This is not a rare occurrence, as many cities have demolished their then obsolete fortification walls in the 19th century, and one can find many examples in European cities, such as Lyon, France (Tatom, 2004). The fortifications have survived in some cities such as Quebec City, where the effect of a barrier is still present. The relevance of discussing fortification walls in spite of their removal in Montreal remains as it is argued that their influence continues to shape subsequent urban development in its place due to the shape and size of the land that is freed up. This phenomenon is known as fringe belt development (Whitehand and Norton, 2004). Often redevelopment of fortification walls has come in the form of urban boulevards or other high-traffic streets which at times create ring roads. In doing so, a city replaces one urban barrier with another, although of a higher level of permeability, where a high-traffic street can also be

Figure 4.7. Map of the city of Montreal in 1725, by Chaussegros de Léry. Archives nationales (France) (Source: www.vieux.montreal.qc.ca).

an urban barrier the characteristics of which are discussed at some length later in the following chapter. It is not the focus of this research to go into detail on the removal of urban barriers and their continued influence, this question should be addressed independent of this research. The fortification wall can be characterized as being artificial in nature, and acting at the City/Settlement scale of resolution. Fortification walls define the city's outer limits and create a firm edge that was intended to defend the city from outside attack. Their configuration is linear although the composition will vary from city to city based on fortification types, perhaps adding water courses or doubling of walls etc. By design they would fall under the category of almost impermeable barriers. In Montreal there were three access or crossing points (Figure 4.7) with outside routes, one along what is now Notre-Dame Blvd to the west, another coinciding with St. Laurent street to the north, and finally another gate along what is now de la Commune st. to the east. In terms of its relative position, fortification walls, at the time of construction, fall at the limit of the city/settlement by design. Thereby, defining the urban organism as it existed in 1739, although over time as the city expanded the walls no longer served as the edge but created a barrier between the 'old' city and the newer surrounding development, constituting a dividing axis or internal periphery.

Canals

The next human made barrier built in Montreal was the Lachine Canal which opened in 1825. The canal "bypasses the Lachine Rapids … and forms a navigable link between the great lakes and the lower St. Lawrence River" (Bliek and Gauthier, 2006: 5). Canals are defined as "an artificial channel filled with water and designed for navigation, or for irrigating land, etc." ('Canal', Collins English Dictionary). The Lachine Canal was initially intended for navigation only, although its hydraulic power

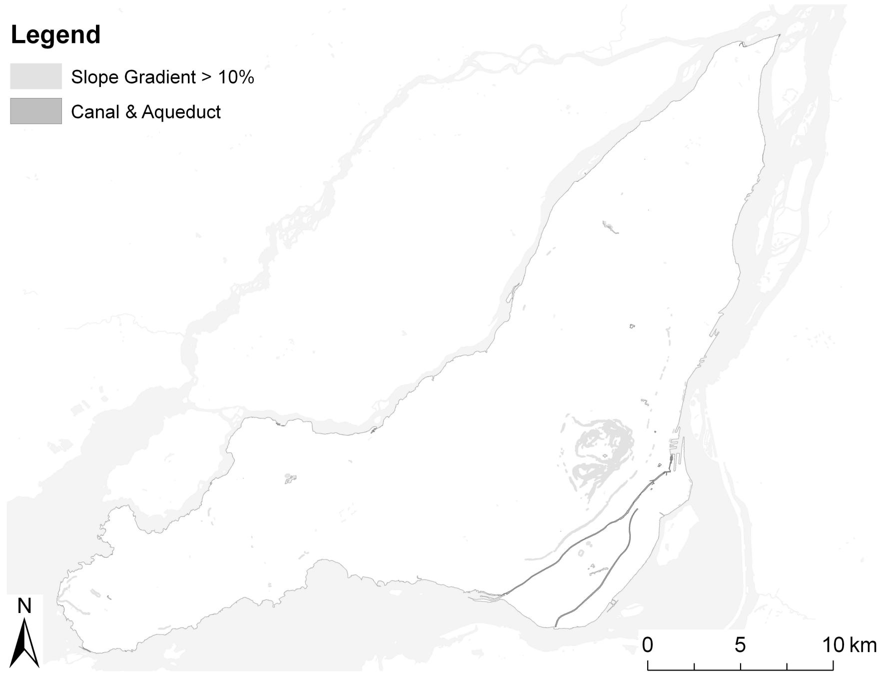

Figure 4.8 The Lachine canal and Montreal aqueduct, in a territorial context.

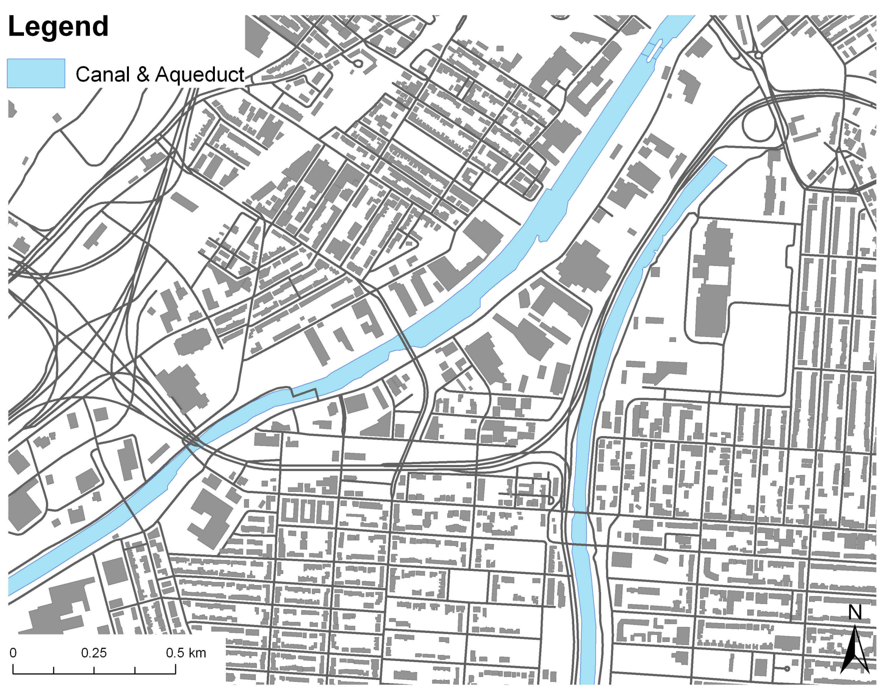

Figure 4.9. Lachine Canal and aqueduct in its urban context of the Sud-Ouest Borough.

was later used for industrial purposes. This artificial/human-made barrier is linear in nature and is exerting its influence at the territorial/regional level of spatial resolution. It is highly impermeable, as it is similar to a river, in that it is not intersected by streets per se but rather crossed by bridges, which appear at moderate to low frequency. The permeability of a canal can vary from case to case. It will be dependent upon the relative position of the canal within the urban organism among other things. In some cases the canal could be crossed at high frequency, leading to fairly high levels of permeability. The canal initially acted as a territorial boundary separating territorial modules, but through the process of morphogenesis and growth of the urban organism as we see it today, it has since been incorporated into the fabric and acts accordingly as a dividing axis separating urban tissues, while also acting at the city/settlement scale.

Railroads

Following the introduction of the Lachine Canal, came the development of the railroad network in the Montreal landscape. One consequence of the introduction of this infrastructure was the further suburbanization of industry in Montreal which was dependent on its access to artificial inter-city thoroughfares (canals and railways) and led to further expansion of the city itself as new 'settlements' appeared along the routes of the railway due to the need for easy access by workers to employment opportunities (Marsan, 1981). The initial relationship between the railway and its surrounding urban fabric was arguably much less segregated than we know it today. The developments in rail technologies which led to faster trains and the requirement for more segregated rights of

Figure 4.10 Introduction of the railway network to the Montreal urban landscape.

way. That said, as it exists today, railway infrastructure is isolated from other transportation networks and quite segregated from its surrounding urban tissues. Connection points come in the form of freight rail yards for unloading goods for instance which are normally found in industrial areas. There exist a few stops for commuter rail which seemingly allow for a direct connection between pedestrians and the rail network but again this is by a designated ‘station’ which ranges from a more formal inter-modal station such as the ‘Gare Centrale’ or a more modest platform which can be seen at certain commuter stations throughout the city. This infrastructure was intrusive in some respects as it required tunneling for it to access the city centre (Figure 4.11), such is the case for the line which currently connects the Town of Mont Royal (TMR) to downtown

Figure 4.11 Aerial view of the Mount Royal Tunnel in the downtown core of Montreal (Source: Hanna, 1998: 51).

via a direct route through the mountain. This line, originally developed by the Canadian Northern Rail Company, was the catalyst for the development of TMR, and also dug a trench right through downtown Montreal (Hanna, 1998).

The railways inherent morphological characteristics are similar to the Canal by their artificial/human-made nature, and constitute a territorial/regional level barrier that possess a linear configuration. Railways also possess dedicated/segregated right-of-ways, with infrequent crossing points, which implies a high level of impermeability. The relative position of such a barrier is usually at the confines of the territorial module and it acts as a dividing axis. This is the case for much of the network, there is a significant level of intrusiveness when this infrastructure was introduced to existing tissues as they either severed existing connections between certain neighborhoods or disrupted other urban fabrics through the tunneling process of placing the lines underground. The relative position of rail lines is very important to its impact on the urban organism. Looking at Montreal, there are some cases where the rail line runs along the Saint-Jacques escarpment. This position in the system causes little physical disruption to settlement patterns, and the subsequent development of urban tissues as the rail line is fundamentally superimposed on another pre-existing barrier, thereby minimizing its impact. In other cases, the rail line runs in

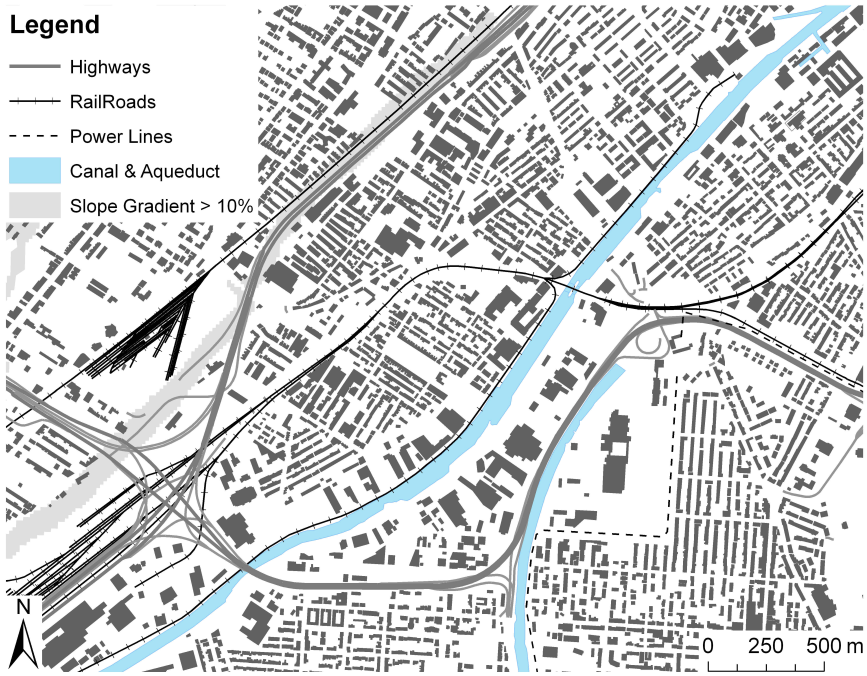

Figure 4.12 The position of a railway defining and dividing urban tissues.

between two urban tissues (Figure 4.12). The impacts of this composition are not necessarily that straight forward as there are three potential situations: 1. where the rail line pre-dates the urbanization of the surrounding area; 2. where the rail line was introduced after urbanization, in which case it is likely to sever connections between the adjacent tissues and; 3. a pre-existing line in what became a densely populated area, gradually became an impermeable barrier, as the evolution of rail technologies required a protected and enclosed right-of-way. Arguably, if the rail line pre-dates the urbanization of the area, it would have been influential in the humanization process of the area in similar ways seen with the natural barriers discussed above as land subdivision would have been in congruence with the rail line allowing for a more coherent tissue to form rather than one that was disrupted after the fact. In all likelihood, those tissues which pre-date urbanization along the rail routes would be more inner-city tissues than those further away from the city centre. The evaluation of the impacts of rail lines on the urbanization patterns of Montreal, while interesting, is not the focus of this research, but would be interesting to explore at a later date.

Highways

Figure 4.13 Introduction of the highway network to the Montreal urban landscape.

The next artificial, linear barrier is arguably the most intrusive of them all as the introduction of highways in the urban organism has come with some of the most detrimental effects. Overall, highway networks can be classified as a regional, and/or national system, which connects cities to one another. They possess dedicated right-of-ways and usually have no at-grade intersections. They connect to the local street networks via interchanges and service roads and they are highly impermeable, as crossing points are quite infrequent, coming normally in the form of overpasses or underpasses for the local street network or via pedestrian only crossings (even rarer). Although the impact on development is similar regardless of whether the highway is elevated or at grade, the difference in impacts between the physical designs would be a point for further exploration, as there are surely questions regarding at grade versus elevated or buried infrastructure (Figure 4.14). Highways rarely have intersections as they are designed to

Figure 4.14 Decarie Highway (left) and Metropolitaine Aut (40) (right) in Montreal, examples of urban highways bisecting urban tissues (Source: Google Street View, 2011).

insure quick and efficient traffic flow and therefore crossing points are minimized. The same can be said for the frequency of direct connections via on and off ramps as they tend to be spaced apart. It should be noted that this can vary based on the relative position of the highway (i.e. within the urban organism vs being located on the fringe or in rural areas). An important characteristic of highways is that they connect but do not intersect with any other system except via the intermediary infrastructure of interchanges or viaducs. The relative position of highways within the urban organism is twofold. Originally, highways were intended to circumvent cities and serve as a way for traffic to bypass urban areas, which by design would locate them at the fringe of the territorial module, and acting in a similar fashion to a river for instance, framing the urban organism in later development. With the introduction of the 'urban' highway to the system, this infrastructure eventually cut its path into the city in some already pre-existing urban environments, which created an anti-nodal dividing axis through the introduction of an impassable barrier. This splitting has its position within the urban organism and therefore is dividing it at the city/settlement level and/or the urban tissue level. Worth noting as well is that in the case of the fringe highway, although a highway remains an impassable barrier, these infrastructures often serve as a vector of urbanization in a similar fashion to railroads which spurred suburban development and opened up access to new areas for development. Generally resulting in isolated settlement areas, i.e. "disurban" forms (to re-use a term from earlier).

High Tension Power-Lines

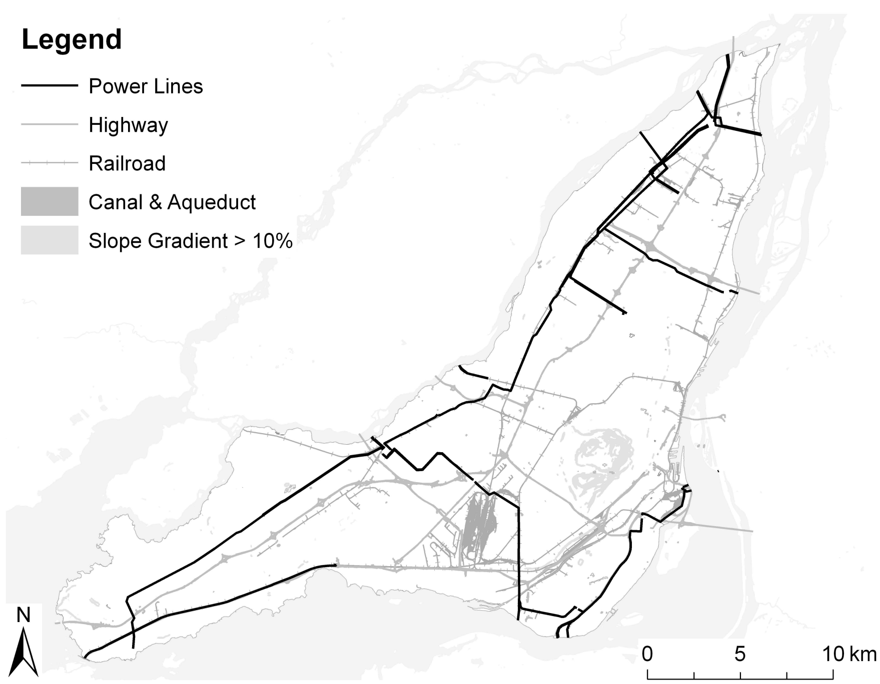

Figure 4.15 Introduction of high-tension power-lines to the urban landscape.

The last artificial, linear barrier is a less obvious one: high-tension power-lines (Figure 4.15). This infrastructure is related to the transportation of electricity and it generally occupies right-of-ways similar to that of the highway or railroads. Within the contemporary urban environment, power-lines often come in the form of buried infrastructure, but there are still strategic connection points which exist as above ground networks. Hence, Power-lines do not necessarily form a contiguous above ground network. Yet, these networks are associated to the territorial/regional scale as their connections span outside of the urban environment. Power-lines are an interesting case because they can be perceived as quite permeable in terms of a pedestrian's ability to cross their path, as the wires are elevated and there is an abundance of open space underneath to cross. In this regard, as can be seen in Figure 4.16, the path associated with this infrastructure is similar in size, and arguably in its impacts, to a rail line or highway or even a river in some cases. Since the space underneath cannot be built up the infrastructure is crossed only infrequently by the local street network. The intersections are then found at a similar frequency to those found at a highway and therefore power lines could be described as moderately permeable (350 to 500m between crossings). The crossings points are at grade as the power lines pass overhead, but it is more the right-of-way of the infrastructure (a result of

Figure 4.16 Aerial photograph of power-lines. Note the width of the right-of-way (Source: Google Maps 2009).

land ownership as well) which creates the barrier effect, and more specifically breaks in the urban tissue resulting in a spatial and social disconnection. In terms of its relative position, considering its similarities with a highway or river for instance, it would constitute a territorial boundary, running at the confines of the territorial module.

Rail Yards

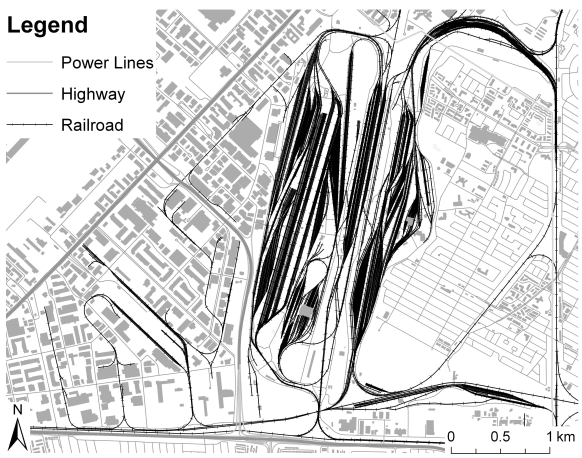

Figure 4.17 The Canadian National (CN) Taschereau (right side) and Canadian Pacific (CP) (left) railyards.

The next category to consider are barriers which are artificial and puncture the landscape, they are similar in effect and configuration to the natural, non-linear (polygonal) barriers described earlier (i.e. a lake or mountain). The first such artificial barrier to consider is the case of rail yards. Rail yards are usually found in industrial areas or former industrial areas and were originally used as locations to switch locomotives, conduct repairs, store containers, or essentially ‘park’ trains when not in use. Rail yards exist at the city/settlement scale as they can occupy large areas similar to a whole neighborhood, they are also non-linear and can range in both size and shape. Rail yards are highly impermeable, arguably even more so than railroads, due to the size and concentration of industrial activity at their location which adds to the barrier effect as the area to cross becomes much larger. Formal crossing points would be non-existent as these areas are intended to be isolated from through traffic. One would be restricted to circumventing a rail yard, likely by automobile rather than walking as the areas are often quite large. Rail yards also constitute an example of a large mono-functional zone as they are dedicated to industrial use where one would definitely not find any residential function within. This is important to point out as large (non-residential) mono-functional zones will be shown to have just similar boundary impacts to the linear barriers discussed earlier. In terms of the rail yards relative position, they exist in close proximity to main lines of the railway network and due to their size and configuration exist at the city/settlement scale and would constitute an anti-nodal dividing axis.

4.3.3 Large Mono-Functional Zones

Rail yards provide the case of a polygonal barrier made up of a concentration of linear infrastructure and associated facilities. These zones provide us with the a primary example of large mono-functional zones as barriers. This category is more complicated than our previous types as they are tightly linked to size and scale of both the land-use in question and the level of spatial resolution of the inquiry. In other words, the size and configuration of the “zone” will determine at what level of spatial resolution it exerts an impact as a barrier.

Parks

Let's start by considering the case of parks, which come in various sizes ranging from large regional or national parks aimed at preserving wildlife and natural landscapes, to more local parks and squares. Local parks are essentially invisible when considering the city at the territorial or city/settlement scale and therefore would exert no barrier effect at that scale. But at a closer resolution, they may in fact act as the edge of a neighborhood dividing one area from another. Parks therefore exist at all scales including the urban tissue level, down to the smaller scale of the 'block' or the 'lot/parcel' scale. Their barrier effects and impacts for other large mono-functional zones are dependent on the specific use in question as well as the scale at which they exert the most influence. This idea of the large mono-functional zones as barriers stems from previous work pointing to the existence of border vacuums (Jacobs, 1961), which looked at large parks as neighborhood boundaries. We will touch on the neighborhood scale later on but we posit that the principles hold true at the city/settlement scale with very large parks which exist at this scale of resolution. It may seem counterintuitive to refer to a large park as an urban barrier, as they are enjoyed by most people who are drawn to them and they are usually welcome additions to any neighborhood. If we return to the definition provided by Larochelle and Gauthier (2002), urban barriers constitute elements in the urban landscape where "*la traversée a pied s'avère fatigante, difficile ou impossible, dangereuse ou interdite*" (2002: 6), and apply such as definition to parks, one can see that parks acting as a barrier is dependent on the ability to cross them. This 'cross-ability' results from the distance one would have to travel and the more or less hospitable conditions present within the park (i.e. the time of day where night time may constitute a time of danger, or the actual topography of the park which may make the direct crossing more difficult than an urbanized setting). Finally, the limited number of crossing paths would also infer a certain level of impermeability which is a key condition of urban barriers. Mont-Royal park for instance (Figure. 4.18), is a large park which one can move about in many directions, but given the conditions and size of the park the crossing conditions can become difficult. Looking at the parks size, it is similar to that of an entire neighbourhood and therefore it easily defines the areas around it as an edge.

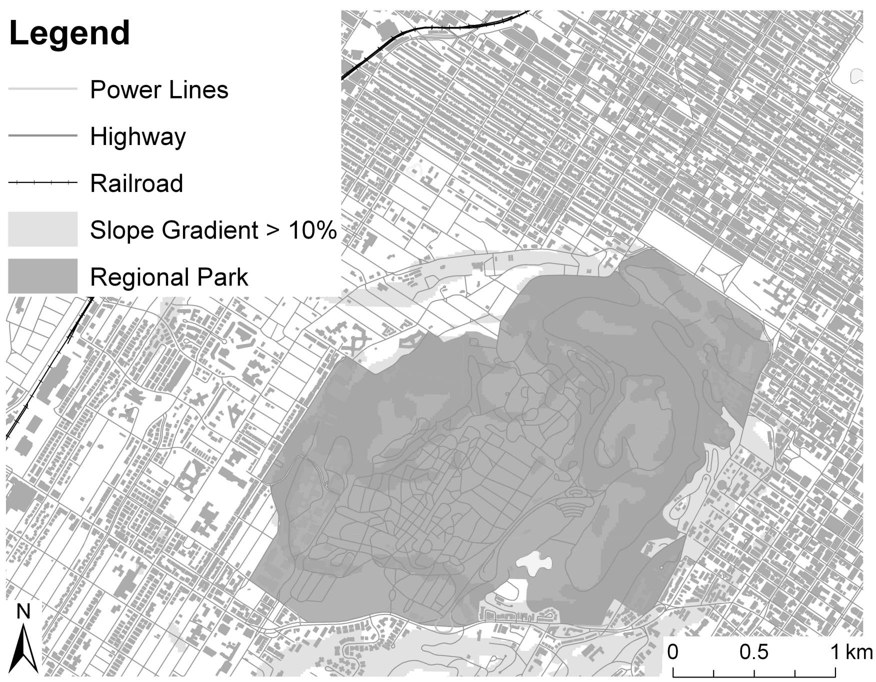

Figure 4.18 Mount Royal Park, an example of a regional park acting as an urban barrier.

Airports

Airports (Figure 4.19) are another large (non-residential) mono-functional zone. They are necessary to facilitate regional, national and international transportation. Their physical footprint on the landscape is very important, and their composition is highly impermeable, as crossing points again are non-existent. Airports occupy a large area, similar in size to that of Mont-Royal in Montreal's case. Major airports often occupy a space larger than multiple 'neighbourhoods' and would therefore disrupt the urban fabric in a manner which would constitute a boundary between residential tissues or between residential and other specialized tissues. In addition, there are external impacts of airports due to flight patterns, take-off and landing patterns and the noise related to air traffic which limits development in proximity to them. Such conditions

Figure 4.19. Pierre Elliot Trudeau Airport (Source: Google Maps 2009).

increase the physical impact of the airport on its surroundings. Smaller airports do exist and should be acknowledged as having similar impermeability issues but the physical footprint would be different as well as the range of development restrictions due to air traffic. When constructed they would normally be found on the outskirts of urban environments, although there are exceptions to this. Therefore, their relative position within the system is at the fringe of the urban organism, and its influence is at the city/settlement scale. Post-construction, it is not irregular to have development expand around airports as they are economic generators and have associated industrial and commercial uses depending on their size. The urban development would still be restricted by the above described conditions.

Industrial/Commercial Clusters

The next type of large mono-functional zone is associated with two types of specialized tissues; industrial or commercial (Figure 4.20). These zones are unique compared to all other categories previously discussed as they tend to possess a functioning internal street network that, in some cases, may even mirror networks found in surrounding residential tissues, such as a continuous grid, or loop and loli-pop configurations for instance. The presence of a street network naturally denotes a certain level of permeability and connectivity with adjacent areas but this permeability can vary. While they have an internal street network, these zones usually have limited connections to the surrounding residential street networks. The barrier effect caused by these industrial and heavy commercial clusters is due to a degree of isolation from a lack of continuity of street networks internally which creates similar conditions as seen with regards to large parks where the distance that one needs to travel to go from one residential environment to the next is significant enough to constitute an impediment. If the zone is quite large in size, or does not have sufficient sidewalks present, or an

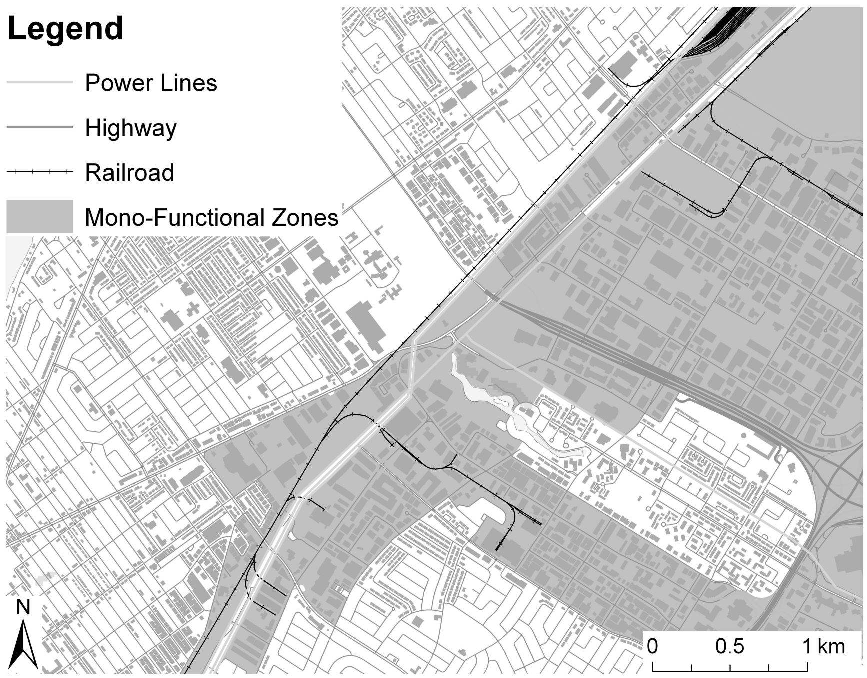

Figure 4.20. Large industrial zone in Montreal.

abundance of heavy industrial traffic, for instance, then the crossing of it can become difficult similar to the conditions found when considering large urban parks. The impact of large mono-functional zones are usually felt at the city/settlement level of spatial resolution. The dimensions and configuration of these areas can vary as each area will be relatively unique in terms of specific uses. Acknowledging the variability of such conditions, the permeability of the barrier is also difficult to pin down but would usually lean towards moderately permeable to permeable due to the presence of a street grid, but this use and lack of connection to its surrounding urban environment creates another ‘border vacuum’ similar to the parks described by Jacobs. The identification of these forms is first and foremost due to their relationship with the other linear boundaries. That is to say, if a large industrial or commercial zone runs from one first order linear barrier to another, for instance, they are revealed by the linear barrier structure and form an impassable extension of the surrounding barriers. These zones may also run along a linear barrier for instance, extending the barrier effect outwards as is the case with commercial and industrial development along highway routes, similar to the development of industrial activity previously found along canals and subsequently railways. Large mono-functional zones are therefore also distinguished based more on the size and concentration of similar land-uses (non-residential obviously).

4.3.4 A Mosaic of Specialized Tissues

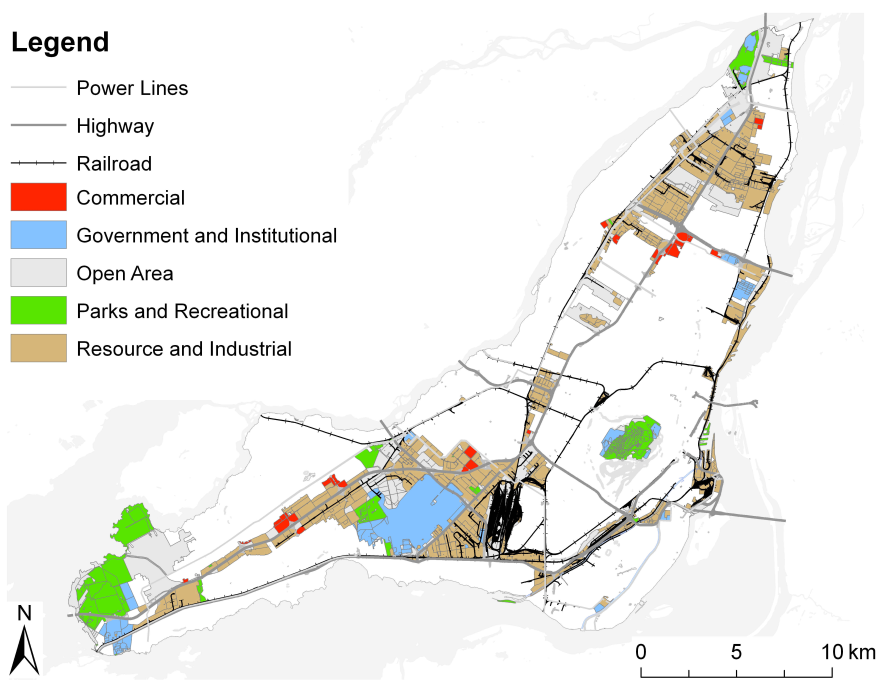

Figure 4.21. The network of mono-functional zones on the island of Montreal.

All of the above mentioned large mono-functional zones, including rail yards, when compiled together, constitute a patch framework in their own right (Figure 4.21). They create a layer of barriers which divide and separate residential tissues just as much as the linear and non-linear barriers initially discussed, but this layer itself is also crossed and fragmented by barriers (such as highways, railways, power lines, etc.) in some cases. The impacts of these infrastructures are not intrusive per se but are usually associated with the economic development and functioning of these areas, but they also serve to isolate certain tissues creating enclaves of specialized tissues. Depending on their surrounding edges, these are tissues which posses varying levels of flexibility in terms of their redevelopment potential or ability to support more commercial or industrial development within an isolated or enclaved patch. What is essentially created here is a mosaic of specialized tissues which, as previously pointed to, would have arguably more development potential as the barrier effects of certain specialized tissues could be potentially mitigated allowing for expanded mixed-use environments which would lead to increased quality of life perhaps. This is of course dependent on the size, configuration and relative position of the specialized tissue in question.

4.4 Conclusion

Having described the varying types of barriers at play at the territorial and city/settlement scale, it must be noted that these barriers are not alone in framing residential tissues within the city. Another type of infrastructure also exerts a divisive quality on urban tissues: these are major traffic streets which contribute another layer to our enquiry of the townscape mosaic structure.

5. Urban Boundaries | Chapter Five

5.1 Introduction

The previous chapters outlined in detail all the elements considered to be first order urban barriers based on their physical characteristics and hinted at the physical impacts they may induce. These elements are mainly a part of the territorial/regional scale with the occasional exception of a barrier existing at the scale of the city/settlement. They are generally highly impermeable. The strong local influence they are exerting will be demonstrated in the forthcoming chapters. These are not the only infrastructures that define the urban landscape, which brings us to our next area of concern; the major traffic routes within the street network itself, often referred to as urban thoroughfares. These major traffic routes constitute a second order of barrier. In many cases they are less physically divisive in terms of their physical structure, and therefore are more fittingly described as urban boundaries. They will be shown to possess different spatial properties than the first order barriers previously discussed. Thoroughfares are not alone in this second tier, as through their identification and mapping another layer of mono-functional zones will be revealed. I begin by defining what exactly constitutes an urban thoroughfare as well as attempt to resolve confusion in categorizing them.

5.2 Defining Urban Thoroughfares

Urban thoroughfares or major traffic routes are most often found in the form of at grade infrastructure that may be closely integrated with their surrounding urban environment or isolated from it by design. In contrast to first order barriers, their barrier effect does not result strictly from the physical massing of the infrastructure per se, but the level of difficulty in crossing them, which is associated and influenced by such factors as the width of the roadway, the volume, speed and composition of the traffic, and street environment adjustments (e.g. traffic lights, pedestrian crossings, pedestrian traffic islands). Empirical research has shown that high volumes of traffic cause roadways to restrict pedestrian flows (Soguel, 1995), an effect often referred to as “dynamic severance” (Guo et al., 2001). But just how are streets which constitute major urban thoroughfares identified? One method would be to count the level of traffic and compare the composition and width of the street to others of similar characteristics to determine baseline statistics and distinguish those streets which would qualify as thoroughfares and barriers. Such a method would be quite tedious and time consuming, and such an approach would be outside the scope of this morphological analysis. What can be done is to look at various works that have been exploring the concept of thoroughfares up to this point and compile the physical characteristics which can help to identify the routes that fall into this category. I will begin by looking at the traditional models of route specialization.

5.2.1 The Specialization of Routes

According to the morphological model presented by Caniggia and Maffei (2001), within the urban organism there are two types of specialized streets. Firstly, commercial routes, generally equipped with distinct facilities, which tend to be positioned in a central location within residential tissues and act as a centralizing nodal axis. Secondly; streets specialized in traffic movement (i.e. thoroughfares) which act as a dividing anti-nodal axis and tend to be located in peripheral locations i.e. at the limits of morphological areas. This anti-nodality is based on the relative position of the route within the system. These basic route types are further explored in the authors' theoretical model for the specialization of streets which denotes a more complicated structure (Figure 5.1). Here, a more complex alternation of street type is provided which can be modeled as follows, [4,3,2,2,…2,3,1,3,2,…2,2,3,4] where route '4' would constitute a dividing axis (i.e. a thoroughfare in our case), '2' a type of regular street, residential in general, '3' assuming complimentary functions for commercial (1) or thoroughfares (4) generally equipped with distinct facilities (2001, 184). Evidently, the reality does not always obey to the theoretical model, especially when the road network is the result of planning and regulatory practices informed by normative transportation models.

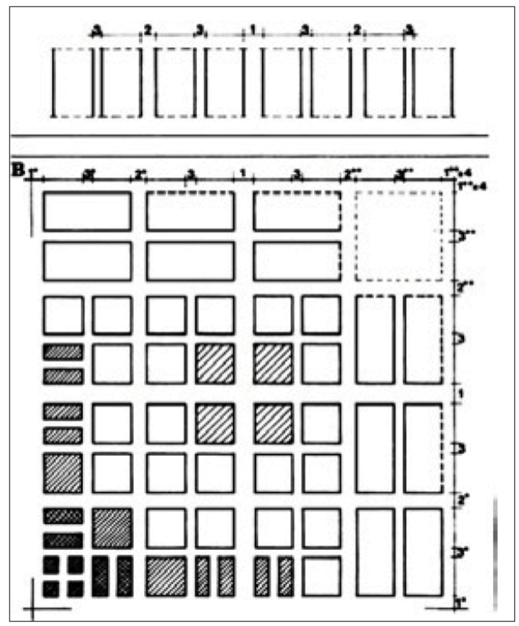

Figure 5.1. The specialization of routes (Source: Caniggia and Maffei, 2001: 171).

5.2.2 Normative Transportation Theories and Road Designation

When one consults the nomenclature of a map of the city for instance, highways and major traffic routes are identified by specific designations. But such designations are not always consistent, as they could refer to roads whose configuration varies in different urban contexts. It is the opinion of this research that it is not adequate to rely on these designations as it can be argued that they do not address properly the issue of physical form. Furthermore, as Marshall points out from a functional perspective:

> "Any particular street will tend to have 'multiple personalities', that is, have a variety of different characteristics that are present simultaneously. For example, Marylebone Road in London is a major traffic route and bus route; it serves as a ring road and bypass to central London; it has the form of a dual carriageway boulevard; it is designated a Red Route and part of the Transport for London network; it is the A501" (Marshall, 2006: 23).

Similar conditions can be found here in Montreal where, for instance, Peel Street which is part of a contiguous transportation network linking regional roads but does not necessarily meet the physical requirements of a major traffic route on parts of its course. In this case, Peel is alternatively a commercial street, route 112 in the transportation network and a residential street. These multiple personalities are not the only challenge as "any particular street is likely to have a variety of official designations" (2006: 23), and "a wide variety of street types is observable across a variety of contexts" (2006: 52). That is to say that there are many different street classification schemes that can exist simultaneously. Adding to the problem is that there are no standard hierarchical classification procedures. The classification practices used vary by country, by city and even by profession (i.e. engineering or planning).

> "The institution of Civil Engineers has noted this as a confusion of different systems of road classification, that are each directed towards different purposes. Those purposes include distinguishing administrative responsibility for routes (e.g. national trunk road), assisting with information (e.g. route signing), or distinguishing road standard (e.g. dual carriageway) or construction criteria (e.g. based on the design life measured in 'millions of standard axles')" (2006: 23-24).

Marshall demonstrates this fact through his compilation of a Catalogue of Street Classification Systems (2006: 264) which range from functional classification schemes to more design based ones, with many using similar terminology to designate differing types of streets. But all is not lost as even though the terminology differs in cases,

> "the basic principles tend to follow a general pattern, with a spectrum from major roads to minor roads. Major roads tend to be associated with strategic routes, heavier traffic flows, higher design speeds, with limited access to minor roads with frontage access. Minor roads tend to be associated with more lightly trafficked, local routes, with lower design speeds and more frequent access points and with access to building frontages" (2006: 47).

The consequences of these associations can be summarized as roads designated as 'streets' (an implication of built frontages and public space) are normally found at the lower end of the spectrum. As well, there tends to be greater segregation of transportation modes at either extreme of standard hierarchies: segregated vehicular traffic at one end and segregated pedestrians at the other, with all-purpose roads in between. Finally, most route types appear to be designated according to traffic function, although some at the lower end (e.g. street, mews, etc.) also imply a relationship with their respective urban tissues (Marshall, 2006: 47).

5.2.3 Thoroughfares: A Contemporary Perspective

Coming back to the morphological approach, Larochelle and Gauthier (2002) touch on the issue of thoroughfares in their work and provide a morphological analysis illustrating the difference between two major categories of traffic axis types: the urban boulevard and the urban highway (Figure 5.2). Their analysis points to many distinctions between the two types including the physical composition (width, landscaping, etc.), the users (limited to motorized transport or more inclusive in the case of the urban boulevard), the presence of sidewalks or lack thereof. These differences are important but there are three fundamental differences that are much more striking within the work. These are related to categories of intersections and their frequency, their relationship with the parcel structure of the urban tissue, and relative position.

	Voie urbaine espress	Autoroute
Nature	**Voie intraurbaine**	**Voie interurbaine**
Définitions (Selon PRobert)	**Boulevard:** rue très large, généralement plantée d'arbres	Large route protégée, réservée aux véhicules automobiles, comportant 2 chaussées séparées [...] sans croisements ni passsages à niveau
Usagers	Automobilistes Cyclistes Piétons	Automobilistes
Relation avec le parcellaire et le bâti	**Avec** «bande de pertinence» donc façades principales	**Sans** «bande de pertinence» ni adresses civiques
Configuration	**Avec ou sans** terre-plein Avec trottoirs Alignements d'arbres	Chaussées séparées Sans trottoirs
Intersections	**À niveau** relativement rapprochées (180 m max. recommandé)	**Viaducs / Échangeurs**
Position relative	Aux confins des tissus urbains (agit comme axe diviseur)	Aux confins des modules territoriaux (barrière infranchissable)

Table 5.1: Morphological differences between Highways and urban boulevards (Source: Larochelle and Gauthier, 2002).

With regards to intersections: urban boulevards possess at grade crossings, whereas highways usually connect to the regular street system via interchanges or bypass them via overpasses. It is widely acknowledged that a highways' primary function is that of moving automobile and other motorized traffic quickly and efficiently between or around cities and in some circumstances through urbanized areas. It is for these reasons that connections are usually relatively infrequent by design, reinforcing the "divisive" nature of highways and making them easily distinguishable from surrounding urban tissues. Also worth mentioning is that intersection spacing denotes the scale of the networks, highways being at a regional scale and urban boulevards at the city/settlement scale. Considering their relationships with their surrounding building and parcellar structure, or what can be referred to as the presence (or lack) of 'pertinent strips[i]', the importance of which is conveyed by more recent work by Gauthier (2009) who states,

> "*On y remarque qu'une des principales distinctions entre ces deux objets tient du fait que le boulevard, quelle que soit sa largeur ou sa capacité, est bordé de 'bandes de pertinences', ou séries des parcelles portant des bâtiments qui y ont leur adresse civique. C'est cette caractéristique qui fait que, contrairement à l'autoroute, le boulevard urbain est assimilable aux modèles culturels associés de longue date à la vie urbaine: en l'occurrence le modèle de la 'rue', comme espace de vie et espace social et économique, dont Jane Jacobs nous a montré l'importance cruciale*" (Gauthier, 2009: 98).

If we look at the highways based purely on a network perspective, having direct connections to the local street network would lead to their inclusion as a part of the street network of the city, but their spatial syntax and role in the city's morphogenesis demonstrates their disruptive and divisive qualities in the urban environment. Gauthier clearly points out that highway's represent a break in the evolution of assimilated street types within the urban organism. Urban boulevards have a direct connection to their surrounding environments whereas a highway represents a route based on efficiency of movement thereby eliminating them as a true type of 'street'.

Larochelle and Gauthier have provided a clear distinction between two categories of traffic axes, but there are other types of streets which exist that would constitute major urban thoroughfares but that are not necessarily urban boulevards, strictly speaking. In

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[i] A pertinent strip includes all the built lots referred to the same street front. Its length depends on the single phase, according to the transformation to the building types (Caniggia and Maffei, 2001: 248).

other words, contemporary transportation and civil engineering have produced new categories of roadways that share only some of the characteristics generally found in traditional urban boulevards.

5.2.4 Functional Definition of Thoroughfares

The functional definition of a thoroughfare includes a wide range of street types. According to the Institute of Transportation Engineers' (ITE) Report on major urban thoroughfares, the latter include,

> "major streets (and their rights-of-way, including improvements between pavement edge and right-of-way line) in urban areas that fall under the conventional functional classes of arterials and collector streets. Thoroughfares are multi-modal in nature, and are designed to integrate with and serve the functions of the adjacent land uses" (ITE, 2006: 13).

ITE further categorizes thoroughfares into two subcategories of 'thoroughfare types'; the first are "thoroughfares in areas with traditional urban qualities serving compact, walkable mixed-use environments" (2006: 46), and second are "vehicle mobility priority thoroughfares serving single-use areas or districts, or any area where the movement of vehicular traffic is a high priority" (2006: 46). A further break down is provided in the following table outlining the entire spectrum of thoroughfare types according to ITE (Figure 5.3).

The ITE table follows the progression of major to minor street types previously presented by Marshall. The definition of a thoroughfare presented by the ITE appears comprehensive but has brought too much into the discussion and again lacks specificity. While all the categories of thoroughfares are established on technical grounds, such

Thoroughfare Type	Functional Definition
Freeway/Expressway/ Parkway	Freeways are high speed (50 mph +), controlled-access thoroughfares with grade-separated interchanges and no pedestrian access. Includes tollways. Expressways and parkways are high- or medium-speed (45 mph +), limited-access thoroughfares with some at-grade intersections. On parkways, landscaping is generally located on each side and has a landscaped median. Truck access on parkways may be limited.
Rural Highway	High speed (45 mph +) thoroughfare designed to carry both traffic and to provide access to abutting property in rural areas. Intersections are generally at grade.
High Speed Boulevard (see Chapter 11 for design guidance)	High speed (40 to 45 mph) divided arterial thoroughfare in urban and suburban environments designed to carry primarily higher speed, long distance traffic and serve large tracts of separated single land uses (for example, residential subdivisions, shopping centers, industrial areas and business parks). High speed boulevards may be long corridors, typically 4 to 8 or more lanes and provide very limited access to land. May be transit corridors and accommodate pedestrians with sidewalks or separated paths, but some high speed boulevards may not provide any pedestrian facilities. These boulevards emphasize traffic movement, and signalized pedestrian crossings and cross-streets may be widely spaced. Bicycles may be accommodated with bike lanes or on separate paths. Buildings or parking lots adjacent to boulevards typically have large landscaped setbacks. They are primary goods movement and emergency response routes and widely use access management techniques.
Low Speed Boulevard (see Chapters 8, 9 and 10 for design guidance)	Walkable, low speed (35 mph or less) divided arterial thoroughfare in urban environments designed to carry both through and local traffic, pedestrians and bicyclists. Boulevards may be long corridors, typically 4 lanes but sometimes wider, serve longer trips and provide limited access to land. Boulevards may be high ridership transit corridors. Boulevards are primary goods movement and emergency response routes and use access management techniques. Curb parking may be allowed on boulevards. Multiway boulevards are a variation of the boulevard characterized by a central roadway for through traffic and parallel roadways for access to abutting property, parking and pedestrian and bicycle facilities. Parallel roadways are separated from the through lanes by curbed islands with landscaping; these islands may provide transit stops and pedestrian facilities. Multiway boulevards often require significant right-of-way.
Avenue (see Chapters 8, 9 and 10 for design guidance)	Walkable, low-to-medium speed (30 to 35 mph) urban arterial or collector thoroughfare, generally shorter in length than boulevards, serving access to abutting land. Avenues serve as primary pedestrian and bicycle routes and may serve local transit routes. Avenues do not exceed 4 lanes and access to land is a primary function. Goods movement is typically limited to local routes and deliveries. Some avenues feature a raised landscaped median. Avenues may serve commercial or mixed-use sectors and usually provide curb parking.
Street (see Chapters 8, 9 and 10 for design guidance)	Walkable, low speed (25 mph) thoroughfare in urban areas primarily serving abutting property. A street is designed to connect residential neighborhoods with each other, connect neighborhoods with commercial and other districts, and connect local streets to arterials. Streets may serve as the main street of commercial or mixed-use sectors and emphasize curb parking. Goods movements is restricted to local deliveries only.
Rural Road	Low speed (25-30 mph) thoroughfare in rural areas primarily serving abutting property.
Alley/Rear Lane	Very low-speed (5-10 mph) vehicular driveway located to the rear of properties, providing access to parking, service areas and rear uses such as secondary units, as well as an easement for utilities.

Table 5.2: Functional definition of thoroughfare types (ITE, 2006:11).

classification fails to acknowledge their distinctive physical characteristics. Taking into account the said physical characters, as we build towards a morphologically based definition, allows for a finer classification, while militating for the exclusion of some types of routes from the list.

For instance, the ITE has included freeways as a category of thoroughfares, even if the latter do not provide access to abutting properties, a previously defined feature of urban thoroughfares. Freeways are defined as “high-speed, controlled-access thoroughfares with grade separated interchanges with no pedestrian access” (ITE, 2006). Freeways are clearly distinct from both other types in the same category; the Expressway and Parkway, as both include at grade crossing intersections. Within the category of Freeways/Expressways/Parkways, the naming can be misleading , for example, as the expressions Freeway or Expressway have been traditionally used as alternate terms for highway in the Montreal context.

On the other end of the spectrum, the ITE report has included local street types in their thoroughfare classification. This is another point of contention since avenues, streets, rural roads, and alleys do not possess the same physical characteristics as high and low speed boulevards. It is again my opinion that they do not constitute categories of thoroughfares, as they are generally shorter and do primarily accommodate “through traffic”, i.e. circulation that travels between neighbourhoods rather than locally.

The middle section of the ITE classification distinguishes a category of street types which includes expressways, parkways, high-speed boulevards, and low-speed boulevards. High-speed urban boulevards according to ITE are designed to serve higher-speed, long distance traffic ... and "buildings adjacent to boulevards typically have large landscaped setbacks" (2006) hence, implying a relationship to the parcellar structure and the presence of pertinent strips. Low-speed boulevards are designed to carry both through and local traffic, but are designed to serve longer trips. This means that boulevards exist outside of the strictly local street network or, put another way, exist at a scale that is larger than the urban tissue as they are designed to carry through traffic, linking multiple neighbourhoods or districts together which is a defining characteristic of an urban thoroughfare.

5.2.5 The Urban Boulevard VS The Functional Arterial

Urban boulevards have been described as a multi-functional type of arterial, one which is much more integrated and suited for the urban context than the latter. Jacobs et al. (2002) identified three types of urban boulevards. The first type possesses: "a wide central landscaped median flanked on either side by roadways and sidewalks. The central median may be a pedestrian promenade; or it may simply be planted with grass, trees and shrubbery" (2002: 5). The second type of boulevard is really nothing more than a street with "a wide central roadway and broad, tree-lined sidewalks along each side. It is characterized by gracious tree plantings, wide walkways, the anticipation of well designed buildings and, in some cases, a desired high-status address, rather than a distinctive design" (2002: 5). Finally, the third type of boulevard is the multi-way boulevard, which is distinctly different from the other two as it is

> "designed to separate through traffic from local traffic and, often – unlike others- is designed for recreation. It is characterized by a central roadway of at least four lanes for generally fast and nonlocal traffic; on either side of this roadway are tree-lined medians that separate it from parallel, one-way side access roads for slow-moving traffic… The access roads generally allow for one or two lanes of parking and one moving lane." (2002: 5).

While these are all distinct compositions of boulevards, the idea is much the same, that this type of thoroughfare and its sub-categories, have a high level of integration within the urban environment evidenced by the presence of pertinent strips along these route. In this way, they contribute to the overall livability and/or 'placeness' of an area. Morphologically speaking, they are assimilable to the cultural model of the street, which exists to support buildings that have their address on them.

The functional arterial on the other hand has arguably been intentionally designed to serve independently of the urban realm, with little integration with the surrounding urban environment. They have been designed primarily for the accommodation of traffic flows. Little to no attention is given to contributing to a 'sense of place'. This 'placelessness' has been defined as "the casual eradication of distinctive places and the making of standardized landscapes" (Carmona et al. 2003: 101) and is a major component contributing to the problem of 'disurban creation' (Marshall, 2006). These functional arterials often do not provide pertinent strips implying that they do not have direct access to buildings along them. There are cases where series of buildings may be present but their appearance is irregular and erratic. Such functional arterials break with an immemorial urban tradition according to which streets - as opposed to roads - are created, first and foremost, to provide access to buildings. The creation of streets is at the heart of the morphogenesis of cities.

5.3 Route Identification

Having established two types of thoroughfares which serve as boundaries within the system, we now take a look at their physical composition and other morphological criteria which we can use to distinguish them from other routes within the network. The work of Stephen Marshall (2005) provides two strong criteria that allow to distinguish between routes within a given network; these are the principles of 'arteriality' and 'access constraint'.

5.3.1 Arteriality

'Arteriality' is defined as "the manifestation of strategic contiguity in networks, in which each route must be connected to another route of the same tier or higher tier" (Marshall, 2005: 291). The principle of 'arteriality' is applicable at any scale as, for any given level or area there may be locally strategic elements which are locally contiguous. More specifically, dealing explicitly with a road network, 'arteriality' implies that each route must connect to either

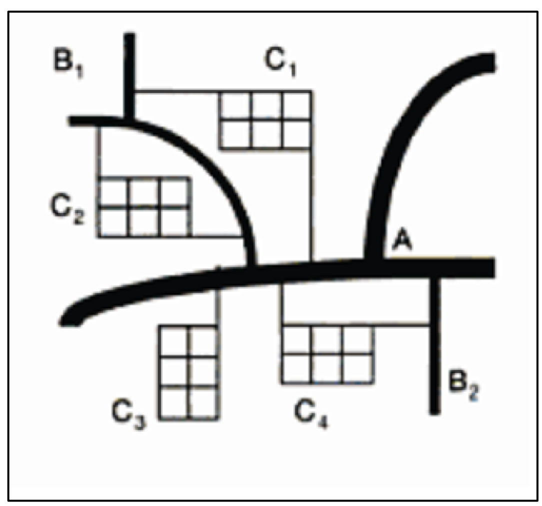

Figure 5.2: The theoretical properties of arteriality (Marshall, 2005: 62).

a route of the same status or higher. “The result is that the highest status routes form a single contiguous system (A), but sets of lower elements are not necessarily contiguous (B,C). For any given level, the set of all elements from the top down to that level will form a single contiguous system (A+B; or A+B+C)” (2005: 62) (Figure 5.4).

According to Marshall, “the outstanding feature that the national road network possesses is that strategic routes all connect up contiguously” (2005: 60) and the direct connections to this national network which are often major routes and thoroughfares of some sort also connect upwards (to highways, for instance) in a specific manner. This contiguous connection and the behaviours of this concept are related to the idea of arteriality, which “is a property typical of road networks around the world – although it is not limited to the road network context. ‘Arteriality’ is a key property of structure …as it

Figure 5.3: Upward connectivity as a physical characteristic for thoroughfare identification.

can be spatially used to organize routes and structure hierarchies" (2005: 61). An interesting point is made by Marshall regarding what exactly is being ranked by arteriality, as he makes a distinction between the 'traditional city' as compared with the contemporary city. "In the traditional case [the urban street network]: all the main streets connect up, focusing on the central square. In the modern case, arteriality ranks traffic routes, it is the national traffic network that links up contiguously" (2005: 184). Arterials are not to be confused with the property of arteriality, as both urban boulevards and arterials can possess a high level of arteriality but they have been shown to be different from one another morphologically.

5.3.2 Access Constraint

Access constraint is another property of road classification identified by Marshall. It is based on the suggestion that "a residential road should not connect directly to a motorway, except via intermediate distributors" (2005: 162) (Figure 5.5). It is defined as "a form of stratification by which routes may only connect to other routes of the same or adjacent tier" (2005: 291). This characteristic is a "condition typical of 'modern', 'planned', or 'hierarchical' layouts, whereby each road type is controlled in terms of which other types it may connect to" (2005: 172). It is a staple of modern post-war suburban development in particular and to some is a desired property for roads in general, since it can be argued to minimize conflict, boosting both safety and efficiency of the network. However, access constraint is not generally beneficial for a public transport system or pedestrian networks (2005: 179). While access constraint has been built into more modern road layouts, "it has often been retrofitted to traditional street grids, where main streets have side streets closed off, to improve traffic circulation and safety on main

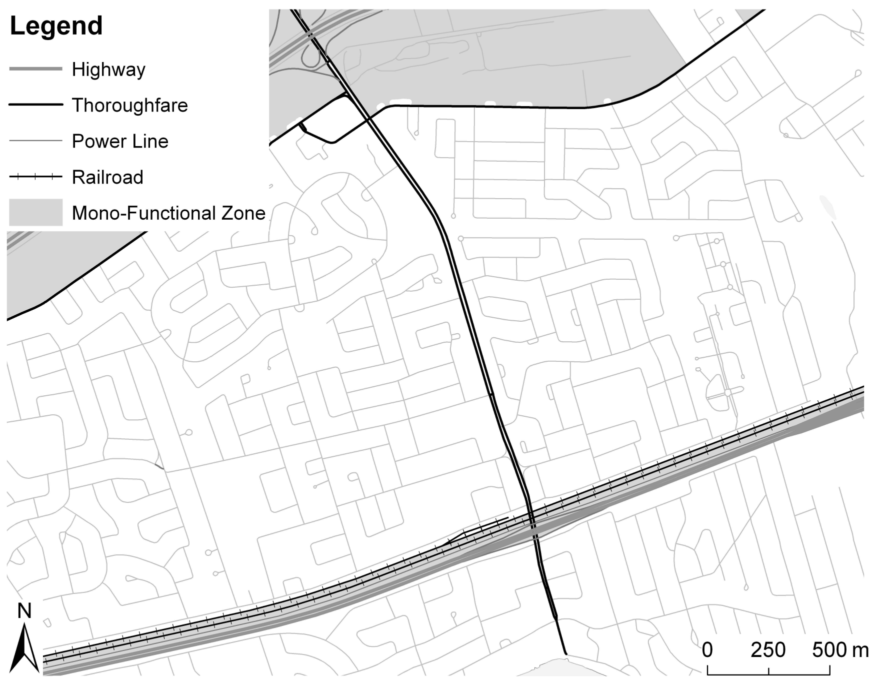

Figure 5.4: Access constraint as a physical characteristic for thoroughfare identification.

routes" (2005: 172). One needs only to look at streets such as Saint Denis Street in Montreal for examples where traffic engineers intervened to prohibit turning in certain directions.

These two major physical criteria allow us to distinguish between major routes within the street system by limited access and their upward connections. Realizing this, 'arteriality' then becomes the major determining factor for identifying the major thoroughfares and they will form a contiguous network. Although, in more traditional urban environments - at least those which pre-date the introduction of highway and traffic engineering's normative models focused on a strict organization of functional arteries - the determining factors are other.

5.3.3 Other Morphological Criteria

Apart from these two major physical characteristics, urban boulevards and functional arterials are also intra-urban routes, connecting various districts and/or 'neighborhoods'. They are linear in configuration and designed for higher traffic flow, while spanning significant distances. As a consequence, they often constitute crossing points of the first order barrier network, where overpasses, gates or bridges grant some permeability to the barrier and ensure minimal levels of connections between adjacent urban sectors. They often connect directly to the highway system denoted by their arteriality. The level of spatial resolution, at which arterials manifest themselves is the city/settlement scale.

Considering the arterials' relationship with the parcel and building structure, the functional arterial would possess at best irregular 'pertinent strips', as they are characterized by limited access to abutting properties. In many cases no access will be granted to buildings from such arterials. Congruent with the general post WWII planning practices, access to abutting properties is also often limited to heavy commercial or industrial uses, such as gas stations, strip malls, warehouses, and services catering to motorists, etc. Typical urban boulevards, on the other hand, possess regular 'pertinent strips' and are therefore framed by continuous series of facades. Intersection spacing is also different between the two as the urban boulevard will possess at grade intersections, preferably within 180m spacing (Larochelle and Gauthier, 2002: 6), whereas the intersections are much more sparse with the more modern functional arterial. Within a functional hierarchy, arterials are "similar in function to freeways but with at-grade intersections and direct access to abutting property. "In practice, access is usually limited to intersections at one-half to one-mile [or 0.8 to 1.6 km] intervals" (Jacobs et al., 2002: 91), a similar frequency as intersections with urban highways. Due to the presence of pedestrians, urban boulevards will tend to have more signalized formal intersections, where as functional arterials will aim to have less formal intersections in order to keep traffic flow moving. Arterials usually connect to other arterials or to more local streets via appropriate turning lanes etc., as to not interrupt traffic flow. In terms of relative position within the system, they usually act as a dividing axis between districts or morphological units that correspond to neighborhoods. Hence, arterials are usually deployed at the edges of the urban tissue.

Exceptions do exist to these rules, where a thoroughfare will end up in a central position relative to the morphological unit that it crosses. Such is the case with Sherbrooke street in Montreal. In most of its course, it runs along the top of the escarpment, an escarpment which constitutes a natural barrier that divide up morphological units. In Westmount though, Sherbrooke street runs in a central position within a plan unit that is framed by a hilly terrain to the North and an escarpment to the South. In its Westmount segment, Sherbrooke street is serving the role of a thoroughfare and of a local commercial street. Sherbrooke street being the only 'east-west' connection explains why it assumes the function of a thoroughfare. A central position and permeable street network explain the function of local high street assumed by the street in Westmount on the other hand. What this is example does point to, though, is that the nature or function of a street which possesses a high degree of arteriality is still dependent on its relative position within the system, that is, its position relative to other barriers, leading to it being centrally located or peripherally located, and this position will influence the conditions found along the street in question.

With the physical characteristics[ii] described, we can now identify the major thoroughfares throughout the Montreal urban landscape (Figure 5.7). This process is tedious in some respects as it requires visual assessment and cross referencing between the above described physical attributes, especially in more traditional tissues which pre-

Figure 5.5: The identified thoroughfare network for the island of Montreal.

[ii] A table demonstrating the varying types of major thoroughfares discussed here is available in Appendix B.

date widespread automobile use. There are some clear patterns in the density of thoroughfares and types found on the island of Montreal, there is clearly higher density in the inner-city made up of the Plateau, Mile-End neighborhoods as well as downtown Montreal in and around the central business district (CBD). If we compare this with the urbanized areas in 1952 (Figure 5.8), it is clear that these areas correspond to the older parts of the city. This era corresponds with a pre-highway Montreal before the widespread introduction of car oriented suburban development, with the urbanized area corresponding to the railway network and along much of the shoreline of the island. There is an decrease in the thoroughfare density moving east, with a few exceptions which appear to correspond to older villages and towns which were annexed with

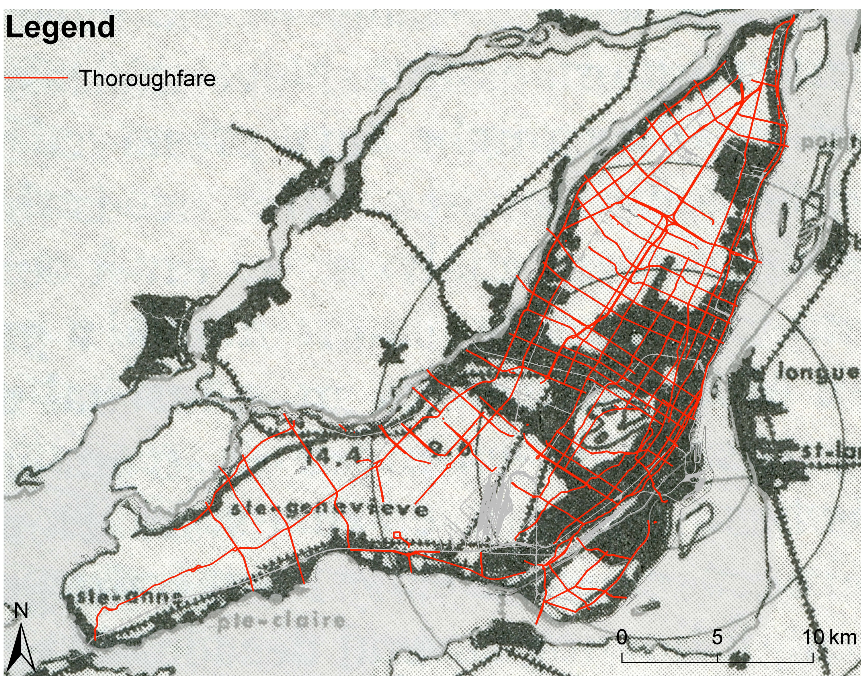

Figure 5.6: Thoroughfares overlayed with 1952 urbanized areas (Source: Marsan, 1981: 332).

Montreal as it grew over time, giving them similar patterns as found in the centre city.

Finally, to the West, there is clearly the lowest thoroughfare density; in these conditions thoroughfares fall under the category of functional arterials. These are designed for high-speed and automobile travel and therefore are spaced out and isolated in many ways from surrounding tissues, getting closer to highways in function than an urban boulevard and a regular street. These arterials were functionally deployed in conjunction with the introduction of highways to the urban landscape which opened up land further from the centre for speculative development. These patterns will be further explored in the coming chapters looking at the urban landscape mosaic.

5.4 Mono-functional Zones Revisited

Once the network of urban thoroughfares (functional arterials and urban boulevards) is mapped, another layer of mono-functional zones is revealed (Figure 5.10), that exerts an impact at a 'local' scale. Such zones are not "visible" at the territorial/ regional scale. They can be assimilated to what Jane Jacobs was referring to in her work on border vacuums (1961). These second order mono-functional zones, include commercial, industrial uses, open spaces or parks. They puncture the landscape and can have varying configurations. The criterion that applies for their identification is similar to those applied to first order mono-functional zones. There are two categories of second order mono-functional zones. The first category pertains to zones that puncture the residential tissue in question creating a hole in an otherwise continuous fabric. Parc Lafontaine, in the Plateau-Mont-Royal for instance, is a large local park that includes

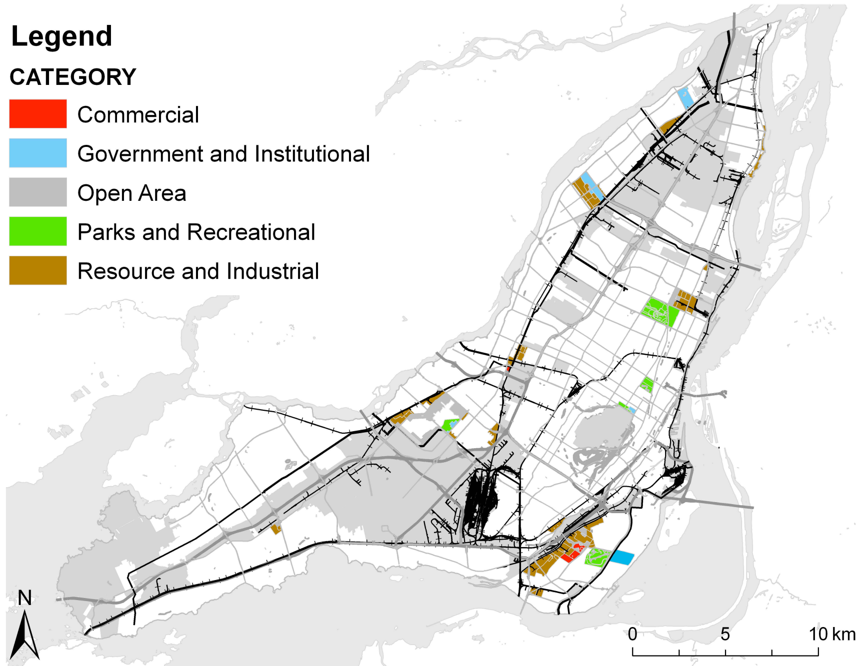

Figure 5.7: The second order mono-functional zones revealed by the thoroughfare network.

features such as human-made lakes which makes direct crossing difficult. By their scale alone, such parks constitute barriers and define the edges of neighbourhoods that they border. Neighbourhoods on either side of such parks would be considered distinct. The second category of second order mono-functional zones pertains to the zones that act as a barrier due to the fact that they span from one barrier to the next: for instance, from one first order barrier to a thoroughfare or between two thoroughfares.

5.5 Conclusion

This second layer of boundaries add substance and depth to the urban landscape, creating a matrix of barriers and boundaries (Figure 5.11) which delineate distinct residential and mixed-use areas on the island of Montreal. These areas can vary in their internal land-uses, internal street configurations etc. The matrix at this point comes closer and closer to identifying distinct 'neighbourhoods' on the island, although there may still exist more local scale boundaries, such as more local traffic streets or specialized tissues (i.e. large park) which follow more closely the theories identified in the specialization of streets. These routes would not necessarily span long lengths within the system, but at the territorial or city/settlement scale they are not visible. They may become visible when one zooms into a patch or small area of patches for a particular inquiry. In particular there may exist varying level of arterials within post-war developments which divide distinct residential tissues within a patch and funnel traffic outwards to main arterials identified and up to highways, following the principles of arteriality. The identification and analysis of such route types is not covered in this thesis.

Figure 5.8: The matrix of urban barriers and boundaries.

6. Exploring The Urban Landscape Mosaic | Chapter Six

6.1 Introduction

Having established the elements which constitute urban barriers and boundaries in detail, we now consider them as a morphological framework impacting/defining the urban landscape of the Island of Montreal. When combined, these barriers and boundaries form a network that fragments the urban landscape. Such a network acts as a matrix that defines the inhabited/inhabitable spaces of the city. By analogy, mapping the cities barriers and boundaries is like producing an x-ray of the skeleton that holds the parts together. These defined areas, or patches, also result in the formation of a mosaic structure similar to a stain glass window for instance, which can be referred to as the urban landscape mosaic. The analysis of Montreal's urban landscape mosaic will be conducted using two distinct fragmentation geometries and will explore patterns in configuration and dimension as well as fragmentation both quantitatively and qualitatively using descriptive statistics, visual assessment and various metrics such as the effective mesh size (M_{eff}) and mesh density (S_{eff}). The effective mesh size, to recap, is a metric which expresses the probability that two random points in a region are connected (Jaeger et al., 2007). While not based on morphological criteria, we will use the administrative boundaries which delineate the 2004 amalgamated boroughs for the island of Montreal[iii] as a reporting area (Figure 6.1). These administrative boundaries are also useful as a contextual point of reference when discussing landscape patterns as we can

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[iii] I am aware that certain areas on the island of Montreal have since de-merged from the City of Montreal, but to keep with an island wide analysis, these administrative boundaries simply serve as a point of reference.

discuss their relative position (geographically) within the mosaic. As well, these boundaries would also coincide with areas which have an abundance of socio-economic and demographic information, useful for future research, which could be compared with levels of fragmentation between each borough and the island as a whole.

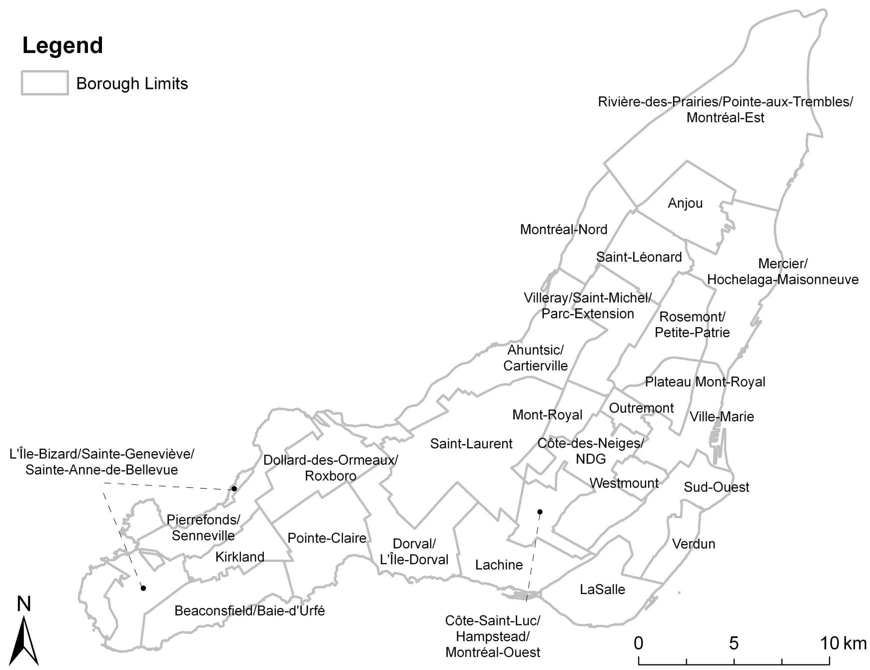

Figure 6.1 The Island of Montreal 2004 Borough administrative boundaries (L'Ile Bizzard is not shown).

6.2 Fragmentation Geometry One

The first fragmentation geometry (FG1) is created through the identification, mapping and subsequent removal of the layer of urban barriers identified in Montreal's urban landscape. The said barriers correspond to what has been described earlier as the "first order barriers". Conducting this analysis allows for a preliminary assessment of inhabited / hospitable settling areas on the island of Montreal. This leads to the creation of a mosaic structure made up of individual patches of land which are composed of mainly residential and/or mixed use tissues (Figure 6.2). The following section (6.3) will take into consideration second order barriers such as thoroughfares and will produce a more thorough account of the meshing that informs the city spatial layout. Yet a two pronged analysis is useful as the first step provides a basis for comparison when considering the fuller picture at step two.

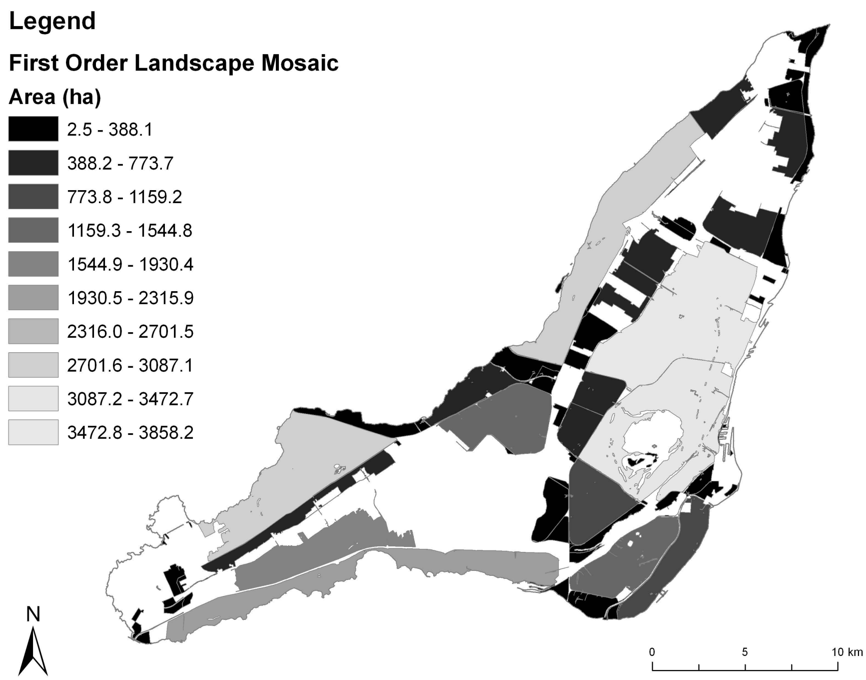

Figure 6.2: The urban landscape mosaic - fragmentation geometry one (FG1).

6.2.1 Landscape Pattern Analysis

In terms of descriptive statistics, FG1[iv] is composed of 94 patches larger than 2.5 ha [v], with patch sizes which range from 2.51 to 3858.2 ha, occupying a total land area of

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[iv] The complete data set pertaining to size and configuration by patch can be found in Appendix C.

[v] The true patch count for FG2 was significantly higher (910 patches) if we were to include those smaller than 2.5 ha. Patches smaller than 2.5 ha were ignored in the analysis in order to reduce spaces between highways etc which were smaller than an average Montreal block.

30038.76 ha. The mean and median patch size were calculated as 319.6 ha and 38.7 ha respectively, the large discrepancy between the two results implies that there are significantly more small patches than large ones. This is confirmed by the distribution of the patch area within FG1 (Figure 6.3), which indicates that the largest concentration of patches are those which are smaller than or equal to 10.0 ha in size. As well, the majority of patches is less than or equal to 120 ha. In order to assess the landscape mosaic for its internal patterns we will categorize the patches based on their size (in ha) and explore the patterns present within each category beginning with the patches which are larger than 1500 ha.

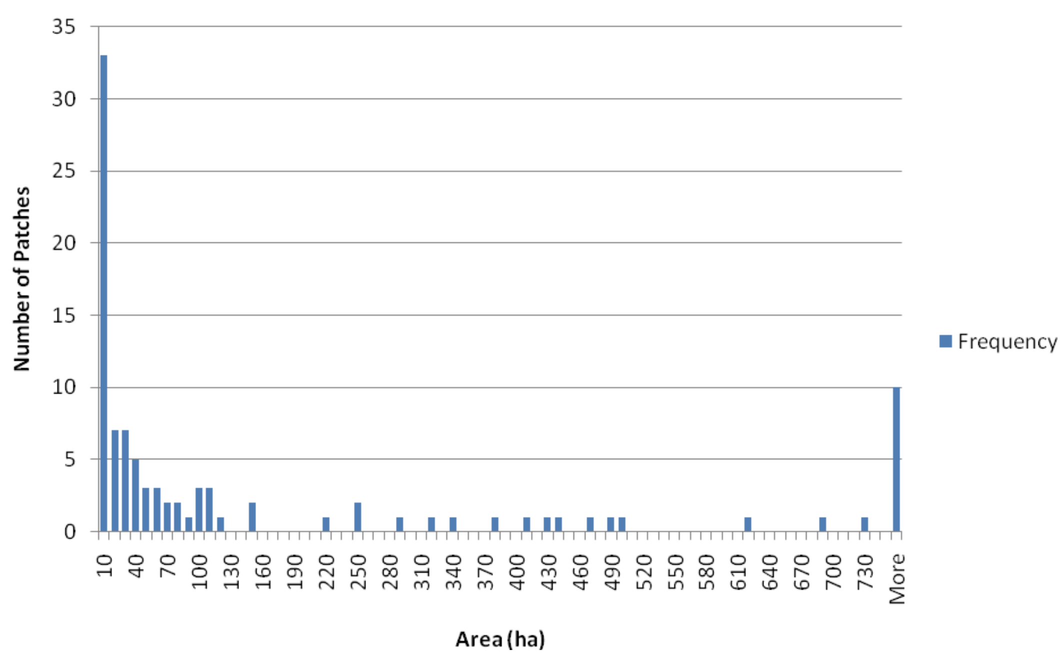

Figure 6.3: FG1 - distribution of patches by area.

Patches Larger than 1500 ha

We begin by considering those patches which are greater than 1500 ha [vi] (Figure 6.4). Patches within this category account for 6.4% (6 of 94) of the FG1 patch mosaic while occupying a significant amount, 54.9% (16503.9 ha out of 30038.8 ha), of the inhabited space on the island. This category contains elongated patches along the islands edges, and more compact shaped patches in what is the Downtown of the island. In terms of their relative position, there are clear breaks in their presence in the East of the island and towards the centre, arguably presenting a gap which separates the West Island from the inner-city. This separation coincides with the presence of large industrial zones on either side which disconnect and cut away from large patches through the segregation of

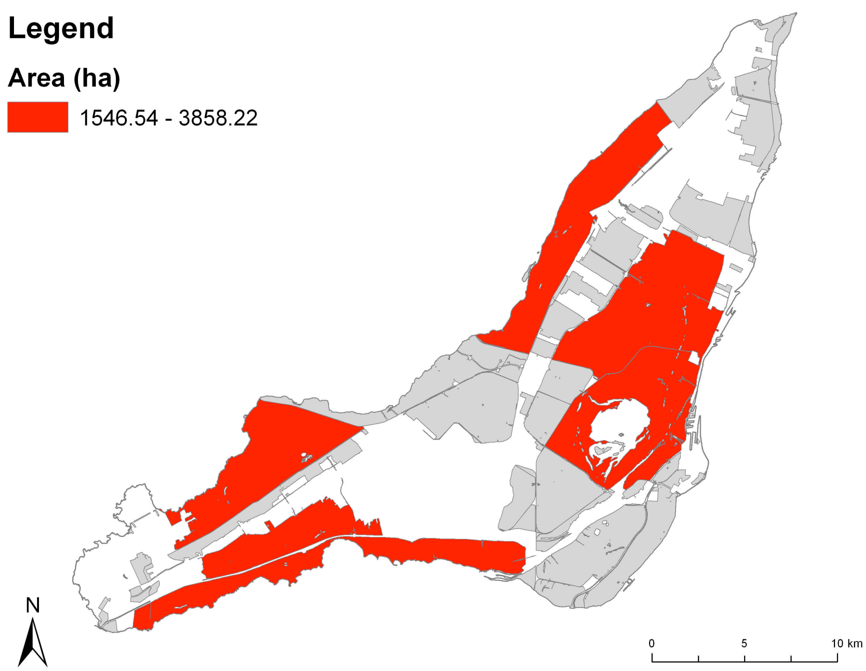

Figure 6.4: FG1 - Patches larger than 1500 ha.

[vi] It is worth noting that no patches have areas between 1550 ha and 2300 ha.

land uses. While there are elongated shapes within this category, based on size alone, these patches would have the ability to support multiple ‘neighborhoods’ presenting regular configurations due the abundance of residential land within. Rather than a homogenous blend of residential development within, these patches are subject to further fragmentation by urban boundaries in the form of major urban thoroughfares and smaller yet still significant mono-functional zones.

Patches between 500 and 1500 ha

The patches between 500 and 1500 ha (Figure 6.5) account for 7.4% of the patches in FG1, and occupy 22.2% (6663.0 ha out of 30038 ha) of the mosaic. They display a distinct pattern towards the centre of the island, with a lone patch to the west which is extremely elongated in shape and another to the east which is much more compact. The patches grouped in the centre themselves vary in shape, but are all relatively compact and large enough to support varying types of internal development. They occupy the previously described ‘gap‘ separating the West Island from the centre. Within this category, the most concerning of the patches is the elongated one located in the west which runs between a highway (and associated specialized tissues) and high tension power-lines. The space available would not be a hospitable settling environment conducive of supporting compact residential development. But this patch is located in a suburban area, and would be defined by auto-centric development where accessibility is built in terms of automobile access rather than pedestrian access.

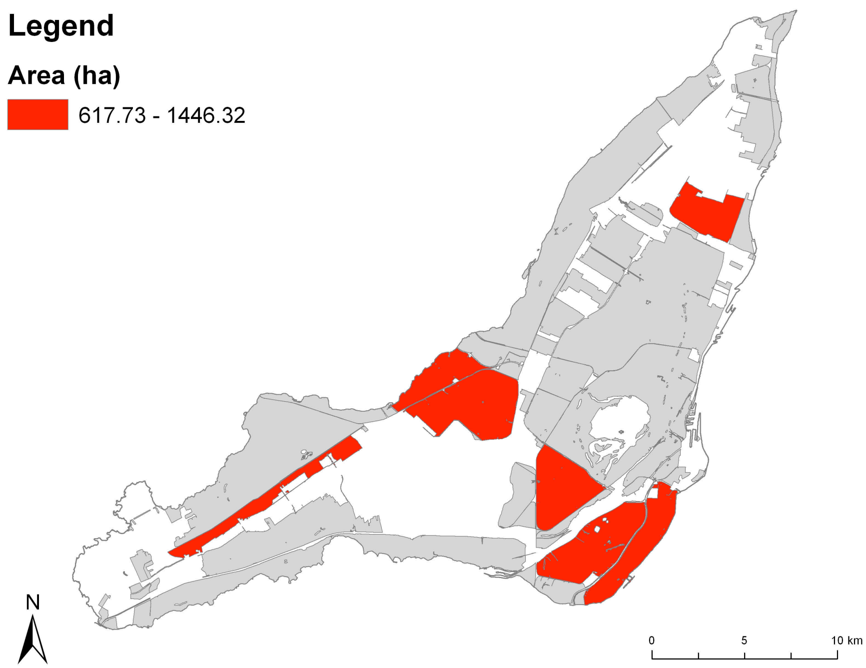

Figure 6.5: FG1 - patches between 500 and 1500 ha.

Patches Between 120 and 500 ha

Patches between 120 and 500 ha (Figure 6.6) make up 16% (15 of 94) of the patches in FG1, and occupy 16.7% (5024.5 ha out of 30038.8 ha) of the landscape mosaic. They are located along industrial infrastructure and surround the centre city. There are no patches in this category located in the western portion of the island. This category displays patches with more capricious shapes as well as more compact configurations, depending on the space between barriers. Three patches of quite elongated shapes are present here pressed between a rail line and a natural barrier. While squeezed between two barriers, the size of the patch may meet the thresholds[vii] to support multiple 'neighbourhood' developments within, but the elongated configuration may

[vii] Threshold refers to the magnitude or intensity that must be exceeded for a certain reaction, phenomenon, result, or condition to occur or be manifested.

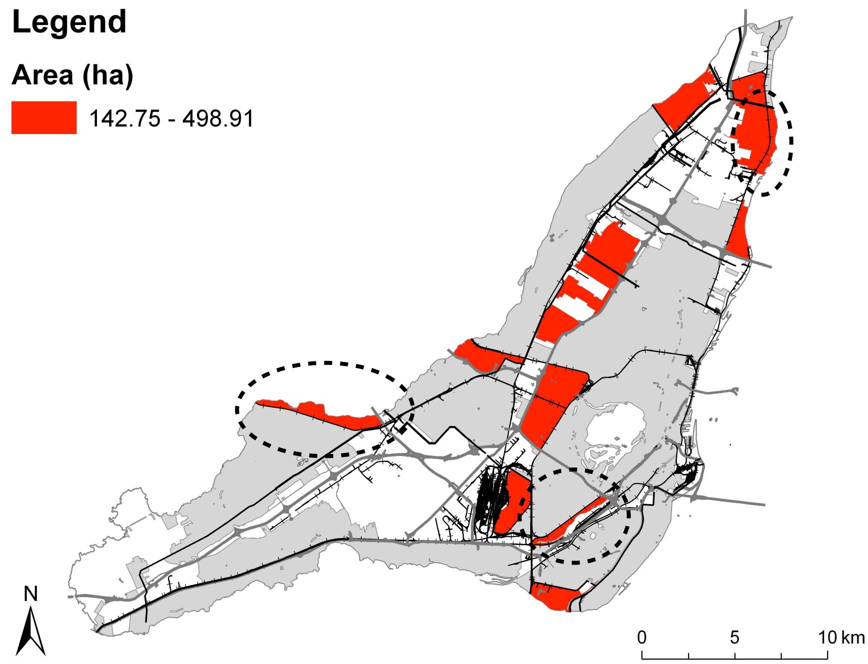

Figure 6.6: FG1 - Patches between 120 and 500 ha. Three patches formed from the presence of railway and natural barriers possessing similar shapes are highlighted.

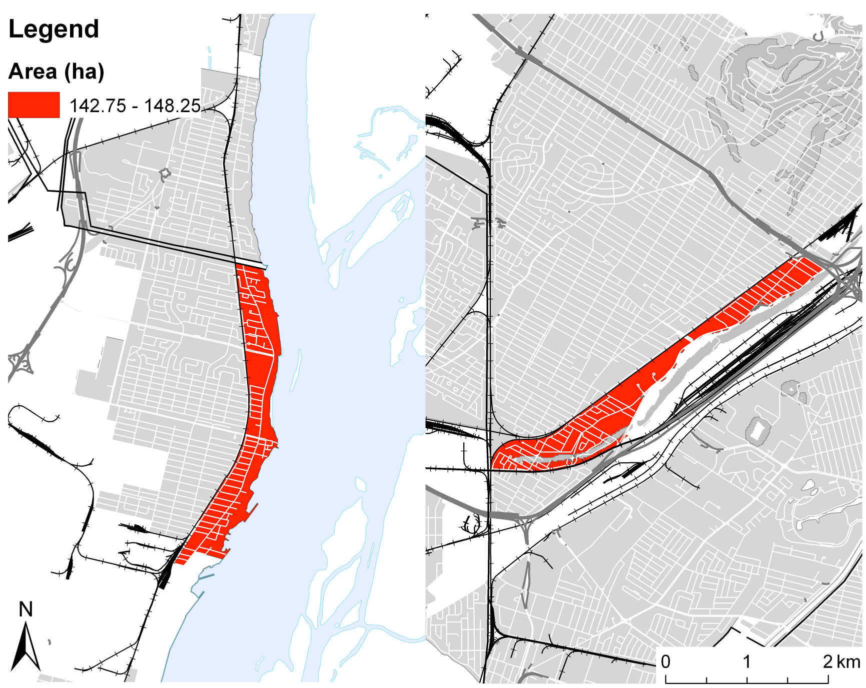

Figure 6.7: Two capricious patches formed by the presence of railways and natural barriers.

hinder coherent development within. In this case, this is demonstrated in Figure 6.7, which presents two patches sharing similar size and configuration but in different geographical areas on the island. In this case, as the configuration of the patch becomes less compact, the centrality and ability to move multi-directionally is compromised arguably limiting the internal development potential of the patch. These patches are very similar in size and relative position to similar barrier types. In one case the patch is between a railway and a river and in the other a railway and an escarpment. What is interesting in this case is that one is found on the edge of the island (left) and the other is found in a much more central location (right) at the top of the escarpment. They both however result from similar conditions being present and also contain similar street network patterns and development types within.

Patches Between 40 and 120 ha

The next category contains patches between 40 and 120 ha (Figure 6.8) which accounts for 19.1% (18 of 94) of patches within FG1, occupying 4.5% (1359.8 out of 30038.8 ha) of the landscape. There are some clusters present in four distinct areas; the Boroughs of the Sud-Ouest and Lachine to the west, Ahuntsic-Cartierville and Ville Saint-Laurent in the north, and Riviere-des-Prairies/Pointe-aux-Trembles to the far east of the island. If the linear infrastructure (highway, rail lines, canal and high-tension power-lines) is superimposed onto FG1 (Figure 6.9) one can see that these groups of patches correspond to areas with a high concentration of multiple major infrastructure networks,

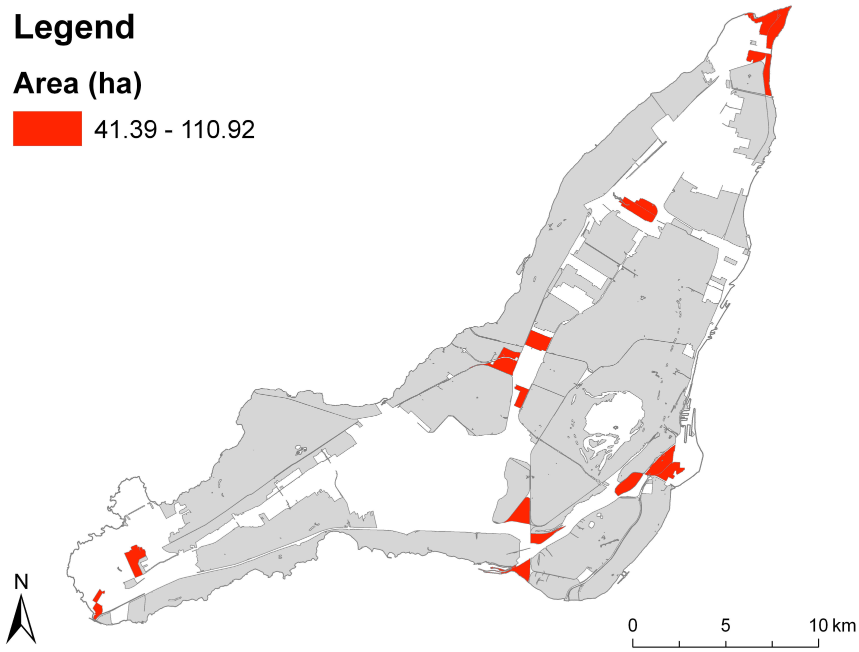

Figure 6.8: FG1 - patches between 40 and 120 ha.

Figure 6.9: FG1 - patches between 40 and 120 ha with linear urban barriers.

running in close proximity, especially in the the southern portion of the island. Contrasting between the two figures, there is what appears to be a lone patch of residential tissue in the east, which falls within the borough of Anjou. This patch though is bisected by a high-tension power line, leaving two smaller patches. The majority of patches in this category are are surrounded by impermeable barriers such as highways, railways, and power lines. These relatively impermeable barriers limit the number of external connections, thereby increasing the importance of streets which allow for continuous movement within and through the patch. These conditions may lead to instances of a street having to function as both a main commercial artery and traffic artery within a patch. A reality that could present its own set of complications, and would be worth future consideration. Patch isolation when considered along with a patches' relative level of compactness, may not be conducive to support local services as these barriers can greatly effect catchment areas. In the Sud-Ouest for instance (Figure 6.10), the neighbourhood of Pointe-St-Charles is visible as two distinct patches bisected by a rail line. Local amenities present are located in the Northern portion, with little available in the South. The railway reduces crossing points between the two sectors, this lack of permeability impedes pedestrian access to amenities for inhabitants to the South. Similar conditions exist in the neighbourhood of St-Henri as well, where the southern sector of the neighborhood is highlighted in this category. Local amenities including access to the metro network are located in the northern portion of the neighborhood (not highlighted in this category). These two working class neighbourhoods share similar conditions as they are crossed by railway infrastructure. This, coupled with a decline in manufacturing and industrial uses in the area and Montreal as a whole, raise the question of industrial obsolescence in Western Cities. While this topic is heavily discussed and researched, little is discussed regarding the obsolescence of the associated transportation networks which were once at the heart of these neighbourhoods. With the conversion of many industrial spaces to other uses (often residential or commercial) these routes no longer serve the same purpose and in the case of St-Henri and Pointe-St-Charles, the potential benefits of their removal or transformation to other corridor types should be explored. Certain instances of barrier removal or mitigation would allow for the potential of increasing connectivity between patches in fragmented areas, leading to improved permeability between patches, and increases in pedestrian catchment areas. Such interventions coupled with new development, thereby increasing the population base, may also lead to

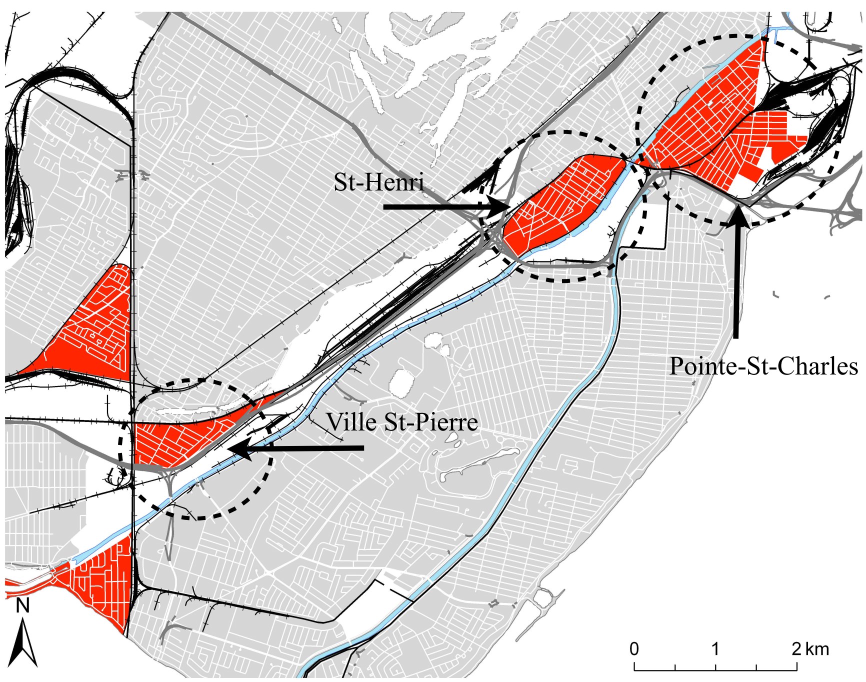

Figure 6.10: Close up of isolated residential patches in the Sud-Ouest and Lachine boroughs.

potential improvements in walkability and increase the capacity for and equal distribution of more services of proximity. Alternatively, there is Ville-St-Pierre in the borough of Lachine which is located between a highway to the south, and a railway and escarpment to the north. This small residential neighbourhood is extremely isolated and due to the presence of the escarpment to the north, the potential removal of such a barrier may result in little improvement to the settling area without major redevelopment. The conditions discussed are present in each area originally highlighted, but the internal and external conditions all differ. The ideas presented would require exploration and are ideas for future discussion rather than direct recommendations, they are used to demonstrate the applicability of the landscape mosaic approach to understanding the city.

Patches Between 10 and 40 ha

The next category contains patches between 10 to 40 ha, which consists of 16.0% (15 of 94) of patches in FG1 (Figure 6.11), which occupy 1.1% (337.76 ha of 30038.76 ha) of the inhabited landscape. The patches within this category represent a form of interstitial tissue[viii]. They are patches of a limited size and are usually found in between linear infrastructure running in parallel or at the border of linear infrastructure and larger mono-functional zones, but are larger than the previously discussed residual spaces. Their limited size coupled with the isolation caused by first order barriers is a cause for concern regarding their ability to serve as hospitable settling environments. As well, in terms of their relative position, these patches are not centrally located in the downtown or Plateau-

[viii] Interstitial tissues are defined as the connective tissue between the cellular elements of a structure.

Mont-Royal for instance; two locations which possess higher building and population densities. This condition leads to the assumption that the densities within these patches would be relatively small, and therefore the ability to support the services of proximity,

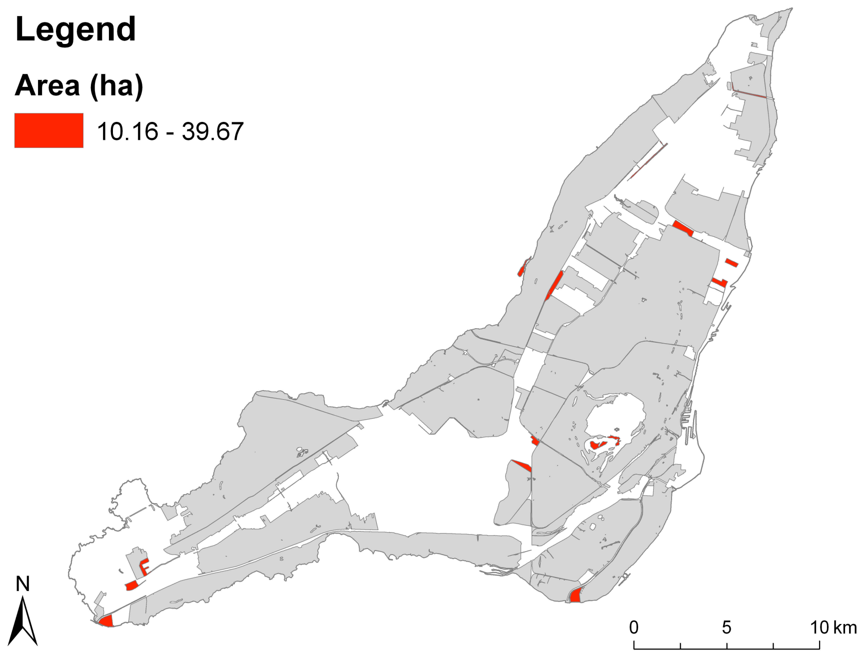

Figure 6.11: FG1 - patches between 10 and 40 ha.

outside of specialized services, would be compromised, and the viability of these patches as walkable communities could be called into question[ix]. Examples of some patch conditions found here include those which are divided by high-tension power lines on one side from surrounding tissues (Figure 6.12 & 6.13). This type of barrier limits the through connections to neighbouring patches which are in close proximity, placing a higher traffic emphasis on the streets which are continuous outside of the patch. The

[ix] The issue of built density is quite interesting, and while assumptions are made regarding this condition a direct correlation is not established as this is outside of the scope of this research.

remaining internal streets network may not be suitable for supporting local commercial uses, or in some cases this may also result in the superimposition of commercial activity along a major thoroughfare for lack of alternatives.

Figure 6.12a: (left) & 6.12b: (right) Patches segregated by high-tension power lines in two different urban contexts.

Figure 6.13a: (left) & 6.13b: (right) - Two patches which are surrounded by mono-functial zones.

Two other examples of small extremely isolated patches are those which are completely surrounded by large mono-functional zones (Figure 6.14 & 6.15). A lack of through continuity of the street networks present here when coupled with patch size severely impacts catchment size, regardless of the patches having relatively regular compact configurations. These conditions would have a drastic effect on the services that such a patch would be able to support. One could speculate that anything more than a local convenience store, if that, would not be present without being extremely specialized in nature. These patches may be optimal if one works in very close proximity but beyond that one could doubt the population supporting substantial public transit use, leaving the automobile as a likely means of transportation.

Patches Less than 10 ha

The largest number of patches are smaller than or equal to 10.0 ha in size (Figure 6.14). This category represents 35.0% (33 of 94) of the patches within FG1. This category contains many patches which can be characterized as residual spaces resulting

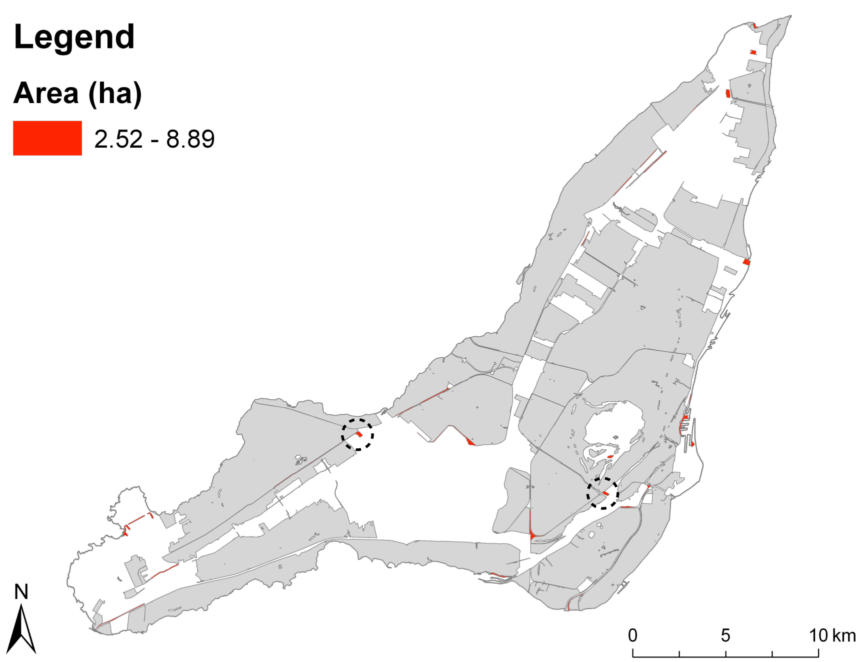

Figure 6.14: FG1 - patches smaller than 10 ha, also referred to as residual tissues (two inhabited patches are highlighted).

from their relative position between two first order barriers running in parallel, usually between highway lanes and/or interchanges, in close proximity. Patches in this category also come in the form of open spaces or parking lots in industrial areas next to highways for instance. What is concerning in these cases is that these patches are zoned as residential, a function which they are not necessarily suited for. In some cases, they are sometimes delineated by linear barriers on one side and a large mono-functional zone on the other, a condition which implies potential for expansion via the redevelopment of surrounding tissue, which would not require the removal of regional infrastructure. Patches which are completely bordered by linear impermeable barriers would be limited by their size and isolation which would make it quite difficult to support residential development let alone services of proximity, arguably eroding the settling environment within the tissue. An example of such a condition is the patch framed by the Decarie Highway, leading into the Turcot Interchange, the St-Jacques escarpment, a rail line and the (currently empty) former Glen rail yard site, the future home of the Mcgill Univeristy Health Centre (MUHC). This patch (Figure 6.15) consists of one block and a half of residential tissue, it is extremely isolated from its surrounding patches by urban barriers. Also, the southern edge of the block is the home of a car

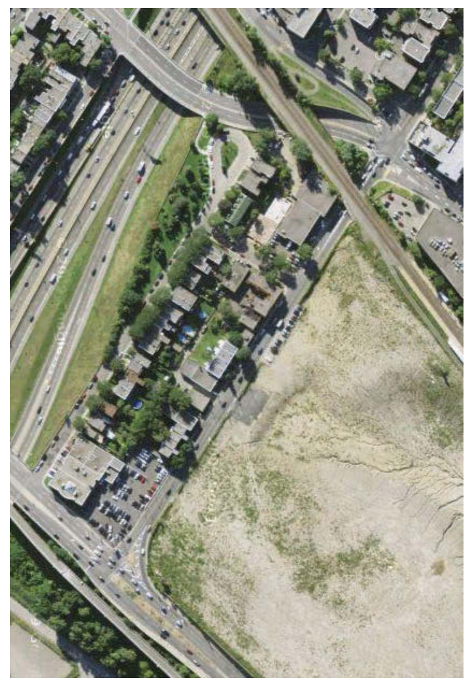

Figure 6.15: Example of an isolated patch of residential tissue framed by highway, railway, escarpment and former rail yard.

dealership fronting onto a major urban thoroughfare. This type of specialized commercial use is the only type of commercial use present within this patch. Another example, located in the Pierrefonds/Roxboro borough of Montreal, is home to the Cloverdale Co-op, one of the largest housing co-ops in Canada, and home to many under-privileged families with a large immigrant population. This patch is surrounded by the Parc-Nature du Bois-de-Liesse and a high tension power-line to the North creating an isolated residential pocket (Figure 6.5). The internal street network is composed of curvilinear cul-de-sacs with rectangular multi-level apartment buildings at irregular angles to the street. Accessibility within this area to public transportation and services of proximity may be compromised due to the physical conditions present.

Figure 6.16: The Cloverdale Housing Co-op in Pierrefonds, an isolated pocket of under privilige.

6.2.2 Quantifying Shape

I have pointed to shape patterns above but the mosaic structure can be quantified to determine shape patterns independent of patch size. FG1 reveals unique shape patterns (Figure 6.17) in the urban landscape mosaic model through the Exchange Area property. Namely, Exchange allows for the identification, through quantification, of patches which display more compact or more elongated shape patterns regardless of patch size. In this

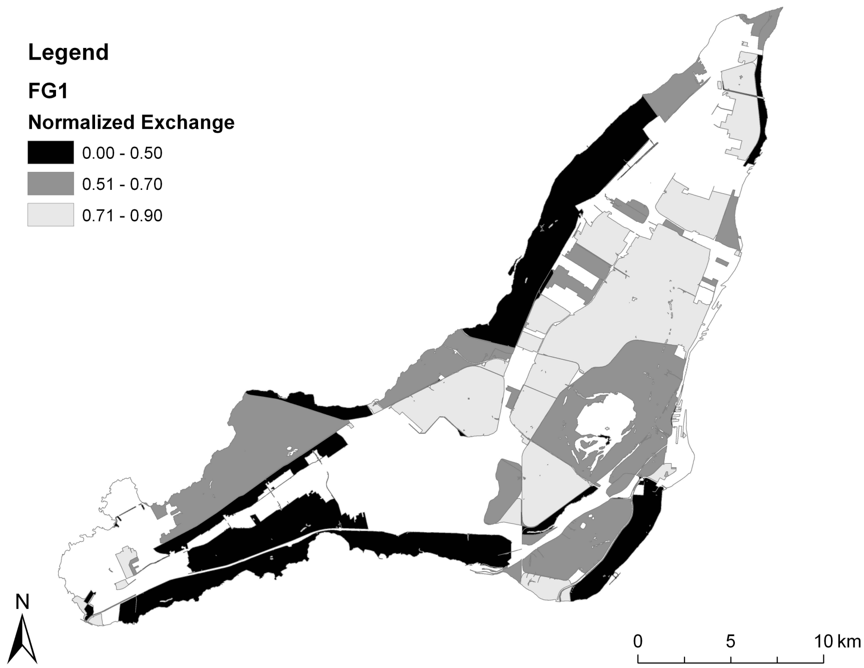

Figure 6.17: An assessment of patch shape (compactness) based on the area exchange property.

example, clear areas of elongated patches exist running along the shore line of the island, as well as between a railway and the escarpment and along a highway path and a power line. These patches, especially those at the lower level (i.e. if nExchange is less that 0.5), would represent patches which may not represent hospitable settling environments. In FG1 though, these patches are not too common and many of those highlighted as having a low exchange, are compensated by being much larger patches which arguably mitigates the impacts of the patch shape itself. Such large patches could theoretically contain many neighbourhoods within (obviously dependent on their sizes), inversely if the exchange value were to be extremely low (i.e. lower than 0.3 for instance) the patch may not have the width to support a compact enough neighbourhood with barriers running closely together and potentially having a major impact on the internal conditions of the patch.

This idea will be explored further in the following chapter as the quantification of shape also allows for a comparison of shape impact on other quantifiable features.

6.2.3 Quantifying Fragmentation

In FG1 the calculated effective mesh size (m_{eff}) for the entire island of Montreal is 12.21 km^2 (or 1221 ha) with an effective mesh density (S_{eff}) of 8.19 meshes per 100 km^2. This implies is that if a point was chosen at random on the island, the area that would be accessible on average would be 12.21 km^2 or in terms of mesh density, that within every 100 km^2 there are 8.19 individual meshes. For discussion purposes this mesh density translates to 81.9 patches per 1000 km^2, or 0.82 patches per 10 km^2. With no point of comparison these numbers do not demonstrate much but they do provide an overall assessment of the island of Montreal in terms of its fragmentation level. These results become more useful as I move forward comparing them to more localized results by borough. In terms of fragmentation levels by borough (Figure 6.19 & Table 6.1), the most fragmented borough was L'Ile-Bizard/Sainte-Genevieve/Sainte-Anne-de-Bellevue (M_{eff} = 1.59 km^2; S_{eff} = 63.05) , and the least fragmented borough was the Rosemont/ Petite-Patrie borough (M_{eff} = 56.80 km^2; S_{eff} = 1.76). In the case of Rosemont/Petite-Patrie, the borough contains no first order barriers within. Its limits run along a railway, separating it from the Plateau-Mont-Royal Borough, and an escarpment to the south. To the North it has no physical barriers impeding movement between it and Villeray/Saint-Michel/Parc-Extension. Through the CBC method for calculating the effective mesh size, in the case of Rosemont/Petite-Patrie the effective mesh size is more than three and a half

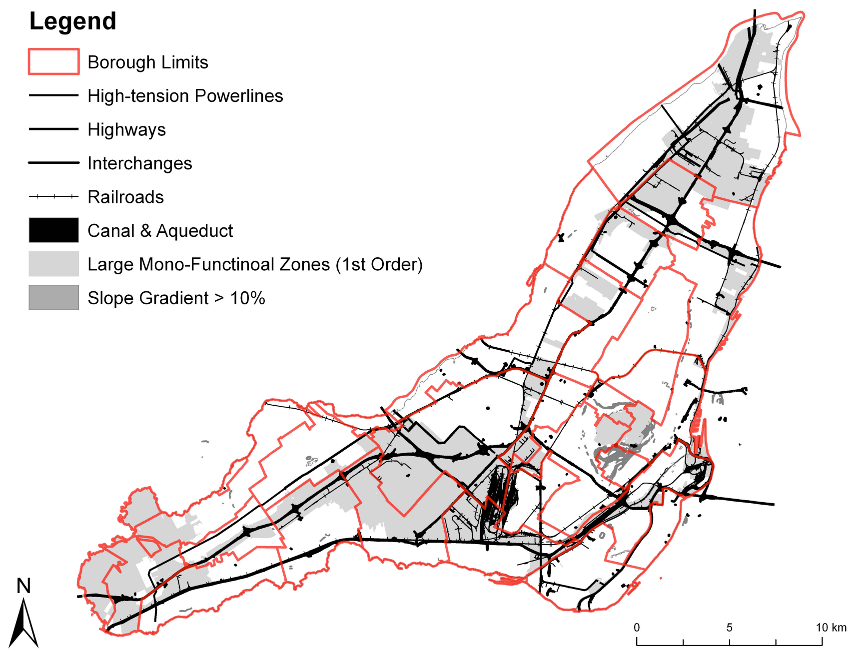

Figure 6.18: Network of first order barriers (Highway, Rail, Powerlines, Slopes, Mono-functional Zones, etc.) and the administrative boundaries of Montreal.

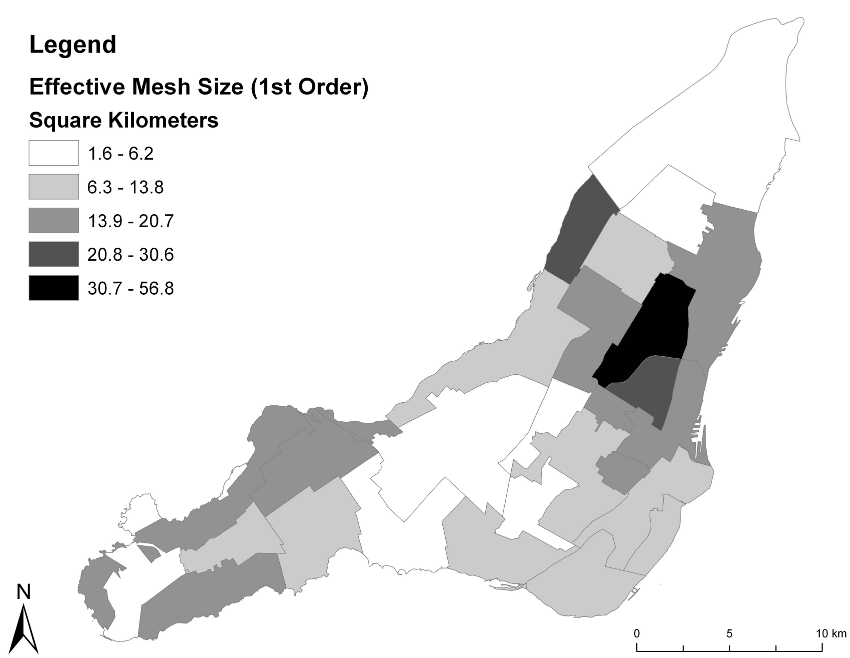

Figure 6.19: FG1 - effective Mesh Size (CBC) by Borough.

Borough	Area (km^2)	$M_{eff}CBC$ (km^2)	S_{eff} (per $100km^2$)
L'Ile-Bizard/Sainte-Genevieve/Sainte-Anne-de-Bellevue	16.56	1.59	63.05
Anjou	13.86	2.96	33.80
Mont-Royal	7.87	3.27	30.60
Cote-Saint-Luc/Hampstead/Montreal-Ouest	10.04	4.78	20.92
Saint-Laurent	42.93	5.02	19.91
Riviere-des-Prairies/Pointe-aux-Trembles/Montreal-Est	61.61	5.47	18.28
Dorval/L'Ile-Dorval	20.89	6.20	16.13
Verdun	6.07	8.60	11.63
Lachine	17.88	8.60	11.63
Sud-Ouest	16.23	8.62	11.61
LaSalle	16.12	8.70	11.50
Kirkland	9.67	10.06	9.94
Pointe-Claire	18.92	10.56	9.47
Saint-Leonard	13.55	10.76	9.30
Ahuntsic/Cartierville	25.52	11.97	8.35
Cote-des-Neiges/Notre-Dame-de-Grace	21.17	13.76	7.27
Pierrefonds/Senneville	26.90	14.94	6.69
Beaconsfield/Baie-d'Urfe	17.00	15.28	6.55
Westmount	4.02	17.44	5.73
Villeray/Saint-Michel/Parc-Extension	16.46	18.96	5.27
Ville-Marie	13.84	18.98	5.27
Mercier/Hochelaga-Maisonneuve	25.47	19.08	5.24
Outremont	3.82	19.65	5.09
Dollard-des-Ormeaux/Roxboro	17.32	20.71	4.83
Montreal-Nord	10.93	27.32	3.66
Plateau Mont-Royal	8.14	30.62	3.27
Rosemont/Petite-Patrie	15.89	56.80	1.76

Table 6.1: FG1 - effective mesh size and mesh density results by borough.

times larger than the size of the borough itself, implying that there is very little in terms of fragmentation impacting this borough. A similar ratio is found in the Plateau Mont-Royal borough, the second least fragmented borough, which is bordered by a railway, escarpment and Mount-Royal, but still has connections to much of the centre of the island and downtown. Looking at the most fragmented boroughs there are a mix of conditions present, with the most fragmented boroughs having more large mono-functional zones within their areas. These barriers lead to the presence of isolated residential pockets within the borough with little permeability between them and their closest residential patch resulting in little in terms of walkable connections between them. Residents would have to rely on personal automobiles, or public transportation in order to access neighbouring patches. In this regard the barrier with the most impact on the fragmentation levels appears to be these large mono-functional zones which segregate residential tissues from one another. Much of the linear transportation infrastructure is absorbed or buffered by large non-residential mono-functional zones. Boroughs which appear to be fragmented by transport infrastructure are mainly the Sud-Ouest (M_{eff} = 8.62 km^2; S_{eff} = 11.61) and Lasalle (M_{eff} = 8.70 km^2; S_{eff} = 11.50) which share very similar results. Their effective mesh size results are close to half of the actual borough size in each case. When comparing the two though, there are clearly larger individual residential patches in Lasalle. The Sud-Ouest contains small isolated residential patches (notably the Southern part of St-Henri, and both parts of Pointe-St-Charles). What leads to the similarity in results in this case, is the point of contact between the Sud-Ouest and the Ville-Marie borough and beyond via the tunneled portion of the Ville-Marie Expressway which mitigates the barriers physical impact. This creates a very large patch in the mosaic, in some ways skewing the results found in the Sud-Ouest and accounting for the overall results discusses here. The pure quantification of fragmentation at this level does provide interesting information as a means of comparison which is flexible based on the choice of reporting area, but as with most metrics it is not possible to capture the effects of barriers which may still have psychological impacts and physical impacts through changes in urban tissues present in the case of fringe-belt development.

6.3 Fragmentation Geometry Two

The addition of the network of identified thoroughfares and second-order mono-functional zones to the barrier structure (and subsequent removal) from the mosaic model results in a more complex and fragmented urban landscape mosaic (Figure 6.20) compared to FG1.

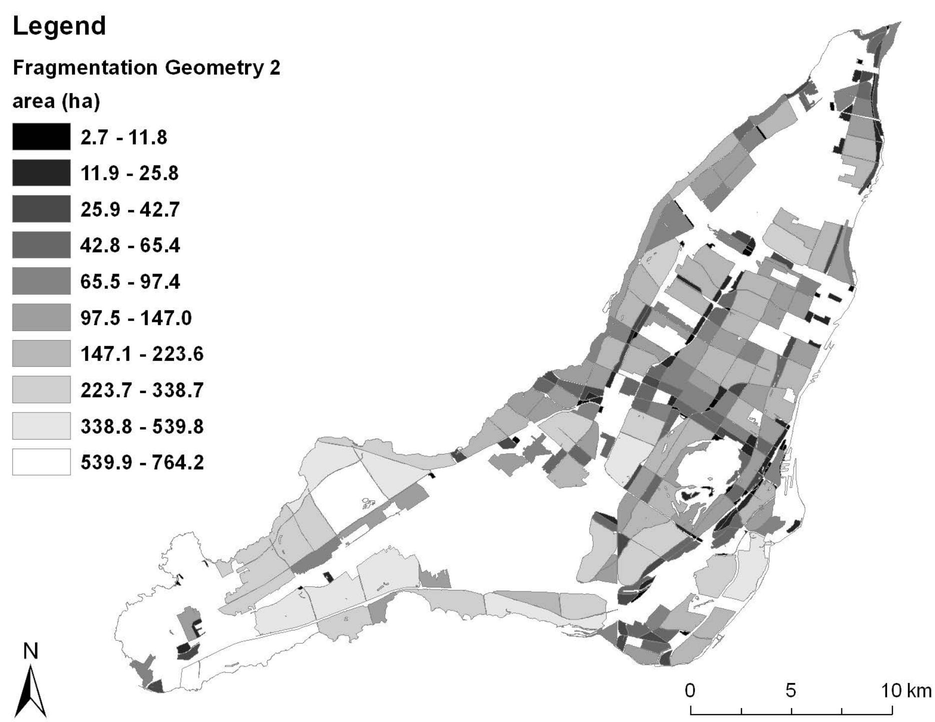

Figure 6.20: The second order fragmentation geometry (FG2).

6.3.1 Landscape Pattern Analysis

In our second fragmentation geometry (FG2)[x], the patch count is 296 residential or mixed-use patches, which occupy a total land area of 27232.7 ha. The smallest patch size is 2.6 ha, while the largest is 764.23 ha, significantly smaller than the largest patch in FG1. The median and mean patch size were measured as 57.30 ha and 92.94 ha respectively, which are much closer in size than our previous fragmentation geometry. FG2 clearly demonstrates much more regularity to the patch structure as there are various groups of similar patch size and shape throughout the mosaic. Patch size appears to be finest in the downtown and plateau areas of the island, corresponding to areas of early urbanization. Patch size appears to increase as we look towards the east and even further increases in the west of the island, adhering to the urbanization patterns of Montreal where the most recently urbanized areas possess a larger patch structure. Another patch pattern which appears in FG2, is the presence of elongated patch configurations along the edges of the island running along the St-Lawrence River. These elongated patch types occur regularly and likely possess similar internal development patterns due to being limited by their very small width. Elongated patch configurations are also visible adjacent to Mount-Royal, in the centre of the island, in some cases demonstrating an alteration of patch orientation from North/South which is found in the plateau for instance to East/West in the downtown or North of the mountain itself. This is indicative of natural features having similar influence on development patterns whether being in the form of a river or mountain.

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[x] Patch size, configuration and street network connectivity data is available in appendix D.

In terms of distribution by patch area (Figure 6.21), FG2 displays a majority of patches being smaller than 10 ha, similar to what was found in FG1. The distribution also demonstrates that there are more relatively small patches in FG2 compared to FG1, as indicated by the mean and median patch size. The patch sizes relative to each other are no longer so drastically different as there is a steady overall decrease in the frequency of

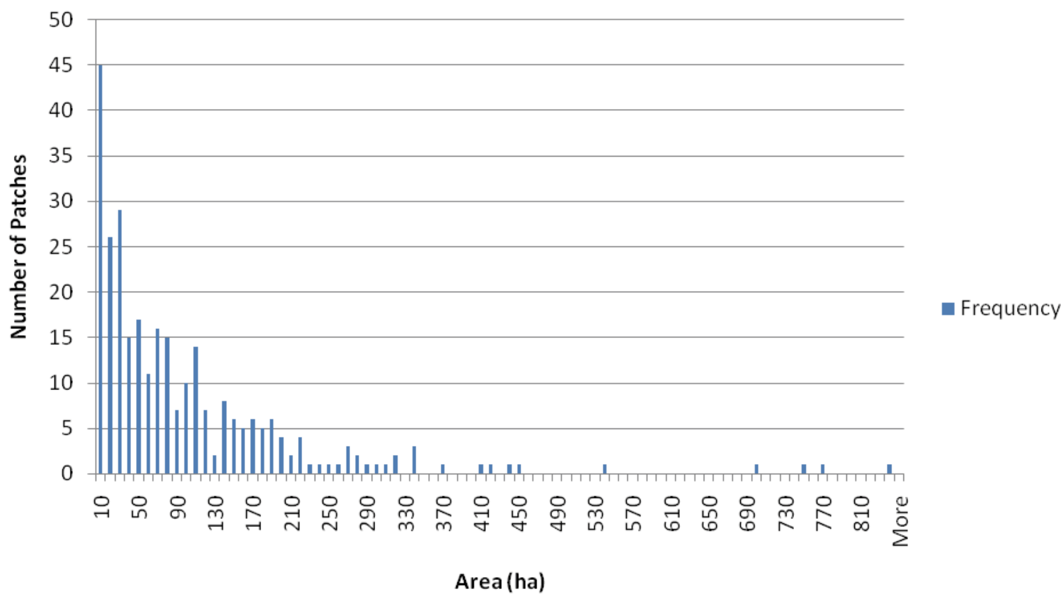

Figure 6.21: FG2 - the distribution of patches by area.

patch size spanning from the majority of patches appearing in the less-than-10-ha range, slowly decreasing into the 300-ha range, with larger patches appearing interspersed between 330 ha and 770 ha. This is perhaps indicative of a threshold patch area existing within Montreal's urban landscape, pointing to a potential 'neighbourhood unit' of certain size and configuration, which most likely varies by period of development which corresponds to improvements in transportation technology (i.e. street car suburbs vs post-war suburban development).

Patches Larger than 250 ha

Similar to the treatment of FG1, we will begin by analyzing the largest patches, in this case, patches which are larger than 250 ha (Figure 6.22). This category contains 8.1% (24 of 296) of patches, with the majority of these patches being located in the western portion of Montreal and occupying 33.1% (9008.7 ha of 27232.7 ha) of the identified inhabitable/inhabited area on the island. There is a clear concentration of larger patches in the Western portion of the island, an area which is characterized by more typical suburban development of lower built densities and curvilinear street structures. The relative position of the patches is indicative of a pattern related to patch size and the

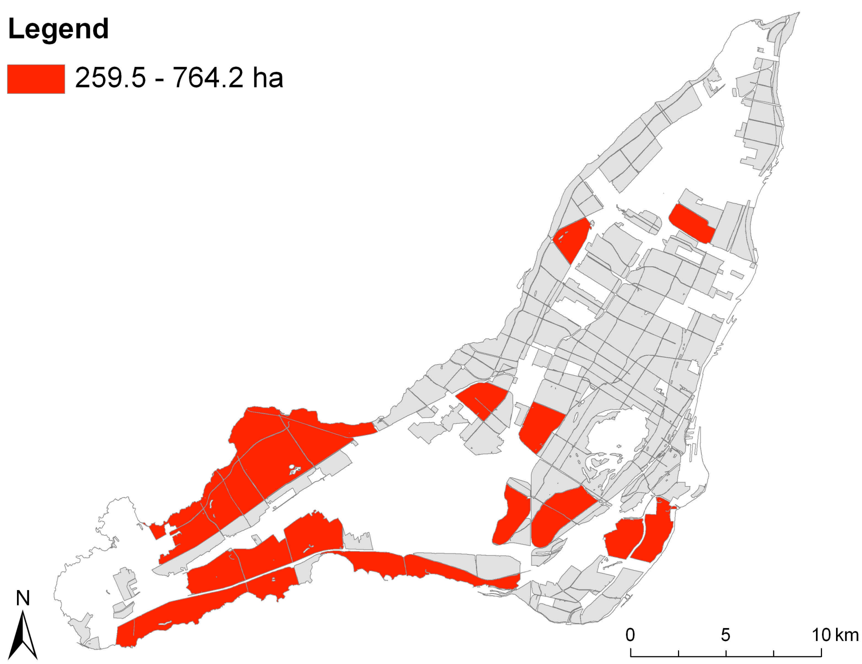

Figure 6.22: FG2 - patches larger than 250 ha.

urbanization of the island. These larger patches are associated with auto-centric post war suburban development where the distribution of functional thoroughfares were meticulously planned and were part of a larger hierarchy of route types which were aimed at limiting through traffic within a given area.

Patches between 120 and 250 ha

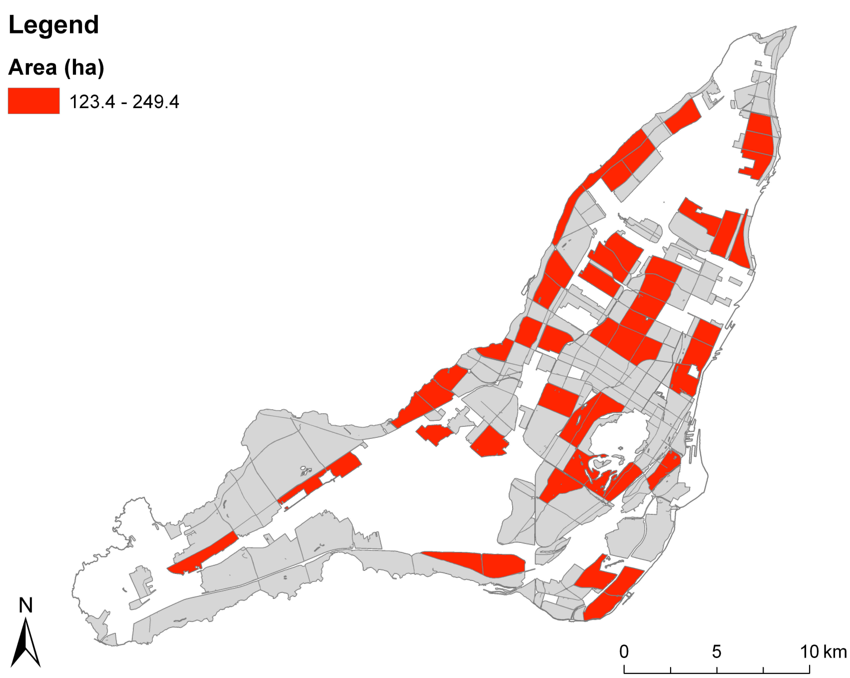

Figure 6.23: FG2 - patches between 120 ha and 250 ha.

In the 120 to 250 ha range, we have 17.1% (50 of 296) of patches (Figure 6.23), which occupy 30.9% (8425.3 ha out of 27232.7 ha) of the mosaic. There are concentrations in the eastern portion of Montreal, coming in the form of linear strips of similar sized and shaped patches, reflecting regularity in the allotment system in Montreal's urbanization as well as standardization in the distribution of major thoroughfares indicating also that a spatial logic is at play within the urban organism even at this scale. In terms of patch configuration, there are some elongated patches in the West adjacent to the path of the highway and along the shore in the East, but overall there is regularity in the configuration or relative compactness in the patch structure.

Patches between 40 and 120 ha

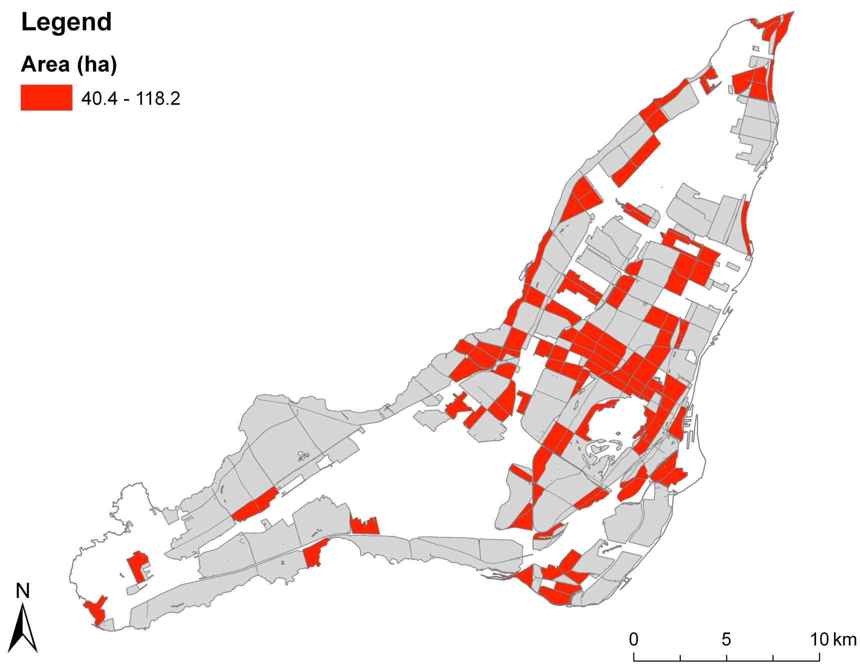

Figure 6.24: FG2 - patches between 40 and 120 ha.

The 40 ha to 120 ha (Figure 6.24) patch size category consists of 32.8% (97 of 296) of the patches for the island of Montreal, occupying 27.9% (7602.3 ha out of 27232.7 ha) of the inhabited landscape. Patches within this category display a clear concentration in the downtown and Plateau Mont-Royal, Mile-End area, associating this category with older and denser parts of the city. There are also other pockets of similar patches throughout the centre and eastern portion of the island, indicative of areas which were urbanized earlier on as their own unique settlements which were later amalgamated into the City of Montreal as it expanded around them, thus accounting for similar patch size and configuration. A note-worthy fact pertaining to this category are patches which exist unchanged from the isolated patches of the same size discussed in FG1, for instance, the perviously explored neighbourhoods of St-Henri and Pointe-St-Charles which, experience a higher level of isolation due to the high prevalence of impermeable barriers. What is interesting is that these patches are similar in size to many of the patches found in the Plateau-Mont-Royal area, an area composed of multiple 'neighbourhoods' which is highly permeable due to the presence of a street grid pattern and possesses many services of proximity throughout. This raises the idea that the internal offer of a patch may also be dependent upon the type of barrier or boundary which defines it. Urban boulevards for instance serve a traffic function but do not disrupt the regularity of the grid present in many cases allowing for continuity of routes and larger overall permeability where one can travel easily from patch to patch in this context. This is much more difficult in areas with conditions such as St-Henri and Pointe-St-Charles creating unsuitable conditions for continuous routes to develop and evolve to meet local needs by capturing a larger catchment area regardless of the individual patch size. Another notable characteristic of this range is the mean and median patch size is in proximity to the theoretical "neighborhood unit" (Perry, 1929 & Duany et al., 2000) where a so-called optimal site size of approximately 65 ha is prescribed to meet a neighbourhood's land requirements for sustainable development. This adds another layer to the discussion pointing to a short coming of such a view as with a lack of continuity and permeability between these ‘neighbourhoods’ would result in potentially non-optimal settling environments as far as supporting mixed-use, walkable development capable of supporting local services of proximity is concerned.

Patches between 10 and 40 ha

Patches between 10 ha and 40 ha (Figures 6.25) make up 25.0% of the mosaic (74 of 296) and occupy 6.3% (1716.3 out of 27232.7 ha) of the inhabited landscape mosaic. Patches within this category display a pattern of linear trenches or extreme elongation in terms of configuration, or a similar divided ‘trench’ of rectangular patches running side by side. If we superimpose highways, railways and power-lines onto this category (Figure 6.26), the pattern which emerges indicates that these elongated patches and ‘trenches’ of smaller patches are found along the pathways of first order linear barriers, mainly major infrastructure networks such as highways, railways, and power lines. Such a pattern is notably absent in the western portion of the island, an area which corresponds to more recent suburban development, pointing to highway development following the path of the

Figure 6.25: FG2 - patches between 10 and 40 ha.

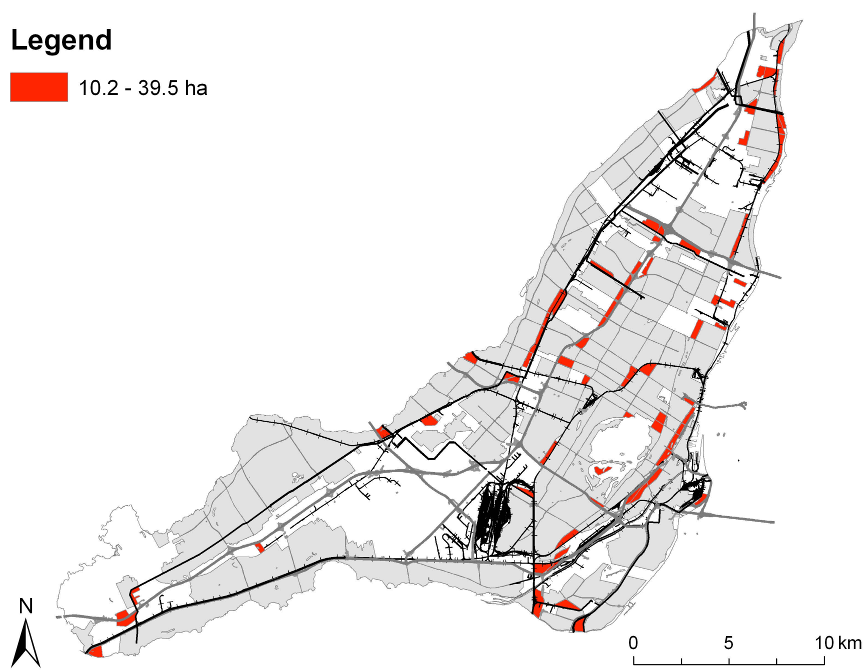

Figure 6.26: FG2 - patches between 10 ha and 40 ha with first order linear barriers.

railway in the case of Autoroute 20 (in the south), or in the case of Autoroute 40, the highway pre-dating or driving the urbanization patterns in this area. If we take a closer look at the case of Autoroute 40, in an inner-city context, where such interstitial tissues did develop (Figure 6.27) there is a clear pattern of urban tissues where no through routes exist. In this case, one must leave the patch in order to reach another street within the patch itself. This lack of permeability within the patch presents a condition which is not necessarily hospitable for settlement in the sense of fostering walkability and provision of local services. Similar to those patches previously discussed, these patches would also be

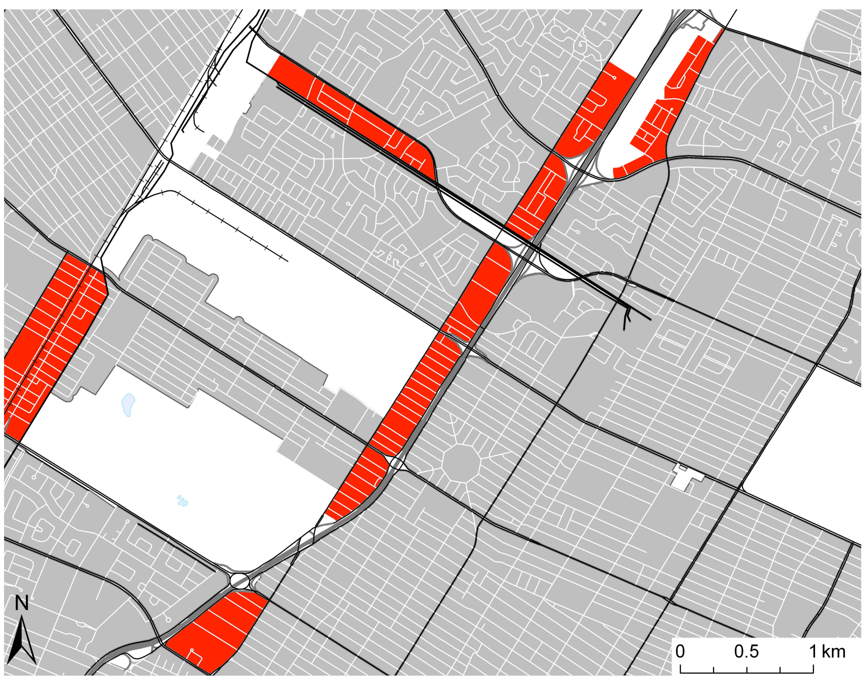

Figure 6.27: Interstitial tissues found along the north side of Highway 40, a clear case of severance from street patterns to the south of the highway emerges.

susceptible due to proximity of the highway for deteriorated environmental, physical and economic conditions. Also worth noting in this particular case, are the internal street patterns themselves in some of these patches which clearly display patterns which correspond to the patterns found to the immediate south of the highway as opposed to north of the thoroughfare (urban boundary) where alternate street patterns exist. This demonstrates clearly a potential case of physical severance of the urban tissue by the highway along its path.

A similar trench of elongated patches also exists along the Ville-Marie Expressway (Figure 6.28), eluded to in the previous category. This trench is unique as the highway along this path is at first above ground, then underground for a stretch then recessed as we move east to west, with plans to continue covering the exposed eastern portions. In this case, even though the highway is buried, it still exerts a barrier effect through its outward connections to thoroughfares running in parallel. The urban tissues found here are relatively older, compared to the west island for instance, possess a

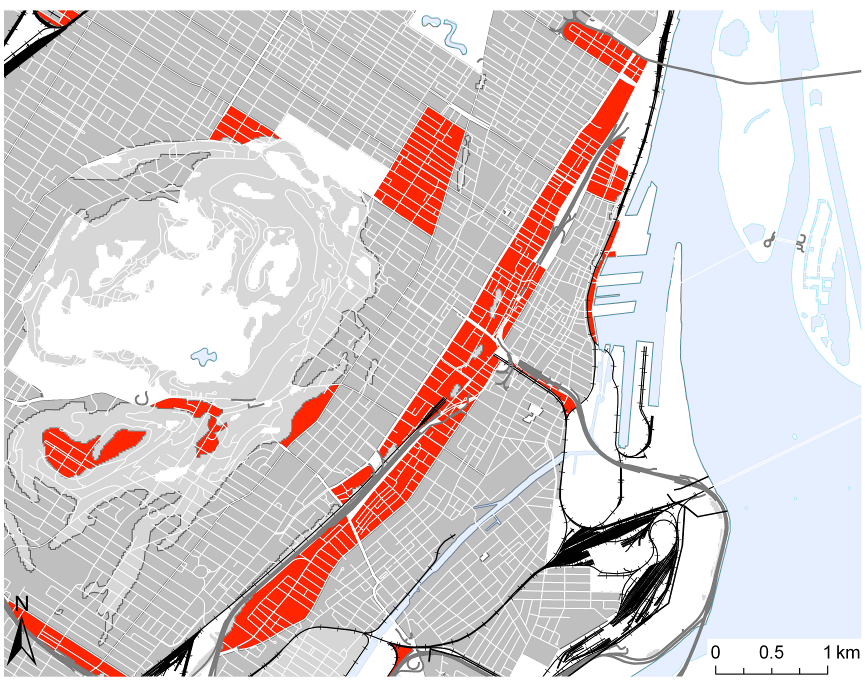

Figure 6.28: Trench of interstitial tissues along the path of the Ville-Marie Expressway.

relatively smaller block structure, and therefore an abundance of through routes crossing the patch are present within the identified areas. The historic old city of Montreal is also clearly visible; while not a patch in this category, it is surrounded by these interstitial tissues. The trench of interstitial tissues also borders with the Sud-Ouest Borough. The case of the 'trenching' effect raises questions of the impacts of buried or covering highways in urban areas and what improvements this truly offers beyond an increase in permeability through these interstitial tissues. Internal peripheries are already established and mitigating their impact on the urban form may prove more complicated than simply addressing the visible presence of the highway itself. The impacts of the barrier on the internal spatial logic of surrounding patches is likely to persist beyond the removal or mitigation of such a barrier without specific attention, a reality that one should keep in mind when assessing such conditions. The specific interstitial patches in this example also demonstrate variations of grid-type street patterns, likely due to the abundance of alterations to the urban fabric due to the introduction of the highway. Assessing this in detail would require an in depth analysis of the spatial impacts of urban highways in pre-existing tissues and is beyond the scope of this analysis.

The above examples of urban highways also raise questions regarding the strategic importance which may result from the connections between highways and thoroughfares within the urban organism. For instance, where these thoroughfares would thereby possess a higher strategic importance in terms of traffic flows, functioning in a similar capacity to service roads, thereby further bisecting urban tissues. Even more so is the case of the deployment of highways within the urban organism where the connections to streets in pre-existing urban areas may have just as detrimental impacts to the internal spatial logic of urban tissues as the highway itself. For example, such conditions alter the role of a street within the urban tissue due to its now strategic traffic importance, where it previously served a local commercial function for instance. This could potentially have very serious spatial impacts on the internal functioning of the tissue, such as the collapse of commercial activity resulting from the creation of internal peripheries within urban tissues where they previously did not exist. This could appear along the route itself or within the urban tissue due to a shift in centrality within a morphological area. These conditions represent cases which could lead to tissue malformations and an overall decrease in the quality of urban form.

Patches Smaller than 10 ha

I complete the analysis of FG2 with the patches which are smaller than 10 ha (Figure 6.29) which make up 15.5% (46 of 296) of the mosaic, and occupy 0.9% (236.1 out of 27232.7 ha) of the land area. Patches of this size are sprinkled throughout the mosaic with a larger concentration of them appearing in the centre of the island, more specifically in downtown. In this case these interstitial tissues tend to be located between a major urban thoroughfare and another first order barrier in the form of a highway or rail line. Looking closer at the inner-city of Montreal (Figure 6.30), one can see that there are clear concentrations of these small interstitial tissues once again along the path of the Ville-Marie Expressway, as well as at other crossing or intersection points between major

Figure 6.29: FG2 - patches which are smaller than 10 ha.

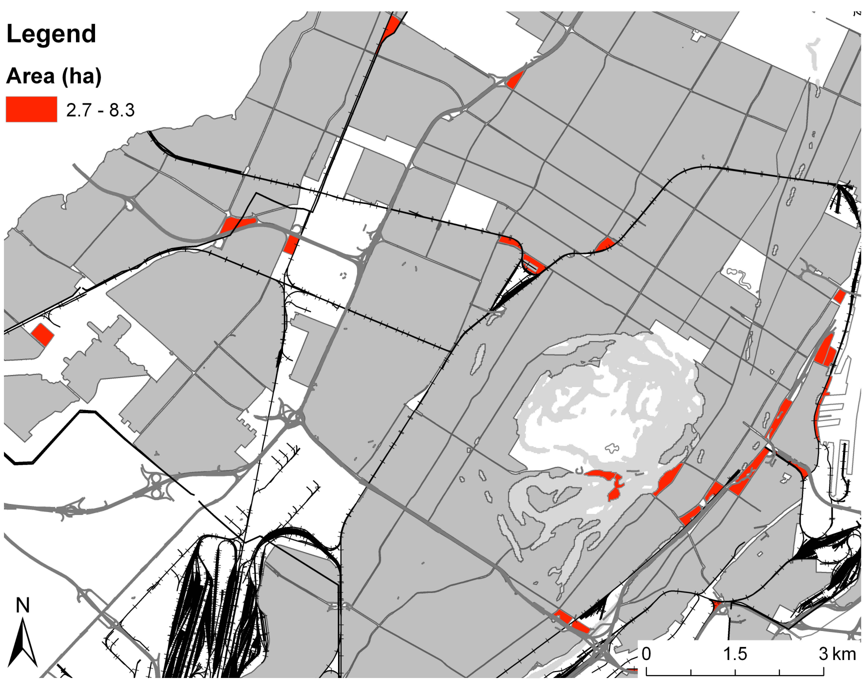

Figure 6.30: FG2 - a closer look at small interstitial tissues.

thoroughfares and railways or highways, although with less cases of consistent group patterns arising. Outside of the downtown, interstitial tissues are found along linear infrastructures, such as the small patches located just to the North of the Turcot interchange, and in the area of Mile-End and Parc-Extension where the configuration of the railway and the thoroughfare structure have left small residential tissues. The peripheral location of these patches and close proximity to major transportation infrastructure no doubt would impact the internal conditions of these patches environmentally, physically, and even economically as such conditions tend to coincide with lower property values and health concerns etc.

6.3.2 Quantifying Shape

In FG2 the patch structure is more refined and can be quantified and qualified in terms of shape using the area exchange property (Figure 6.31). Similarly to FG1, there are elongated patch shapes which appear along the shore of the island. These are pressed between a railway and the shore and represent some of the earlier developed areas on the island of Montreal. At the very least pre-dating the deployment of the highway system and the subsequent post-war suburban development. There are similar patches which appear along the path of a highway in the West and in the downtown along the Ville-Marie Autoroute. These patches are quite small as there has been shown to be quite the fragmented landscape in this area. Other notable occurrences of capricious patch shape are found around Mount-Royal, and along the steepest parts of the escarpment. Patches which have exchange values of less than 0.5 represent areas with a low compactness level, and dependent on the relative size (and in this case there are no overly large patches present) they would represent more at risk patches in terms of their ability to support higher-density residential or mixed use walkable environments. They may still be perfectly viable in terms of development standards for lower density residential development.

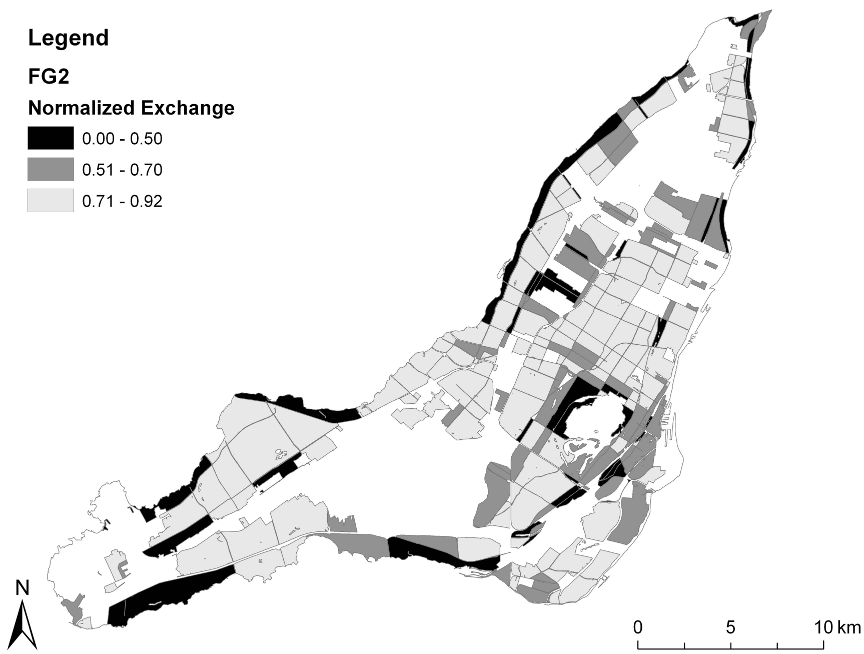

Figure 6.31: FG2 - assessment of patch configuration (compactness) based on the area exchange property.

6.3.3 Quantifying Fragmentation

In the second order mosaic the effective mesh size (m_{eff}) was calculated as 1.29 km^2 (129 ha) for the entire island of Montreal. The effective mesh density (S_{eff}) for the second order was calculated as 77.73 meshes per 100 km^2. These results imply that there is a significant increase in fragmentation when the urban boundaries are introduced to the

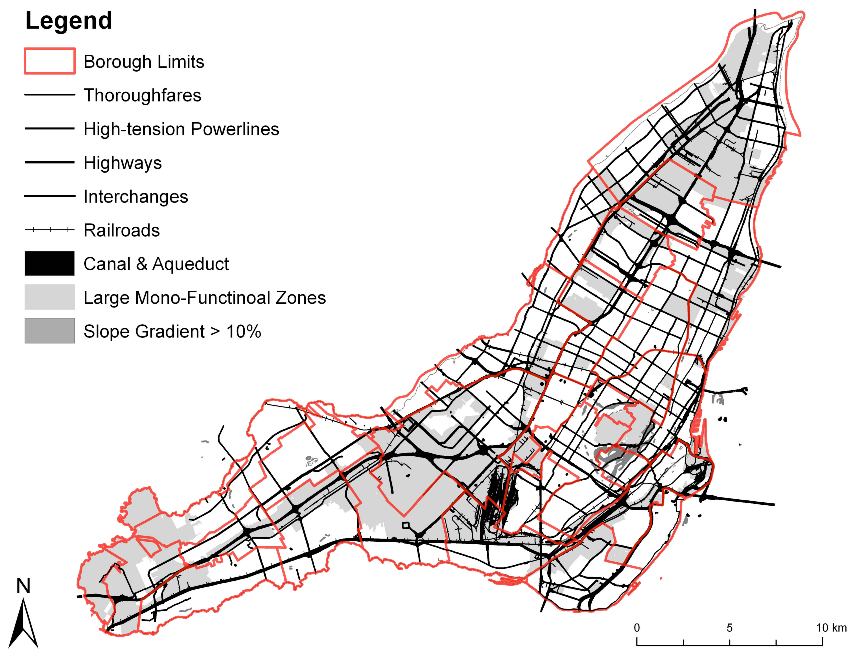

Figure 6.32: First and Second order barrier network with borough limits.

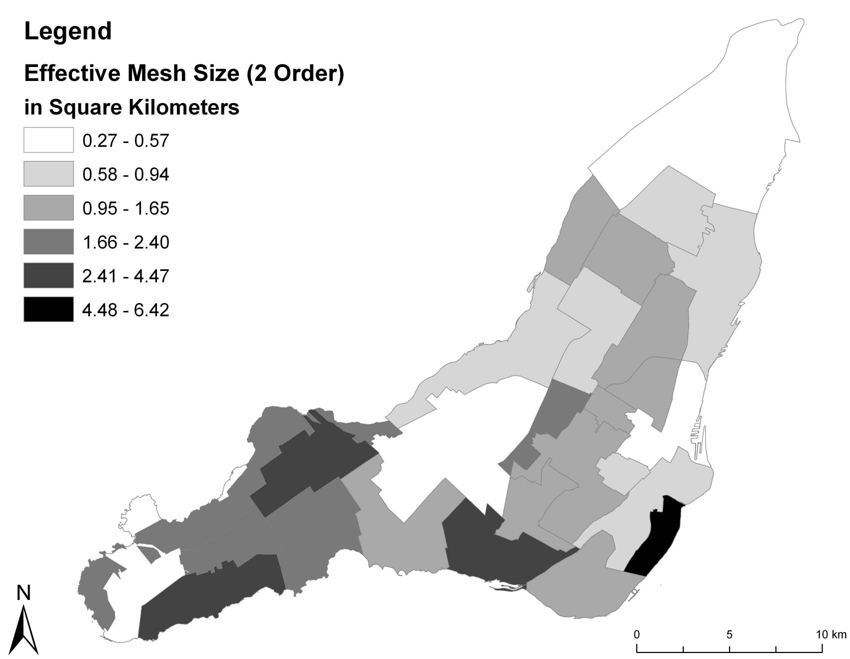

Figure 6.33: FG2 - effective mesh size by borough.

model (Figure 6.32). In this case the fragmentation levels are much higher across the board, with a much smaller effective mesh size overall. The borough with the highest fragmentation levels (Figure 6.33 and Table 6.2) is once again L'Ile-Bizard/Sainte-Genevieve/Sainte-Anne-de-Bellevue (M_{eff} = 0.27 km^2; S_{eff} = 376.43 meshes per 100 km^2) and the borough with the least fragmentation is Verdun (M_{eff} = 6.42 km^2; S_{eff} = 15.58 meshes per 100 km^2). Across the board there is little variance in terms of the resulting fragmentation levels, when compared with FG1. The three most fragmented boroughs L'Ile-Bizard/Sainte-Genevieve/Sainte-Anne-de-Bellevue; Riviere-des-Prairies/Pointe-aux-Trembles/Montreal-Est; and Saint-Laurent are located in areas where there are the largest concentrations of large mono-functional zones indicative of the fact that there are much more specialized uses in these boroughs than residential development. The borough of Anjou also possesses similar conditions in terms of the presence of large mono-functional zones. The Ville-Marie borough, home to Montreal's Central Business District (CBD), is also one of the more fragmented patches in FG2 (M_{eff} = 0.57 km^2; S_{eff} = 176.01 meshes per 100 km^2). This is accounted for by a higher built density and density of thoroughfares through increased route and tissue specialization which is typical of CBD development, along with the present first order barriers of the Ville-Marie Expressway and Mount-Royal. Other notable results are the West Island having significantly lower fragmentation levels, with the exception of L'Ile-Bizard/Sainte-Genevieve/Sainte-Anne-de-Bellevue discussed above. Otherwise, Pierrefonds/Senneville, Pointe-Claire, Dollard-des-Ormeaux/Roxboro and Beaconsfield/Baie-D'Urfe make up four of the top six least fragmented boroughs, which are all significantly less fragmented than the averages for the island as a whole.

Borough	Area (km^2)	M_{eff}CBC (km^2)	S_{eff} (per 100km^2)
L'Ile-Bizard/Sainte-Genevieve/Sainte-Anne-de-Bellevue	16.56	0.27	376.43
Riviere-des-Prairies/Pointe-aux-Trembles/Montreal-Est	61.61	0.42	238.87
Saint-Laurent	42.93	0.48	207.13
Ville-Marie	13.84	0.57	176.01
Anjou	13.86	0.62	161.45
Villeray/Saint-Michel/Parc-Extension	16.46	0.63	159.48
Westmount	4.02	0.77	130.23
Sud-Ouest	16.23	0.86	115.84
Mercier/Hochelaga-Maisonneuve	25.47	0.89	111.86
Ahuntsic/Cartierville	25.52	0.94	106.66
Saint-Leonard	13.55	1.03	96.72
Plateau Mont-Royal	8.14	1.12	89.14
Outremont	3.82	1.17	85.11
LaSalle	16.12	1.22	82.01
Rosemont/Petite-Patrie	15.89	1.22	81.98
Dorval/L'Ile-Dorval	20.89	1.26	79.33
Cote-des-Neiges/Notre-Dame-de-Grace	21.17	1.39	72.11
Montreal-Nord	10.93	1.39	71.86
Cote-Saint-Luc/Hampstead/Montreal-Ouest	10.04	1.65	60.72
Kirkland	9.67	1.95	51.32
Mont-Royal	7.87	2.12	47.16
Pierrefonds/Senneville	26.90	2.32	43.14
Pointe-Claire	18.92	2.40	41.58
Lachine	17.88	3.12	32.02
Dollard-des-Ormeaux/Roxboro	17.32	4.35	22.97
Beaconsfield/Baie-d'Urfe	17.00	4.47	22.36
Verdun	6.07	6.42	15.58

Table 6.2: FG2 - effective mesh size and density results by borough (ordered by fragmentation; most fragmented to least fragmented).

An alternative interpretation of the effective mesh size is the use of the result in determining threshold averages. As the fragmented area is translated into a mesh structure where the measure is arguably indicative of the size of the un-fragmented area one would have around oneself if a point was randomly chosen. That said, in the boroughs of the Plateau-Mont-Royal (M_{eff} = 1.12 km^2) and Outremont (M_{eff} = 1.17 km^2) for instance, being in the most dense areas of the island and arguably very desirable living environments. These results that the optimal patch threshold could be understood as being approximately 1.15 km^2 (115 ha). This result is larger than the prescribed neighbourhood unit area of 65 ha, but could serve as a benchmark for an optimal development area size to inform future walkable neighbourhood development in Montreal. Further research or use of such a measure on other cities for instance may reveal other effective mesh sizes associated with areas that are deemed to be optimal living environments. Such a comparison of a range of patches or neighbourhood unit sizes by city would be quite interesting.

6.4 Conclusion

Two fragmentation geometries have been explored here, each possessing individual properties and usefulness. The first fragmentation geometry demonstrates the impacts of major infrastructure networks and large mono-functional zones on the spatial structure of inhabited spaces on the island of Montreal. This geometry also allows for the identification of areas which can be described as highly isolated from neighbouring patches. Extremely small and capriciously shaped patches appear to be more at risk for what can be qualified as tissue malformations, and can be identified more easily using these methods. In the case of smaller patches this may increase their need to be self-sustaining in terms of service provision and walkability, or highlighting potentially problematic configurations within the landscape. These isolated patches could be explored for varying types of interventions for instance that could improve the quality of life for residents. As well, smaller patches surrounded by first order barriers could be described as enclaves of residential tissues, in some cases this may be desirable or by design. The adaptation of fragmentation analytical methods is demonstrated to be applicable here in determining areas within the city which experience higher levels of fragmentation comparatively. In this case we used the administrative borough lines but other means could be selected as well, such as defining reporting areas based on a tiered system of barriers perhaps by their relative position to natural barriers to distinguish those which may be more detrimental than those running along the path of a pre-existing edge.

The second fragmentation geometry introduced urban boundaries and other mono-functional zones to the mosaic. This further refined the mosaic structure and provides a more detailed assessment of the existence of a threshold patch size and shape emerging from the exercise of mapping neighbourhood edges. Notable conditions which emerged in this geometry were trenches of small patches along highways for instance which raise the question of the impact of highways on urban form as well as issues related to the connections between highways with the regular street network. These connections, which immediately place a higher traffic importance on these routes, combined may be just as detrimental to the internal functioning of bordering patches as the highway itself, when running in parallel in close proximity to one another. As well, an overall increase in patch size from inner-city to suburb appears indicative of an evolution of lifestyle and development patterns based on a shift to a more auto-centric lifestyle and normative planning models which remove the ‘urban’ quality from certain types of transportation infrastructure.

Overall other patterns which emerged were the adaptation or emergence of irregular patch configurations along major natural barriers such as rivers or steep slopes. Similar patch patterns and shapes were visible at the base of Mount-Royal for instance and along the shore of the island. These configurations were largely irregular and elongated in terms of their overall shape. Considering the methodology and approach alone, a similar assessment could be done involving the mosaic of specialized tissues, which is also crossed by barriers. Small enclaved pockets of non-residential could then be identified as well.

7. Quality of Urban Form: Connectivity | Chapter Seven

7.1 Introduction

The analytical value and practical usefulness of the landscape mosaic structure for urban studies goes way beyond an assessment of patch pattern. If the patch size configuration and relative position (i.e. relative to other patches of relative to different types of barriers and spatial features for instance) allow for preliminary analyses and for classification purposes, then such classification opens up the possibility of a wide array of comparative analyses that digs into the relationships between the morphological characters of the landscape mosaic and other characters of form that have an impact on the quality of the said form and more generally on the quality of life. By analogy, in similar ways that landscape fragmentation of natural habitats has an impact on ecosystems and fauna's quality of life, it is perfectly conceivable that urban landscape fragmentation exerts an impact on urban ecosystems as well as such matters as the spatial distribution of activities, amenities and their associated transportation requirements. While developing a framework that allows to address such complex relationships (chapters 2 to 6), this study has to limit itself, as a first step, to more purely morphological considerations, starting with the study of the impacts of the mosaic structure, more specifically of the patches' size and configuration, on the character of the street network deployed within the patches. Here we continue our exploration with a continued focus on the second fragmentation geometry (FG2) formed through the mapping of urban barriers and boundaries (Figure 7.1). Again these spaces are indicative of a more 'neighbourhood' level patch structure when considering the city scale[xi]. In the previous chapter we considered the emerging landscape patterns in terms of configuration

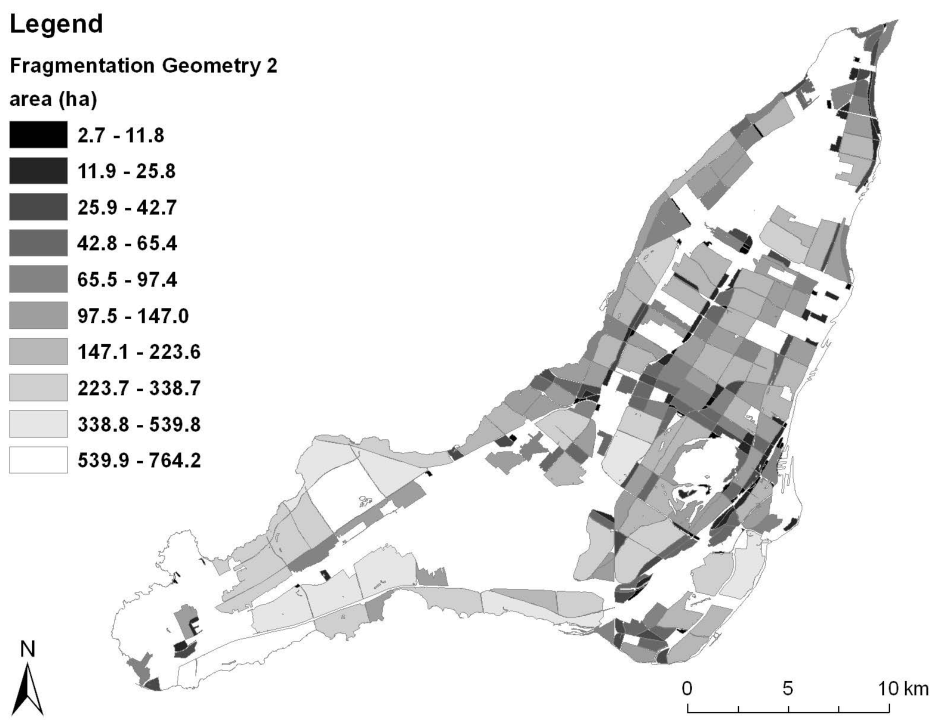

Figure 7.1 - The urban landscape mosaic - FG2.

and dimension, and their overall fragmentation, but what are the impacts of such features and patterns on quality of urban form? Drawing from the literature, one factor in the quality of urban form is the performance of street networks. This performance can be measured in various ways with the central logic being based around the idea that increased frequency of intersections denotes more path choices and therefore greater connectivity/permeability which is defined as the "extent to which an environment allows a choice of routes both through and within it" (Carmona et al., 2003:64). Permeability of

[xi] This 'neighbourhood' level patch structure is accurate at the city scale, but there may be other barriers at play internal to the individual patch which are not visible at this scale of resolution.

street networks, in combination with appropriate service provision within a given residential area increases overall accessibility thereby contributing to an increased quality of life. Given our landscape mosaic, we are able to isolate the internal street networks for each patch within FG2 and quantify their performance. The quantification of street networks contributes to the understanding of the quality of urban form in two ways; first, it facilitates comparing connectivity and permeability to both dimension and configuration and second, studies conducted on connectivity at the city scale have traditionally used administrative boundaries, postal codes, census tracts or disemmenation areas as the reporting areas to assess connectivity. In this case the reporting area is informed by the mapping of urban barriers and boundaries isolating patches based on morphologically defined edges which in itself provides a new perspective on the internal conditions in specific physically defined areas.

7.2 Quantifying Street Networks

Many metrics exist which can be used to assess the connectivity/permeability of a street network. In this analysis the metrics used were street density, four-way intersection density, four-way intersection frequency, the link-node ratio, and the alpha index[xii]. These metrics were chosen from a range of metrics which focus on varying attributes of street network connectivity. The approach taken in this research aims to demonstrate which aspects of connectivity, if any, may be affected by patch size and/or configuration.

[xii] A full description of the metrics is available in the methodology, Chapter 3.

7.2.1 Street Density

Street density measures the street length per unit of area (Figure 7.2), in this case we are using street length (in kilometers) per square kilometer. Overall street density is highest in the historic Old City[xiii] district of Montreal and second highest in the Plateau Mont-Royal between Sherbrooke street (and the Sherbrooke escarpment) and St-Joseph Boulevard (a previously identified thoroughfare) as well as in the Southern half of St-Henri in the Sud-Ouest. An area surrounded by a rail line and the Lachine Canal, largely isolated yet internally well connected in terms of street density. Around these areas, the density lowers progressively outwards roughly following urbanization patterns of

Figure 7.2: Street density by patch - FG2.

[xiii] This is the highest in terms of larger areas. There were smaller patches with higher densities. These patches tend to be strips of residential development surrounded by wooded areas or regional parks which skew their density in a similar way of comparing gross vs net population densities.

Montreal, with a few exceptions. There are instances of moderately lower density areas

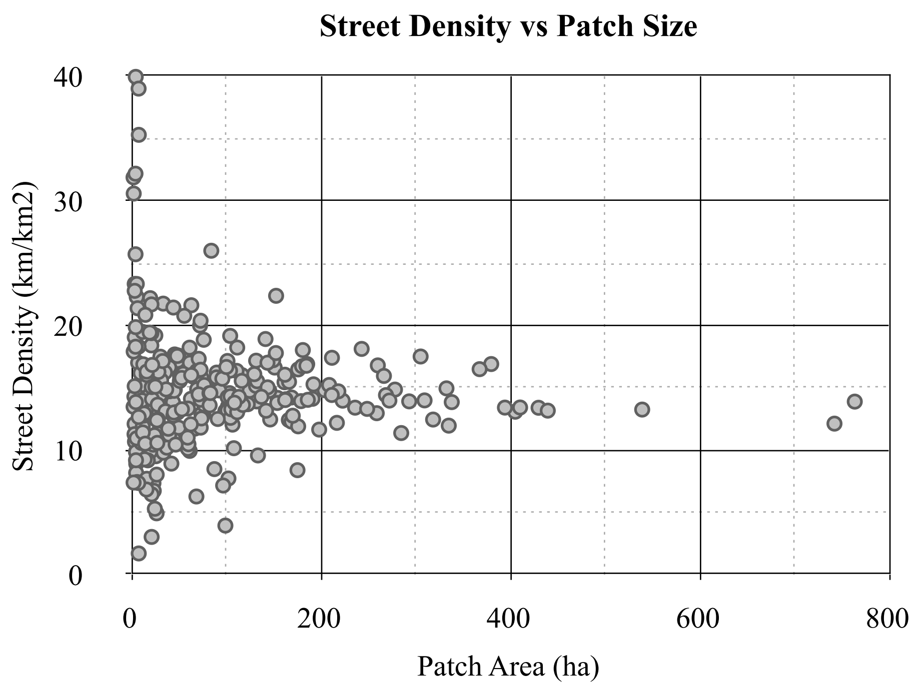

Figure 7.3: Comparing street density and patch size [$R^2 = 0.0024$].

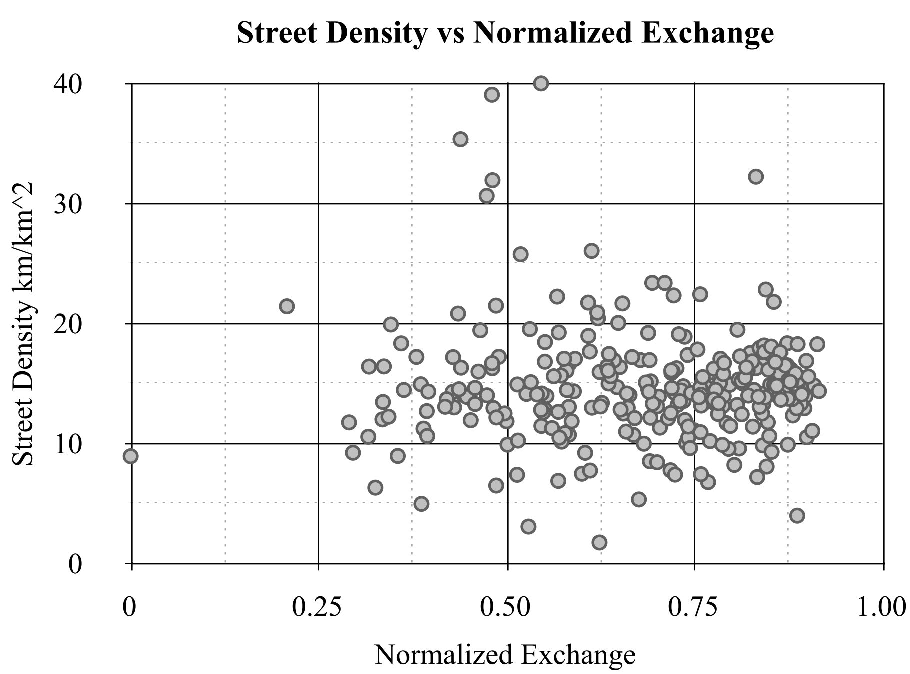

FIgure 7.4: Comparing street density and patch configuration [$R^2 = 0.0012$].

(compared to the average), clearly visible in the Western portion of the island. These patches are characterized by more recent auto-centric development with larger block sizes based on more recent normative planning models, as such these results are not unexpected. Similar conditions of street density are found in more urban locations such as just North of the Plateau. These areas correspond to areas which were urbanized following a grid-type street pattern but are characterized by larger block sizes as well and therefore exhibit a lower street density. There are visible patches of extremely low street density in smaller and more capriciously shaped patches but there is not specific pattern which emerges to establish a specific trend.

Looking at a comparison between street density and patch size and shape (Figure 7.3 & 7.4), one can see that the most variation in street density is found in the smallest patches. As the patch size increases, the street density decreases and increases to moderate values between 10-15 km/km2. In terms of patch shape, there is no particularly discernible pattern, implying that there is little relationship between street density and patch shape ($R^2 = 0.0012$). Street density could be and likely is more related to period of development, and one may expect to see similar patterns grouped together.

7.2.2 Four-Way Intersections: Density

In terms of the density of four-way intersections, this metric is appropriate as the intersection type is distinguished. With many metrics involving intersection density, only cul-de-sacs are omitted. This approach blurs the results of connectivity as three-way, and

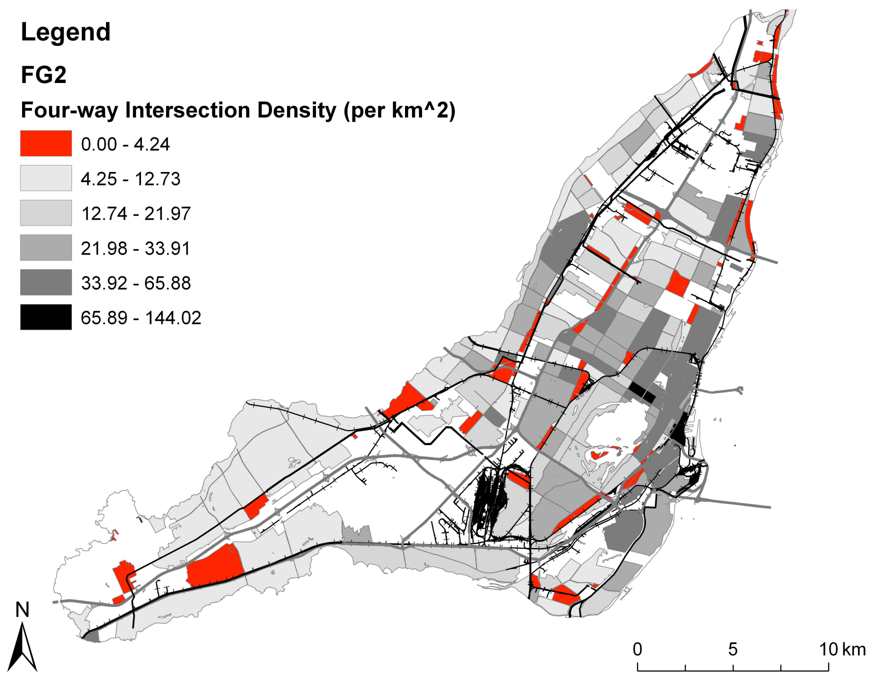

Figure 7.5: Four-way intersection density (intersections/per km^2) [mean = 16.7; Stdev = 18.1].

to a lesser extent two-way intersections, are given the same importance in the assessment and the widespread deployment of three-way intersections over four-way intersections would lead to less route choice, comparatively speaking, and therefore a much less permeable street network. The area with the highest four-way intersection density is once again the Old City of Montreal (75.4 intersections/km^2), and radiates out to the Plateau Mont-Royal, Downtown, Sud-Ouest and East along the shore. The areas with the lowest density of four-way intersections are found in the West in more recently developed areas characterized by curvilinear street patterns with many three-way intersections. In terms of an extreme low density of four-way intersections, these conditions are found sprinkled throughout usually within smaller patches or what appear to be elongated patch shapes. If these two variables are compared, one can see that in terms of patch size (Figure 7.6) there is little relationship outside of the occurrence of very large patches possessing

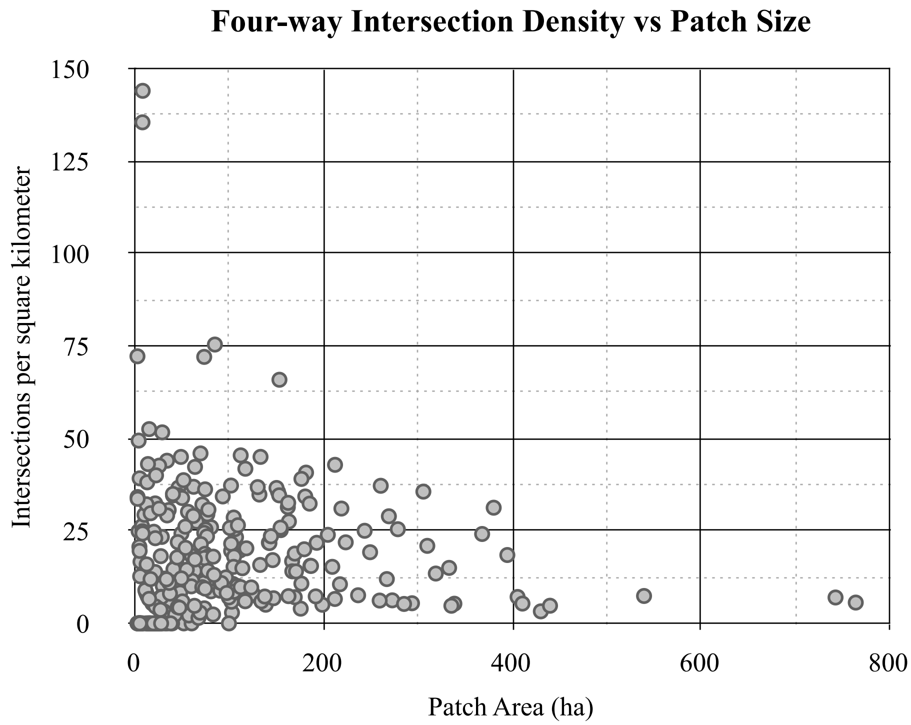

Figure 7.6: Comparing four-way intersection density and patch size [$R^2 = 0.0003$].

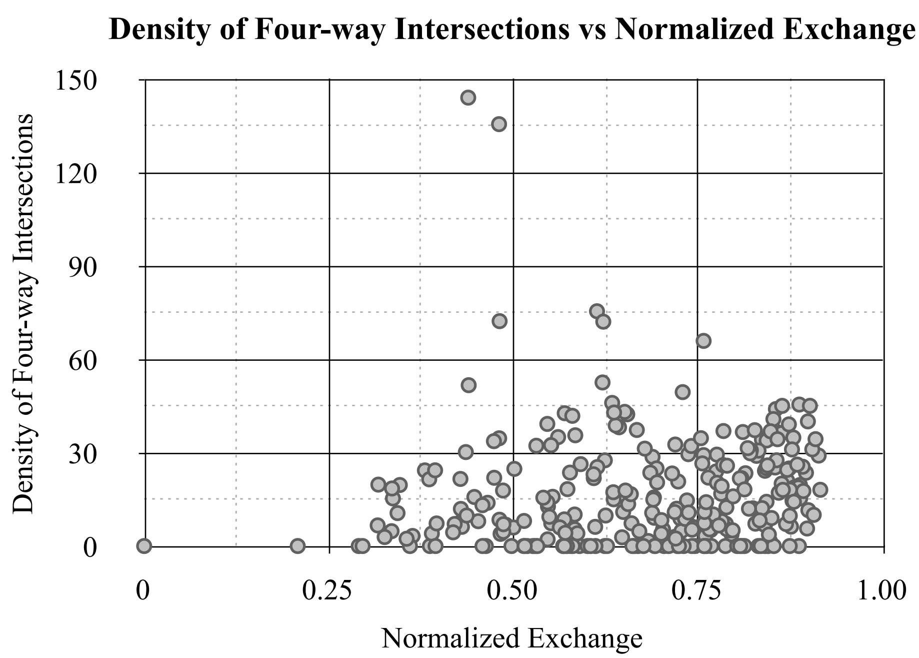

Figure 7.7: Comparing four-way intersection density and patch configuration [$R^2 = 0.0077$].

relatively low four-way intersection densities, a previously eluded to conclusion. In terms of the patch shape (Figure 7.7) there is no visible pattern between the two variables.

7.2.3 Four-Way Intersections: Percentage

Another way of looking at the distribution of four-way intersections is the frequency of their occurrence within a particular patch. Obviously a higher percentage return would denote more four-way intersections and therefore a more connected and permeable street network not accounting for block size, but still grid-style development. The results from this metric (Figure 7.8) demonstrate that the suburban development types to the West possess very low frequencies, which is not striking on its own. Patches of similar results are found across the island corresponding to more recently developed areas of Montreal. The result of having no four-way intersections appears reserved to smaller patches once again, namely those found along highways and railways. These areas correspond to patches which are extremely small and simply crossed by streets with no through streets internally or where they are more elongated and running along major barriers which causes adaptations to the street pattern into three-way intersections with a route running parallel to the barrier; this is more regular in the case of railways but can be found along other barriers as well.

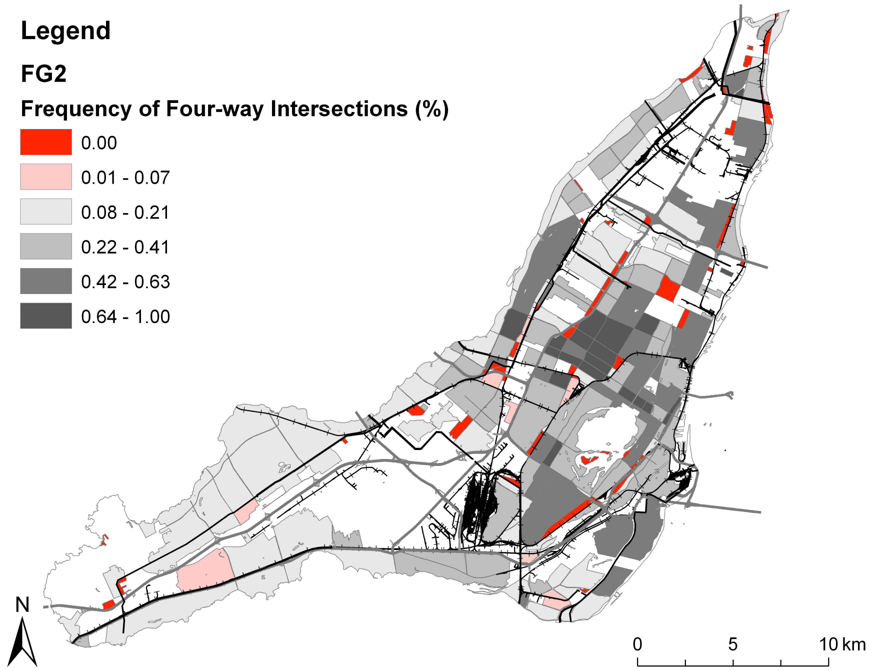

Figure 7.8: The frequency (%) of four-way intersections by patch.

In terms of comparing the patch size and shape, the patch shape (Figure 7.9) displays a very slight pattern of large patches and very low frequency of four-way intersections once again demonstrative of larger more suburban patches characterized by curvi-linear street patterns. In terms of patch shape, from the graph (Figure 7.10) there is very minor pattern of decreasing frequency of four-way intersections with decreasing normalized exchange. This is indicative of a pattern potentially, especially with regards to the spatial distribution of these patches which have been previously established.

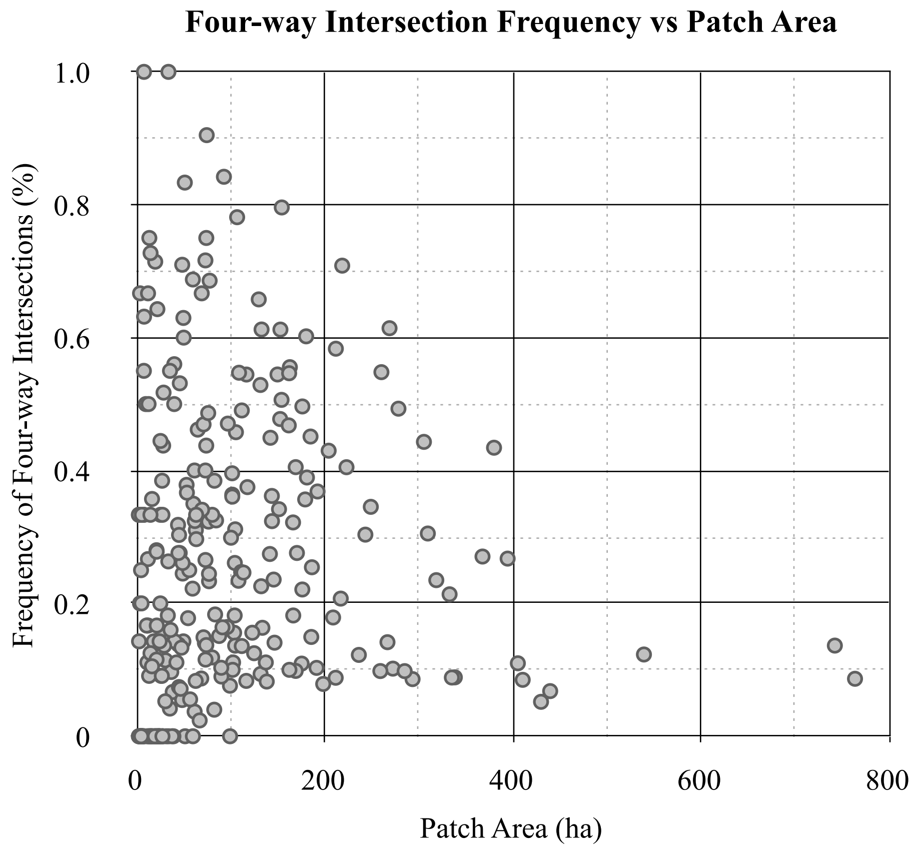

Figure 7.9: Comparing the frequency of four-way intersections and patch area [$R^2 = 0.0052$].

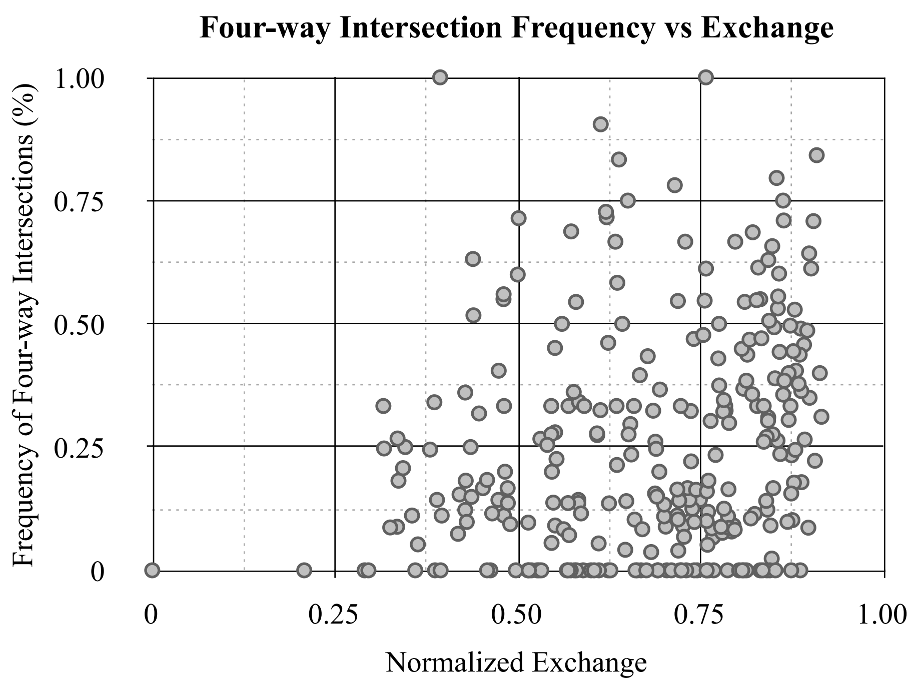

Figure 7.10: Comparing the frequncy of four-way intersections and patch shape [$R^2 = 0.0469$].

7.2.4 Link-Node Ratio

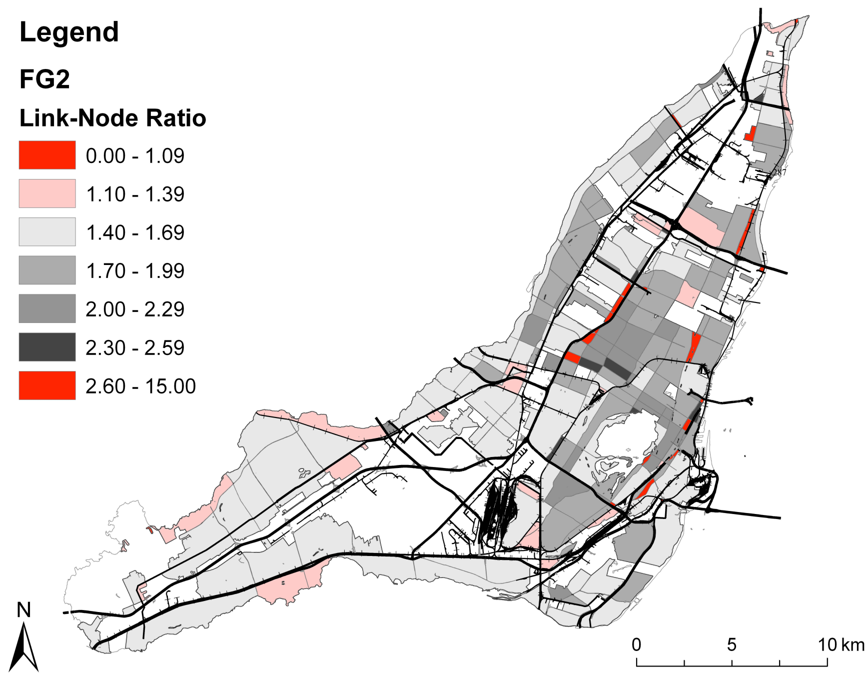

Figure 7.11: The link-node ratio by patch [Mean = 1.69; Stdev = 0.30].

The Link-Node Ratio (LNR)[xiv] demonstrates a concentration of highly internally connected patches in the Plateau-Mont-Royal, the Mile-End/Parc-Extension, in parts of downtown and in Montreal West. These high connectivity levels can be attributed, in the Plateau and Mile-End for instance, to the development of a highly connected grid-iron street pattern with many streets which continue from patch to patch. Old Montreal's street network, on the other hand, is characterized by a more organic structure comprised of some three-way intersections and dead ends. Other areas such as the Sud-Ouest have railways and highways defining their patch structure with relatively impermeable barriers which lead to infrequent crossing points and therefore more dead ends and three-way

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[xiv] LNR is an index of connectivity. Prescribed results should range between 0 and 2.5, with 2.5 representing a perfect grid. For a full description of the index, see Chapter 3.

intersections being present along these barriers which would lower the LNR values for these areas. In the Sud-Ouest, namely the neighbourhoods of St-Henri, Pointe-St-Charles and Little Burgundy represent areas of relatively lower connectivity when compared to the LNR levels found in surrounding patches.

Considering LNR compared to the patch size (Figure 7.12), there is a clear pattern within the extreme results (where the LNR is equal to 0 or greater than 2.5) when patch size is smaller than 50 ha. Extreme results of zero, indicate no internal network present or extremely high results of fifteen or even six are extraordinary and represent conditions of relatively low connectivity in the sense that there would be many links present with a lack of nodes implying patches which are merely crossed by streets with little or no internal connectivity.

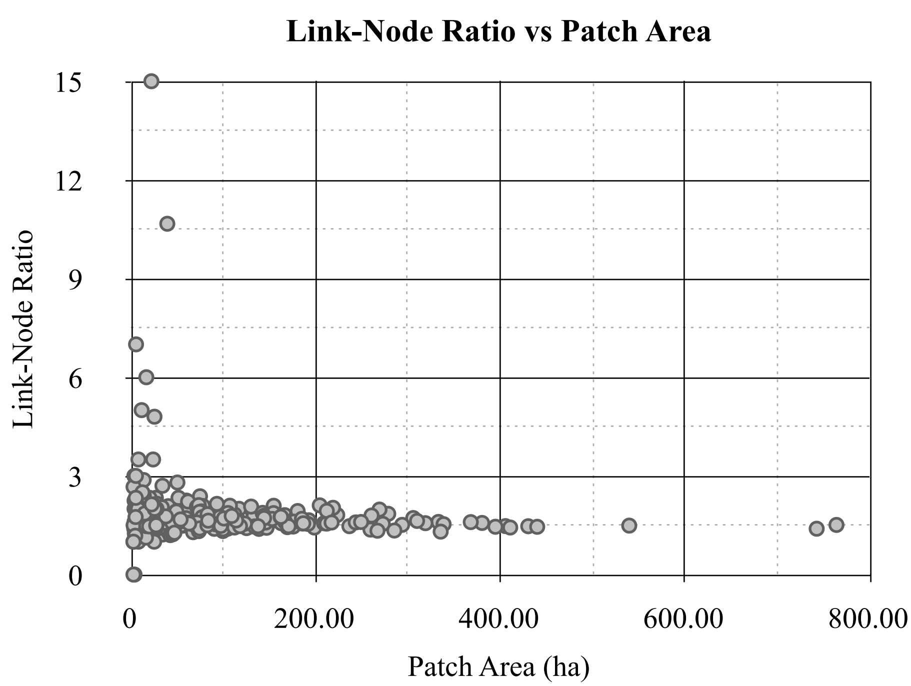

Figure 7.12: Comparing the link-node ratio and patch area [R^2 = 0.0186].

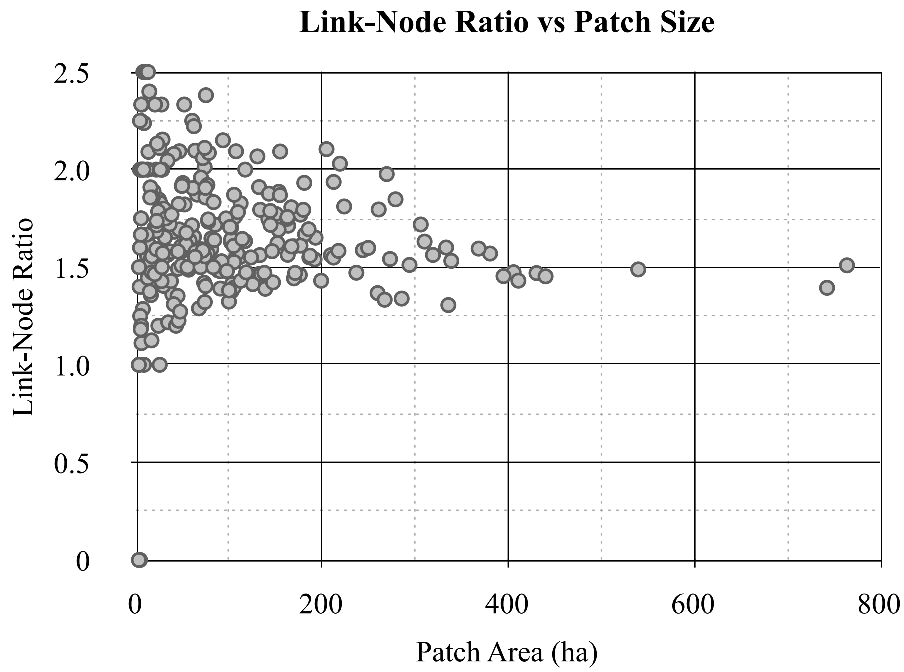

Figure 7.13: Comparing link-node ratio and patch size. Only results within prescribed range of 0 to 2.5 [$R^2 = 0.0186$].

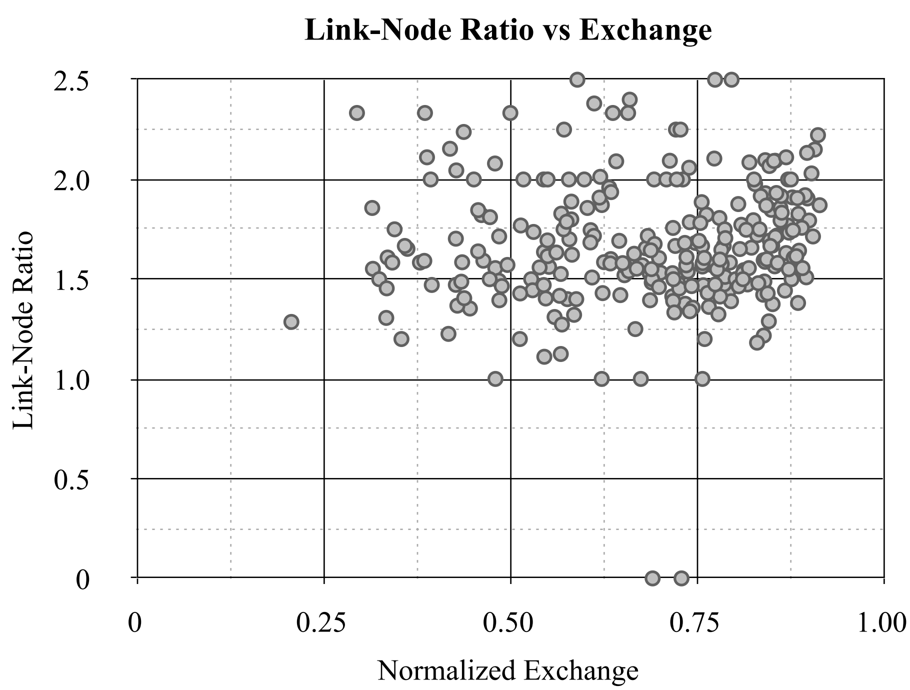

Figure 7.14: Comparing link-node ratio and patch configuration [$R^2 = 0.0308$].

A closer look at the 0 to 2.5 range (Figure 7.13) displays a weak trend demonstrating more LNR regularity as patch size increases. Although the majority of patches exist in the less than 200ha range and display a wide range of LNR results. In terms of patch size (Figure 7.14) there is no visible pattern especially in regards to results outside the 0 to 2.5 range. Within the range of 0 to 2.5 ha, there is still no discernible pattern emerging. Indicating that shape alone appears to have little effect on LNR.

7.2.5 Alpha Index

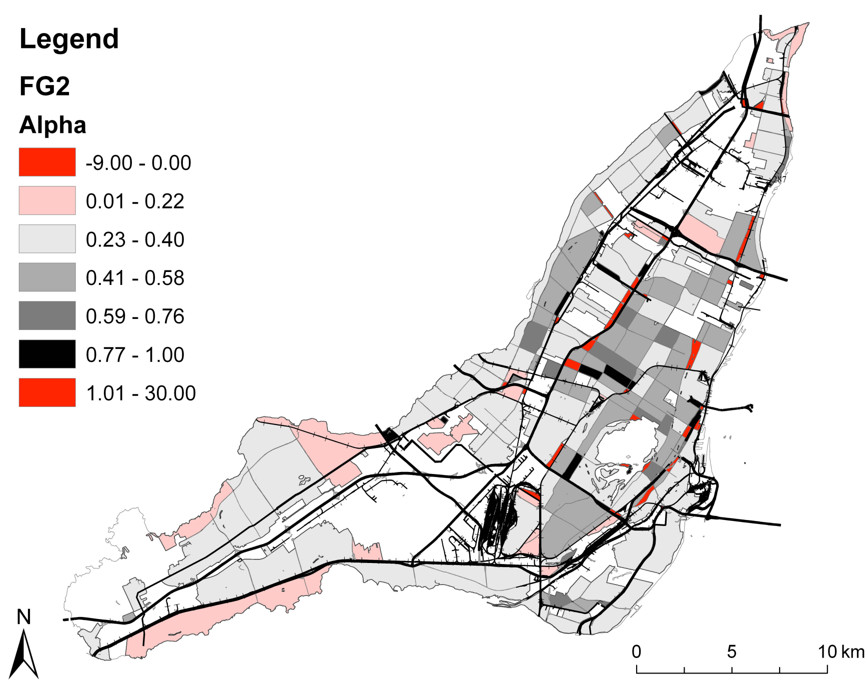

Figure 7.15: Connectivity within each patch, measured in terms of the alpha index [mean = 0.40; Stdev = 0.18].

The Alpha index returns values between 0 and 1 and can be interpreted as the percentage of connectivity of the network (i.e. 0.2 would indicate a 20% connected network). Clear patterns of higher connectivity are once again shown in the downtown, Plateau and Mile-End areas. There are lower alpha levels in the west relative to the more urban development in the centre and even towards the east. Two notable areas which display very low connectivity are Ville-St-Pierre and Saint-Raymond neighbourhoods. Considering patch size (Figure 7.16), the most glaring results are those once again out of

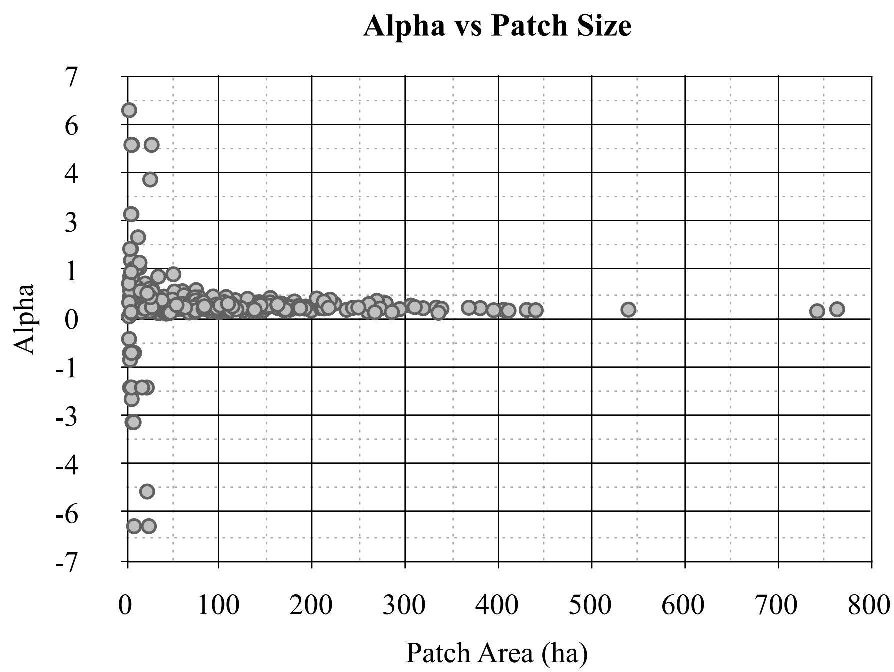

Figure 7.16: Comparing the alpha index and patch size [$R^2 = 0.0017$].

the intended range[xv] of the metric of 0 to 1. These patches are quite small (less than 50 ha) and correspond to the interstitial tissues previously identified and discussed in chapter six. This measure shows that their internal networks do not seemingly function properly due to their position relative to barriers and boundaries, usually running directly adjacent

[xv] For a full description of the metric and its intended results or range, see Chapter 3.

to largely impermeable barriers. In this case this affirms the idea that infrastructure introduced after urbanization can create trenches of tissue malformations, i.e. non-coherent street networks. A closer look at the alpha values within the prescribed range reveals a broad range in the 0 to 100 ha size as well as the 100 to 200 ha range. Overall there is a minor pattern of lower connectivity with extremely small patches and with quite large patches but no direct connection when considering the overall relationship.

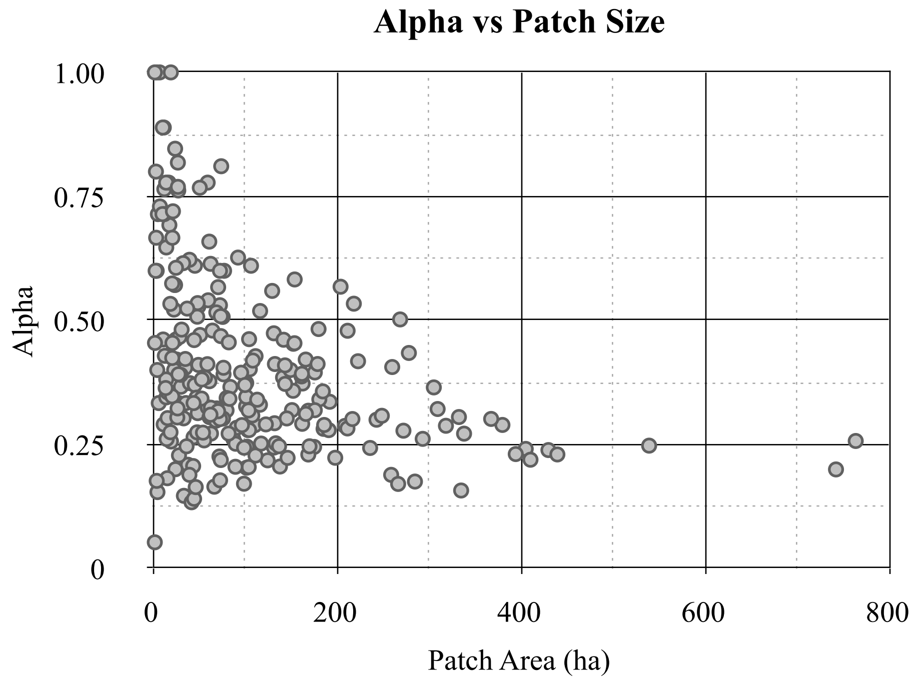

Figure 7.17: Comparing the alpha index and patch size, results within the presribed range of 0 to 1 [R^2 = 0.0017].

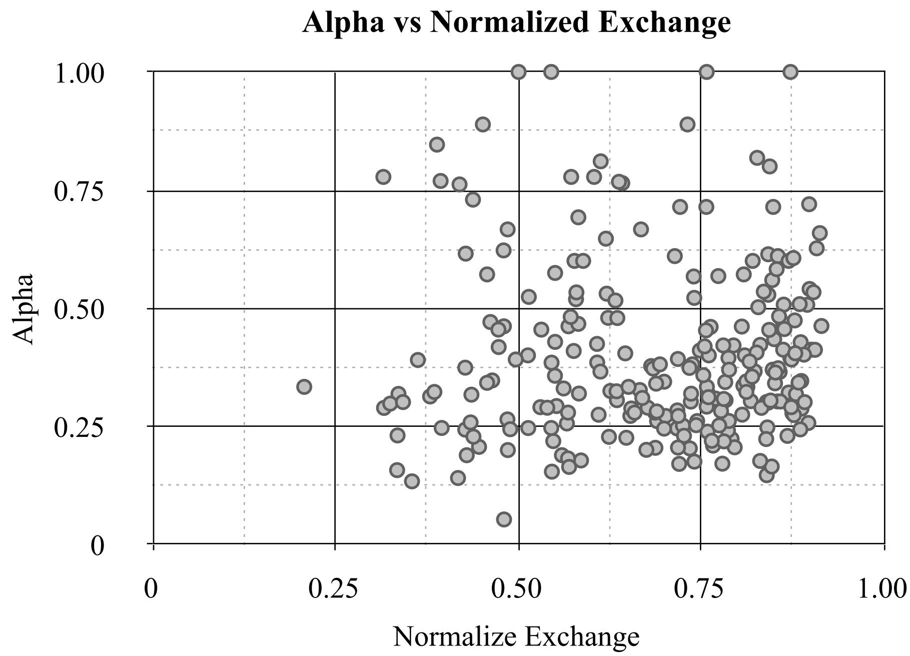

Figure 7.18: Comparing the alpha index and patch configuration [$R^2 = 0.0177$].

7.5 Conclusion

In this chapter I have demonstrated that there are actually few overall patterns in terms of patch size and shape with the connectivity or performance of internal street networks. Anywhere a pattern did emerge it was usually with regards to a smaller patch size resulting in extreme results from certain metrics implying no actual viable network being internally present. The majority of these patches would merely be crossed. From the visual assessment, these patches are spatially located usually running along major infrastructure and/or natural barriers. Also, they result from the configuration of highways and their upward connecting thoroughfares leading to a barrier and boundary running in close proximity to one another. In terms of patch configuration, plotting the results showed very little, implying that no definable pattern is present when considering street networks. This reinforces the idea that we are dealing with extremes here, e.g. that an extremely small patch regardless of shape is more likely to have connectivity issues. An extremely elongated patch would intuitively have similar issues but it appears that these elongated shapes, at such an extreme, are not common place. Based on configuration alone, elongated patches can be wide enough to contain a full block many times over, with a grid network within, which would display a highly connected network, and the impacts would be undetectable by the metrics explored here. If other variables were considered the outcome may be different. One such variable could be street 'depth', in which streets are ranked in their centrality based on their connections to everything else around them. In this variable, the depth of a main street would be compromised in elongated patches with barriers running in closer proximity to one another. Also, in regards to configuration, rectangular patches running length wise along a highway for instance display similar configuration to the rectangular configurations found in the Plateau-Mont-Royal, a neighbourhood known for its density and broad range of commercial offer. The similarity in configuration leads me to believe that the configuration itself is not mutually exclusive from size, e.g. that a very large patch, regardless of configuration would not be impacted in any way by its configuration. This is dependent on the idea of scale, as one only has to consider the island of Montreal itself which does not necessarily have the most compact configuration, contains many smaller patches some of which may be more hospitable settling environments than others, but this is dependent on size and configuration not configuration alone. Finally, another aspect of pattern analysis which may impact internal quality of urban form, in this case connectivity, is the issue of patch orientation. The existence of patches which are rectangular in shape yet display a drastic shift in orientation may also disrupt the internal spatial logic of the patch, especially when this shift in patch orientation is not accompanied by an adaptation of the street-patterns and development type within the patch. Patch orientation is worth exploring further and should be pursued in future research projects.

8. Conclusion | Chapter Eight

This thesis has explored a few different ideas; first and foremost, it presents an in-depth exploration of the presence of urban barriers within the urban landscape. It took up the charge of clarifying and defining, based on morphological characteristics, the types of barriers which exist within and exert pressures upon the urban landscape. The result of this exploration was the establishment of a taxonomy of urban barriers, which is applicable to any city, not exclusively Montreal. Urban barriers have been eluded to previously in the literature but never compiled in a complete manor discussing their individual physical characteristics and impacts. A notable contribution in this section of the thesis is the development of the concept of border vacuums, expanding this idea to include varying land types beyond parks, more specifically large mono-functional zones acting as urban barriers. These mono-functional zones also constitute a layer of specialized tissues which exists at the territorial scale and could be explored uniquely for their own inherent physical qualities, and the identification of industrial and commercial enclaves. Specialized tissues are arguably less resilient overtime than railways and highways for instance and present more flexible opportunities to expand and reshape certain areas of the city.

Secondly, this thesis engaged in a debate on the question regarding the nature of major urban thoroughfares as a secondary barrier or urban boundary. In doing so, issues pertaining to the disconnection of highways from the evolution of street types over time were identified. Highways are isolated and divisive by design sacrificing at times local accessibility for regional mobility. Another issue raised regarding thoroughfares has been the blurring of the concept of the urban boulevard to include a type of pseudo-highway, referred to as "functional arterials", which lack connections to adjacent urban tissues and is dedicated by design to traffic flow, displaying similar characteristics to highways themselves, such as access constraint and high-speed traffic. Alternatively, urban boulevards as a thoroughfare type possess the ability to support traffic in an inclusive and urban context where 'sense of place' is not sacrificed, acting as a contributing component of the urban environment. These two very distinct realities for thoroughfares can be qualified in terms of their ability to act as dividers and seams, with seams possessing coherent pertinent strips, and more direct street connections, characteristics typical of urban boulevards found in pre-war urban developments. The functional arterial on the other hand, has much more in common with a highway and is much less 'urban', in that it displays irregular connection to surrounding urban tissues and limited street connections. A secondary contribution from the identification and subsequent mapping of thoroughfares was the revealing of a second tier layer of mono-functional zones (i.e. neighbourhood parks) which also constitute boundaries.

Thirdly, the overlaying of these two networks, barriers and boundaries, creates a morphological matrix which delineates the hospitable settling environments found on the island of Montreal, in the urban landscape mosaic. The mosaic approach, through the use of fragmentation geometries, can be used to reveal patterns within the urban landscape pertaining patch size or configuration, which may impede the functionality of a patch, or impact their ability to support services of proximity. A major point which should be explored further is the impact not only of highways on urban form but the impact of highway connections to the regular street network. These connections can result in irregular patch patterns as was demonstrated in chapter 7, and may also result in transformations within an urban tissue via a higher traffic importance being placed on a route. This increase in traffic volume, depending on what type of street it was originally, may cause a shift in the internal spatial logic of the urban tissue, causing the collapse of adjacent uses along the route, and/or furthering the divisive effects of highways creating smaller pockets of isolated urban tissues. These conditions would not necessarily appear at all times but could be just as detrimental to the internal spatial logic and functioning of urban tissues. This should be explored in-depth at a later date. As well, the discussion on urban thoroughfares identified different types of urban thoroughfares. Future research on fragmentation by these boundaries could rank the divisive qualities of individual thoroughfares indicative of varying permeability levels. This classification could identify those which act as either dividers or seams for instance, an important distinction as they both constitute edges but there is a higher degree of urbanity associated to seams over thoroughfares which act more as dividers.

This thesis also puts forth a different perspective of the urban landscape, which explores the existence and impacts of urban barriers and boundaries as a morphological matrix defining inhabited/inhabitable settling environments within the City. This methodology results in an abstraction of the urban landscape into a patch mosaic structure, which was used to explore the internal quality of urban form in terms of the level of connectivity of the patches internal street network. The measures presented (Street density, four-way intersection density and frequency, the link-node ratio and the alpha index) displayed minimal patterns of influence in regards to patch shape and size. As these two variables were isolated, it is the contention here that these two variables are not mutually exclusive, e.g. that patch size and configuration are linked in terms of their ability to present a hospitable settling environment. That said, individually each variable may have an impact such as an extremely small patch (more likely) or an extremely elongated patch shape (less likely) which would have impacts on the overall street network in terms of its network depth, an attribute which was not explored here. As well, the patch shape and size variables may impact other aspects of urban form such as built density, land value, presence, or lack thereof, of commercial activity for instance. Additional applications of the landscape mosaic as a morphological framework could include more than just physical conditions, e.g. built densities, but could explore them in relation to socio-economic conditions, such as demographic information, through the use of Geographic Information Systems (GIS) platforms.

For planning purposes, the application of the mosaic structure in informing form-based codes at a city-wide scale may prove useful as well. The urban landscape mosaic allows for the identification of patch patterns based on physical characteristics, and can also identify individual patches, or enclaves, where appropriate physical codes[xvi] could be deployed to promote, transform or sustain existing internal conditions. Such an approach could be especially useful in identifying malformations in urban tissues and/or enclaves of urban tissues which are inadequately sized or shaped, where a shift in use or a consolidation of certain types of uses, such as industrial or heavy commercial for

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[xvi] "In essence, coding generates urban order by the generic specification of allowable and necessary components and relationships" (Marshall, 2010: 6)

instance, could be better suited to certain urban locations allowing them to be enclaved from their surrounding tissues yet still in close proximity to the labor market. Such conditions coupled with sustainable transportation access could ease the demand on the automobile by creating areas within the inner-city that could compete with more suburban commercial campus-type designs which are located further from the inner-city. In addition, residential enclaves (those that wish to be so) are protected from surrounding development through urban barriers.

Considering the mosaic of specialized tissues, the existence of which was discussed but not explored in depth, this layer is in a state of flux as urban tissues are more flexible for redevelopment than linear infrastructure in most cases. The identification of priority zones for redevelopment which may also include obsolete transport infrastructure could be done in order to create an aggregate zone of residential or mixed-use development which would have the size required to support population numbers and densities which could thereby support more services of proximity.

In terms of measuring connectivity within patches, the size of the patch appears to have an impact exclusively on the Alpha index, a result only detectable in the extremely small patches (less than 55 ha). Such patches displayed internal street networks which lack through routes and are crossed by streets but lack any coherent internal network, leading to an abundance of links and a lack of nodes. In such cases, in order to move to other areas within the patch one must leave the patch and return along another parallel street. Such conditions may be linked to other developmental issues which should be explored further (i.e. internal land values, and built densities) to assess whether the size and shape of patches has an impact on such other aspects of urban form. Other metrics such as the link-node ratio also demonstrate areas of extreme network issues, but overall there does not appear to be any relationship across the board. Issues pertaining to patch size and configuration and their impact on internal street networks seems to exist at the extremes, e.g. an extremely elongated shape where the Normalized exchange is less than 0.5. There may also exist issues regarding patch configuration in the mid range as well but this is where the issues likely exist due to both the size and shape of the patch itself. As said, the issues or patches which are more likely to pose problems to supporting hospitable settling environments are those which are extremely small or extremely elongated. The combined presence of both conditions, (e.g. elongated shape and small size) would be the most worrisome. Alternatively, with certain shapes such as a slightly elongated rectangle, there appears to be issues with patch size rather than configuration as a large patch of similar shape may be said to be appropriate, while a smaller patch of similar shape could result in inhospitable settling conditions. There are questions revealed by this research regarding the issue of patch orientation within the mosaic. The orientation of rectangular patches in the Plateau-Mont-Royal area for instance run north-south, in some more problematic areas, instances of smaller rectangular patches running east-west appear, giving the impression of an elongated configuration but this is not the case, as this is more a condition resulting from a change in patch orientation from north-south to east-west. Given that, future research exploring the urban landscape mosaic should also explore the impacts (if any) of changes in patch orientation and street grid orientation for instance.

Overall, this thesis' major contributions are rooted in clarifying the concept of urban barriers and boundaries and establishing a detailed taxonomy. In terms of its empirical contribution, this research produced knowledge on Montreal's landscape fragmentation and, in exploring the relationship between the landscape mosaic and morphological characters of the form (the internal street network), it demonstrated the applicability of the adaptation of urban morphological and landscape fragmentation methods to the study of the urban landscape mosaic. These methods have opened up more possibilities and questions than they have closed off, which is not necessarily a bad thing, as the use of morphologically defined areas could produce much knowledge regarding urban conditions which pertain to more to the physical reality of the city as opposed to at times random and arbitrary administrative boundaries. As well, the mosaic structure and barrier/boundary matrix provides a model against which the introduction or removal of barriers can be assessed. The model can inform the introduction of new barriers along pre-existing edges of patches, which would arguably have less impact than bisecting patches within the landscape. Alternatively, the removal of barriers where two patches could be combined to form a larger more coherent patch could be identified. Such as assessment could be extremely useful for urban planners in providing empirical evidence on the fragmentation of the city, the creation of new enclaves, or identifying areas which could benefit most from barrier removal. The strategic locating of new infrastructure connections or their removal can have tremendous impacts on their surrounding urban environments, and has great potential to drastically alter the urban landscape both positively and negatively.

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Taxonomy of Urban Barriers | Appendix A

Urban Barrier	Image	Definition	Level of Spatial Resolution	Configuration	Degree of Permeability	Composition	Intersections/Crossings	Relative Position
River		Defined as "a natural stream of water of fairly large size flowing in a definite course or channel or series of diverging and converging channels" ("River", Collins English Dictionary).	Territorial/Regional	Linear	Highly Impermeable (intersection spacing > 500m apart)	NA	No intersections; there is the opportunity for direct connections with street networks via a ferry system in some urban environments. This natural element is crossed by bridges for automobile and rail traffic, these crossings are usually fairly infrequent.	On the borders of territorial modules (insuperable barrier).
Lakes		Defined as an "inland body of water, generally large and too deep to have rooted vegetation completely covering the surface" ('Lake', World Encyclopedia)	Territorial/Regional	Non-linear	Highly Impermeable (intersection spacing > 500m apart)	NA	No direct intersections; usually crossed bridges or marine transport.	On the borders of territorial modules (insuperable barrier).
Steep Slopes > 10%		Areas of increased slope or which experience a drastic change in slope which impedes development or pedestrian movement. (i.e. escarpments, mountains, etc.)	Territorial/Regional	Linear	Highly Impermeable (intersection spacing > 500m apart)	NA	No direct intersections; conditions street networks to adapt to the slope or and also be mitigated by use of stairs or elevators in some cases.	On the borders of urban tissues (acts as dividing axis).

Figure A1: Taxonomy of natural barriers.

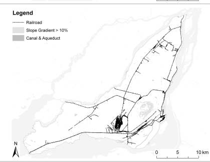
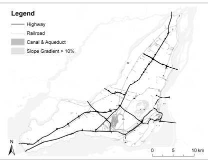
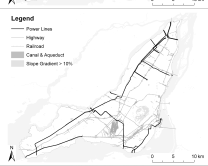
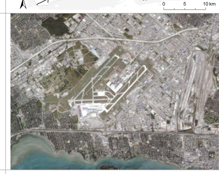
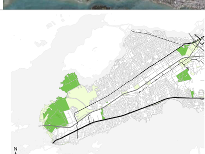
Urban Barrier	Image	Definition	Level of Spatial Resolution	Configuration	Degree of Permeability	Composition	Intersections/Crossings	Relative Position
Fortification Walls		A defensive wall or other reinforcement built to strengthen a place against attack.	Settlement/City	Linear	Highly Impermeable (intersection spacing > 500m apart)	Dedicated Right-of-way	Infrequent intersections with street network; traditionally would have been formal points of entry to the fortified city.	On the borders of urban tissues (acts as dividing axis).
Canal		An artificial waterway constructed to allow the passage of boats or ships inland or to convey water for irrigation.	Settlement/City	Linear	Highly Impermeable (intersection spacing > 500m apart)	Dedicated right-of-way;	Bridges; crossing are largely separated (distance?)	On the borders of urban tissues (acts as dividing axis).
Railroad		A track or set of tracks made of steel rails along which passenger and freight trains run.	Territorial/Regional	Linear	Highly Impermeable (intersection spacing > 500m apart)	Dedicated right-of-way;	Mainly through viaducs and interchanges, there are the occurances of at grade signalized crossings but these tend to be located in more suburban or rural settings	On the borders of territorial modules (insuperable barrier).
Autoroute/Highway		Large route protégé, reservee aux vehicules automobiles comportant 2 chaussees separees [...] sans croisements ni passages a niveau. (Larochelle & Gauthier 2002)	Territorial/Regional	Linear	Highly Impermeable (intersection spacing > 500m apart)	Separated rights of way with no sidewalks.	There is no actual intersection, although these infrastructures do 'connect' through Viaducs / Echangeurs	On the borders of territorial modules (insuperable barrier).
High-tension Power-Lines		Infrastructure related to the transportation of electricity; occupies a similar right of way as a highway. In many urban environments they do not form a continuous system, with a combination of underground and above ground networks.	Territorial/Regional	Linear	Moderately Permeable (Intersection spacing 350m to 500m)	Dedicated right-of-way; although these areas are quite permeable in terms of pedestrian movement, but interrupt street network connections similar to railroads or highways.	At grade; widely spaced similar to those crossings seen with highways, and canals. (distance?)	On the borders of urban tissues (acts as dividing axis).
Large Mono-Functinoal Zones - Type A		Specialized tissues such as industrial parks or large mono-functional areas such as airports. Generally, large urban areas where the use is other than residential.	Territorial/Regional	Non-linear	Variable permeability (dependent on presence and type of internal street network)	Usually spanning between two linear barriers, further enclosing a defined patch. - Possesses pertinent strips. Large specialized tissues may contain a street network of varying complexity providing access to buildings and facilities.	At grade. Possesses internal street network and therefore direct connections to the surrounding networks.	On the borders of urban tissues (acts as dividing axis).
Large Mono-Functional Zones - Type B		Corresponds to parks which serve multiple neighbourhoods which are regional in scale. (i.e. Mount Royal).	Territorial/Regional	Non-linear	Highly Impermeable (intersection spacing > 500m apart)	Large parks, wooded areas etc. They will not possess internal street networks and they will be crossed infrequently by limited routes.	Limited through routes.	On the borders of urban tissues (acts as dividing axis).

Figure A2: Taxonomy of artificial (human-made) barriers.

Major Urban Thoroughfares | Appendix B

Thoroughfare	Definition	Nature	Level of Spatial Resolution	Relation to the Built Environment	Configuration	Intersections/Crossings	Relative Position
Autoroute/Highway	Large route protégé, reservee aux vehicules automobiles comportant 2 chaussees separees [...] sans croisements ni passages a niveau. (Larochelle & Gauthier 2002)	Inter-urban Route	Territorial/Regional	Without “pertinent strips” nor civic addresses.	Separated rights of way with no sidewalks.	Viaducts / Interchanges	On the borders of territorial modules (insuperable barrier).
Functional Arterials	Similar in function to freeways but with at-grade intersections and direct access to abutting property. (In practice, access is usually limited to intersections at one-half to one-mile intervals). (Jacobs et al. 2002, P.91)	Intra-Urban Route	City/Settlement	Possesses irregular 'pertinent strips' characterized by intermitent civic addresses.	Displays high levels of arteriality (Marshall, 2005); direct link with highway infrastructure therefore will carry high levels of traffic.	At grade, relatively largely spaced (more than 180m) and at irregular intervals	At the periphery of urban tissues (usually acts as a dividing axis).
Urban Boulevard	Boulevard: rue tres large, generalement plantee d'arbres (Larochelle and Gauthier 2002).	Intra-Urban Route	City/Settlement	Possesses "pertinent strips" therefore principal facades.	Avec ou sans terre-plein, Avec trottoirs alignments d'arbres.	At grade intersections, relatively close together (180m max. recommended).	At the periphery of urban tissues (usually acts as a dividing axis).

Figure B1: Comparison of major urban thoroughfares.

Fragmentation Geometry One: Patch Data | Appendix C

Figure C1: FG1 - key map for patch data by ID number.

ID	Area (ha)	Area (km^2)	Perimeter (m)	Exchange	nExchange
1	34.2848	0.3428	2751.1142	294043.5823	0.8577
2	3.7301	0.0373	5153.0222	2642.7848	0.0709
3	5.7717	0.0577	6141.5016	4972.3568	0.0862
4	44.5831	0.4458	4682.1227	217231.3505	0.4873
5	33.1367	0.3314	2599.0781	271223.6753	0.8185
6	3.0165	0.0302	3092.6858	0.0000	0.0000
8	25.2970	0.2530	3166.9770	204968.6160	0.8103
10	246.6932	2.4669	16290.1702	1833053.6593	0.7431
11	4.1288	0.0413	2094.7657	7828.2833	0.1896
13	72.9920	0.7299	12401.9968	473316.6194	0.6485
14	24.0358	0.2404	3885.0786	122462.4390	0.5095
15	6.3941	0.0639	3419.0815	11365.5370	0.1778
16	103.1710	1.0317	5663.5731	739736.3395	0.7170
17	2308.9484	23.0895	67567.1962	3782057.4663	0.1638
18	55.9986	0.5600	5562.9967	344503.3909	0.6152
19	5.5242	0.0552	2428.2713	26913.9868	0.4872
20	2.8148	0.0281	1521.7232	16830.8712	0.5980
21	7.0788	0.0708	2390.5177	14716.7566	0.2079
22	3.8044	0.0380	2074.7643	8346.9464	0.2194
23	2.7690	0.0277	1131.5802	13324.2824	0.4812
24	5.0511	0.0505	2805.3388	9892.5637	0.1959
25	101.6432	1.0164	4837.7927	798508.9319	0.7856
26	1268.2770	12.6828	32847.9394	8636332.3927	0.6810
29	148.2513	1.4825	15512.8764	404800.3043	0.2731
30	4.2692	0.0427	957.1310	29487.3401	0.6907
31	901.9750	9.0197	37919.0059	3839707.4926	0.4257
33	5.9049	0.0590	5120.2050	0.0000	0.0000
34	63.8094	0.6381	4506.3852	417313.2496	0.6540
35	1546.5423	15.4654	40274.0793	7508462.9767	0.4855
38	71.1699	0.7117	5135.1410	502174.8499	0.7056
39	370.1998	3.7020	11412.3378	2392045.7999	0.6462
40	23.7967	0.2380	4765.1563	121482.0506	0.5105
42	3.1377	0.0314	4441.0308	2721.9724	0.0868
43	3.0225	0.0302	923.9083	20963.7260	0.6936
44	105.2534	1.0525	6573.7789	692883.3691	0.6583
45	1016.7961	10.1680	15878.3724	8548713.2755	0.8408
46	20.3576	0.2036	3590.1067	115468.1175	0.5672
47	11.0065	0.1101	3157.3820	42006.3049	0.3817
48	2.6117	0.0261	738.5676	20239.5261	0.7750
49	689.0349	6.8903	40450.1003	1734989.7740	0.2518

ID	Area (ha)	Area (km^2)	Perimeter (m)	Exchange	nExchange
50	13.1037	0.1310	2373.6594	99306.2161	0.7579
51	5.4416	0.0544	1058.4505	41429.2873	0.7614
52	3.6986	0.0370	6498.2058	2448.4979	0.0662
53	8.5456	0.0855	3405.7408	36981.0277	0.4328
55	3.8161	0.0382	6396.7686	0.0000	0.0000
57	3.4065	0.0341	1085.3315	27422.6468	0.8050
59	2816.1746	28.1617	43147.5955	17530686.9700	0.6225
61	336.5071	3.3651	16090.9845	1125279.7406	0.3344
62	6.9438	0.0694	4947.7481	16529.5969	0.2381
63	407.8767	4.0788	10120.4484	3531804.4805	0.8659
64	50.0326	0.5003	5127.0039	308375.8960	0.6164
68	8.8870	0.0889	6514.7096	10308.9038	0.1160
69	1446.3193	14.4632	23318.8777	11370239.4878	0.7862
71	88.2322	0.8823	7268.4168	686887.8912	0.7785
72	437.9872	4.3799	9220.5110	3925460.2961	0.8963
73	41.3935	0.4139	4308.9694	272555.4303	0.6585
74	617.7301	6.1773	16525.9743	3844134.4039	0.6223
75	3089.2028	30.8920	108476.5735	20521573.9880	0.6643
76	97.4049	0.9740	4327.8087	833981.0537	0.8562
77	311.9459	3.1195	11409.9195	2179098.0702	0.6986
78	281.5027	2.8150	7397.5910	2447665.5613	0.8695
79	24.0953	0.2410	6035.5176	139295.0990	0.5781
80	39.6674	0.3967	8008.6160	144587.6746	0.3645
81	15.3183	0.1532	1810.6734	94751.4879	0.6186
82	13.7441	0.1374	3034.2635	68177.6030	0.4961
83	2.7872	0.0279	765.0106	20465.3030	0.7343
84	5.6014	0.0560	965.0237	49202.3301	0.8784
85	428.9295	4.2893	22661.2000	2693248.4677	0.6279
86	2.5188	0.0252	1863.0690	5074.2190	0.2015
87	3858.2236	38.5822	51546.1826	28990692.3348	0.7514
88	37.7222	0.3772	5038.3599	192326.6092	0.5099
89	480.9276	4.8093	13558.5315	4304782.9519	0.8951
90	51.8674	0.5187	3815.7785	344036.4421	0.6633
91	94.6999	0.9470	6475.6746	524022.0532	0.5534
92	215.5433	2.1554	8691.1542	1322250.1257	0.6135
93	722.8985	7.2290	15080.2409	5552222.0747	0.7681
94	3.0052	0.0301	3041.9004	3977.3564	0.1324
95	4.2982	0.0430	3339.6883	6131.4101	0.1427
96	12.0276	0.1203	7191.5768	14872.1208	0.1237
97	3.3858	0.0339	3313.0177	5105.7456	0.1508
98	142.7497	1.4275	9902.4992	427892.2052	0.2998
99	2884.7923	28.8479	50755.5535	11585326.0705	0.4016

ID	Area (ha)	Area (km^2)	Perimeter (m)	Exchange	nExchange
100	498.9055	4.9891	17742.7486	3661966.4433	0.7340
101	3.0750	0.0308	5017.4842	3313.3325	0.1078
102	10.1640	0.1016	4648.2933	14188.9966	0.1396
103	7.8550	0.0785	1193.0686	57400.2943	0.7308
104	248.8195	2.4882	7915.4696	2140345.6419	0.8602
105	467.6320	4.6763	15502.9261	3263136.0113	0.6978
106	64.9460	0.6495	5269.4415	274429.3578	0.4226
107	47.5396	0.4754	3158.4172	379199.5685	0.7977
108	4.8372	0.0484	1388.2229	40223.8548	0.8316
109	2.7185	0.0272	830.9034	16823.4240	0.6189
110	94.1088	0.9411	6801.1760	632552.0996	0.6722
111	110.9229	1.1092	7123.4946	607857.6573	0.5480

Figure C1: FG1 patch data - size and configuration.

Fragmentation Geometry Two: Patch Data | Appendix D

Figure D1: FG2 - key map for patch data by ID number.

ID	Area (ha)	Perimeter (m)	Exchange	nExchange	Links	Nodes	CDS	3-way Intersections	4-way Intersections	# of Intersections	4-way Intersection Density (int/km^2)	Freq 4-way Intersections (%)	Intersection Density (int/km^2)	Street Length (km)	Street Density (km/km^2)	LNR	Alpha
1	34.10	2922.19	291656.9	0.86	97	62	5	38	15	57	43.99	0.26	167.15	7.41	21.73	1.56	0.303
4	88.14	5715.23	608624.1	0.69	89	60	7	41	8	53	9.08	0.15	60.13	7.45	8.45	1.48	0.261
5	31.13	2421.86	256563.2	0.82	63	38	3	27	4	35	12.11	0.11	105.96	5.77	17.47	1.66	0.366
6	104.08	7329.43	715837.5	0.69	130	85	8	61	12	77	10.66	0.16	68.37	16.38	14.54	1.53	0.279
8	24.79	2933.41	200541.5	0.81	9	6	3	3	0	3	0.00	0.00	12.10	2.36	9.51	1.50	0.571
9	62.07	5256.59	423625.9	0.68	48	29	2	28	1	27	1.61	0.04	43.50	6.15	9.91	1.66	0.377
12	28.62	2779.30	232995.7	0.81	34	22	6	10	7	16	23.38	0.44	53.45	4.47	14.93	1.55	0.333
13	35.75	3267.18	231271.2	0.65	44	26	2	23	1	24	2.80	0.04	67.14	5.22	14.62	1.69	0.404
14	6.13	1398.92	44240.9	0.72	10	6	0	5	0	6	0.00	0.00	97.93	1.36	22.26	1.67	0.714
15	50.13	3284.29	375507.6	0.75	37	22	1	18	3	21	5.98	0.14	41.89	5.53	11.03	1.68	0.410
18	63.37	3905.88	533950.6	0.84	65	31	2	21	9	29	14.20	0.31	45.76	8.93	14.09	2.10	0.614
19	72.99	12402.00	473316.6	0.65	98	69	12	46	8	57	10.96	0.14	78.09	14.58	19.97	1.42	0.226
20	26.45	2133.08	210329.5	0.80	19	12	1	7	1	11	3.78	0.09	41.59	2.51	9.48	1.58	0.421
21	23.81	3869.95	122362.8	0.51	6	5	3	2	0	2	0.00	0.00	8.40	1.74	7.32	1.20	0.400
23	102.97	5663.59	739292.0	0.72	41	29	2	22	3	27	2.91	0.11	26.22	7.92	7.69	1.41	0.245
24	80.73	3729.19	613721.6	0.76	94	59	0	49	7	59	8.67	0.12	73.09	12.16	15.06	1.59	0.319
25	198.79	7826.05	1575402.9	0.79	196	137	10	100	10	127	5.03	0.08	63.89	23.09	11.62	1.43	0.223
26	38.79	2985.26	297520.7	0.77	49	36	6	23	2	30	5.16	0.07	77.34	5.38	13.86	1.36	0.209
27	102.49	5283.46	753690.6	0.74	95	69	9	41	6	60	5.85	0.10	58.54	13.81	13.47	1.38	0.203
28	333.17	12366.86	2117624.7	0.64	421	263	29	184	50	234	15.01	0.21	70.23	49.73	14.93	1.60	0.305
29	11.83	2464.76	56924.3	0.48	14	9	0	6	1	9	8.45	0.11	76.05	1.92	16.20	1.56	0.462
30	430.39	12044.34	3269024.2	0.76	438	298	28	249	14	270	3.25	0.05	62.73	57.54	13.37	1.47	0.239
35	44.88	5750.09	218062.6	0.49	94	63	5	41	8	58	17.82	0.14	129.23	9.61	21.41	1.49	0.264
36	18.60	2650.93	108414.2	0.58	17	9	2	6	1	7	5.38	0.14	37.63	1.98	10.65	1.89	0.692
38	7.08	2390.52	14716.8	0.21	9	7	3	4	0	4	0.00	0.00	56.51	1.51	21.36	1.29	0.333
39	15.17	2102.34	112084.5	0.74	20	13	5	7	1	8	6.59	0.13	52.73	1.51	9.97	1.54	0.381
40	405.75	9270.93	3195261.2	0.79	429	291	27	220	29	264	7.15	0.11	65.07	52.96	13.05	1.47	0.241
41	236.69	10565.30	1013398.7	0.43	234	159	12	114	18	147	7.60	0.12	62.11	31.66	13.38	1.47	0.243

ID	Area (ha)	Perimeter (m)	Exchange	nExchange	Links	Nodes	CDS	3-way Intersections	4-way Intersections	# of Intersections	4-way Intersection Density (int/km^2)	Freq 4-way Intersections (%)	Intersection Density (int/km^2)	Street Length (km)	Street Density (km/km^2)	LNR	Alpha
42	104.81	6922.54	721366.6	0.69	198	142	27	77	30	115	28.62	0.26	109.72	20.06	19.14	1.39	0.204
45	2.77	1131.58	13324.3	0.48	12	12	6	4	2	6	72.23	0.33	216.69	0.88	31.86	1.00	0.053
49	305.88	7968.76	2625068.1	0.86	440	256	10	121	109	246	35.63	0.44	80.42	53.48	17.48	1.72	0.365
50	99.66	7864.59	777223.7	0.78	139	105	13	67	7	92	7.02	0.08	92.31	13.05	13.09	1.32	0.171
53	539.80	13503.14	4541869.3	0.84	521	350	25	249	40	325	7.41	0.12	60.21	71.39	13.22	1.49	0.247
54	338.74	12180.24	2379305.2	0.70	331	216	13	165	18	203	5.31	0.09	59.93	46.82	13.82	1.53	0.272
57	44.44	4395.53	198636.5	0.45	46	34	12	7	7	22	15.75	0.32	49.51	6.14	13.81	1.35	0.206
58	278.80	7370.52	2371717.1	0.85	279	151	7	57	71	144	25.47	0.49	51.65	41.34	14.83	1.85	0.434
59	3.91	903.90	27058.1	0.69	3	2	1	1	0	1	0.00	0.00	25.54	0.47	12.07	1.50	-2.000
60	51.93	4736.45	240214.5	0.46	51	28	0	23	0	28	0.00	0.00	53.92	8.26	15.91	1.82	0.471
61	90.56	4568.41	657391.0	0.73	142	96	7	72	8	89	8.83	0.09	98.27	14.67	16.19	1.48	0.251
63	3.82	969.24	26877.6	0.70	3	1	0	1	0	1	0.00	0.00	26.19	0.43	11.25	3.00	-1.000
64	40.95	3382.03	300899.2	0.73	74	44	2	32	6	42	14.65	0.14	102.57	6.02	14.69	1.68	0.373
65	380.42	12425.82	2578288.1	0.68	449	286	12	122	119	274	31.28	0.43	72.03	64.21	16.88	1.57	0.289
67	5.65	4766.83	0.0	0.00	7	1	0	1	0	1	0.00	0.00	17.70	0.50	8.86	7.00	-2.333
68	63.81	4506.39	417313.2	0.65	152	100	9	48	27	91	42.31	0.30	142.61	13.78	21.60	1.52	0.272
69	12.54	2221.69	56731.4	0.45	14	7	1	5	1	6	7.97	0.17	47.83	1.49	11.86	2.00	0.889
71	269.31	7574.70	2232447.5	0.83	257	130	3	46	78	127	28.96	0.61	47.16	38.74	14.39	1.98	0.502
73	76.87	4645.38	566325.7	0.74	113	72	7	37	21	65	29.51	0.32	91.33	13.40	18.83	1.57	0.302
74	272.88	8825.80	2389502.2	0.88	276	179	12	143	17	167	6.23	0.10	61.20	38.06	13.95	1.54	0.278
75	49.40	4578.75	187748.3	0.38	95	60	11	30	12	49	24.29	0.24	99.19	8.47	17.14	1.58	0.313
76	319.05	12504.30	2090552.2	0.66	311	199	16	111	43	183	13.48	0.23	57.36	39.64	12.42	1.56	0.288
77	21.88	3420.50	115733.3	0.53	3	2	1	1	0	1	0.00	0.00	4.57	0.66	3.00	1.50	-2.000
79	25.61	3406.17	123587.4	0.48	24	5	0	4	1	5	3.90	0.20	19.52	3.30	12.88	4.80	4.000
81	24.41	3833.40	111813.5	0.46	24	13	1	8	0	12	0.00	0.00	49.16	3.23	13.22	1.85	0.571
82	259.54	16134.17	1116556.4	0.43	268	196	33	122	16	163	6.17	0.10	62.85	33.54	12.93	1.37	0.189
83	132.22	12903.71	647492.5	0.49	148	101	5	72	9	96	6.81	0.09	72.61	22.67	17.15	1.47	0.244
84	4.82	1255.09	27862.1	0.58	7	5	2	3	0	3	0.00	0.00	62.19	0.52	10.78	1.40	0.600

ID	Area (ha)	Perimeter (m)	Exchange	nExchange	Links	Nodes	CDS	3-way Intersections	4-way Intersections	# of Intersections	4-way Intersection Density (int/km^2)	Freq 4-way Intersections (%)	Intersection Density (int/km^2)	Street Length (km)	Street Density (km/km^2)	LNR	Alpha
85	101.95	5749.64	679957.5	0.67	166	102	6	47	38	96	37.27	0.40	94.16	17.46	17.13	1.63	0.327
86	132.86	6873.05	734711.9	0.55	164	105	12	58	21	93	15.81	0.23	70.00	18.44	13.88	1.56	0.293
87	142.10	15182.94	864879.8	0.61	213	122	9	78	31	113	21.82	0.27	79.52	26.84	18.89	1.75	0.385
88	293.81	7356.33	2317306.4	0.79	325	215	29	164	16	186	5.45	0.09	63.31	40.79	13.88	1.51	0.261
89	25.79	2608.86	146832.0	0.57	64	35	2	21	11	33	42.65	0.33	127.96	4.95	19.18	1.83	0.462
90	204.59	6855.76	1584156.4	0.77	261	124	10	55	49	114	23.95	0.43	55.72	30.23	14.78	2.10	0.568
91	20.36	3590.11	115468.1	0.57	34	24	3	0	0	21	0.00	0.00	103.16	4.51	22.17	1.42	0.256
92	4.27	1132.77	28553.8	0.67	5	4	3	1	0	1	0.00	0.00	23.41	0.45	10.64	1.25	0.667
94	4.83	1037.88	34895.3	0.72	9	4	1	2	1	3	20.72	0.33	62.15	0.68	14.17	2.25	2.000
95	5.10	1693.36	27834.0	0.55	12	6	0	3	2	6	39.22	0.33	117.65	2.04	39.93	2.00	1.000
96	4.88	1384.82	25290.9	0.52	8	4	1	3	0	3	0.00	0.00	61.52	1.25	25.69	2.00	1.667
97	8.26	1910.27	51527.0	0.62	2	2	1	1	0	1	0.00	0.00	12.10	0.14	1.67	1.00	-1.000
98	46.32	2853.14	396407.3	0.86	67	32	0	13	17	32	36.70	0.53	69.08	6.86	14.81	2.09	0.610
100	138.75	5972.83	1105392.6	0.80	132	95	10	65	7	85	5.05	0.08	61.26	20.55	14.81	1.39	0.205
101	151.81	11054.70	886013.9	0.58	271	167	9	76	54	158	35.57	0.34	104.08	25.19	16.60	1.62	0.319
104	192.79	12568.99	1558877.0	0.81	213	129	15	67	42	114	21.79	0.37	59.13	29.40	15.25	1.65	0.336
105	8.12	2389.57	39003.2	0.48	55	20	0	5	11	20	135.50	0.55	246.36	3.17	38.99	2.75	1.029
106	5.44	1058.45	41429.3	0.76	6	5	2	3	0	3	0.00	0.00	55.13	0.73	13.34	1.20	0.400
107	29.63	6148.51	172672.6	0.58	45	25	3	12	3	22	10.13	0.14	74.25	3.84	12.97	1.80	0.467
111	60.19	4122.40	344938.0	0.57	36	16	0	4	11	16	18.27	0.69	26.58	6.07	10.08	2.25	0.778
112	27.11	3536.07	104879.9	0.39	7	3	2	1	0	1	0.00	0.00	3.69	1.33	4.90	2.33	5.000
114	8.33	2581.40	36553.5	0.44	47	21	2	3	12	19	144.02	0.63	228.03	2.94	35.28	2.24	0.730
115	764.23	14051.97	6858601.8	0.90	797	528	31	438	43	497	5.63	0.09	65.03	105.95	13.86	1.51	0.257
116	21.58	3148.49	118889.6	0.55	52	26	1	18	7	25	32.44	0.28	115.87	3.96	18.38	2.00	0.574
118	125.34	5367.92	980221.0	0.78	130	92	12	58	10	80	7.98	0.13	63.83	18.47	14.73	1.41	0.218
119	209.31	7177.25	1858901.6	0.89	292	187	8	125	32	179	15.29	0.18	85.52	31.81	15.20	1.56	0.287
121	84.88	5078.29	520330.7	0.61	340	198	1	121	64	197	75.40	0.32	232.10	22.05	25.97	1.72	0.366
122	27.85	3219.26	230408.5	0.83	16	8	2	4	2	6	7.18	0.33	21.55	3.15	11.33	2.00	0.818

ID	Area (ha)	Perimeter (m)	Exchange	nExchange	Links	Nodes	CDS	3-way Intersections	4-way Intersections	# of Intersections	4-way Intersection Density (int/km^2)	Freq 4-way Intersections (%)	Intersection Density (int/km^2)	Street Length (km)	Street Density (km/km^2)	LNR	Alpha
123	56.34	7210.21	245329.2	0.44	119	80	12	36	17	68	30.17	0.25	120.70	11.69	20.75	1.49	0.258
124	60.24	4043.16	377483.4	0.63	65	41	3	29	0	38	0.00	0.00	63.08	8.02	13.31	1.59	0.325
125	117.17	6524.25	679196.7	0.58	190	95	5	38	49	90	41.82	0.54	76.81	18.74	15.99	2.00	0.519
126	410.89	11397.73	3144764.7	0.77	415	290	31	216	22	259	5.35	0.08	63.03	55.02	13.39	1.43	0.219
128	13.93	1749.17	90593.4	0.65	23	8	0	2	6	8	43.09	0.75	57.45	2.27	16.29	2.88	1.455
129	62.27	3431.22	488361.5	0.78	115	73	2	36	23	71	36.94	0.32	114.02	10.58	16.98	1.58	0.305
131	4.01	932.65	27826.7	0.69	10	5	0	4	1	5	24.93	0.20	124.64	0.94	23.31	2.00	1.200
132	111.54	9560.42	353637.8	0.32	149	96	7	44	22	89	19.72	0.25	79.79	18.22	16.33	1.55	0.289
133	440.12	13063.26	3201225.2	0.73	497	342	33	268	21	309	4.77	0.07	70.21	57.83	13.14	1.45	0.230
134	7.60	1355.69	44933.2	0.59	15	6	0	3	2	6	26.30	0.33	78.90	1.29	16.98	2.50	1.429
136	34.37	2648.38	288897.7	0.84	28	23	10	12	0	13	0.00	0.00	37.82	3.36	9.77	1.22	0.146
137	335.57	16386.00	1124000.1	0.33	286	219	38	118	16	181	4.77	0.09	53.94	40.05	11.93	1.31	0.157
139	8.03	1150.74	70104.3	0.87	12	6	0	3	2	6	24.91	0.33	74.73	1.47	18.28	2.00	1.000
140	46.21	4331.99	392166.2	0.85	105	62	4	38	16	58	34.62	0.28	125.51	8.16	17.65	1.69	0.370
141	10.22	1779.45	79211.5	0.78	15	6	0	3	3	6	29.36	0.50	58.73	1.65	16.15	2.50	1.429
142	90.38	6402.63	649955.3	0.72	146	105	8	64	10	97	11.06	0.10	107.33	14.28	15.81	1.39	0.205
143	48.74	3840.81	297603.3	0.61	89	59	4	46	3	55	6.16	0.05	112.84	8.57	17.59	1.51	0.274
144	368.17	9525.87	3094243.0	0.84	536	336	7	180	89	329	24.17	0.27	89.36	60.63	16.47	1.60	0.301
145	20.18	2476.32	101133.6	0.50	21	9	2	2	5	7	24.78	0.71	34.69	1.98	9.83	2.33	1.000
147	40.46	3930.39	194429.4	0.48	52	25	0	11	14	25	34.61	0.56	61.80	6.72	16.62	2.08	0.622
150	2.93	731.11	24478.8	0.84	8	3	0	2	1	3	34.17	0.33	102.50	0.52	17.88	2.67	6.000
151	108.69	6230.27	837532.3	0.77	88	56	9	33	11	47	10.12	0.23	43.24	11.00	10.12	1.57	0.308
152	13.11	1654.59	84271.0	0.64	23	11	1	4	5	10	38.14	0.50	76.29	2.21	16.86	2.09	0.765
153	175.87	6682.23	1231319.0	0.70	111	76	11	47	7	64	3.98	0.11	36.39	14.70	8.36	1.46	0.245
154	73.54	4044.02	457118.8	0.62	153	76	2	21	53	74	72.06	0.72	100.62	14.97	20.35	2.01	0.531
155	223.56	9217.53	1059456.3	0.47	230	127	6	58	49	121	21.92	0.40	54.12	31.16	13.94	1.81	0.418
156	112.24	4940.08	995480.2	0.89	201	110	6	49	51	104	45.44	0.49	92.66	20.43	18.20	1.83	0.428
157	65.40	4030.09	407861.7	0.62	73	39	0	15	18	39	27.52	0.46	59.63	10.39	15.88	1.87	0.479

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158	5.65	1836.40	30903.2	0.55	10	9	4	2	1	5	12.73	0.20	63.67	1.11	14.09	1.11	0.154
159	310.04	10268.24	2699029.2	0.87	367	225	12	135	65	213	20.97	0.31	68.70	43.28	13.96	1.63	0.321
161	45.52	3183.69	347686.9	0.76	62	34	1	20	10	33	21.97	0.30	72.49	6.70	14.73	1.82	0.460
162	57.31	5498.97	313000.3	0.55	36	22	4	16	1	18	2.14	0.06	38.56	5.32	11.39	1.64	0.385
163	243.62	6671.37	2052010.9	0.84	319	201	0	112	61	201	25.04	0.30	82.51	44.08	18.09	1.59	0.300
165	4.05	1506.02	29496.6	0.73	9	4	1	1	2	3	49.43	0.67	74.15	0.77	19.03	2.25	2.000
166	3.66	1002.36	21589.3	0.59	7	5	2	2	0	3	0.00	0.00	81.90	0.52	14.27	1.40	0.600
168	5.40	970.70	42457.2	0.79	5	3	1	2	0	2	0.00	0.00	37.07	0.53	9.81	1.67	3.000
169	169.54	7958.18	1473120.5	0.87	189	131	9	91	12	122	7.08	0.10	71.96	24.06	14.19	1.44	0.230
170	67.44	3751.79	571475.1	0.85	58	45	3	32	1	42	1.48	0.02	62.28	7.89	11.69	1.29	0.165
171	74.49	3865.12	642773.1	0.86	78	42	6	7	27	36	36.25	0.75	48.33	11.75	15.78	1.86	0.468
173	5.53	1058.70	44380.7	0.80	3	2	1	1	0	1	0.00	0.00	18.09	0.45	8.14	1.50	-2.000
174	48.07	3355.07	336592.3	0.70	53	33	3	23	4	30	8.32	0.13	62.41	6.26	13.02	1.61	0.344
175	11.45	1640.96	83825.6	0.73	14	7	1	5	1	6	8.73	0.17	52.41	1.64	14.34	2.00	0.889
176	50.14	3255.56	422501.9	0.84	56	29	2	6	17	27	33.91	0.63	53.85	8.80	17.56	1.93	0.528
177	153.30	7678.89	1161107.2	0.76	315	167	2	59	101	165	65.88	0.61	107.63	34.27	22.36	1.89	0.453
178	15.71	1787.95	117079.1	0.75	19	14	3	9	0	11	0.00	0.00	70.03	2.22	14.14	1.36	0.261
179	13.04	1867.74	98834.4	0.76	10	6	2	3	0	4	0.00	0.00	30.67	1.42	10.87	1.67	0.714
180	69.62	3932.11	441079.2	0.63	96	49	1	15	32	48	45.96	0.67	68.95	11.36	16.32	1.96	0.516
181	80.81	4214.24	633366.1	0.78	112	68	5	32	21	63	25.99	0.33	77.96	12.10	14.98	1.65	0.344
182	15.25	1699.97	123932.2	0.81	26	17	3	12	0	14	0.00	0.00	91.80	2.31	15.14	1.53	0.345
183	147.04	5623.78	1234840.9	0.84	128	90	12	50	10	71	6.80	0.14	48.29	18.28	12.43	1.42	0.223
184	181.50	8758.84	1546110.5	0.85	337	202	12	103	74	190	40.77	0.39	104.68	32.67	18.00	1.67	0.341
185	40.37	3422.57	226242.9	0.56	38	29	1	4	14	28	34.99	0.50	69.98	4.48	11.21	1.31	0.189
186	23.56	2148.13	174707.7	0.74	25	14	1	11	0	13	0.00	0.00	55.17	2.45	10.41	1.79	0.522
187	132.07	4899.56	1160690.6	0.88	170	89	2	39	46	87	34.83	0.53	65.87	19.98	15.13	1.91	0.474
188	60.76	3676.71	546360.2	0.90	40	21	1	12	7	20	11.52	0.35	32.91	6.35	10.44	1.90	0.541
189	35.90	2579.15	298603.7	0.83	43	25	5	5	11	20	30.64	0.55	55.71	5.82	16.20	1.72	0.422

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190	74.92	4120.55	459622.4	0.61	50	21	0	2	19	21	25.36	0.90	28.03	9.67	12.91	2.38	0.811
191	51.64	3352.17	329696.3	0.64	56	24	0	4	20	24	38.73	0.83	46.47	8.02	15.53	2.33	0.767
192	34.25	2509.20	259372.5	0.76	27	10	0	0	10	10	29.20	1.00	29.20	4.99	14.58	2.70	1.200
193	61.97	4222.25	565846.9	0.91	100	45	0	24	18	45	29.05	0.40	72.62	11.27	18.19	2.22	0.659
194	19.64	2396.74	113929.0	0.58	17	10	0	9	0	10	0.00	0.00	50.93	2.82	14.38	1.70	0.533
195	55.09	4118.89	483594.7	0.88	75	50	5	31	8	45	14.52	0.18	81.68	8.87	16.10	1.50	0.274
196	107.27	4508.50	766737.7	0.71	67	32	0	5	25	32	23.30	0.78	29.83	12.89	12.02	2.09	0.610
197	71.59	4615.29	530219.7	0.74	105	51	2	26	23	49	32.13	0.47	68.45	12.38	17.30	2.06	0.567
199	48.87	3096.97	422128.4	0.86	69	36	5	8	22	31	45.02	0.71	63.43	8.57	17.53	1.92	0.507
200	102.08	4453.88	906292.1	0.89	92	56	1	24	20	55	19.59	0.36	53.88	13.43	13.16	1.64	0.346
201	176.61	6816.48	1541494.6	0.87	253	143	4	60	69	139	39.07	0.50	78.70	29.05	16.45	1.77	0.395
202	150.20	5512.02	1217292.0	0.81	195	110	9	36	55	101	36.62	0.54	67.24	25.82	17.19	1.77	0.400
203	78.04	3749.14	640995.6	0.82	73	35	0	10	24	35	30.75	0.69	44.85	10.86	13.92	2.09	0.600
205	24.13	2109.71	185259.1	0.77	7	2	1	1	0	1	0.00	0.00	4.15	1.62	6.71	3.50	-6.000
206	50.45	5847.14	252201.7	0.50	28	10	5	2	3	5	5.95	0.60	9.91	5.94	11.77	2.80	1.267
207	4.01	1011.22	27719.3	0.69	5	0	0	0	0	0	0.00	0.00	0.00	0.61	15.10	0.00	-1.200
208	166.73	7051.33	1302398.2	0.78	159	88	1	47	28	87	16.79	0.32	52.18	20.65	12.39	1.81	0.421
209	169.55	5532.08	1492967.2	0.88	143	89	10	37	32	79	18.87	0.41	46.59	20.79	12.26	1.61	0.318
211	218.99	6204.72	1980774.0	0.90	201	99	3	28	68	96	31.05	0.71	43.84	32.17	14.69	2.03	0.534
212	30.88	3591.58	112219.8	0.36	38	23	4	12	1	19	3.24	0.05	61.52	4.44	14.38	1.65	0.390
213	93.22	4001.09	847259.9	0.91	86	40	2	3	32	38	34.33	0.84	40.76	13.76	14.76	2.15	0.627
214	12.42	1837.16	65924.4	0.53	26	18	3	5	4	15	32.21	0.27	120.80	2.42	19.46	1.44	0.290
215	133.26	4769.66	1201033.7	0.90	183	102	4	24	60	98	45.03	0.61	73.54	20.65	15.50	1.79	0.412
216	130.26	4789.20	1104705.6	0.85	153	74	1	24	48	73	36.85	0.66	56.04	20.93	16.07	2.07	0.559
217	154.73	5020.82	1321578.5	0.85	113	54	5	6	39	49	25.22	0.80	31.69	21.90	14.16	2.09	0.583
218	105.17	6556.59	598140.0	0.57	116	76	10	53	9	66	8.56	0.14	62.76	13.21	12.56	1.53	0.279
219	11.71	1584.22	77705.2	0.66	10	2	0	2	0	2	0.00	0.00	17.08	1.64	13.96	5.00	-9.000
220	31.91	4143.93	182679.9	0.57	28	16	0	14	0	16	0.00	0.00	50.13	4.97	15.59	1.75	0.481

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221	6.51	1643.52	39050.4	0.60	4	2	0	2	0	2	0.00	0.00	30.74	0.48	7.41	2.00	-3.000
222	13.66	1863.09	75269.6	0.55	21	13	2	9	1	11	7.32	0.09	80.53	1.74	12.74	1.62	0.429
223	142.69	5512.15	1150685.6	0.81	137	73	4	38	31	69	21.72	0.45	48.36	18.74	13.13	1.88	0.461
224	73.55	3583.47	640241.6	0.87	95	45	0	27	18	45	24.47	0.40	61.18	12.08	16.42	2.11	0.600
225	76.51	3599.47	685470.0	0.90	73	38	1	18	18	37	23.53	0.49	48.36	9.84	12.86	1.92	0.507
226	22.28	2524.24	117288.8	0.53	15	1	0	1	0	1	0.00	0.00	4.49	3.13	14.06	15.00	-5.000
227	134.14	5677.26	997898.2	0.74	85	58	9	33	8	49	5.96	0.16	36.53	12.80	9.54	1.47	0.252
228	21.71	2384.85	132075.1	0.61	32	19	1	9	5	18	23.03	0.28	82.92	4.70	21.67	1.68	0.424
229	163.33	6637.83	1398386.7	0.86	149	87	6	27	45	81	27.55	0.56	49.59	22.95	14.05	1.71	0.373
230	102.11	6762.74	437173.2	0.43	109	64	3	30	22	61	21.55	0.36	59.74	14.52	14.22	1.70	0.374
231	2.83	754.66	20660.6	0.73	2	0	0	0	0	0	0.00	0.00	0.00	0.38	13.45	0.00	-0.600
232	59.91	3097.79	543027.0	0.91	48	28	1	19	6	27	10.02	0.22	45.07	6.57	10.97	1.71	0.412
233	29.04	3402.75	127571.3	0.44	59	42	13	8	15	29	51.66	0.52	99.87	4.72	16.25	1.40	0.228
234	28.26	3265.61	118796.5	0.42	28	13	0	10	2	13	7.08	0.15	46.00	3.85	13.61	2.15	0.762
235	16.80	1948.74	102611.1	0.61	6	1	0	1	0	1	0.00	0.00	5.95	1.29	7.67	6.00	-2.000
236	69.99	5942.25	270085.8	0.39	78	49	5	24	15	44	21.43	0.34	62.87	10.40	14.86	1.59	0.323
237	99.75	4544.91	884275.3	0.89	29	21	8	12	0	13	0.00	0.00	13.03	3.90	3.91	1.38	0.243
239	15.23	1819.46	94498.8	0.62	21	11	0	2	8	11	52.53	0.73	72.23	3.17	20.83	1.91	0.647
240	106.00	4206.12	944959.8	0.89	116	66	7	31	27	59	25.47	0.46	55.66	14.04	13.25	1.76	0.402
242	49.32	3094.28	412565.1	0.84	46	24	1	16	6	23	12.17	0.26	46.63	6.40	12.99	1.92	0.535
243	179.63	5513.65	1550289.6	0.86	183	102	1	61	36	101	20.04	0.36	56.23	24.97	13.90	1.79	0.412
244	14.05	1670.11	92906.8	0.66	12	5	0	5	0	5	0.00	0.00	35.58	1.81	12.90	2.40	1.600
245	154.50	6213.58	1303822.4	0.84	157	84	5	32	40	79	25.89	0.51	51.13	21.25	13.76	1.87	0.454
246	5.50	973.58	48061.1	0.87	3	1	0	1	0	1	0.00	0.00	18.18	0.54	9.83	3.00	-1.000
247	16.78	1715.46	137722.9	0.82	28	18	4	6	5	14	29.79	0.36	83.41	2.69	16.00	1.56	0.355
248	105.21	4198.91	963065.9	0.92	116	62	1	42	19	61	18.06	0.31	57.98	15.04	14.29	1.87	0.462
249	186.12	9530.37	1284402.8	0.69	307	198	4	135	29	194	15.58	0.15	104.23	31.41	16.87	1.55	0.281
250	74.42	3674.92	659088.2	0.89	61	32	0	14	14	32	18.81	0.44	43.00	9.57	12.86	1.91	0.508

ID	Area (ha)	Perimeter (m)	Exchange	nExchange	Links	Nodes	CDS	3-way Intersections	4-way Intersections	# of Intersections	4-way Intersection Density (int/km^2)	Freq 4-way Intersections (%)	Intersection Density (int/km^2)	Street Length (km)	Street Density (km/km^2)	LNR	Alpha
251	17.82	2003.90	107715.6	0.60	13	7	1	4	0	6	0.00	0.00	33.67	1.63	9.15	1.86	0.778
252	24.86	3272.78	96830.5	0.39	19	9	2	6	1	7	4.02	0.14	28.16	2.78	11.16	2.11	0.846
253	162.87	5568.57	1235129.2	0.76	197	126	6	95	12	120	7.37	0.10	73.68	22.78	13.99	1.56	0.291
254	21.60	3335.61	100454.8	0.47	43	27	1	13	3	26	13.89	0.12	120.35	4.18	19.36	1.59	0.347
255	180.67	5492.33	1549089.7	0.86	199	103	0	36	62	103	34.32	0.60	57.01	30.18	16.70	1.93	0.483
256	117.02	13476.57	658446.3	0.56	165	101	17	47	7	84	5.98	0.08	71.79	18.17	15.53	1.63	0.330
257	104.66	7362.71	352484.5	0.34	148	92	4	58	16	88	15.29	0.18	84.08	17.11	16.35	1.61	0.318
258	191.75	7000.51	1265147.9	0.66	211	137	1	107	14	136	7.30	0.10	70.93	27.02	14.09	1.54	0.279
259	37.26	4366.03	191625.6	0.51	50	35	5	23	3	31	8.05	0.10	83.20	5.53	14.84	1.43	0.246
260	11.12	1410.87	94438.9	0.85	10	6	0	3	1	6	8.99	0.17	53.97	1.17	10.54	1.67	0.714
261	6.00	1121.27	39558.2	0.66	7	3	0	2	1	3	16.66	0.33	49.97	0.66	10.92	2.33	5.000
262	212.07	6612.74	1649869.9	0.78	251	162	3	125	14	159	6.60	0.09	74.98	30.53	14.39	1.55	0.282
263	6.22	1279.14	44176.2	0.71	10	5	0	5	0	5	0.00	0.00	80.38	1.45	23.31	2.00	1.200
264	4.00	946.65	33774.6	0.84	8	5	0	3	0	5	0.00	0.00	125.03	0.91	22.76	1.60	0.800
265	260.69	8678.81	2154963.0	0.83	334	186	9	77	97	177	37.21	0.55	67.90	43.72	16.77	1.80	0.406
266	14.54	1580.04	123958.4	0.85	11	8	2	5	0	5	0.00	0.00	34.38	1.34	9.23	1.38	0.364
267	36.52	2699.76	277074.6	0.76	49	31	6	18	4	25	10.95	0.16	68.45	4.78	13.09	1.58	0.333
268	73.69	8142.13	432218.9	0.59	74	56	17	31	3	26	4.07	0.12	35.28	8.68	11.78	1.32	0.178
269	69.15	7063.42	225122.6	0.33	39	26	3	13	2	23	2.89	0.09	33.26	4.32	6.25	1.50	0.298
271	39.51	5535.86	114781.1	0.29	32	3	1	2	0	2	0.00	0.00	5.06	4.62	11.68	10.67	30.000
272	212.24	7019.52	1350141.9	0.64	306	158	2	63	91	156	42.88	0.58	73.50	36.89	17.38	1.94	0.479
273	144.17	7645.25	831144.6	0.58	177	99	5	54	34	94	23.58	0.36	65.20	24.49	16.98	1.79	0.409
274	96.54	4909.44	760899.7	0.79	133	76	0	55	12	73	12.43	0.16	75.62	15.16	15.70	1.75	0.395
275	5.10	1602.92	17658.2	0.35	7	4	0	1	1	4	19.60	0.25	78.40	1.01	19.84	1.75	1.333
276	77.43	3674.51	677018.3	0.87	104	60	0	42	14	60	18.08	0.23	77.49	11.76	15.19	1.73	0.391
277	267.12	7093.33	1925423.4	0.72	340	255	29	154	32	226	11.98	0.14	84.61	42.54	15.93	1.33	0.170
278	5.00	1545.12	17987.7	0.36	5	3	0	1	0	3	0.00	0.00	60.01	0.91	18.27	1.67	3.000
279	77.35	3550.21	680365.8	0.88	82	47	2	31	11	45	14.22	0.24	58.18	10.53	13.62	1.74	0.404

ID	Area (ha)	Perimeter (m)	Exchange	nExchange	Links	Nodes	CDS	3-way Intersections	4-way Intersections	# of Intersections	4-way Intersection Density (int/km^2)	Freq 4-way Intersections (%)	Intersection Density (int/km^2)	Street Length (km)	Street Density (km/km^2)	LNR	Alpha
281	91.70	4457.30	658619.0	0.72	101	66	5	43	10	61	10.91	0.16	66.52	11.43	12.47	1.53	0.283
282	2.97	1023.16	14060.8	0.47	12	8	1	2	1	7	33.68	0.14	235.73	0.91	30.56	1.50	0.455
285	146.12	4907.75	1255292.4	0.86	174	110	4	62	25	106	17.11	0.24	72.54	21.52	14.73	1.58	0.302
287	33.57	4058.95	143949.2	0.43	45	22	0	16	4	22	11.91	0.18	65.53	5.75	17.12	2.05	0.615
288	153.03	7394.57	1153483.7	0.75	198	117	6	52	53	111	34.63	0.48	72.53	27.18	17.76	1.69	0.358
289	112.20	5554.35	700940.6	0.62	123	86	5	53	11	81	9.80	0.14	72.20	14.60	13.01	1.43	0.228
290	21.84	2619.80	106183.1	0.49	12	7	1	3	1	6	4.58	0.17	27.47	1.40	6.42	1.71	0.667
291	25.25	2592.15	170644.7	0.68	5	5	2	3	0	3	0.00	0.00	11.88	1.33	5.26	1.00	0.200
292	162.18	5284.63	1325099.2	0.82	194	111	2	54	51	109	31.45	0.47	67.21	25.00	15.42	1.75	0.387
293	144.34	5473.39	988991.1	0.69	182	106	1	64	34	105	23.56	0.32	72.75	21.66	15.01	1.72	0.372
294	8.22	1844.16	32390.0	0.39	7	2	0	0	2	2	24.32	1.00	24.32	1.04	12.62	3.50	-6.000
295	16.39	2082.83	93230.8	0.57	9	8	5	2	0	3	0.00	0.00	18.30	1.12	6.81	1.13	0.182
296	21.94	2740.97	116750.5	0.53	33	19	5	14	0	14	0.00	0.00	63.82	3.30	15.03	1.74	0.455
297	137.76	7866.51	545382.0	0.40	153	104	14	70	10	90	7.26	0.11	65.33	19.63	14.25	1.47	0.246
298	123.40	4588.03	1078613.9	0.87	124	80	3	54	12	77	9.72	0.16	62.40	16.85	13.66	1.55	0.290
300	16.69	1834.17	136688.4	0.82	28	19	0	13	2	19	11.98	0.11	113.81	2.72	16.27	1.47	0.303
301	12.54	1585.24	99968.2	0.80	10	4	1	1	2	3	15.95	0.67	23.93	1.43	11.39	2.50	2.333
302	7.74	1199.77	56026.7	0.72	4	2	0	0	0	2	0.00	0.00	25.84	0.57	7.33	2.00	-3.000
303	5.37	1887.29	15887.7	0.30	7	3	1	2	0	2	0.00	0.00	37.22	0.49	9.16	2.33	5.000
304	176.57	5810.63	1301523.5	0.74	153	95	9	63	19	86	10.76	0.22	48.70	20.97	11.88	1.61	0.319
305	73.61	3496.31	656903.0	0.89	84	54	5	31	13	49	17.66	0.27	66.57	10.31	14.01	1.56	0.301
306	97.40	4847.28	811575.5	0.83	37	25	8	6	8	17	8.21	0.47	17.45	6.94	7.13	1.48	0.289
307	53.53	2913.73	473311.5	0.88	63	39	2	18	14	37	26.15	0.38	69.12	8.44	15.76	1.62	0.342
308	63.67	8084.29	404359.6	0.64	60	38	5	15	11	33	17.28	0.33	51.83	10.18	15.99	1.58	0.324
309	71.52	6011.04	312248.8	0.44	84	53	6	38	7	47	9.79	0.15	65.72	10.33	14.44	1.58	0.317
310	42.72	5126.34	151801.6	0.36	30	25	16	4	1	9	2.34	0.11	21.07	3.80	8.89	1.20	0.133
311	15.10	3041.40	47735.6	0.32	13	7	4	0	1	3	6.62	0.33	19.87	1.58	10.49	1.86	0.778
312	27.21	2186.94	230129.2	0.85	20	14	3	9	1	11	3.68	0.09	40.43	2.18	8.00	1.43	0.304

ID	Area (ha)	Perimeter (m)	Exchange	nExchange	Links	Nodes	CDS	3-way Intersections	4-way Intersections	# of Intersections	4-way Intersection Density (int/km^2)	Freq 4-way Intersections (%)	Intersection Density (int/km^2)	Street Length (km)	Street Density (km/km^2)	LNR	Alpha
313	19.83	1893.24	160033.7	0.81	41	28	3	23	0	25	0.00	0.00	126.06	3.85	19.41	1.46	0.275
314	4.84	1388.22	40223.9	0.83	13	11	0	5	0	11	0.00	0.00	227.40	1.56	32.16	1.18	0.176
315	44.89	3156.30	292491.5	0.65	49	31	2	16	8	29	17.82	0.28	64.60	5.72	12.75	1.58	0.333
316	28.49	3973.92	141672.5	0.50	22	14	5	9	0	9	0.00	0.00	31.59	3.54	12.43	1.57	0.391
318	45.45	6470.53	190091.3	0.42	38	31	4	17	2	27	4.40	0.07	59.41	5.90	12.99	1.23	0.140
319	74.48	6009.47	408581.9	0.55	87	62	11	36	7	51	9.40	0.14	68.47	9.32	12.51	1.40	0.218
320	37.95	4155.37	195471.9	0.52	23	13	1	10	0	12	0.00	0.00	31.62	3.86	10.17	1.77	0.524
321	82.95	4211.47	596860.8	0.72	81	54	4	43	2	50	2.41	0.04	60.28	12.06	14.54	1.50	0.272
322	47.22	3368.79	269231.6	0.57	42	33	5	12	2	28	4.24	0.07	59.30	4.92	10.41	1.27	0.164
323	2.83	876.55	21461.5	0.76	3	3	2	1	0	1	0.00	0.00	35.34	0.21	7.37	1.00	1.000
324	166.93	5778.07	1269988.6	0.76	249	155	12	106	26	143	14.08	0.18	77.45	28.53	15.45	1.61	0.311
325	63.23	3701.27	423833.9	0.67	59	38	2	29	3	36	4.74	0.08	56.94	7.61	12.04	1.55	0.310
326	118.22	5946.28	916790.5	0.78	112	76	12	26	24	64	20.30	0.38	54.14	16.07	13.59	1.47	0.252
327	100.78	4046.89	795174.1	0.79	145	85	2	55	26	83	25.80	0.30	86.33	16.77	16.64	1.71	0.370
328	83.13	3754.76	718824.0	0.86	77	42	3	22	15	39	18.04	0.38	46.91	11.28	13.57	1.83	0.456
329	27.50	2293.53	223495.5	0.81	27	18	5	8	5	13	18.18	0.38	47.27	3.40	12.36	1.50	0.323
330	83.88	6077.02	384161.0	0.46	100	61	6	38	11	60	13.11	0.18	71.53	12.21	14.55	1.64	0.342
331	217.44	10095.25	745825.4	0.34	209	132	21	79	23	111	10.58	0.21	51.05	26.44	12.16	1.58	0.301
332	27.87	5987.85	109928.6	0.39	18	9	1	8	0	8	0.00	0.00	28.71	2.94	10.55	2.00	0.769
333	249.40	6432.96	1949814.7	0.78	243	152	13	77	48	139	19.25	0.35	55.73	33.12	13.28	1.60	0.308
334	742.80	22185.00	3612959.3	0.49	601	431	50	284	52	381	7.00	0.14	51.29	89.85	12.10	1.39	0.200
335	285.40	9703.35	2116502.3	0.74	229	171	18	102	15	153	5.26	0.10	53.61	32.36	11.34	1.34	0.175
336	53.86	3387.10	374021.4	0.69	57	34	4	14	11	30	20.42	0.37	55.70	7.13	13.25	1.68	0.381
337	185.31	8094.97	1020768.6	0.55	244	144	11	58	60	133	32.38	0.45	71.77	31.02	16.74	1.69	0.357
338	114.00	4990.10	785739.8	0.69	125	76	7	45	17	69	14.91	0.25	60.53	16.24	14.24	1.64	0.340
339	109.29	4761.34	825773.4	0.76	98	55	2	19	29	53	26.54	0.55	48.50	15.05	13.77	1.78	0.419
340	170.85	10592.78	932475.8	0.55	150	102	15	41	24	87	14.05	0.28	50.92	21.75	12.73	1.47	0.246
341	162.58	5723.20	1168927.4	0.72	188	107	10	41	53	97	32.60	0.55	59.66	26.05	16.02	1.76	0.392

ID	Area (ha)	Perimeter (m)	Exchange	nExchange	Links	Nodes	CDS	3-way Intersections	4-way Intersections	# of Intersections	4-way Intersection Density (int/km^2)	Freq 4-way Intersections (%)	Intersection Density (int/km^2)	Street Length (km)	Street Density (km/km^2)	LNR	Alpha
342	394.89	19488.16	1325037.0	0.34	461	317	44	162	73	273	18.49	0.27	69.13	52.84	13.38	1.45	0.231
343	186.77	9003.06	1009204.2	0.54	198	127	13	67	29	114	15.53	0.25	61.04	26.16	14.01	1.56	0.289
344	5.22	999.04	43601.5	0.83	7	4	1	2	0	3	0.00	0.00	57.45	0.72	13.82	1.75	1.333
345	25.78	2131.65	226114.7	0.88	38	19	1	9	8	18	31.03	0.44	69.81	3.88	15.06	2.00	0.606
346	22.48	1983.64	202019.8	0.90	32	15	1	5	9	14	40.03	0.64	62.27	3.78	16.81	2.13	0.720

Table D1: FG2 patch data - size, configuration, internal street networks, connectivity.