On Urban Form and Accessibility to Fresh Food: An Enquiry into the Spatial Distribution of Fresh Food Retail Establishments, in Relation to Transportation Networks and the Built Environment: A Montreal Case Study

Jing Xie

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By: Jing Xie

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Signed by the final examining committee:

(Norma Rantisi) ______________ Chair

(Alan Nash) ______________ Examiner

(Sébastien Lord) ______________ Examiner

(Pierre Gauthier) ______________ Supervisor

Approved by ______________

Chair of Department or Graduate Program Director

____

Dean of Faculty

Date ______________

Abstract

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Jing Xie

This thesis discusses the relationship between urban form and accessibility to fresh food in Montreal. Anchored in the disciplines of urban morphology and retail geography, it mobilizes GIS-based spatial and network analysis, as well as methods for measuring travel times by transportation modes. Establishments selling fresh fruits and vegetables are used as a proxy for healthy and nutritious food retailing. A three-pronged analysis is performed that looks into the establishments' spatial distribution; the physical and spatial characteristics of their surroundings; and their accessibility by active and collective transportation modes. A morphological approach reveals fine spatial articulations between retail location and specific characteristics and properties of the urban system, including its transportation infrastructures. The importance of accessibility to fresh food on public health cannot be over-emphasized. Furthermore, a supply system that reduces automobile dependence is a crucial step towards social and environmental sustainability and equitability.

Key words: retail geography, access to fresh food, sustainable transportation, urban form

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Chapter 1 Introduction

1.1 Research Context

Access to fresh and healthy food is an essential aspect of sustainable living. Accordingly, access to food has caught the attention of urban studies, planning and public health researchers in recent decades. An influential concept has emerged: food deserts. A food desert has been defined as a geographic area where affordable and nutritious food is difficult to obtain because of a lack of grocery stores and other types of healthy food providers, particularly for those without access to an automobile (Gallagher, 2011). To identify food deserts, numerous scholars have assessed accessibility to fresh food by considering food policy, social economy, and geographical accessibility; however, very few have investigated links between accessibility to fresh food and urban form. This research is not about food deserts per se, though some of its results can contribute to the discussions triggered by that line of enquiry. Food desert research points to the issue of geographical accessibility to healthy food, in particular by transportation modes other than the automobile. It provided the "pretext" and a starting point for devising our own enquiry on such matters. This research aims at focusing on the relationships between urban form, transportation networks and the location of retail establishments selling fresh fruits and vegetables (as a proxy for fresh and healthy food). It wishes more specifically to analyze the spatial distribution and the spatial contexts of such establishments, in order to measure in particular their accessibility by active and collective modes of transportation.

1.2 Montreal

Montreal metropolitan area has a population of more than 3,800,000 (including 1,800,000 on the eponym island). It is the second largest city in Canada, and it is ranked 14^{th} out of 140 cities in 2015 Global Liveability Ranking by the Economist Intelligence Unit (EIU, 2015). Montreal is known for its cultural diversity, and advanced economy. It is in many ways a typical North American city whose urban form evolved in parallel to transportation developments. Founded in 1642, it experienced development in pre-automobile, automobile and post-automobile eras. Different modes of transportation — walking, cycling, public transit, and automobile co-exist in the city. According to Apparicio, Cloutier and Shearmur (2007), food desert is not a significant problem in Montreal, since in general the city offers good geographic accessibility to fresh food stores. Yet, Montreal offers an excellent context to study spatial factors that affect accessibility to fresh food. Its wide array of urban conditions, its diversified retail landscape as well as its varied transportation options allow for tracing a contrasted portrait and conducting comparative analysis. In particular, Montreal has a very good public transit system, which has a long history, starting in 1861 (Société de transport de Montréal). It is worth mentioning that Montreal Metro is the busiest subway system in Canada and is the third busiest in North America (American Public Transportation Association, 2015).

1.3 Research Objective and Questions

The primary objective of this research is to discuss the relationship between urban form and accessibility to fresh food in Montreal. Methods are mobilized from the disciplines of urban morphology and urban transportation to study the spatial and physical characteristics of the built environment, considered as a system, as well as the transportation options available to fresh food customers. More specifically, a three-pronged analysis is performed on spatial distribution of fresh food retail establishments, their surrounding built environments and their accessibility by active and collective transportation modes. In general, this research aims to provide a better understanding of how urban form and accessibility to fresh food are intertwined and how these spatial conditions might differ according to different types of retail establishments. A taxonomy is produced to present key results of the research.

The over-arching research questions are:

- What are the spatial distribution patterns of fresh food retail establishments in relation to the built environment in Montreal?;
- How do such patterns affect accessibility to fresh food?

Three major sub-questions are addressed to help meeting the research objectives. First, how different categories of establishments selling fresh fruit and vegetables spatially distribute in Montreal? Then, what are the characteristics of the built environments in which different categories of fresh food retail establishments are located? Third, how do the built environments, including the characteristic of the transportation infrastructures, impact the accessibility to fresh food retail establishments?

1.4 Research Rationale

On the whole, the great majority of researchers tend to explain urban sustainability based on ecological, social and economic aspects, focusing on considerations such as environment, policy, social economy, transportation, etc. (Black,1996; Chiesura, 2004; Steg and Gifford, 2005; Kenworthy, 2006). However, studies about access to fresh food, which closely relate to public health and social equity, are relatively scarce in urban sustainability studies. Fresh fruit and vegetables are crucial for public health because they act as the most significant way to provide vitamins and other crucial nutrients that the human body need. On the "supply side" of the equation, connecting agricultural producers and urban inhabitants is key. Part of the supply chain concerns the different types of retail establishments and their location within the city. On the "demand side", there are issues pertaining to the presence or absence of establishments – as in so-called food deserts –, as well as the less explored issue pertaining to the physical assess to the said establishments by customers using different modes of transportation. The importance of accessibility to fresh food cannot be over-emphasized. It is a crucial component of urban sustainability.

Studying the situation in the US, Bassford (2010) indicated that Food deserts derived from "Supermarket redlining", a phenomenon which occurred in the 1960s and 1970s. With many middle-class residents moving to the suburbs in the 1960s and 1970s, supermarkets move out from urban centers. Retailers chased larger and less expensive tracts of land, while seeking simplified and business-friendly zoning and other regulations, more homogenous consumer preferences, and sectors with lower crime rates. Lower-income residents who remained in inner cities were often deprived of basic services and amenities for daily living. This situation kept deteriorating and gradually resulted in food deserts in many inner city locations. Later on, access to fresh food has deteriorated as well in some suburbs, due to poor quality of public transit and pauperizing communities, among other factors. Access to fresh food is a "hot" research topic currently. Even though the conditions in Montreal do not compare to those in many other North American cities, they do reflect an evolution in the practices of the retail sector that are associated with the evolution of urbanization patterns and of the modes of transportation. In short, Montreal experienced a pre-automobile era and an automobile era which have left traces in its built landscape. The former era is characterized by accessibility by foot, even in so-called "streetcar suburbs", whereas the latter era relies on individual motorization. Montreal still has a number of vibrant densely built inner-city neighborhoods from the pre-automobile period that are often granted with a local commercial street. Yet, the city did not escape the low-density suburban development model and its characteristic mono-functional zoning. As a consequence, it displays a good variety of urban environments and contrasted food retail geographies.

Most inner city districts that were produced before automobile era are still compact and walkable. In such an environment, retail establishments tend to be centrally located within their neighborhood. The outer city suburbs, which were generated with the development of freeways during automobile era, are sprawled. In such environments, retail facilities tend to be spread out along commercial thoroughfares, the so-called “strips” as well as power centers and lifestyle retailing clusters. There, it is the automobile that makes everything relatively accessible. Besides of the two forms of inner city and sprawled outer city, there exist certain contrasting urban forms and contexts that fall in between. This study contends that the conditions of accessibility to fresh food are various and complex, particularly in the later “hybrid” contexts. Therefore, it is useful to do research on the geography of fresh food retail establishments while focusing on urban morphology aspects. Numerous scholars have studied accessibility to fresh food in terms of geographic location in order to identify food deserts, and the majority examine food accessibility in relation to aspects such as income, ethnicity, price, etc. (Chung, Mysers, 1999; Zenk et al., 2005; Powell et al., 2007; Raja et al., 2008). However, very few consider urban form and accessibility to fresh food. Therefore, this thesis attempts to fill this gap, using Montreal’s diverse and contrasted contexts as a case study to better understand the dynamics of built environments, transportations as well as fresh food retail establishments types and their and locations.

1.5 Research Hypotheses

This research hypothesizes that different spatial logics inherited from different periods of urban development inform the fresh food retail geography. The research aims at unveiling the said logics and at measuring some of their impacts on accessibility to fresh food.

It hypothesizes further that:

1. A retail geography prevails that corresponds to pre-automobile era spatial patterns,

according to which, in densely built environments, small establishments are accessible by foot;

2. A retail geography prevails that corresponds to the automobile era spatial patterns, according to which, in low-density built environments, large establishments are accessible by automobile;
3. Mid-size establishments might be found in a variety of locations (spatial pattern/ built environment), in particular along thoroughfares and public transit infrastructures, and are accessible by multiple transportation means (foot, bicycle, public transit and automobile).

1.6 Structure and Organization

This thesis is organized around eight chapters. The introduction chapter gives a brief overview of the thesis. A theoretical framework follows, that situates this research within the literature pertaining to sustainable city and planning, food deserts, smart growth and transit-oriented development, urban form, land use and transportation.

Chapter three presents the methodology used in this research. It outlines the data collection, data preparation, and the specific methods used for morphological analyses. A classification of fresh food retail establishments is produced, comprised of four different categories: small size, medium size, large size, and farmer markets.

Chapter four quantitatively analyzes the spatial distribution of different categories of fresh food retail establishments in Montreal using point pattern analysis method. Chapter five explores the built environment in Montreal at two levels of spatial resolution respectively: 1. city-wide, and; 2. local. At the city-wide level, the analysis characterizes the location of different categories of establishments relative to predominantly residential areas; relative to specialized routes (i.e. thoroughfares) and public transportation infrastructure (i.e. bus routes). At the second level, i.e. at the local scale, the analysis focuses on the built environments in which different categories of establishments are located, by considering the characteristics of urban tissues that fall within the ten-minute walkable catchment areas (i.e. pedestrian sheds) of establishments, as well as the number of dwellings that fall within such a spatial-temporal threshold. Chapter six assesses morphological conditions within residential tissues, which helps explain, not only the presence or absence of establishments, but also the "intensity" of service offered. "Shifting gears", the seventh chapter discusses the impacts of location and context on accessibility by different transportation modes. This chapter relates to the previous two chapters and discusses how transportation modes are associated with different categories of establishments and built environments. The final chapter concludes the fourth, fifth, sixth and seventh chapters, by discussing the relationship between urban form and accessibility to fresh food and by providing suggestions for better city planning.

Chapter 2 Theoretical Framework

2.1 Introduction

Numerous scholars have studied access to healthy food from the perspectives of food deserts, food policy, social economy, and so on, but very few combine fresh food retail establishment distribution with urban form and transportation. Therefore, this theoretical framework aims at narrowing and refining this research topic in order to highlight the meaning and significance of this study for the reader. This chapter reviews literature that discusses what a sustainable city "should be like" according to normative sustainable planning approaches. Smart growth and transit-oriented development (TOD) are explored. Smart growth is an urban planning and transportation normative theory that aims to foster sustainable development. Transit-oriented development focuses on the key dimensions of the land use in relation to public transportation. Then, explanatory (i.e. scientific) theories in retail geography are explored to understand the changes of spatial distribution of retail between pre-automobile and post-automobile eras. Different classifications of food stores are also discussed based on a mix of scientific and processional retail literature. Thirdly, contemporary literature regarding healthy food accessibility and food desert is examined.

Based on the literature reviewed, a theoretical framework is proposed, that stresses:

1. why food is central to urban sustainability;
2. why the study of fresh food retail distribution is important in contemporary cities, and;
3. how the problem of accessibility is intertwined with urban form.

To go further and closer to this study topic, this theoretical framework discusses scientific theories for the study of urban form and specific analytical methods that are used in studies of accessibility and walkability.

2.2 Sustainable Development

2.2.1 Sustainable Cities and Development

There is no comprehensive or unified definition for “sustainable city” (sometimes labeled “eco-city”), but all definitions are based on the principle that cities “should” be built and managed according to the precepts of sustainable development. The term “should” is important here. It points to the normative nature of the discourse (as opposed to scientific and empirically based theoretical discourses). In 1987, a definition for sustainable development came out from the Brundtland Report of the World Commission of Environment and Development, as actions that “meet the needs of the present generation without compromising the ability of future generations to meet their own needs.” Sustainable development was derived from an economic perspective that considered whether the limited natural resources can continuously support human’s life on Earth. So the essence of economic sustainability is also to explore ways to satisfy human’s present and future needs of production (Basiago, 1998). Social sustainability builds the link between social justice conditions and environmental decay. It implies a system of social organization that assuages poverty. In its environmental aspects, sustainability implies proper rates of use and regeneration, as to address the destruction and repair of environmental resources. Basiago (1998) also discusses the relationship between economic, social, and environmental sustainability. He points out that environmental sustainability should be the precondition of economic sustainability, and that a sustained economic growth should not be at the cost of environmental sustainability. Although a sustainable environment system cannot guarantee to achieve economic and social sustainability, it is a necessary ingredient to achieve the sustainability of the entire system.

2.2.2 Smart Growth and Transit-oriented Development (TOD)

Various disciplines have different prescriptions and explanations to offer in relation to the sustainable city. In this study, only a few disciplinary fields need to be explored. This section focuses on architecture and transportation. Smart growth (compact city) and transit-oriented development (TOD), are opposed to “sprawled growth”. Both are urban planning and design approaches fostering the idea of sustainable development of contemporary city (Burchell, Listokin, Rutgers, 2000).

According to Smart Growth America, ‘Smart Growth’ is an approach for city and town development, which promotes housing and transport facilities being constructed near jobs, shops and schools in urban, suburban and rural contexts. Edwards and Haines (2007) suggest that smart growth supports local economies and protects the environment. They explain that smart growth concept emerged during the 1990s and continues to influence community planning and design to promote a better, more equitable and more affordable built environment. The goal of smart growth is to coordinate infrastructure and development investments. It aims to develop walkable and compact communities in which housing is located near jobs or public transits as well as in proximity to stores and services (Burchell, Listokin, Rutgers, 2000; Daniels 2001; Edwards, Haines, 2007). There does not exist any universal definition for smart growth, but according to Knaap and Talen (2005, 28: 108), the most recognized principles are the following:

- Create a range of housing opportunities and choices;
- Create walkable neighborhood;
- Encourage community and stakeholder collaboration;
- Foster distinctive, attractive places with a strong sense of place;
- Make development decisions predictable, fair, and cost-effective;
- Mix land uses;
- Preserve open space, farmland, natural beauty, and critical environmental areas;
- Provide a variety of transportation choices;
- Strengthen and direct development toward existing communities; and
- Take advantage of compact building design (Knaap and Talen, 2005, 28: 108).

Transit-oriented development (TOD) is “a type of community development that includes a mixture of housing, office, retail and/or other amenities integrated into a walkable neighborhood and located within a half-mile of quality public transportation” (Reconnecting America, 2015). TOD zoning strategies have been summarized as the ‘ABC’ in which, “A” stands for active pedestrian friendly streets, “B” for building intensity and scale, and “C” for careful transit integration (Holmes, Hemert, 2008). Peter Calthorpe, a founder of the TOD approach, described urban design principles in his seminal book *The Next American Metropolis: Ecology, Community, and the American Dream* (1993:43) as following:

- Organize growth on a regional level to be compact and transit-supportive;
- Place commercial, housing, jobs, parks, and civic uses within walking distance of transit stops;

- Create pedestrian-friendly street networks which directly connect local destinations;
- Provide a mix of housing types, densities, and costs;
- Preserve sensitive habitat, riparian zones, and high quality open space;
- Make public spaces the focus of building orientation and neighborhood activity;
- Encourage infill and redevelopment along transit corridors within existing neighborhoods (Calthorpe, 1993 :43).

Kenworthy (2006) argues that “sustainable urban form and transport are at the core of developing an eco-city.” He also points out that a compact, mixed-used urban form with sufficient green spaces and farm lands is critical for a sustainable city. Meanwhile, Handy (2005) argued that public transportation system, walking and pedestrian environments must be strengthened in order to reduce automobile dependence.

Both Smart Growth and TOD are key doctrines fostering the concept of sustainable city or sustainable planning. Smart Growth and TOD have common principles, which focus on compact and mixed-used urban form and pedestrian walkable built environments linked by good and effective public transit. The exploration of smart growth and TOD literature was meant to stress how the questions of land use, transportation and access to services and amenities, by means other than the automobile, are central to current planning debates. The following section of this Chapter investigates the links between urban form, land use and transportation, while exploring methodological means to assess these links empirically.

2.2.3 Sustainable Development and Food

Preserving farmland is advocated as a principle for smart growth (Knaap and Talen 2005). Numerous scholars have suggested that farmland and other forms of urban agriculture could not only play a part in ecosystems and in greening the environment, but also directly affect the production and consumption of food (La Rosa, Barbarossa, Privitera, Martinico, 2014; Zasada, 2011; Zezza and Tasciotti, 2010). A healthy food system is one of the critical factors for a sustainable community. A well-developed local food economy is an effective approach to insure the vitality of a community or city (Feenstra, 1997). Viljoen and Wiskerke (2012) contend that food and eating environments are key for sustainable urban development and should be considered essential in any urban development strategy. Public health scholars have repeatedly explained that healthy eating and food environment is one of the most critical methods to decrease obesity rate and other associated diseases (Morland, Roux, Wing,2006; Story, Kaphingst, Robinson-O'Brien, Glanz,2008; Hesketh, Waters, Green, Salmon, Williams, 2005). Wiskerke (2009) analyzes the relationship between food geography and sustainable regional development. He explains how food relates to sustainable development by illustrating the emerging new food geography that develops along three partly interrelated and mutually reinforcing societal axes (Figure 1). He contends that food impacts many aspect of urban life, such as economy, transport, health, environment, employment, social inclusion and justice, so food supply and demand (market), policy makers and actors (government), food consumers (civic society) are closely linked, which illustrates how food plays an important part in sustainable development.

Hence, both normative and scientific literature stress the importance of access to healthy food in urban contexts. Wiskerke Model of “integrated and territorial mode of food governance (Figure 1) illustrates the complexities of food procurement and access, as the governance model implies, interactions between government, the private sector, and the civic society. Transportation and land-use planning can play a key role here, as it can help articulating the procurement efforts with the citizens’ needs (including for the most vulnerable populations) while reducing the dependence on cars. Yet, good land-use and transportation planning need to rely on evidence-based approaches. Here, retail geography, spatial statistics, urban morphology and urban transportation studies provide essential theoretical and analytical tools, as will be discussed in the following sections.

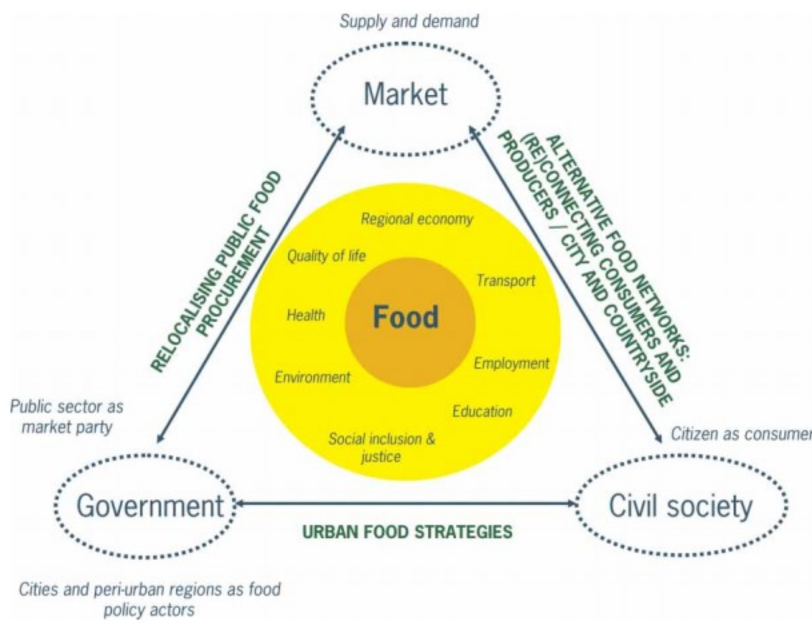

Figure 1. The integrated and territorial mode of food governance (Wiskerke, 2009)

2.3 Retail Geography

In the early 1980s, retail geography mainly explored the spatial variation in demand and supply of retail activities, such as illustrated by the books *Retail Location and Retail Planning* (Guy, 1980) and *Retail Geography* (Dawson, 1981). A large number of urban and economic geographers have discussed the importance of retail location since then (Davies, 1984; Jones and Simons, 1987). The definition of retail geography appeared in the 5th edition of Dictionary of Human Geography (2011). "Retail geography is the study of interrelations existing between spatial patterns of retail location and organization on the one hand, and the geography of retail consumer on the other. Retail geography is often situated at the overlap of related sub-fields, including ECONOMIC GEOGRAPHY, the geography of SERVICES and URBAN GEOGRAPHY" (p. 653). Since the mid-1990s, "new" retail geography, a term first coined by Wrigley and Lowe (1996), has become popular. The approach stresses the importance of studying locational patterns and issues in retailing, while making good use of the developing geographical information systems (GIS) and spatial modeling techniques and tools.

2.3.1 Retail Locations and Distributions

In this section, new kinds of retail, such as online/ telephone/ TV shopping, will not be explored. The developments of these retail formats are built upon information technology and internet communication. Though gaining in importance, these retail and consuming practices are less spatially bounded than "brick and mortar" retailing. They would call for a totally different research approach. Traditional retail locations are mainly comprised of high street or town center, shopping centers or malls, and power centers. The “high street” (U.K.) or the “main street” (U.S.A.) is one of the most traditional locations for retail. It still remains at the heart of most towns and cities, in particular in Europe (Birkin, G Clarke, MP Clarke, 2002). However, planners have expressed concerns about the future of high streets or city center retailing for a long time, mainly due to the competition of out-of-town development. In Western countries, many cities have seen their downtown cores transforming from core retail areas to office and service centers. Also, facing the competition from new electronic retail channels, some retail activities are experiencing difficult time and are even disappearing (Cope, 1996; Birkin, G Clarke, MP Clarke, 2002). To revive or support the vitality of high street and town center retail, Peter Shearman Associates (1996) and the Gloucestershire Local Enterprise Partnership (2013) have identified a number of principles that could be summarized as such:

1. Create a broad and diverse retail offer to consumers
2. Provide an interesting culture and leisure environment
3. Maintain large-scale office and service development
4. Build various, high-quality, and available modes of transport

The situation described and the principles that should guide interventions pertain to the retail sector at large. The food retail system has its own specificities, as food is a pure convenience product. Yet, food retail has experienced drastic shifts as well. These shifts pertain to the nature of retail establishments, their location as well as their accessibility. From the 1970s and to 1980s, many developed countries experienced an unprecedented period of growth of “superstore” and “hypermarket”. On the one hand, lower prices and all-round shopping in this kind of large retails stores proved highly attractive to consumers. A key factor for their success was the dramatic increase in the utilization of automobile and consumer mobility. Such mobility made it possible to consumers to travel further and to a greater number of retail locations. The consequence was also to weaken the monopolies of local independent retailers (Guy, 1998; Birkin, G Clarke, MP Clarke, 2002). However, since the late 1980s, many developed countries have new planning policies to ban or strictly restrict out-of-town development. Though superstore operators continue to open new stores, the growth rate of superstores has declined, and the upper size limit of new stores are reduced (Guy, 1998).

Apart from stricter planning regimes, superstore operators have faced tough competition from discount stores. Discount stores get significant success in term of their monopoly positions in many poor areas because they are only competing with local independent stores rather than major superstores (Burt and Sparks 1994; Burt and Sparks 1995). Another large format of retailing is shopping center or shopping mall. The great majority of shopping centers locate off center or out of town, though there are certain that locate in city center. A shopping center can be seen as a theme park as it is a retail mall that consists of a large number of shops (Birkin, G Clarke, MP Clarke, 2002).

It is increasingly common to find large supermarkets in shopping centers. In that case, the shopping center offers a one-stop destination to motorized customers, and general retail trends and consuming behaviors associated with automobility extend to food retail. In the Cambridge Dictionary, a retail warehouse is defined as “a large store that sells a particular product in large quantities to consumers at low price." Retail warehouse were first introduced in late 1960s. It refers to a group of single storey retail stores. This kind of stores are more than 1000 sq.m in warehouse type buildings and have parking facilities for consumers. They are also known as "big box" (Jones, 1984). Power centers are "strip centers" that are dominated by a few big box retailers. The size range of power centers is from 23,000 to 70,000 sq.m (Bodkin, Lord, 1997; Hahn 2000). Retail parks in the United Kingdom represents a similar concept than power centers. They are clusters of individual retail warehouses. Power centers are described as "loosely connected" groups of stores as there is little cross shopping at these developments (Birkin, G Clarke, MP Clarke, 2002).

In their most recent incarnation power centers morphed into so-called "life style centers" in which some efforts are put into the design of attractive exterior spaces that emulate urban settings. In part as a consequence of planning policies aiming to prevent out-of-town development, one of the major changes of grocery retail is the appearance of smaller size supermarkets back into town or city centers. Convenience stores are small stores that offer consumers relatively short-period purchases. Because of the relatively low investment and similar operating margins to superstores, the investment return of smaller supermarkets and convenience stores is quite respectable (Guy, 1998; Birkin, G Clarke, MP Clarke, 2002).

As Birkin, G Clarke, and MP Clarke (2002) also pointed out, there are a few other retail location or spaces, such as in airports and railway stations, factory shops and manufacturer outlets, etc. Such facilities are excluded from the corpus of this research, as they are believed to play only a marginal role in food retail. On the other hand, farmers' market as well as "public markets" (facilities rented to farmers and small retailers are known as public markets in Montreal) will be included.

2.3.2 Industrial Classifications of Food Retail Establishments

Standard Industrial Classification (SIC) codes are four-digit numerical codes established by the U.S. government in 1987. SIC codes have been used to identify the primary business of establishments and to facilitate statistical data collection and analysis by federal state and private organizations (SICCODE, 2016). The SICCODE offers definitions in SIC Directory (2016) for different classes of food retail establishments. This research is concerned in particular with:

- *5411 Grocery Store*

Description
Stores, commonly known as supermarkets, food stores, and grocery stores, primarily engaged in the retail sale of all sorts of canned food and dry goods, such as tea, coffee, spices, sugar, and flour; fresh fruits and vegetables; and fresh and prepared meats, fish and poultry.

Illustrated Examples
Convenience food stores-retail, Food markets-retail, Frozen food and freezer plans, Grocery stores, with or without fresh meat-retail, Supermarkets, grocery-retail

- *5431 Fruit and Vegetable Markets*

Description
Establishments primarily engaged in the retail sale of fresh fruits and vegetables. They are frequently found in public or municipal markets or as roadside stands.

Illustrated Examples
Fruit markets and stands-retail, Produce markets and stands-retail, Vegetable

markets and stands-retail

The definitions used by both government and the industry are useful. Firstly, they allow to narrow down the types of establishments that will be studied in this research. Secondly, the classification based on these definitions is used in government databases that will be used to constitute our sample. Other classifications exist that differ from the SIC nomenclature. Some researchers do distinguish supermarkets from smaller food stores, for instance: “supermarkets were defined as large, corporate-owned ‘chain’ stores”, and “grocery stores were defined as smaller non-corporate-owned food stores” (Morland, Wing, Roux, Poole, 2002, p. 24). Chapter four will introduce this research’s own operational classification.

2.4 Food Deserts

In the context of greater attention devoted to health and sustainable city life, researchers have spent research efforts to fresh and healthy food accessibility, for years. When discussing fresh food accessibility, most researchers rely on the notion of “food desert”, which, as previously mentioned, is defined as a geographic area where affordable and nutritious food is difficult to obtain, particularly for those without access to an automobile (Gallngher, 2011).

Food deserts are believed to be a by-product of “Supermarket redlining”. The phenomenon occurred in the 1960s and 1970s. Redlining is associated with the move to the suburbs of middle-class American residents, predominantly whites, in the 1960s and 1970s. Supermarkets moved out from urban centers to follow this demographic group. Businesses including supermarket chains decided to avoid inner-city neighborhoods, i.e. to “redline” those. As a consequence, entrapped lower-income residents lacked access to basic amenities (Bassford, 2010). Since the late 1970s, most food retail establishments focused on “car-borne” consumers, and this situation made inner city food access worse. Even though in some areas or cities, accessibility to food store has increased since 1980, it has increased at a faster rate in higher income areas. In some deprived areas, however, accessibility has declined over the decades. Therefore, a polarization effect with a widening gap in accessibility to food stores has unfolded (Guy, Clarke and Eyre, 2004). Redlining poor areas and low population density in rural areas entailed a shortage of business loans, a factor that has contributed to increasing the problem of food desserts (Eisenhauer, 2001). In many food deserts, full-service supermarkets are absent, while convenience stores and fast-food restaurants are ubiquitous. In such contexts, the term “food swamp” is sometimes used instead of “food desert”. Yet the result is the same, since healthy food is difficult to obtain in both “food swamp” and “food desert” (Leib, 2013).

Researchers suggested that income is correlated with disparities in food access. In the United States, food deserts are found in socioeconomically disadvantaged areas rather than in more advantaged areas (Baker, Schootman, Barnidge, Kelly, 2006). Block and Kouba (2006) suggest that areas with a high proportion of low-income residents have few supermarkets or chain stores per capita. Residents living in socioeconomically disadvantaged areas, have farther distance to travel to food stores (Zenk, Schulz, Israel, James, Bao, Wilson, 2005; Morland, Wing, Roux, Poole, 2002). In Canada, the situations are different. Though income correlates with food access, it does not mean low-income areas are of necessity worse served by stores than other areas, in some Canadian cities, the pattern is reversed. Areas with the shortest distance to the nearest supermarket are those neighborhoods characterized by the low income in Edmonton (Smoyer-Tomic, Spence, Amrhein, 2006). Apparicio, Cloutier and Shearmur (2007) also support that in Montreal, the low-income areas were better served by stores than other areas.

2.5 Spatial Distribution --- Point Pattern Analysis

There is a very important research area in geography and spatial analysis, which relies in particular on geographic information system (GIS). Point pattern analysis is a method for instance that evaluates a set of points on a surface to quantify their spatial distributions (Ervin, n.d.). In general, researchers rely on two interrelated approaches respectively based on point density and point separation. To describe a point pattern, the most important thing is to visualize it as a map, but if one only simply looks at the point objects, there is nothing more than the points themselves. The point pattern needs to be described quantitatively. Centrographic statistics is the most proper descriptive statistical method for spatial distributions (O'Sullivan, Unwin, 2010). O'Sullivan and Unwin (2010) have introduced centrographic statistics in their book *Geographic Information Analysis*. They suggest that in centrography, the basic descriptors for spatial point distributions are divided into two groups. One group includes the measures of centrality, which are mean center, centroid, weighted mean center, median center. The other includes measures of dispersion, standard distance deviation and standard deviational ellipse (specific formulae and explanations about Centrographic statistics can be found in Appendix A).

According to O'Sullivan and Unwin (2010) and Ervin (n.d.), point pattern analysis is concerned with the spatial properties of the entire body of points rather than the derivation of single summary measures. As previously discussed, point pattern analysis evaluates a set of points on a surface for their distributions. There are the three general distribution patterns (Figure 2). First, in random pattern, there is no apparent order of point distribution, all the points are equally likely to occur at anywhere is the pattern, and the locations of points have no impact to each other. Second, uniform distribution is a pattern that every single point is as far as possible from all of its neighboring points. Third, clustered distribution presents that many points occur close together in clusters in a few areas, and there are large areas that contain very few points.

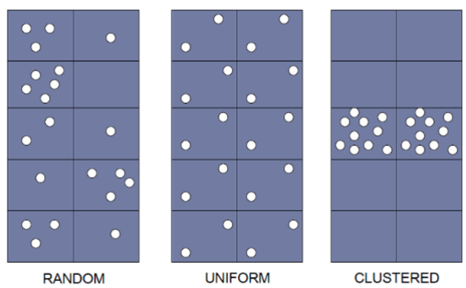

Figure 2. Patterns of points distributions (Ervin, n.d.)

Two main approaches are used in point pattern analysis. One is point density approach that uses "Quadrat Analysis based on observing the frequency distribution or density of points within a set a grid squares" (Briggs, 2007), the other is point interaction approach using "Nearest Neighbor Analysis based on distances of points one from another" (Briggs, 2007), while the two approach are interrelated in practice.

The following section summarizes the depiction of the methods quadrat analysis and neighbor analysis by O'Sullivan and Unwin (2010), Briggs (2007) and Ervin (n.d.). When doing quadrat analysis, the first step is to divide the study area into subsection of equal size, uniform grid network. The next step is counting the frequency (the number of points within each quadrat) of each section, and calculating the variance of each subsection. Then, a further statistic measure, variance to mean ratio (VMR), is created to describe the spatial arrangement of all the points in study area. The VMR trends to 0 for a uniform distribution, equals 1 for a random distribution, and is greater than 1 for clustered distributions. The formulae of frequency (number of points per quadrat), variance, variance to mean ratio (VMR) are (Briggs, 2007):

$$mean = \frac{\sum x}{N}$$

$$variance = \frac{\sum x^2 - [(\sum x)^2/N]}{N-1}$$

$$variance\ to\ mean\ ratio = \frac{variance}{mean}$$

Where *mean* is the average number of points per quadrat, x is the number of points in each quadrat, *N* is the number of quadrats.

A nearest neighbor analysis needs to measure "the distance of each point to its nearest neighboring point and the average nearest neighbor distance for all points" (Ervin, n.d.). A measure of dispersion named Nearest Neighbor Index (NNI) is created by this analysis. Different from quadrat analysis, in nearest neighbor analysis, the NNI trends to 0 for a clustered distribution, approximately equals to 1 for a random distribution, and is greater than 2 for uniform (dispersed) distributions. The formulae to calculate NNI are given as (Briggs, 2007):

$$\bar{r} = \frac{\sum r}{N}$$

$$\mathrm{d} = \frac{N}{A}$$

$$\bar{r}(e) = \frac{0.5}{\sqrt{d}}$$

$$\mathrm{NNI} = \mathrm{R} = \frac{r}{\bar{r}(e)}$$

Where r is distance of each point to its nearest neighboring point, $\bar{r}$ is the mean nearest neighbor distance for all points, *N* is the number of points, d is the density, A is the area of study region, $\bar{r}(e)$ is expected mean.

Briggs (2007) evaluates these two methods. He suggests that quadrat analysis is a simple and valuable method, but it has a few weaknesses. First, the analysis results vary with the size and orientation of quadrats, that is to say, different results can be obtained for the same study area using different quadrat sizes and/or different quadrat orientation. Second, this analysis is based on the point density, but not their arrangement in relation to one another, so variations within the study area might not be recognized. Comparing with quadrat analysis, Briggs (2007) points out that nearest neighbor analysis is not constrained by the quadrat size problem, and distance is taken into account. Yet, he stresses that nearest neighbor analysis also has some disadvantages. NNI highly depend on the size and shape of the study area, and is essentially based on the average nearest neighbor distance. NNI does not incorporate local variation, so it might not recognize local clusters in some areas within a study region. Meanwhile, only based on point location, it does not involve “magnitude of phenomena” at that point. Spatial statistics theories and methods are essential tools in order to quantitatively assess the distribution patterns of different types of retail establishments as we will see. Yet, the urban contexts are not neutral and nondescript surfaces: rather they are displaying spatial logics and configurations that obey their own rules, as urban morphology stipulates it.

2.6 Urban Morphology

Urban Morphology is the study of urban form in order to identify the spatial structures and patters, as well as the formation and transformation processes of the built environment. It seeks to understand the characters of human settlements, and to comprehend the interplay of various built environment elements and their composite spatial arrangements (Conzen, 1990; Kropf 2013; Gold and Revill 2014). Urban morphology is a discipline, defined as “the systematic study of the origin, growth, form, plan, structure, functions, and development of a town, of the urban habitat” (Clark 1985; Singh 1995; Gold and Revill 2014). Kropf (2009) points out that urban morphology is one of a range of ways to understand the diversity and complexity of human settlements.

2.6.1 Urban Morphology Approaches and Key Concepts

The origin of urban morphology in Germany in late nineteenth century later influenced European geography impetus in 1960s (Hofmeister, 2004). Influenced by the work of pioneers of first period of German morphology, particularly influenced by Schluter’s papers in 1899, M.R.G. Conzen, a

German urban morphologist who had trained in Germany and moved to England in 1933, developed an innovative method of town plan analysis (Whitehand ,2001, 2009; Heineberg, 2007). Geisler's maps of German towns influenced M.R.G. Conzen's work a quarter of a century later, which involved mapping English port town of Whitby in 1958 (Whitehand, 2001, 2007). Conzen's remarkable town plan analysis of Alnwick in 1960 is one of the most important publication in urban morphology and had a long lasting influence, even after 50 years, it still have impact (Whitehand, 2007, 2009). Conzen identified a tripartite division of urban form. They are, firstly, town plan, or ground plan, which comprising site streets, plots, and block plans of the buildings; secondly, building fabric (three-dimensional form); and thirdly, pattern of land and building utilization (Cozen, 1960 :4; Heineberg 2007; Kropf, 2001). What is more important than this division of urban form, are concepts that stem from Conzen about the features in urban fabric transformation. The concept of burgage cycle is used to explain the periods of filling-in with buildings, clearing of buildings, and building repletion on backland of medieval towns, and the periods usually happen with functional requirement changes when an urban area is growing (Whitehand, 2001, 2007). Fringe Belts are of various shapes and sizes as the different outward growth of different urban areas (Whitehand, 2001, 2007). Fringe belts usually have larger plot sizes, they are permeable to traffic as they have fewer road crossing (Whitehand and Morton, 2003, 2004). Morphological region refers to an area that has a unitive coherence in its form that differentiates it from surrounding areas (Whitehand, 2001, 2007). The concept of morphological region has a synonym from Italian architectural concept, "urban tissue" (Whitehand, 2007).

In the 1950's, another branch of urban morphology emerged in Italy, based on the seminal work of Saverio Muratori and his assistants, such as Gainfranco Caniggia. Muratori initiated what will later be known as typo-morphological (or process-typology) studies (Moudon, 1994: 290; Moudon, 1997; Gauthier, 2005).

> "For Muratori, the structure of cities could only be understood historically, with building typology as the basis of urban analysis. Urban form and structure, he stipulated, are an aggregate of many ideas, choices, and actions which are manifested in giving buildings and their surrounding spaces (gardens, streets, etc.). These buildings and spaces, called *edilizia* in Italian and loosely translated as the built landscape, can be classified by type, which summarizes the essence of their character. These different types become a tipologia edilizia, or a typology of buildings and related open spaces, which defines the essence of building fabric" (Moudon, 1994: 290-291).

The concept of process typology is attributed to Muratori and was widely developed by a second generation of morphologists, after Muratori's death in 1973, including researchers such as, Maretto, Caniggia, Maffei and Cataldi (Moudon, 1997; Gauthier, 2005). For instance, Caniggia illustrated that human environment is made of "built objects" and identified four levels of spatial resolution, which are, the building, the urban tissue (or built fabric), the city as a whole, and the region (territory). Proponents of the Italian theories and methods contend that the built environment functions as a dynamic spatial system in which built objects are deployed in the said four overlapping scales (Moudon, 1994).

The analysis takes into consideration varying levels of complexity, so that the same object can be considered as highly complex or as a simple component depending on the circumstances. A house for instance is comprised of single components such as bricks and planks as well as by already complex sub-system such as the plumbing system. Yet, when considered at another level of spatial resolution, such as the urban fabric (or tissue), it becomes a simple component (along with the lot and the street segment).

Kropf (2014) pointed out that streets, plots and buildings are fundamental elements in urban morphology, and there is a common feature in the definition of built form, the elements have a hierarchical structure based on the relationship of part-to whole. He proposes a compositional hierarchy of physical built form that refers to both Conzen, and Caniggia and Maffei's concepts. The hierarchy is explained by eight primary levels (Figure 3).

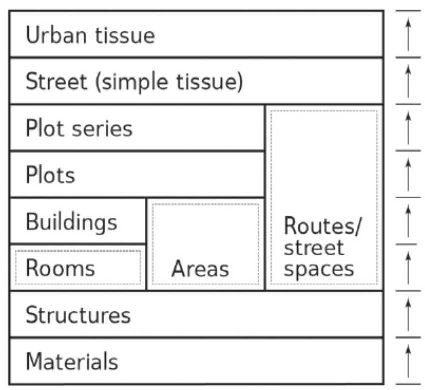

Figure 3. Multi-level diagram showing the position of the route or street space and its relationship to plot series to form the street (Kropf, 2014)

As a discipline, morphology is to the built environment, what linguistics is to spoken language: Where linguists try to decipher the system of language behind spoken language, morphologists try to discover and understand the system of the built environment in the everyday architecture (Gauthier, P. personal communication).

Basic analytical procedures in process typology are the analogical reconstruction and the classification (typology). Muratori's main tools of analysis, the concepts of building type and typology, served as the principal means for studying and learning about urban fabric. Through a genetic approach applied to the formation of built fabrics by means of successive reconstitutions, he revealed the various development phases of the urban fabric (Levy, 1992, 4, translated by P. Gauthier)

- Reconstruction

The theoretical and practical instruments that characterize the discipline are based on a diachronic and analogical reconstruction, carried out on the actual state of the object: in this, they closely resemble the tools typically used by other human sciences, particularly those from some branches of linguistics, such as dialectology and phonology (Caniggia, 89,1, translated by P. Gauthier).

- Typology (classification)

This approach's most important contribution […] consists in the use of the notions of type and typology, mainly at the level of the building, to explain the morphological organization principles of the city and the territory, as well as overall explanation of the built environment and the overlapping of four significant spatial scales: the building, the built fabric, the city and the territory (Gerosa, 1992, 178, translated by P. Gauthier).

2.6.2 Key Notions and Definitions

This study explores the spatial distribution of fresh food retail establishments, in relation to transportation networks and built environment, in order to properly frame the analysis and understand its implication, it is necessary to introduce key notions and definitions that relate to this study.

- Urban tissue

The urban tissue is what the Conzen calls a “plan unit," described as “a unique combination of types of street patterns, buildings, and lot configurations” (Conzen, 1960). Caniggia and Maffei (2001) suggest that urban tissue is made of elements that belong to three sub-systems, they are the streets as part of the street network; the lots as part of the allotment system; the building as part of the building fabric.

Caniggia and Maffei argue that the basic unit of the tissue “is composed of a route with [built] plot series along each side”. The Italian term for it is the “contrada,” which could translate as the “face-block” (i.e. a street segment between two intersections and its adjacent built lot series.

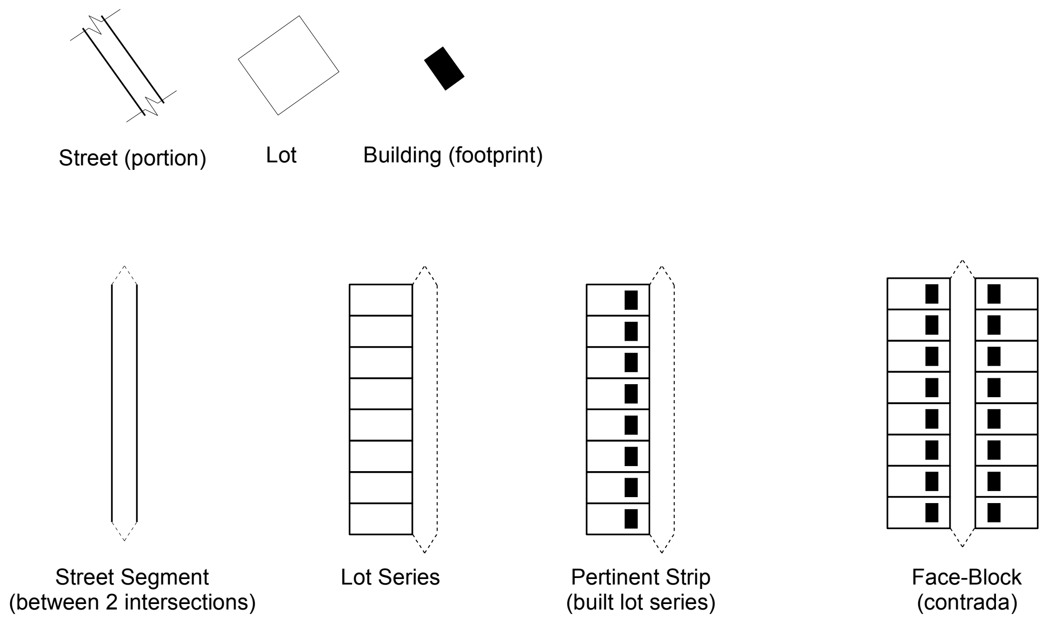

Figure 4. Components of the tissue (Gauthier, 2016)

The geometrical properties and combinatory patterns of streets lots and building produce specific spatial forms, i.e. tissue types, which could be retrieved by analysis. Most tissues in a city are predominantly residential, i.e. accommodating housing and associated urban functions. They correspond to what Jacobs calls the 'ordinary city'. Some tissues can be deemed 'specialized tissues,' they serve non-residential functions. Those can be equated to the non-residential "single massive stretched-out use of territory" described by Jacobs (1961: 261).

A Morphological Region is an urban landscape area that is coherent in its form and that differentiates from surrounding areas (Baker and Slater 1992, p. 43; Whitehand 2007, p. 5). Of all the components and sub-systems of the tissue, the street as part of a street network is the most resilient. While buildings are routinely altered and transformed and while it is fairly common to see lots being truncated, subdivided or amalgamated, it is far more rare for a street to disappear or for new ones to be created in already urbanized areas. In the context of a research project called *An Atlas of Montréal Residential Fabrics,* and pursuant to the work of Kent MacDougall under the supervision of Pierre Gauthier, the latter and Juan Buzzetti have developed a method to delineate what they called 'morphological neighborhood areas' (MNAs) (MacDougall, 2011; Gauthier 2015; Buzzetti, forthcoming). The MNA is similar to the concept of morphological regions, though based predominantly on the geometrical and topological properties of the street networks.

- Morphological neighborhood areas (MNAs)

This research adopts the definition of morphological neighborhood area (or "residential patches" for short) from Gauthier (2015); a MNA is defined as:

> "a geographical unit of reference for the analysis. They consist of internally cohesive (predominantly) residential areas delineated by a combination of first order spatial discontinuities induced by natural and artificial barriers and second order boundary discontinuities induced by differing street network geometrical and topological patterning" (Gauthier, 2015).

The said definition implies that predominantly residential built landscape areas are morphologically distinguishable based on coherent 'internal' properties, and that they could be delineated based on interspersing spatial discontinuities. Gauthier, MacDougall and Buzzetti's work entailed the conceptualization of the notion of urban barriers.

- Barriers

MacDougall (2011) set about clarifying the notion of urban barriers. He stresses that the concept of barrier has regularly been addressed in the urban studies and planning literature, though under a variety of labels or headings, including in some of the most canonical urban studies contributions of the 1960s and 1970s by authors such as Jane Jacobs, Kevin Lynch, and Lewis Mumford.

Mumford has highlighted the impacts of railroads, rail yards and controlled-access highways on the quality of urban form: "(T)he railroad was permitted, or rather, was invited to plunge into the very heart of the town and to create in the most precious central portions of the city a waste of freight yards and marshalling yards […]. These yards severed the town's natural arteries and created an impassable barrier between large urban segments" (Mumford, 1961:461). Mumford extends his criticism to highways: "So too, the transportation and highway engineers who have recklessly driven their multi-laned expressways into the heart of the city and have provided for mass parking lots and garages to store cars, have masterfully repeated and enlarged the worst errors of the railroad engineers" (Mumford, 1961:479, see also Mumford, 1963). Jane Jacobs (1961) also talks at length about the disruptive impacts of high-speed highways on the physical and social fabrics of the neighborhoods in which they were built. She develops the notion of "border," defined as "the perimeter of a single massive stretched-out use of territory [which] forms the edge of an 'ordinary' city." She cites railroad tracts, expressways and water barriers such as canals, rivers and lakes, as examples of urban features that "halt cross-use from both sides" (Jacobs, 1961: 261). Interestingly, she refers as well to barriers such as large parks and large parking areas as examples that have cross-use from both direction, but in variable amounts, depending upon daylight and weather conditions, for instance (1961: 257). Jacobs' definition focuses on the physical and functional effects of barriers on their immediate surroundings. She discusses the “curse of the border vacuums,” by pointing to “blight-proneness” of zones neighbored by various barriers, a category in which she includes large single-use areas such as urban university campuses or large hospital grounds. Lynch touches on similar considerations when discussing the cognitive effects of barriers on the maps that city dwellers mentally build. He defines what he calls the “edges” as: “linear elements not considered as paths [which] are usually but not quite always, the boundaries between two kinds of areas [and that] act as lateral references” in people’s perceptions (1960: 62). Lynch considers that edges vary in intensity when he writes that “[t]hose edges seem strongest which are not only visually prominent, but also continuous in form and impenetrable to cross movement” (Lynch, 1960: 62). He recognizes, as does Jacobs, that some barriers are permeable: “[m]any edges are uniting seams rather than isolating barriers [...],” when they are not impenetrable (Lynch, 1960: 65).

Adapting from Larochelle and Gauthier (2002), MacDougall and Gauthier (forthcoming) offer this definition for urban barriers, described as “extended zones of the built landscape that are affected by discontinuities produced by natural or human-made elements, where pedestrian crossing is tiresome, difficult, impossible, dangerous or forbidden.” MacDougall (2011) has conduct empirical work in Montréal in order to produce a taxonomy of natural and human-made urban barriers. The classification includes linear natural elements, such as rivers and steep slopes, as well as human-made works, such as fortifications, canals, railroads, highways, high-tension power-lines, rail yards, etc. MacDougall also points out categories of areal barriers comprised of large non-residential mono-functional zones such as rail yards, parks, airports, or industrial and commercial clusters. First-order barriers are generally impassable or quasi-impassable by foot in the absence of engineering works, such as bridges, tunnels, staircases, cable car, etc. Figure 5 by Gauthier and Buzzetti (Gauthier, 2015) is an adaptation of MacDougall's mapping of natural and human-made barriers.

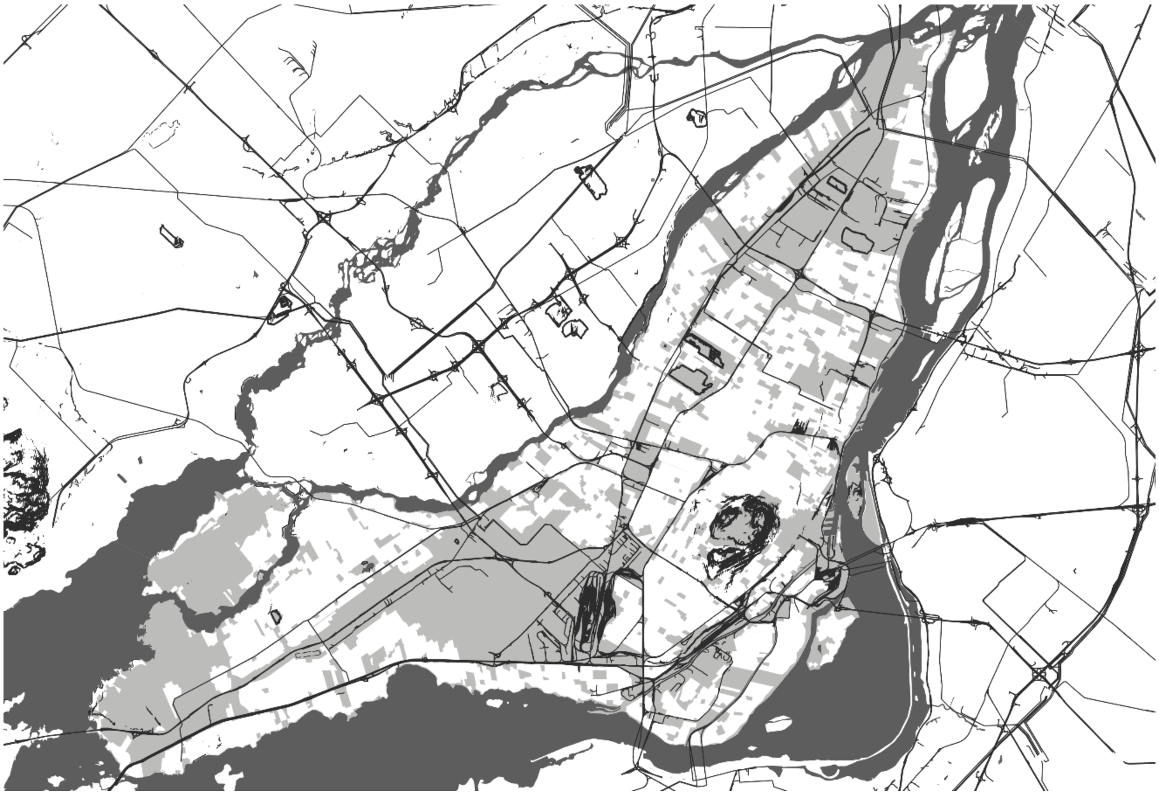

Figure 5. First order barrier, including specialized tissues (courtesy Gauthier and Buzzetti 2015)

- Fragmentation Geometry

The mapping of first-order barriers generates a nexus of threads and meshes that delineate residential tissues aggregates, in order to produce what MacDougall labelled a “Geometry 1,” short-hand for “Fragmentation Geometry,” a term that he had borrowed from Landscape Fragmentation theoretical and methodological apparatus. Gauthier and Buzzetti produced a slightly revised version of MacDougall's Geometry 1. Gauthier depicts the method as follows:

1. **The analytical sequence for producing Geometry 1**

1.1 Identification of all lots with a residential land-use (using CMM data)

1.2 Identification, classification and delineation of linear and areal discontinuities consisting of non-residential land-uses, surface infrastructures, major streams, rivers or bodies of water, as well as unbuildable land (including steep slopes).

1.3 Mapping of linear and areal discontinuities (consisting of areas larger than 1.5 ha. that are comprised of contiguous non-residential land-uses lots and the adjacent streets servicing them, water bodies or unbuildable land.

1.4 Mapping of all (predominantly) residential aggregates larger than 2.5 ha. A residential aggregate is comprised of contiguous residential lots, and the adjacent streets servicing them, that are not bisected by linear or areal discontinuities. It may include non-residential or mixed-use areas (e.g. lots occupied by residential buildings with retail on the ground floor). Any non-residential area, larger than 1.5 ha, that constitutes an enclave in an otherwise contiguous residential aggregate is considered as a local, or second-tier discontinuity.
(Gauthier, 2016)

The delineation of residential aggregates produces a map (Figure 6), which represents Geometry 1 (Gauthier 2015; Buzzetti forthcoming). The production of a Geometry 2 aims at identifying and delineating MNUs, defined as areas that display coherent street network configurations and that are differentiated from the surrounding areas. Pursuant to the work of MacDougall, Gauthier and Buzzetti developed an analogical procedure that allows identifying internally coherent configurations interspersed with tier-one spatial discontinuities (i.e. induced by first-order barriers) and tier-two spatial discontinuities (i.e. induced by local barriers or compositional gaps) (Gauthier, 2016). Gauthier and Buzzetti stress, that internally coherent configurations can be either homogenous or heterogeneous (while displaying a recognizable mix). Gauthier depicts their method as follows:

2. **The analytical sequence for producing Geometry 2**

2.1 Using the urban blocks as a proxy for street network geometry, a cluster analysis of the blocks is conducted based on morphometric (shape), metrological (dimensional) and compositional (topological) variables in order to produce a representation of the spatial distribution of blocks belonging to the different clusters.

2.2 Using a Space Syntax metrics, a quantitative analysis of street integration is conducted and represented spatially.

2.3 Spatial representations of blocks color-coded by cluster, and of streets color-coded according to level of integration allow for triangulation, in order to distinguish and delineate the contours of internally coherent residential aggregates.

2.4 The precise mapping of local discontinuities is validated and further refined by taking the historical agricultural plotting and current allotment system into consideration (in particular when boundaries coincide with allotment parting lines).

(Gauthier, 2016)

Figure 6. Fragmentation Geometry 1 (courtesy Gauthier and Buzzetti 2015)

This research uses the MNAs from Geometry 2 by Buzzetti (forthcoming) for the analysis of the location of retail establishments in relation to residential morphological regions that they serve. Figure 7 represents Geometry 2 (Gauthier 2015; Buzzetti forthcoming).

Figure 7. Fragmentation Geometry 2 (courtesy Gauthier and Buzzetti 2015)

- Major Thoroughfares

Caniggia and Maffei (2001) point to the existence of two categories of specialized routes in addition to the ‘regular’ residential streets: retail streets and high capacity routes, i.e. major urban thoroughfares (MUT) (Gauthier, 2015). MacDougall (2011) turns to the American *Institute of Transportation Engineers* (ITE) for a classification of thoroughfares.

In its 2010 report, the ITE Report defines and classifies thoroughfares from the perspective of their function. Major thoroughfares are defined as such:

> “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 classifications of arterials and collector streets excluding limited-access facilities. Thoroughfares are multi-modal in nature, and are designed to integrate with and serve the functions of the adjacent land use” (ITE, 2010: 208, quoted by MacDougall, 2011, p. 89).

The ITE divides thoroughfares into two categories of thoroughfare types: the first are “thoroughfare in areas with traditional urban qualities serving compact, walkable mixed-use environment”; the 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”. It could be argued that the latter category covers a type of specialized routes, non-accounted for by Caniggia and Maffei: the specialized routes associated with specialized tissues.

The ITE provides definitions for all types of thoroughfares in the following table (Table 1).

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 that 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 both to carry traffic and to provide access to abutting property in rural areas. Intersections are generally at grade.
Boulevard	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 four lanes but sometimes wider, serve longer trips and provide pedestrian access to land. Boulevards may be high-ridership transit corridors. Boulevards are primary goods movement and emergency response routes and use vehicular and pedestrian access management techniques. Curb parking is encouraged on boulevards.
	Multiway boulevards are a variation of the boulevard characterized by a central roadway for through traffic and parallel access lanes accessing abutting property, parking and pedestrian and bicycle facilities. Parallel access lanes 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	Walkable, low-to-medium speed (25 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	Walkable, low speed (25 mph) thoroughfare in urban areas primarily serving abutting property. A street is designed to (1) connect residential neighborhoods with each other, (2) connect neighborhoods with commercial and other districts and (3) connect local streets to arterials. Streets may serve as the main street of commercial or mixed-use sectors and emphasize curb parking. Goods movement is restricted to local deliveries only.
Rural Road	Low speed (25 to 35 mph) thoroughfare in rural areas primarily serving abutting property.
Alley/Rear Lane	Very low-speed (5 to 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 1. Thoroughfare Type Description (ITE 2010 :52, quoted by Macdougall, 2011 p. 90)

Larochelle and Gauthier (2002) stressed the difference between two major categories of traffic axis: the major urban thoroughfares such as boulevards and controlled-access highways. The former have a direct connection to their surrounding environments, they possess at grade intersections and grant access to lots and buildings. Controlled-access highways, though a transportation infrastructure, serves only motorized traffic. They are fundamentally different from thoroughfares, since they do not give access to lots that have their address on it. The distinction might seem trivial but it implies that can do not belong to the “street” category. Controlled-access highways (CAHs) do not stem from the same morphogenetic processes than the streets, including those in the high capacity categories. While the street is a core component of the city tissues, the CAH is a technical infrastructure, an appendage to the street network. CAHs in- and off-ramps, in limited numbers, act as gateways that allow transferring between the arterial system and the highway network, in a similar way than the train station allow the pedestrian to switch to another mode of transportation in the course of his or her journey (Gauthier, personal communication).

This research adopts the definition of thoroughfare from Gauthier (2015). It is defined as:

> “a street granted with a high level of arteriality (connected to street of similar topological level or to controlled-access highways); which spans over the length of several morphological neighborhood areas, to which it provides access, and; that often crosses first order barriers” (Gauthier, 2015).

Arteriality is defined by Marshall (2005: 291) as “the manifestation of strategic contiguity in networks, in which each route must be connected to another route of the same or higher tier.”

2.7 Accessibility and Walkability

Scholars have studied accessibility to different amenities and services. A GIS-based network analysis in conjunction with statistical analysis of socio-economic data is used, for instance, to analyze the urban greenspace accessibility (Comber, Brunsdon, Green, 2008). In that study, a network analysis was performed to measure distances between greenspace access points and the centers of population census output areas, in order to quantify and measure the access to greenspaces by different ethnic and religious groups. A similar GIS-based network analysis method was used to measure accessibility to neighborhood facilities by Lotfi, Koohsari (2009). Larsen and Gilliand (2008) used network-based GIS accessibility measures to determine the food deserts extent in London, Ontario.

The steps for this kind of GIS-based analysis can be summarized as following:

(1) Digitizing the access points of target facilities or services;

(2) Creating output areas centroids;

(3) Calculating the distances between the access points and output area centers;

(4) For each output area, calculating the distance to each access point and storing it in a database;

(5) Analysis of database for access to points and in specific terms of the research aspect of each output area.

Some methods have been applied specifically to the field of food accessibility research, mainly using GIS. Based on network analysis, for example, using road network data, shortest network path is used to better represent actual travel distances instead of Euclidean distance (Wang, Tao, Qiu, Lu, 2016; Ballou, Rahardja, Sakai, 2002). Travel time is becoming another indicator to measure food accessibility. Transportation options, pre-automobile and post-automobile landscape are also considered in research of accessibility (Burns, Inglis, 2007; Wang, Tao, Qiu, Lu, 2016).

Based on GIS network analysis approach, Larsen and Gilliand (2008), as well as Salonen and Toivonen (2013) also consider the difference between different transport modes. Salonen and Toivonen compare different methods for calculating travel time by different travel modes. They build three car models and three public transport (PT) models (see Figure 8). The models are:

The simple car model, which uses national road and street database Digiroad as routing network dataset and use geometry method to determine the drive-through time of each road segment, with two elements, the speed limit and segment length of each road segment;

The intermediate car model, based on simple car model, while factoring in average deceleration of crossroad of each road class during a day is used to adjust to fit the real-life driving time of each road segment;

The advanced car model, built on the intermediate car model, also includes the travel time spent on walking and parking, which in other words, using a “door-to-door approach;”

In the simple PT model, based on a multimodal network dataset created in ArcGIS and the Digiroad data, the travel time by pedestrian segment is calculated using a walking speed of 70 m/min, and the travel time by each public transit mode are calculated using an average speed of respective travel mode (Table 2).

The intermediate PT model, in which transfer times are included upon simple PT model, half a headway time is added to the in-vehicle travel time as a transfer times, when the first public transport vehicle is entered and when transferring from one travel mode to another.

The advanced PT model, based on intermediate PT model, includes the travel times spent on walking from origin to PT and from PT to destination and also uses a “door-to-door” approach, which a take into account daily variation in PT schedules.”

This research will only focus on the simple PT model.

PT travel mode	Average speed (km/h)	Transfer time (average headway time (min)/2)
Bus	26.3	12.3
Tram	13.3	4.7
Metro	39.9	4.5
Train	54.1	14.9

Table 2. Mode-specific average speeds and transfer times used in the simple and intermediate PT model (Salonen and Toivonen, 2013)

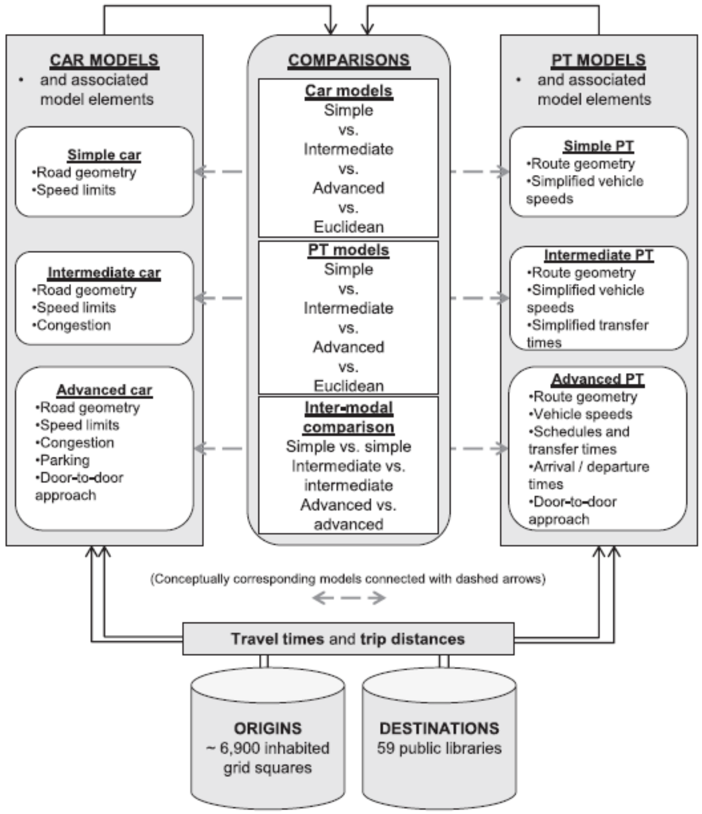

Figure 8. Workflow of the study (Salonen and Toivonen, 2013)

Salonen and Toivonen (2013) define the “door to door approach” by car and by public transport (PT) respectively. A by-car “door-to-door” journey includes four parts, walking from origin point to car parking point, driving journey, looking for a nearest parking space to the destination, walking from parking point to destination (Figure 9). A by-PT “door-to-door” journey also includes four main parts, walking from origin point to appropriate PT stop, waiting for vehicle arrival and departure, staying in vehicle, walking from last stop to destination. If transfers occur, the journey needs to include the time for walking from one stop to another and waiting for the next vehicle until departure (Figure 9).

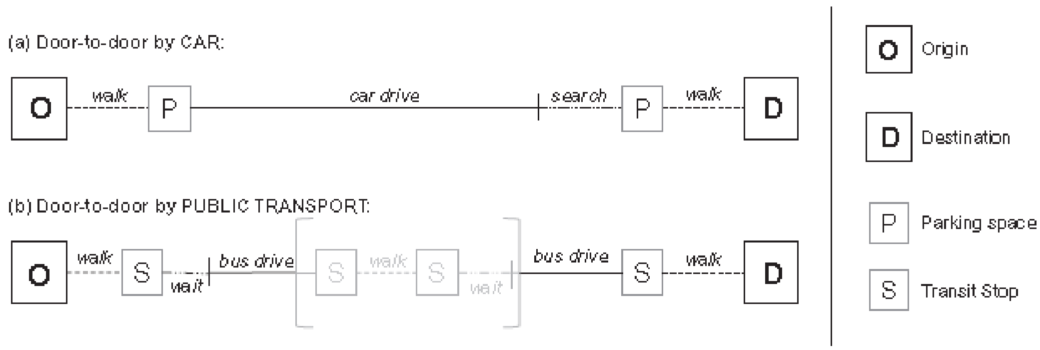

Figure 9. Examples of the door-to-door approach in (a) car journeys and (b) PT journeys (Salonen and Toivonen, 2013)

For car and bus, the accessibility pattern is generally linear along major road networks. While for pedestrian, shop by foot, the walkability catchment, so-called "ped-shed", is a popular analytical method among researchers.

In previous review of smart growth and transit-oriented development, a walkable community or city has been marked as requisite principle to make life more sustainable. The Ped-shed method to measure walkability has been used by many scholars. Schlossberg and Brown (2004) for instance used ped-shed to analyze walkability as one of the indicators to compare transit-oriented development sites, Jones (2001) uses ped-shed analysis to measure both walkability and livability in neighborhood, Newman and Kenworthy (2006) use ped-shed as a method to study urban design in terms of reduce automobile dependence. In the so-called Greenfield Tool Box, the processes for mapping and calculating walkability catchments are explained with detail. According to Greenfield Tool Box, a walkable catchment, or "pedestrian-shed" ("ped-shed" for shot), is a tool to map an area within a five-to-ten-minute walk from a pedestrian destination. It allows to visually understand "how easy it is to move through an area and get to and from a destination.” Usually, most people are comfortable with walking 400 meters which cost 5 minutes on average. To mapping the walkability catchment, identifying and mapping the pedestrian network is the first step. Identification should consider all the possible access infrastructures that pedestrians would use to get to or from a destination, the infrastructures could be streets, footpaths, bridges, etc. Then, based on the identified network, a real walkable catchment will be drawn on. A regular ped-shed is a circle around the destination with a 400-meter radius, which represents the maximum possible walking distance. To identify the actual walking distance, it is needed to measure the walkable distance (400 m.) from a destination along the real pedestrian routes, and this actual walking distance would fall short of the circle that with a 400-meter radius, as it will be constrained by street network and other walking facilities configuration for instance. Finally, within the circle and actual walkable area from the destination, other destinations, like lots, buildings, dwellings, parks can be identified. Larsen, El-Geneidy and Yasmin (2010) examined the travel distances by walking and cycling that people are willing to for different purposes in Montreal (Table 3). Their study points to the fact that the mean distance that Montrealers are willing to walk to go shopping is 754 m., which is the equivalent to a 10-minute walk by a healthy adult in normal circumstances. The mean distance of 2.2 km for cycling also corresponds to a 10-minute trip.

	All		Purpose							
			Work		School		**Shopping**		Leisure	
	Walk	Cycle	Walk	Cycle	Walk	Cycle	**Walk**	**Cycle**	Walk	Cycle
Mean (m)	813	3140	993	3886	757	2273	**754**	**2204**	860	3360
Median (m)	653	2242	801	3067	636	1550	**581**	**1529**	683	2318
85^{th} percentile (M)	1403	5517	1789	6442	1243	4355	**1327**	**3926**	1572	6376
Standard Deviation	604	2792	718	3001	526	2012	**605**	**2145**	642	3158
Number of cases	12831	1421	2381	620	6259	369	**2591**	**205**	1600	227
Percent of total sample (%)	100	100	18.6	43.6	48.4	26.0	**20.2**	**14.4**	12.5	16.0

Table 3. Attributes of walking and cycling to different purposes (Larsen, El-Geneidy and Yasmin, 2010)

2.8 Conclusion

Before the automobile era, city development patterns traditionally tended to be “fine-grained”, compact, and pedestrian-scaled. Since automobile transportation prevailed, many cities have experienced sprawl development along freeway, connecting central city and suburbs. In recent decades, scholars in urban studies, architecture and planning have argued that compact urban development is better to build a sustainable city. Urban form, transportation and land use have very close interactions. This research on urban form and fresh food accessibility will discuss the relationship between fresh food retail establishments, and urban form, including transportation networks that support active (foot and bicycle) and collective (bus, metro) modes of transportation. The research will be conducted by the following sequence: 1. analysis of the spatial distribution of different categories of establishments selling fresh food; 2. analysis of the built environments in which different categories of establishments are located; 3. analysis of the impacts of the location and spatial context on accessibility by different modes of transportation. The following chapter describes the combination of methods that are mobilized to do so.

Chapter 3 Methodology

3.1 Purpose

As the primary objective of this research is to discuss the relationship between urban form and accessibility to fresh food in Montreal, a spatial, including a morphological analysis will focus on the retail establishment location and urban context. This analysis mainly has three steps. The first step explores the spatial distribution of different categories of retail establishments that sell fresh fruits and vegetables by spatial statistical and morphological analytical methods. Then, the characteristics of the built environments in which different categories of fresh food retail establishments are located, are clarified by studying their immediate surroundings. Third, the impacts of location, spatial context, built environments, including the characteristic of transportation infrastructures, on the accessibility to fresh food retail establishments are examined, by assessing the number of dwellings that provide access to retail establishments by active and public transit modes. The key results of the research are presented by a taxonomy. ArcGIS, QGIS and AutoCAD are mainly used in this study.

To perform such an analysis, a sequence of activities that entail data collection, data processing, and analyses is required, which is described in the following sections.

3.2 Data Preparation and Classification

3.2.1 Collecting Data on Establishments

The very first thing to do is collecting data on retail establishments selling fresh fruits and vegetables in the Island of Montreal. Enhanced Points of Interest (EPOI) is a geospatial data that is produced and provided by DMTI Spatial. The EPOI file is a national database of over 1 million Canadian businesses as well as recreational points of interest. Business and recreational establishments are shown in format of location enriched points in the data file with features includes: Coordinate location (X, Y), Standard industry classification code (SIC), Business or recreational names, Address, City, Province, Phone number, Postcode, etc. a selection of specific points is then needed, in order to include only fresh food retail establishments in the Island of Montreal. The Island of Montreal is comprised of 35 portions in the database. Retrieving those requires that one selects feature “City” equals “Montreal”, ”Montreal Est”, “Montreal Nord”, “Saint-Laurent”, “Mont-Royal”, “Lasalle”, etc. Then, according to the previously mentioned Standard Industrial Classification (SIC) codes, for features “SIC_1”, “SIC_2” to “SIC_6”, only code 5411 Grocery Stores, and code 5431 Fruit and Vegetable Markets are selected. However, in the 5411 Grocery Stores, category includes many convenience stores that only seldomly sell small quantities fresh vegetables and fruits. These need to be excluded from the study. Points in the EPOI data file that included the terms “DEPANNEUR”, “TABAGIE”, “COUCHE-TARD” and “BONI-SOIR” in feature(Business or recreational names) Name (convenience store chain names) were deleted. A visual control of every address in Google Street View Map was performed to validate the decision to delete any potential convenience store.

3.2.2 Georeferencing

Cadastral data is geospatial data from Quebec (Province) describing individual lots in Greater Montreal Area. In this research, only lots in Island of Montreal are studied. City of Montreal Cartographic Plans is a dataset that contains building footprints, elevation spot height, and other detail features. Cadastral Data and Cartographic Plans are used as the base map to georeference the above-mentioned collected data pertaining to points corresponding to establishments selling fresh fruits and vegetables in Island of Montreal (use information of addresses and postcodes). That procedure was necessary in order to associate more precisely every point to an actual cadastral lot (in order to “link” the two geographical features in GIS). Google Street View allowed for visual control of the location of the establishments.

Since many points’ locations in EPOI file were slightly offset from the Cadastral data map, some information of establishments needed to be corrected and updated, and some new establishment points needed to be added. A new shapefile was created for new points that replace original points in EPOI data. To check and correct information of every establishment point from EPOI file, several websites were used alone with Google Street View, those websites were, Google Map, Yellow Page, Montreal’s Public Markets, and official websites of retail chains brands such as IGA, Metro, Provigo, Loblaws, etc. These sources of information allowed triangulation. The new shapefile only contains points that represent grocery stores selling fresh fruits and vegetables (excluding convenience stores, delicatessen shops, drugstore, and snack bar, etc.), as well as fruit and vegetable markets, public/ farmers' markets in Island of Montreal. It has features that include: NAME, ADDRESS, POSTCODE, AREA, etc. Finally, 407 retail establishments were identified for study in this research, and among them, there are 7 public/ farmers' markets (Figure 10).

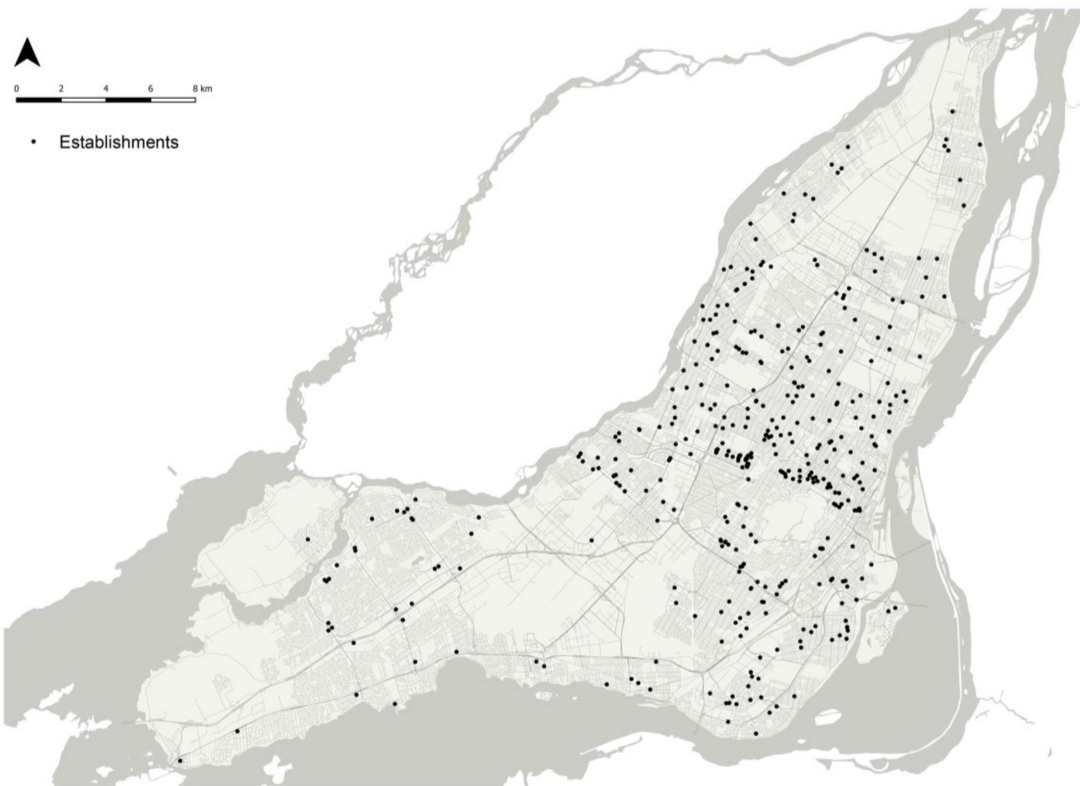

Figure 10. Points of establishments selling fresh fruits and vegetables

3.2.3 Classification of Establishments based on Size

In City of Montreal Cartographic Plans file, building footprints are used to help georeference establishment points, matching points to specific buildings, and more importantly, to figure out the areas of individual establishments. This City of Montreal Cartographic Plans file is an

AutoCAD file, and the building footprints are only lines (A.K.A. polylines features) and therefore they are not closed polygons. This requires some editing in AutoCAD. First, the lines of the footprints are closed one by one. Then they are hatched to create polygons so that can be directly imported and used in ArcGIS. The area of each polygon can be read automatically in ArcGIS. The areas of most establishments equal the areas of building footprints (floor area), but some establishments are located within larger buildings, such as a mall of a shopping center. Google Street View allows for triangulation with floor area data, and in association with websites of the larger building such as shopping center, to approximate the establishment footprint, generate the approximate area of the establishment.

This research aims at comparing and contrasting the spatial distribution patterns of establishments classified by size. As previously mentioned, it is hypothesized that the largest establishments will tend to be distributed along high-capacity road and thoroughfares, whereas small establishments will tend to be located within neighborhoods and in particular those from the pre-automobile era. There is no standardized classification method based on size in the industry. A survey of large corporations' web sites has shown that different companies are classifying their establishments based on criteria of their own (often using different banners to differentiate their stores based on size and associated type of offering). The scientific literature on retail does not offer a standardized classification neither, even though some articles introduce such differentiation by size.

An inductive and deductive analytical procedure was developed to establish a classification of retail establishment based on their size (i.e. floor area). In-house classification from large retail groups, is compared and contrasted to this research empirical data in order to produce a classification based on “operational definitions” of classes.

The above-mentioned feature AREA in the new point shapefile present the approximative areas of establishments. A frequency distribution of areas of establishments was then conducted. An operational definition of classes of establishments was achieved: small establishments are defined as those that have a floor area smaller than 1000 m^2, mid-size establishments have a floor area comprised between 1001 and 4500 m^2, while large size establishments are those that have a floor area of 4501 m^2 and more. Therefore, among the total number of 407 retail establishments selling fruits and vegetables on the Island of Montreal, there are 260 small establishments, 110 mid-size establishments and 30 large establishments, as well as 7 public/ farmers’ markets (Table 4). Figure 11 shows all the points of establishment in different categories. The seven public/ farmers’ markets were included when assessing the opportunity of accessing to fresh food, but the category of public/ farmers’ markets was excluded from the statistical analysis due to the small number.

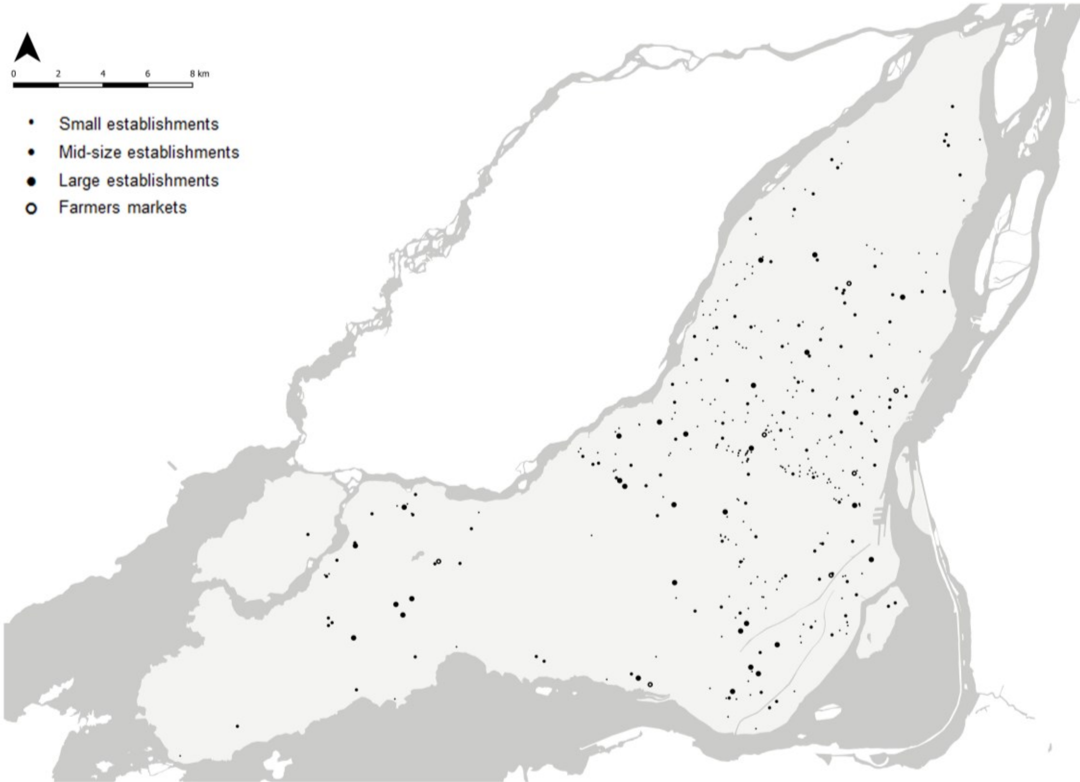

Figure 11. Points of establishments in different categories

Category	Area Interval / m2	Number of Establishments
Small Establishments	0001 - 1000	260
Mid-size Establishments	1001 - 4500	110
Large Establishment	4501 -	30
Public/ Farmer's Markets	null	7

Table 4. Classification of Establishments Selling Fresh Fruits and Vegetables

3.3 Analysis of Spatial Distribution

Spatial distribution analyses of fresh food retail establishments are conducted on different categories of size, using spatial quantitative methods and morphological methods. The quantitative analysis uses the method of point pattern analysis. The study area of point pattern analysis in this study is limited to the residential zones in the island of Montreal. In other words, no establishment was found in areas such as the airport, large railyards or large industrial parks, so conducting point pattern analysis in areas that are predominantly residential (to the exclusion of specialized urban tissues and infrastructure), is expected to be more probing, especially for mid-size and small-size establishments.

3.3.1 Quantitative Analysis

This quantitative analysis uses point pattern analysis method that discussed in preceding chapter. Quadrat analysis and nearest neighbor analysis are carried on to separately study the density of fresh food retail establishments and interaction between establishments, and these two analyses are conducted first on all the establishments, and then on each category.

In quadrat analysis, the first step is to divide Island of Montreal into subsections of equal size uniform grid network. To get more proper, accurate and practical analytical results to reflect the real density of establishments, this quadrat analysis is processed with three different sizes of subsections. The three interval distances between adjacent grid lines are 1 km, 3 km, and 6 km. All sizes of the quadrats are rotated 45 degrees from true north because the vast majority of streets are stretched from northeast to southwest and from northwest to southeast, instead of from true north to true south in the Island of Montreal.

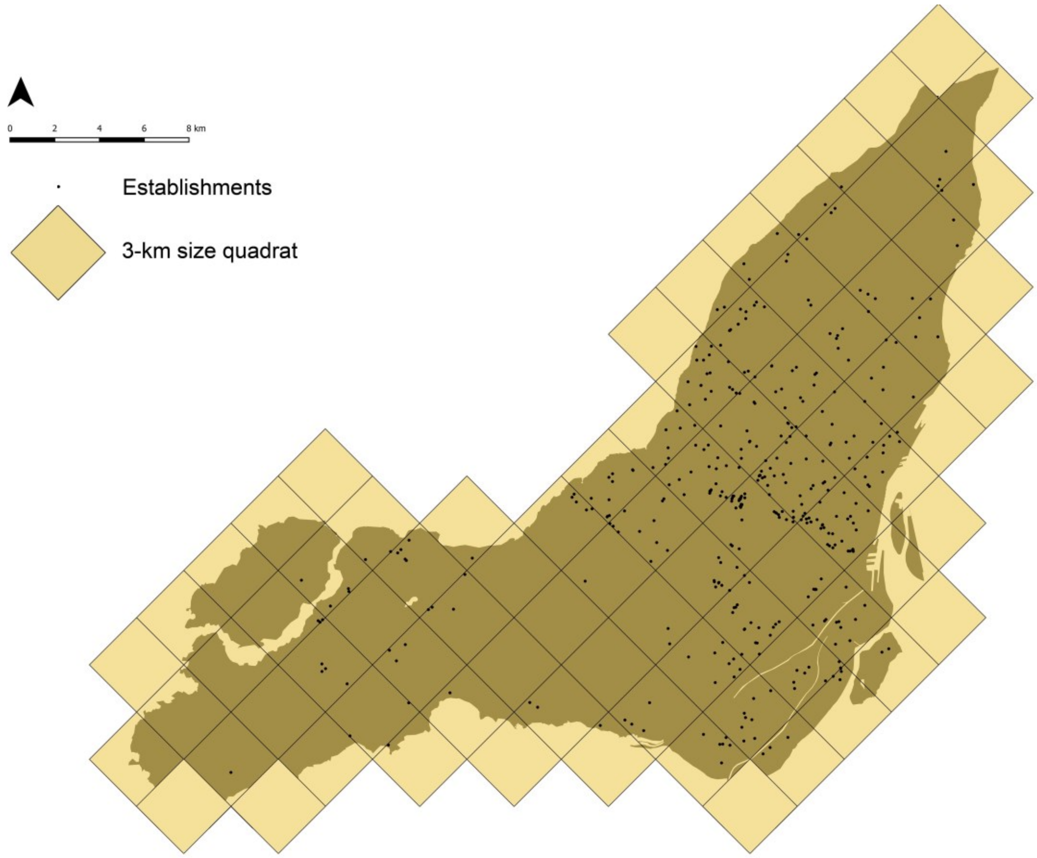

Figure 12. Illustration of rotated 3-km quadrats superimposed on the Island of Montreal

Then, the statistical method that was introduced before, variance to mean ratio (VMR), is used to calculate and characterize the spatial arrangement of all the points in study area, that is, the frequency distribution of fresh food retail establishments in the whole Island of Montreal. This VMR is created for several times respectively based on points of all the establishment, and points of different size categories of establishments.

According to O'Sullivan and Unwin (2010), the VMR trends to 0 for a uniform distribution, equals 1 for a random distribution, and is greater than 1 for clustered distributions. Chi-square (X^2) test is supposed to be conducted for VMR to ascertain if a pattern is significantly more clustered than would be expected by chance (O'Sullivan and Unwin, 2010). The formulae of frequency (number of points per quadrat), variance, variance to mean ratio (VMR), Chi-square (X^2), and degree of freedom (df) are (Briggs, 2007; O'Sullivan and Unwin, 2010):

$$mean = \frac{\sum x}{N}$$

$$variance = \frac{\sum x^2 - [(\sum x)^2/N]}{N-1}$$

$$variance\ to\ mean\ ratio = \frac{variance}{mean}$$

$$X^2 = VMR * (N-1)$$

$$df = N - 1$$

Where *mean* is the average number of points per quadrat, x is the number of points in each quadrat, *N* is the number of quadrats.

In nearest neighbor analysis, the problem of quadrat size does not need to be considered, but distance between nearest points is essential. Nearest Neighbor Index (NNI) is created by this analysis to measure the dispersion of all the points in study area. NNI is also created for several times respectively based on points of all the establishment, and points of different size categories of establishments. NNI trends to 0 for a clustered distribution, approximately equals to 1 for a random distribution, and is greater than 2 for uniform (dispersed) distributions. The formulae to calculate NNI are given as (Briggs, 2007):

$$\bar{r} = \frac{\sum r}{N}$$

$$\mathrm{d} = \frac{N}{A}$$

$$\bar{r}(e) = \frac{0.5}{\sqrt{d}}$$

$$\mathrm{NNI} = \mathrm{R} = \frac{r}{\bar{r}(e)}$$

Where r is distance of each point to its nearest neighboring point, $\bar{r}$ is the mean nearest neighbor distance for all points, *N* is the number of points, d is the density, A is the area of study region, $\bar{r}(e)$ is expected mean.

The methods of quadrat analysis and nearest neighbor analysis are also implemented, by focusing strictly on residential areas (as opposed to the whole island) based on different size categories of fresh food retail establishments. The VMR and NNI that created in this small scale analysis measure the spatial frequency and dispersed distribution in each zone.

3.3.2 Morphological Analysis

Morphological analysis sometimes relies on quantification. Yet, in most circumstances, morphologists are seeking to unveil the rules governing the spatial arrangements of objects and components of the built landscape in order to “read” and characterize typical patterns. The rules that govern the spatial relationships of object in a fixed period of time - i.e. in synchrony – can be referred to as “syntactic rules”. The analysis could focus on the spatial distribution and relationships of objects of the same category such as in the street system or consider the spatial distribution of specialized buildings such as public markets relative to one another. It could also focus on the relationships of objects belonging to different categories, such as the position of buildings relative to their lot and to the street in an urban tissue, or the position of a local commercial street (or high street) within a residential morphological unit. Methods of urban morphology are used in this research to analyze the spatial distributions of fresh food retail establishments (for the four categories of establishments) relative to features and components of the built landscape at different levels of spatial resolution.

First, the spatial distribution and location of establishments relative to “morphological neighborhood areas” is considered. Second, the spatial distribution and location of establishments relative to specialized roads (i.e. major urban thoroughfares) is examined. Third, the spatial distribution and location of establishments relative to presence of a bus stop (within 100 meters) is measured. Fourth, the spatial contexts surrounding the establishments will be characterized using different urban morphological variables. A classification (i.e. a typology) will also be performed to distinguish categories of establishments that can be accessed by walking. The following morphological variables are used: 1. the number of dwellings per hectare; 2. the number of dwellings per hectare of residential lots (to the exclusion of streets, parks and lots accommodating non-residential land-uses); 3. the number of intersection per hectare (an indicator routinely used to assess walkability), and; 4. the average edges per node ratio (i.e. the total number of street segments divided by the total number of intersections) within the pedestrian shed area, which is capturing topological properties of the street system.

The data file of location of buildings (Localisation des immeubles 2011) is from MAMROT, Direction du Bureau municipal, de la géomatique et de la statistique. A building point represents the position of a land or may be constructed of one or more buildings with attributes of number of dwelling units, number of stores of the building, type of building, etc. This data is used to produce the number of dwellings per hectare and the number of dwellings per hectare of residential lots in particular. It will be used throughout for later analyses as well. The land use data including allotment system and footprints is on 2009, so there are small discrepancies between the two datasets.

Morphological analysis on conditions of the residential tissues at the neighborhood level could help explain not only the presence or absence of establishments, but also the level of accessibility. In addition to the said four variables, two indicators are developed to assess the level of accessibility to establishments in residential patches, they are: 1. the coverage level (i.e. the percentage of a residential patch serviced or "covered" by pedestrian sheds), and; 2. the service level within residential patches (expressed in the sum of all pedestrian shed areas divided up by the total area of a residential patch). These two indicators will be explained latter in detail in chapter six.

3.3.3 Correlation Analysis and Regression Analysis

Correlation analyses are conducted between dependent variables and independent variables. The dependent variables are the two indicators on level of accessibility, and the independent variables are the four morphological variables as previously introduced, a socioeconomic variable (i.e. average household income of a residential patch), as well as the average year of a residential patch (i.e. average year of creation of cadastral lot). Average household income and average year are used as variables of control. Considering socioeconomic factor and time of creation could help examine whether and how income and year correlates with presence or absence, and level of access to establishments. Controlling for average income and average year allow to increase the confidence on the results pertaining to the morphological factors that impact on accessibility to fresh food retail establishments.

The smallest geographical unit for census household income data available is dissemination area, meaning that the income data correspond to the average household income in each such area. The most update income data is from the 2006 Canadian Census (CHASS Data Centre, Faculty of Arts & Sciences, University of Toronto), as the 2011 census data is uncompleted. In order to be used in ArcGIS, the household income data needs to be attached to the dissemination area cartographic boundary file. The most update dissemination area cartographic boundary file is on 2011 from Statistics Canada. Minor discrepancies might arise due to the differing years of the data sets. Our own treatment of the said data does affect the accuracy as well. These limitations will be further discussed hereafter.

As in this research, income is analyzed as one of the variables of morphological neighborhood areas (residential patches), the data of household income at level of dissemination area needs to be processed. Firstly, the boundary file and income data require to be joined base on the field "DAUID" (a unique identifier of dissemination area composed of the 2-digit province/territory unique identifier followed by the e2-digit census division code and the 4-digit dissemination area code), and then the file needs to be converted from polylines to polygons. Secondly, joining dissemination area polygon shapefile to the point shapefile of location of buildings (Localisation des immeubles 2011) to give each building point the household income attribute of the dissemination area it falls inside. A point represents the location of a building, which may contain one dwelling unit (i.e. a single family house) or multiple dwellings (i.e. apartment building). To adjust to that fact, we weight the average income figure by the number of dwellings, i.e. households in the building so that:

$$building\ income\ =\ number\ of\ dwellings\ *\ household\ income$$

Third, by joining points of location of buildings to residential patch polygons base on spatial location, each polygon will be given a summation of the building incomes and a summation of number of dwellings/households of all the building points that fall inside it. The variable average household income of a residential patch is:

$$average\ household\ income\ =\ SB\ /\ SD$$

Where SB represents the summation of building incomes within a residential patch, SD is the summation of number of dwellings within a residential patch.

Average year is also analyzed as one of the variables of morphological neighborhood areas (residential patches). An average year represents the average year of creation of cadastral lots within a residential patch. The data of average year comes from cadastral data. First cadastral plan was created in late 19th century, it did record all pre-existing lots. The official cadastre records all initial lots and all those created since.

Pearson's correlation coefficient (r) measures the strength of a linear relationship between paired variables. The correlation coefficient is always between -1 and +1. Positive values suggest positive linear correlation, negative values in reverse, the closer the value is to ±1, the stronger the linear correlation, and a value of zero denotes no linear correlation. The strength of the correlation between paired variables are interpreted by Evans (1996) that correlation coefficient:

- 0.00 – 0.19, very weak correlation (no correlation)
- 0.20 – 0.39, weak correlation
- 0.40 – 0.59, moderate correlation
- 0.60 – 0.79, strong correlation
- 0.80 – 1.00, very strong correlation (perfect correlation)

According to Williams, Anderson and Sweeney (2007), regression analysis is used to model "the relationship between a dependent variable and one or more independent variables". An "estimated regression equation" is developed to "predict the value of the dependent variable given values for the independent variables". While to determine whether the regression equation is satisfied, the following results of regression analysis are taken into account (Minitab, 2016). P-value is employed to measure the significance of association between dependent variable and each independent variable. P-value is used to assess the null hypothesis that the independent variable's coefficient is equal to 0, which indicates that there is no relationship between the paired variables. Usually, a well-used significance level is 0.05, which indicates a 5% risk of concluding that association exists by chance. If p-value ≤ 0.05, the association is significant, otherwise not. R square is always between 0% and 100% which indicates the "percentage of variation in the response that is explained by the model" in order to "determine how well the model fits your data".

The estimated multiple regression equation is (Holt, Sweet, Grace-Martin, 2011, p. 174):

$$Y = a + b_1X_1 + b_1X_1 + b_1X_1 + \ldots\ldots + b_pX_p$$

Where Y is dependent variable, X_1, $X_2,\ldots,X_p$ are dependent variables, a is the intercept coefficient, b_1, $b_2,\ldots,b_p$ are the dependent variable coefficients (slope).

When considering a bivariate linear regression relationship (i.e. between one dependent variable and one independent variable), the estimated equation of the line is supposed to be (Holt, Sweet, Grace-Martin, 2011, p. 167):

$$Y = a + b * X$$

Where X is independent variable, Y is dependent variable, a is the intercept coefficient, b is the variable coefficient (slope).

3.4 Analysis of Accessibility

This section introduces the methods used to analyze the location and spatial contexts of the establishments in relation to their accessibility by active and collective transportation. This study is only concerned with sustainable modes of transportation. For the motorized population, shopping has little limitations and can occur anywhere. Though car is a massively popular mode of transportation, it is not considered in this accessibility analysis. In the context of sustainable development previously described, only active and collective modes of transportation will be studied. Active transportation modes are walking and cycling, and collective transportation mode is by public transit, i.e. bus, in this study's context.

Assessing accessibility first requires a morphological analysis, which includes a topological analysis. To do such an analysis, walkable and "cyclable" catchment areas based on fresh food retail establishments as their centers need to be generated. These catchments are produced based on the map of street network of Montreal. The catchments made in this analysis are adjusted to actual travel routes instead of representing a simple radius as in more rudimentary methods. The resulting walkable and "cyclable" catchments are irregular in shape instead of circular, and they do correspond to actual walking distances (Figure 13, Figure 14). As mentioned previously in the previous chapter, according to Larsen, El-Geneidy and Yasmin (2010), the average walkable distance to go shopping, including grocery shopping, that people are willing to travel in Montreal is around 750 meters. Accordingly distance of actual travel routes of ped-sheds is defined as 750 meters (which corresponds to about 10 minutes of walking for the average person. The average cycling distance to go shopping is around 2,200 meters (corresponding roughly to 10 minutes), so the distance of actual travel routes is 2,200 meters in “cyclable” catchments (Larsen, El-Geneidy and Yasmin,2010). Using public transit, usually involves walking for some segments of the journey, so using collective transportation, it is, in fact, can be described as a combination transportation modes: i.e. “public transit + walking”. Public transit routes and stops, and travel time are considered to analyze the accessibility to fresh food retail establishments by collective transportation. Along with individual public transit line, certain walkable catchments are generated, using transit stops as catchment centers. These catchments are labeled as “combo” catchments (for short of “combination of modes”). After generating all the catchments, a quantitative analysis is conducted to determine the number of dwellings that fall within the different catchment areas.

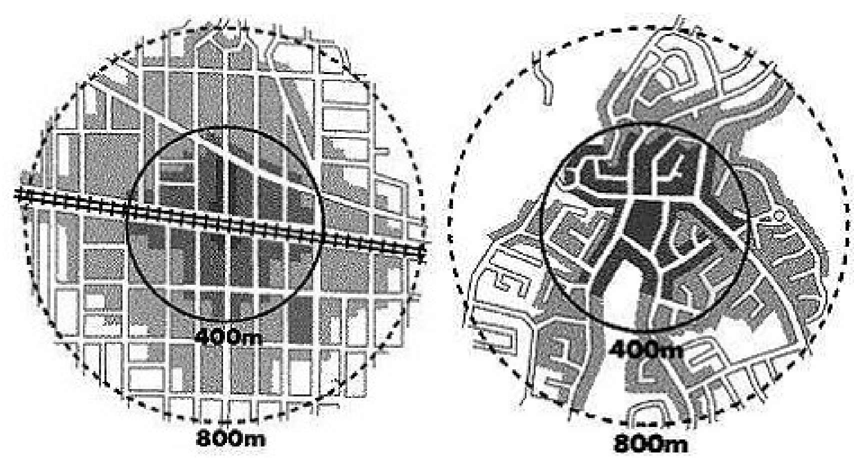

Figure 13. Example of catchments correspond to actual walking distance, superimposed on equivalent Euclidian radius distance (Active Healthy Communities, n.d.)

Figure 14. Catchments correspond to actual walking distance, superimposed on equivalent Euclidian radius distance (Queensland Government and Heart Foundation, 2010)

An actual walking distance is of 400 meters to a transit stops, for instance, corresponds to a 5-minute trip at a walking speed of 80 meters/ min. This study is concerned with fresh food retail establishments that are within walkable distance from transit stops. More specifically, it considers establishments that are located near collective transportation (within 100 meters). Such a distance is chosen because it implies that, under normal circumstances, the bus stop is visible from the establishment, and vice versa. In such conditions, an establishment can be deemed accessible by that mode of transportation by any casual observer (without the need to resort a transit map for instance). Once the establishments accessible by bus identified, the accessibility to/from these establishments by a combination of walking and busing can be assessed. The ten minutes threshold is set as travel time in the study of accessibility to fresh food retail. The potential are broke down to five scenarios. For the purpose of illustration, when considering an establishment as the destination (E) and a dwelling as the point of origin (O) for an allocated travel “budget” of 10 minutes, and while keeping in mind that the establishment is within 100 meters from the nearest bus stop(s) (i.e. about 1 minute of walking), a journey could unravel as follows:

From dwelling to bus stop, 5-minute walking, followed by a 4-minute bus trip, then concluded by a one-minute walk to the store.

The figure 15 summarizes the five time-travel scenarios retained for this study.

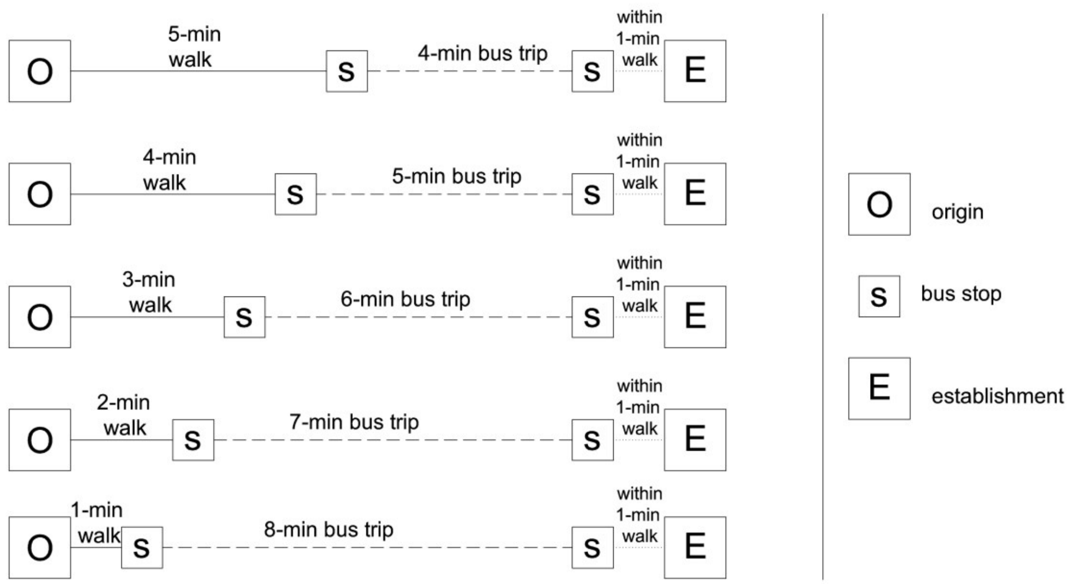

Figure 15. Examples of 10 minutes travel time arrangements using “public transit + walking” combination (inspired by Salonen and Toivonen, 2013)

Assessing the accessibility of an establishment from any dwelling (or vice versa), within the allocated time budget, requires the transposition of travel time into travel distances. According to Sustainable Development Report (2012) from Société de transport de Montréal (STM), the average journey speed on Montreal bus network is 18.2 km/ h, which is about 300 m/ min. The distances of segments corresponding to above-mentioned time arrangements are: a. 400 meters walking to public transit, 1200 meters on the transit, and then, 100 meters or less to destination; b. at next further stop, 320 meters walking to public transit, 1500 meters on the transit, and then, 100 meters or less to destination; etc. (Figure 16). A time of 0.5 minutes is added on and subtracted from each transit travel time to produce time intervals. For example, a transit trip time of 6 minutes (corresponds to 1800 meter trip on transit) has a time interval between 5.5 and 6.5 minutes (corresponds to a transit trip distance interval between 1650 and 1950 meters), the bus stops that fall within this distance interval are considered having the same time on the transit, 6 minutes.

The figure 16 illustrates the transposition of travel times into travel distances for the five scenarios. The first and last leg of the journey is by foot and the intermediate one is by bus. This transposition allows to determine the catchment area of each establishment by a combination of waking and bussing (A.K.A. their "combo shed").

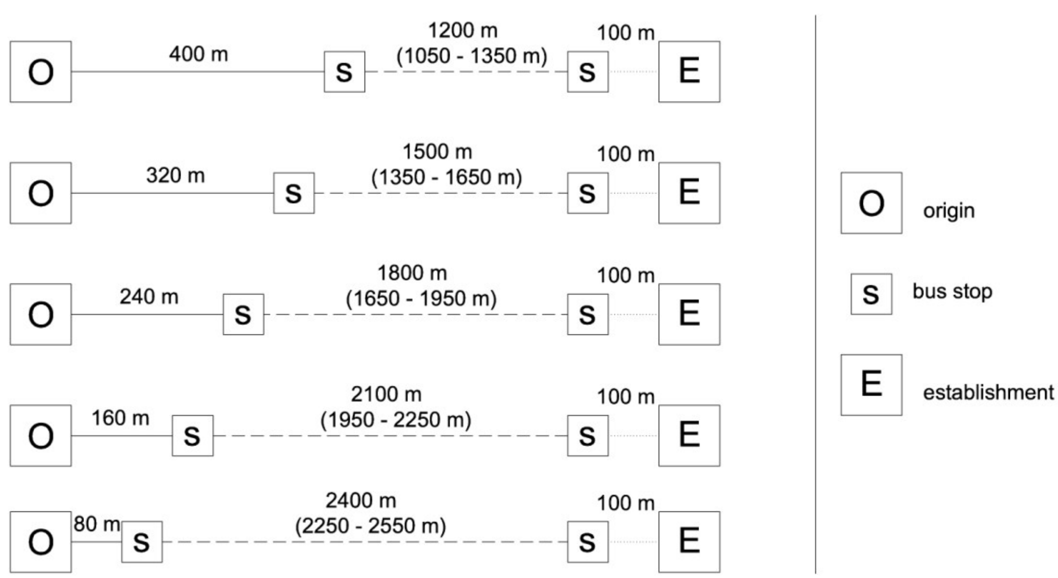

Figure 16. Examples of 10 minutes travel distance arrangements using "public transit + walking" combination (inspired by Salonen and Toivonen, 2013)

Figure 17 is an example of process for generating "combo" catchment area of an establishment and combined walkable and "combo" catchment area.

Figure 17. Generating "combo" catchment area of an establishment

Chapter 4 Quantitative Analysis of Spatial Distribution of Establishments

Spatial distribution analyses of fresh food retail establishments are conducted on three categories base on their size, using both quantitative methods and morphological methods. The quantitative analyses use the method of point pattern analysis. As mentioned, point pattern analysis has two main approaches: quadrat analysis and nearest neighbor analysis. Quadrat analysis is a point density assessment based on observing the frequency distribution or density of points within a set of grid squares, while nearest neighbor analysis measures point interaction based on average spacing of closest points. The two approaches are complementary. Both have advantages and disadvantages.

4.1 Quadrat Analysis

The quadrat analysis was conducted mainly in areas that are predominantly residential zones (to the exclusion of specialized urban tissues and infrastructure) in the island of Montreal, as no establishments are found in areas such as the airport, large railyards or large industrial parks. Since the directions of streets are from northeast to southwest and from northwest to southeast, instead of true north to true south, the quadrats are rotated 45 degree from true north. The result of quadrat analysis is affected by scale because selection of the size of quadrat is always arbitrary. If the quadrat size is too small, a frequency distribution with many 0 and 1 will be produced, and the result will be erroneously assumed to be a Poisson distribution. If the quadrat size is too big, there would be only a small quantity of quadrats which would lead to low variance as the quadrats get similar counts, and the result tends to be a dispersion distribution. Medium-size quadrat is not necessarily the most appropriate size for the analysis. Their analysis is likely to produce high variance, and produce a highly clustered distribution. Therefore, quadrat analysis need to been conducted in different scales (1 km, 3 km, 6 km). Figure 18 is a sample of 3 km size quadrats limit to residential zones.

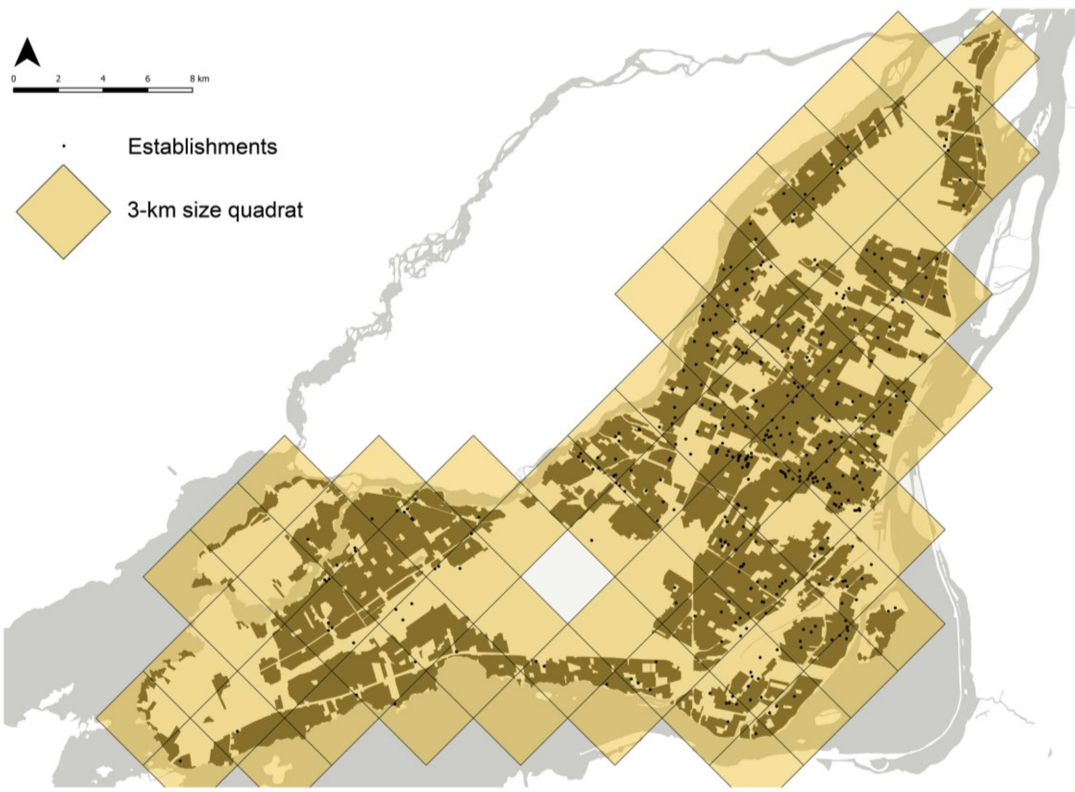

Figure 18. Sample of quadrats limit to residential zones (size 3 km)

- *One-kilometer Quadrat Analysis*

The first analysis considers all establishments irrespective of their size. The Figure 19 shows one-kilometer size quadrats. The labels indicate the number of points of establishments within each quadrats. The map has 501 quadrats. The number of quadrats that have zero point inside is 306. The number of quadrats that contain one point only is 100. That signifies that a one-kilometer quadrat size is too small, resulting in more than 81% of quadrats has zero or one points (Table 5). As mentioned in the methodology, in quadrat analysis, the variance to mean ratio (VMR) trends to 0 for a uniform distribution, equals 1 for a random distribution, and is greater than 1 for clustered distributions.

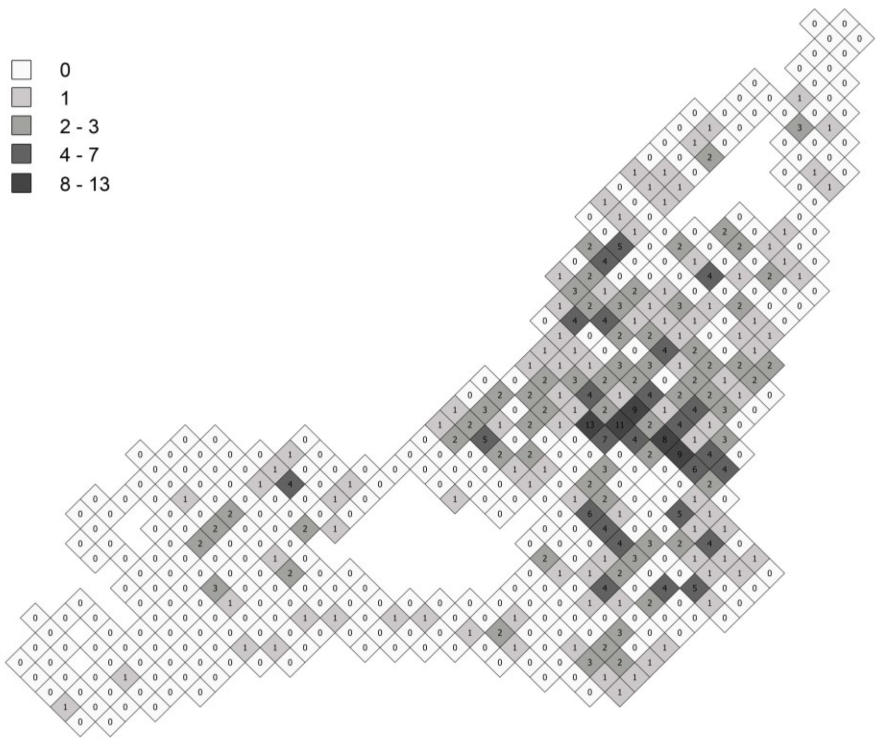

Figure 19. One-kilometer size quadrat map

number of points	frequency	number of points	frequency
0	306	6	2
1	100	7	1
2	49	8	1
3	16	9	2
4	18	11	1
5	4	13	1

Table 5. Frequency of Distribution of Points in One-kilometer Size Quadrats

Although a frequency distribution with many 0 and 1 was produced, a VMR value of 2.793 points out a clustered distribution of all points of establishments in the Island of Montreal. A significant test for VMR was conducted based upon chi-square (X^2) frequency distribution. The test can ascertain if a pattern is significantly more clustered than would be expected by chance.

For 500 degrees of freedom, the value of chi-square at the 1% significance level is 576.493. Therefore, there is only a 1% chance of obtaining a value of 576.493 or greater if the points had been allocated randomly. Since the resulting value of chi-square test in this case is 1396.354 (> 576.493), there is (considerably) less than a 1% likelihood that this clustered pattern could have resulted from a random chance (Table 6).

quadrat size	1 km
N	501
mean	0.81237525
variance	2.268727
VMR	2.792707617
distribution	clustered
X^2 test value	1396.353808
df	500

Table 6. One-kilometer Size Quadrat Analysis (Global)

Quadrat analyses of fresh food retail establishments are conducted on three categories of establishments. Table 7 shows the quadrat analysis results of category of small establishments. The VMR value of 3.226 suggests a clustered distribution. For 500 degrees of freedom, the value of chi-square at the 1% significance level is 576.493. Since the resulting value of chi-square test in this case is 1612.969 (> 576.493), there is (considerably) less than a 1% likelihood that this clustered pattern could have resulted from a random chance.

quadrat size	1 km
N	501
mean	0.518962076
variance	1.674140
VMR	3.225938462
result	clustered
X^2	1612.969231
df	500

Table 7. One-kilometer Size Quadrat Analysis (Small Establishments)

Table 8 shows the quadrat analysis results of category of mid-size establishments. The VMR value of 1.001 suggests a random distribution. For 500 degrees of freedom, the value of chi-square at the 1% significance level is 576.493, and the value of chi-square at the 5% significance level is 553.127. Since the resulting value of chi-square test in this case is 500.309, which is considerably less than 553.127, the pattern does not appear to be significantly different than random.

quadrat size	1 km
N	501
mean	0.219560878
variance	0.219697
VMR	1.000618182
result	random
X^2	500.3090909
df	500

Table 8. One-kilometer Size Quadrat Analysis (Mid-size Establishments)

Table 9 shows the quadrat analysis results of category of large establishments. The VMR value of 1.209 suggests a clustered distribution. For 500 degrees of freedom, the value of chi-square at the 1% significance level is 576.493. Since the resulting value of chi-square test in this case is 604.6 (> 576.493), there is (considerably) less than a 1% likelihood that this clustered pattern could have resulted from a random chance.

quadrat size	1 km
N	501
mean	0.05988024
variance	0.072407
VMR	1.2092
result	clustered
X^2	604.6
df	500

Table 9. One-kilometer Size Quadrat Analysis (Large Establishments)

- *Three-kilometer Quadrat Analysis*

The Figure 20 shows three-kilometer size quadrats labelled the number of points of establishments within each quadrats. There are 77 quadrats at this scale. Compared with one-kilometer size quadrats, this scale has a frequency distribution with much less 0 and 1, and has a higher variance (Table 10).

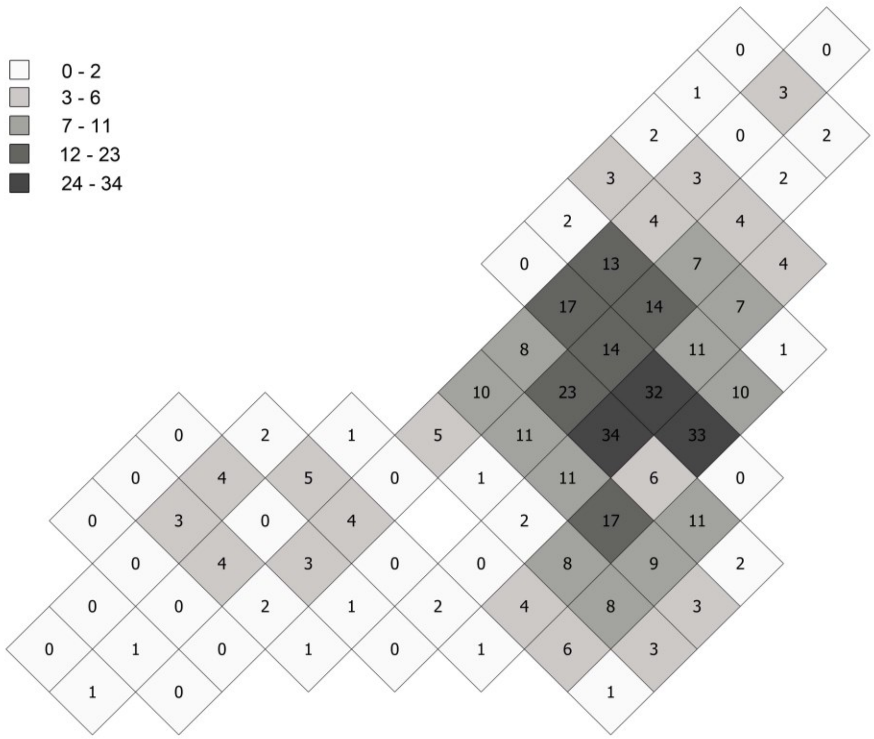

Figure 20. Three-kilometer size quadrat map

number of points	frequency	number of points	frequency	number of points	frequency
0	19	7	2	17	2
1	10	8	3	23	1
2	9	9	1	32	1
3	7	10	2	33	1
4	7	11	4	34	1
5	2	13	1		
6	2	14	2		

Table 10. Frequency of Distribution of Points in Three-kilometer Size Quadrats

Table 11 shows the three-kilometer size quadrat analysis results of all points of establishments in the Island of Montreal. The VMR value of 10.415 suggests a clustered distribution. For 76 degrees of freedom, the value of chi-square at the 1% significance level is 107.583. Since the resulting value of chi-square test in this case is 791.514 (> 107.583), there is (considerably) less than a 1% likelihood that this clustered pattern could have resulted from a random chance.

quadrat size	3 km
N	77
mean	5.285714286
variance	55.048872
VMR	10.41465149
result	clustered
X^2	791.5135135
df	76

Table 11. Three-kilometer Size Quadrat Analysis (Global)

Table 12 shows the quadrat analysis results of category of small establishments. The VMR value of 11.41 suggests a clustered distribution. For 76 degrees of freedom, the value of chi-square at the 1% significance level is 107.583. Since the resulting value of chi-square test in this case is 867.162 (>107.583), there is (considerably) less than a 1% likelihood that this clustered pattern could have resulted from a random chance.

quadrat size	3 km
N	77
mean	3.376623377
variance	38.527341
VMR	11.41002024
result	clustered
X^2	867.1615385
df	76

Table 12. Three-kilometer Size Quadrat Analysis (Small Establishments)

Table 13 shows the quadrat analysis results of category of mid-size establishments. The VMR value of 1.795 suggests a clustered distribution. For 76 degrees of freedom, the value of chi-square at the 1% significance level is 107.583. Since the resulting value of chi-square test in this case is 136.4 (>107.583), there is (considerably) less than a 1% likelihood that this clustered pattern could have resulted from a random chance.

quadrat size	3 km
N	77
mean	1.428571429
variance	2.563910
VMR	1.794736842
result	clustered
X^2	136.4
df	76

Table 13. Three-kilometer Size Quadrat Analysis (Mid-size Establishments)

Table 14 shows the quadrat analysis results of category of large establishments. The VMR value of 1.294 suggests a clustered distribution. For 76 degrees of freedom, the value of chi-square at the 5% significance level is 97.351. Since the resulting value of chi-square test in this case is 98.333 (> 97.351), there is less than a 5% likelihood that this clustered pattern could have resulted from a random chance.

quadrat size	3 km
N	77
mean	0.38961039
variance	0.504101
VMR	1.293859649
result	clustered
X^2	98.33333333
df	76

Table 14. Three-kilometer Size Quadrat Analysis (Large Establishments)

- *Six-kilometer Quadrat Analysis*

The Figure 21 shows six-kilometer size quadrats labelled the number of points of establishments within each quadrats. There are 26 quadrats at this scale. Compared with previous two sizes of quadrat analysis, this scale has a frequency distribution with least 0 and 1, and has the highest variance (Table 15).

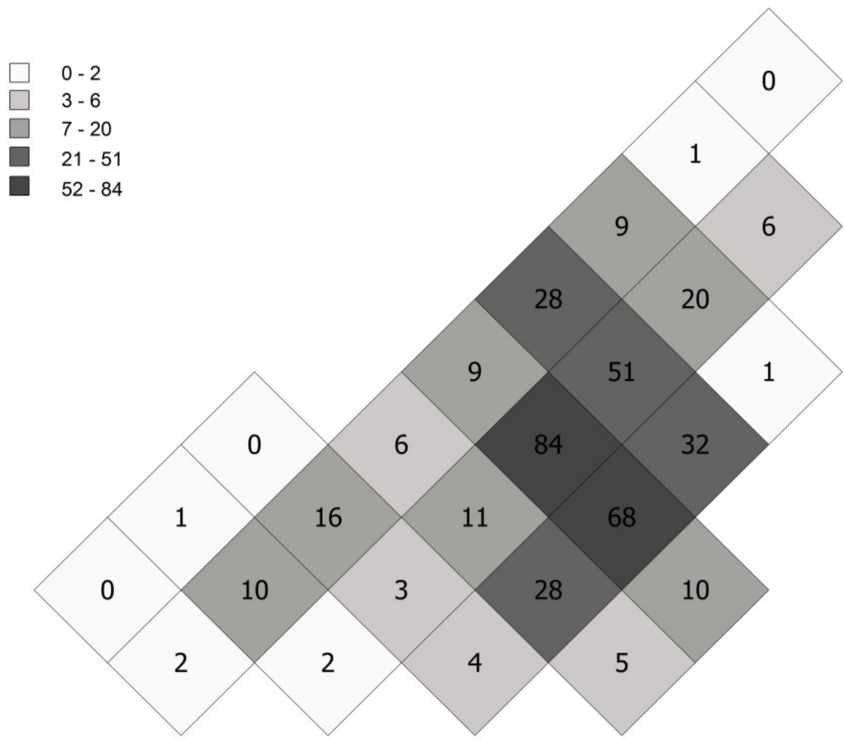

Figure 21. Six-kilometer size quadrat map

number of points	frequency	number of points	frequency	number of points	frequency
0	3	6	2	28	2
1	3	9	2	32	1
2	2	10	2	51	1
3	1	11	1	68	1
4	1	16	1	84	1
5	1	20	1		

Table 15. Frequency of Distribution of Points in Six-kilometer Size Quadrats

Table 16 shows the six-kilometer size quadrat analysis results of all points of establishments in the Island of Montreal. The VMR value of 30.086 suggests a clustered distribution. For 25 degrees of freedom, the value of chi-square at the 1% significance level is 44.314. Since the resulting value of chi-square test in this case is 752.14 (> 44.314), there is (considerably) less than a 1% likelihood that this clustered pattern could have resulted from a random chance.

quadrat size	6 km
N	26
mean	15.65384615
variance	470.955385
VMR	30.08560197
result	clustered
X^2	752.1400491
df	25

Table 16. Three-kilometer Size Quadrat Analysis (Global)

Table 17 shows the quadrat analysis results of category of small establishments. The VMR value of 28.48 suggests a clustered distribution. For 25 degrees of freedom, the value of chi-square at the 1% significance level is 44.314. Since the resulting value of chi-square test in this case is 712 (> 44.314), there is (considerably) less than a 1% likelihood that this clustered pattern could have resulted from a random chance.

quadrat size	6 km
N	26
mean	10
variance	284.800000
VMR	28.48
result	clustered
X^2	712
df	25

Table 17. Six-kilometer Size Quadrat Analysis (Small Establishments)

Table 18 shows the quadrat analysis results of category of mid-size establishments. The VMR value of 4.147 suggests a clustered distribution. For 25 degrees of freedom, the value of chi-square at the 1% significance level is 44.314. Since the resulting value of chi-square test in this case is 103.673 (> 44.314), there is (considerably) less than a 1% likelihood that this clustered pattern could have resulted from a random chance.

quadrat size	6 km
N	26
mean	4.230769231
variance	17.544615
VMR	4.146909091
result	clustered
X^2	103.6727273
df	25

Table 18. Six-kilometer Size Quadrat Analysis (Mid-size Establishments)

Table 19 shows the quadrat analysis results of category of large establishments. The VMR value of 2.475 suggests a clustered distribution. For 25 degrees of freedom, the value of chi-square at the 1% significance level is 44.314. Since the resulting value of chi-square test in this case is 61.867 (> 44.314), there is (considerably) less than a 1% likelihood that this clustered pattern could have resulted from a random chance.

quadrat size	6 km
N	26
mean	1.153846154
variance	2.855385
VMR	2.474666667
result	clustered
t	0.294933333
X^2	61.86666667
df	25

Table 19. Six-kilometer Size Quadrat Analysis (Large Establishments)

4.2 Nearest Neighbor Analysis

Nearest neighbor analyses of fresh food retail establishments are also conducted on categories of establishment size in ArcGIS, using spatial statistics tool “Average Nearest Neighbor”. The result of such an analysis is very dependent on the study area. So, instead of using a default value of minimum enclosed rectangle that encompasses all features, the area of the Island of Montreal is used as study area in this case. As explained in chapter three, in nearest neighbor analysis, the Nearest Neighbor Index (NNI) trends to 0 for a clustered distribution, approximately equals to 1 for a random distribution, and is greater than 2 for uniform (dispersed) distributions.

Figure 22 is the graphical result summary of the global nearest neighbor analysis of all the retail establishments selling fresh fruits and vegetables that was generated in ArcGIS. Nearest Neighbor Index NNI is named Nearest Neighbor Ratio in Figure 22, and the z-score value is a measure of statistical significance which tells whether or not to reject that the points are randomly distributed. It has the same function than the chi square test that was used in quadrat analyses. The top right corner in Figure 22 shows the probabilities (p-value) corresponding to critical z-score values. Z-score is -2.58 or 2.58 at the 1% significance level, and it is -1.96 or 1.96 at the 5% significance level. That is, there is less than 1% chance to accept hypothesis that the points are randomly distributed when z-score less than -2.58 or more than 2.58, and there is less than 5% chance to accept hypothesis that the points are randomly distributed when z-score is between -2.58 and -1.96, or between 1.96 and 2.58.

Given nearest neighbor ratio of 0.693706, the pattern exhibits clustering. Since the z-score value in this case is -11.8213177638 (< -2.58), there is a (considerably) less than 1% likelihood that this clustered pattern could be the result of random chance.

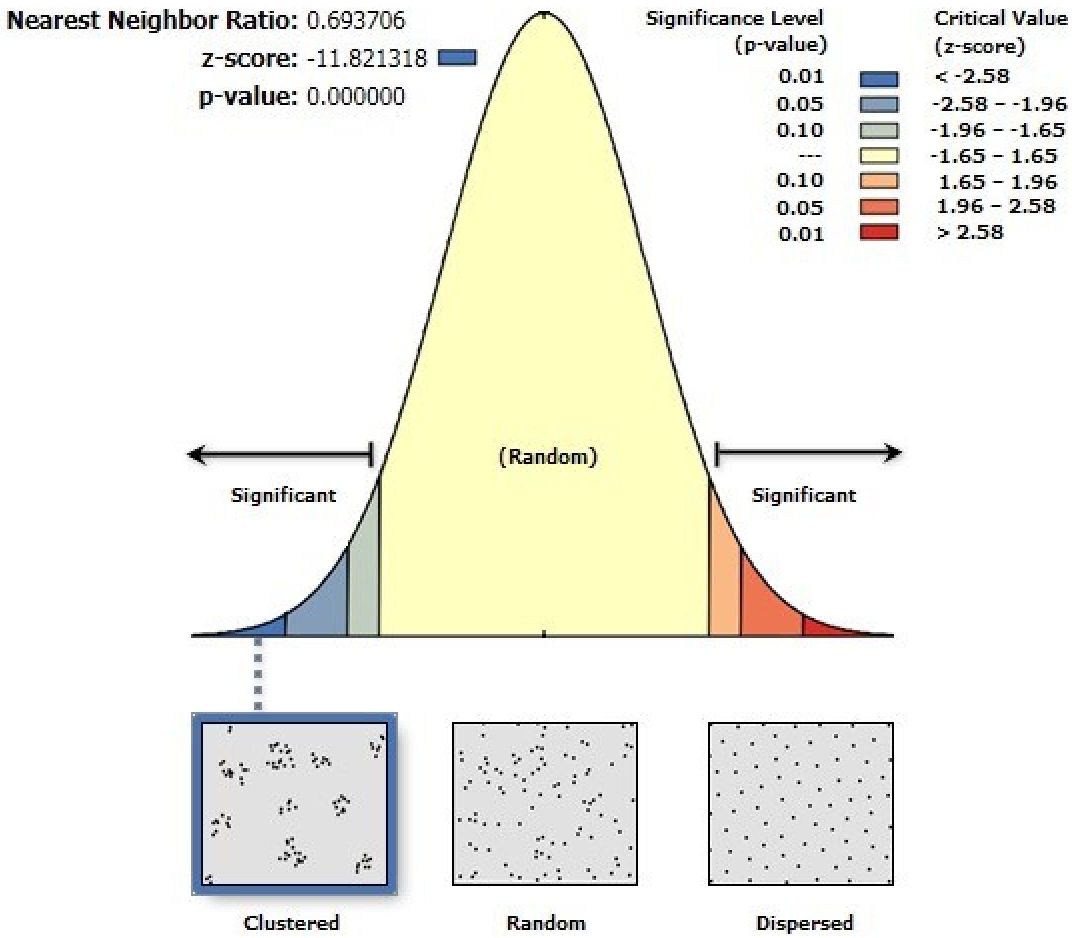

Figure 22. Summary of nearest neighbor analysis (Global)

Figure 23 is the graphical result summary of the nearest neighbor analysis of small establishments. Given nearest neighbor ratio of 0.663893, the pattern exhibits clustering. Since the z-score value in this case is -10.368017 (< -2.58), there is a (considerably) less than 1% likelihood that this clustered pattern could be the result of random chance.

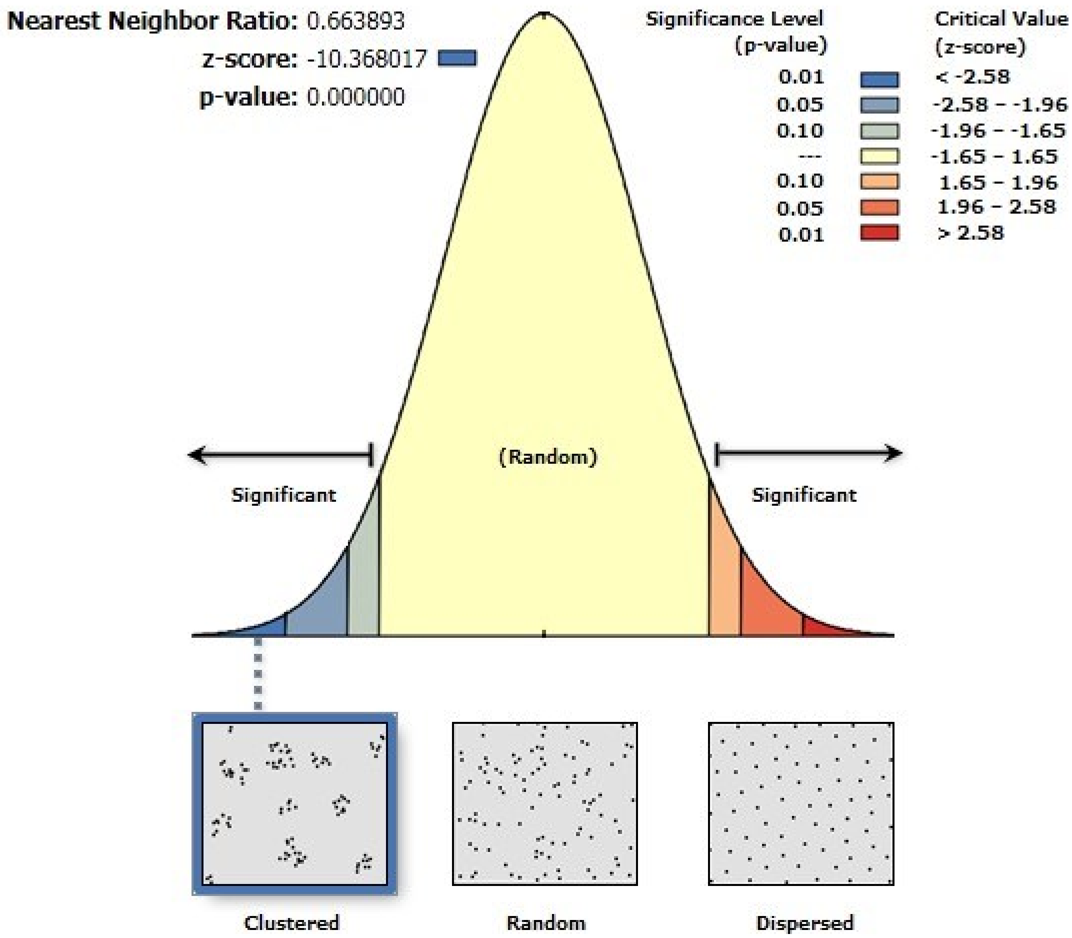

Figure 23. Summary of nearest neighbor analysis (small establishments)

Figure 24 is the graphical result summary of the nearest neighbor analysis of mid-size establishments. Given nearest neighbor ratio of 0.970186, the pattern exhibits a random distribution. Since the z-score value in this case is -0.598197, the pattern does not appear to be significantly different than random.

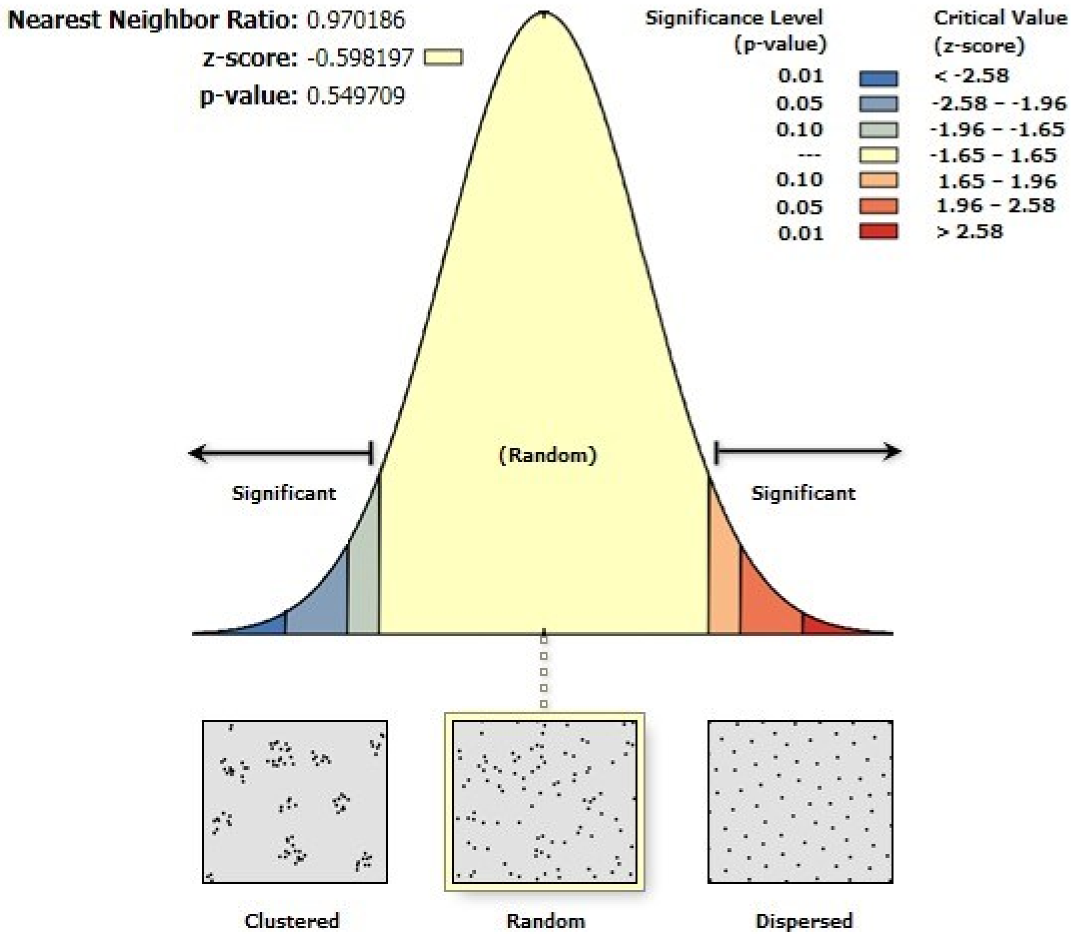

Figure 24. Summary of nearest neighbor analysis (mid-size establishments)

Figure 25 is the graphical result summary of the nearest neighbor analysis of mid-size establishments. Given nearest neighbor ratio of 0.957556, the pattern exhibits a random distribution. Since the z-score value in this case is -0.444746, the pattern does not appear to be significantly different than random.

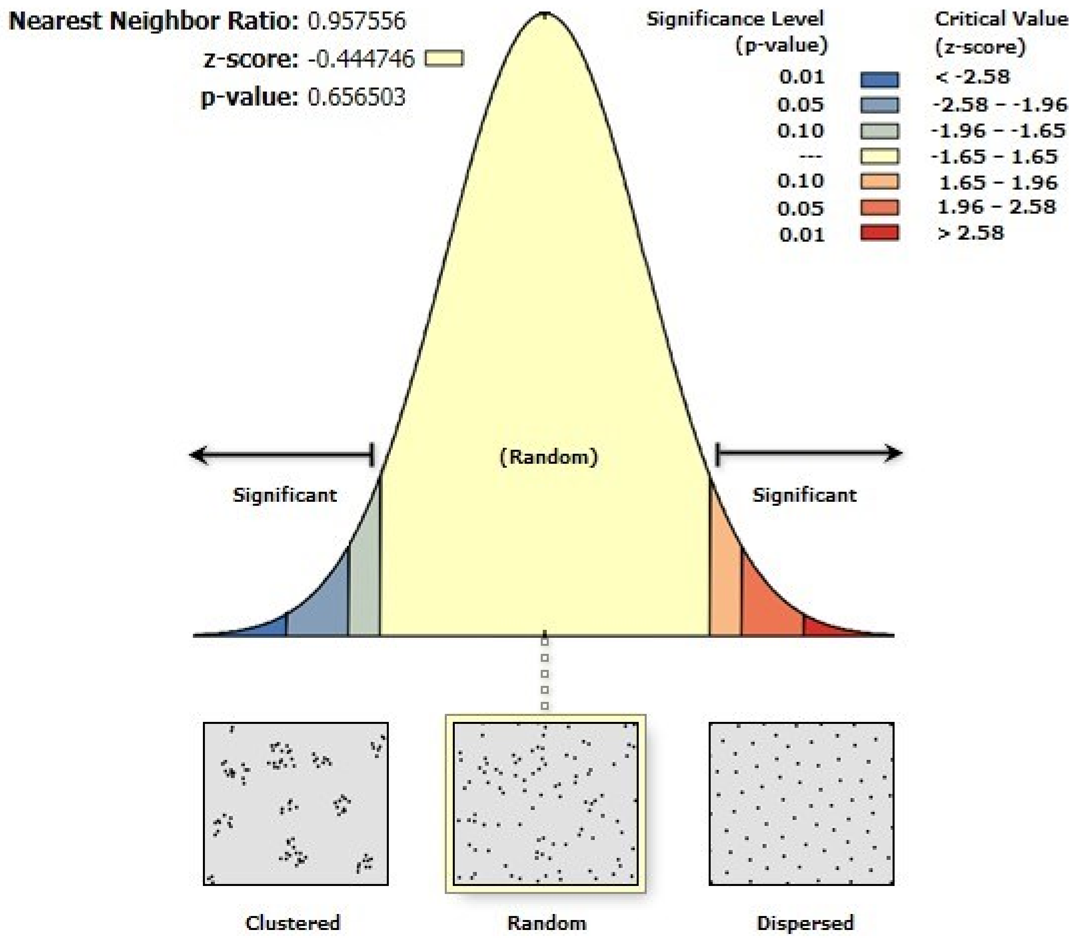

Figure 25. Summary of nearest neighbor analysis (large establishments)

4.3 Conclusion of Point Pattern Analysis

This section explored the spatial distribution of retail establishments selling fresh fruits and vegetables on different categories of sizes, using quantitative methods, quadrat analysis and nearest neighbor analysis. The general conclusions of this study are as follows (Table 20):

	Category of Establishments			
Quadrat Size	**global**	**small**	**mid-size**	**large**
one-kilometer	clustered	clustered	random	clustered
three-kilometer	clustered	clustered	clustered	clustered
six-kilometer	clustered	clustered	clustered	clustered
Nearest Neighbor Analysis	clustered	clustered	random	random

Table 20. Conclusions draw from Point Pattern Analysis

The spatial distributions of global establishments and small establishment exhibit clustered in both quadrat analyses at each quadrat scale and nearest neighbor analysis. In quadrat analyses, mid-size establishments exhibit clustered distribution at three-kilometer and six-kilometer scale, but exhibit random distribution at one-kilometer scale, as well as in nearest neighbor analysis. Large establishments exhibits clustered in quadrat analyses at each quadrat scale, but random in nearest neighbor analysis.

Quadrat analysis is an approach based on the frequency distribution or density of points within a set of subsections of study area, while nearest neighbor analysis is based on the distance between points. As explained previously, the two approaches are interrelated as they both have advantages and disadvantages. Meanwhile, only basing on point location, it does not incorporate magnitude of phenomena at that point. Spatial statistics theories and methods are essential tools in order to quantitatively assess the distribution patterns of points, which correspond here to different types of retail establishments. No matter on the density of points or on the distance between points, small establishments are clustered. This clustered distribution of small establishments implies their locations within specific areas, and their densities differentiate between areas. Mid-size establishments are clustered based on the density of points, which could be the result of disparity of their numbers in inner city or suburbs and the results of their location relative to specific built environment elements. The clustered distribution of large establishments based on the distance between points could be explained by their limited number and their location relative to specific built environment elements. Yet, the urban contexts are not neutral and nondescript surfaces: rather they are displaying spatial logics and configurations that obey their own rules, as urban morphology suggests. The following chapters will explore the spatial distribution of these retail establishments based on a morphological criteria.

Chapter 5 Location of Establishments vs. Morphological Conditions

In this section, methods of urban morphology are used to analyze the location of fresh food retail establishments, relative to features and components of built landscape at different levels of spatial resolution. A set of analyses entailed mapping the different categories of establishments in the point format in ArcGIS in order in particular to assess their spatial distribution relative to residential tissues, thoroughfares, and bus lines and stops. Also, the characters of the urban tissues that fall within the pedestrian sheds of the establishments are assessed quantitatively.

5.1 Location of Establishments Relative to "Morphological Neighborhood Area"

First, the spatial distribution and location of establishments relative to residential tissues is considered. Morphological neighborhood areas (or "residential patches" for short) are used as a geographical unit of reference for the analysis. They consist of internally cohesive (predominantly) residential areas delineated by a combination of first order spatial discontinuities induced by natural and artificial barriers and second order boundary discontinuities induced by differing street network geometrical and topological patterning (Gauthier, 2015).

Figure 26 is an example of residential patch, which illustrates the different cases of locations of establishments relative to residential patches. Establishment A and B are located within the residential patch, the former is peripherally located within the patch, and the latter is centrally located. Establishment C is located outside residential patch. In this research, the peripheral and central areas of a residential patch is defined as a 50% shrinkage of residential patch area from the boundary.

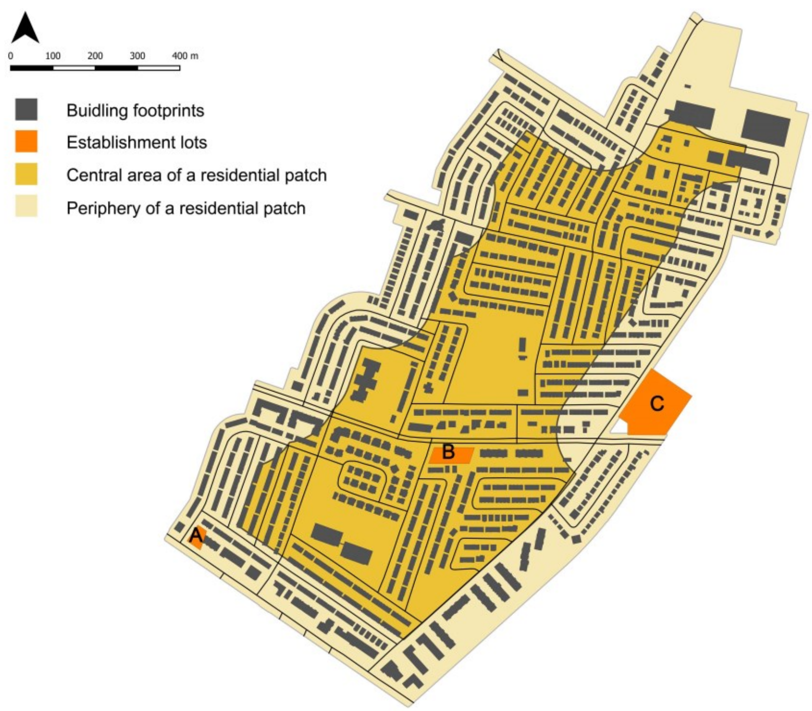

Figure 26. Example of location of establishments relative to residential patch

Figure 27 and Table 21 illustrates the spatial distribution of establishments selling fresh fruits and vegetables in the Island of Montreal relative to the residential patches: 91.92% of small establishments are located within the residential patches. More specifically, 44.62% of small establishments are peripherally located within the residential patches, while 47.31% are centrally located. A majority (60.91%) of mid-size establishments are located outside residential patch. Only 39.09% are located within the residential patches. Of those, 26.36% of mid-size establishments are peripherally located within the residential patches, and 12.73% are centrally located. Large establishments are all located outside residential patches. Globally, among all the establishments, 70.27% are located within patches. Of those, 36.12% are peripherally located within the residential patches, and 34.15% are centrally located.

Figure 27. Different categories of establishment and residential patches

Global	Outside patches	Within patches	Peripherally	Centrally
Count	**121**	**286**	**147**	**139**
Percentage	29.73%	70.27%	36.12%	34.15%
Small establishments	Outside patches	Within patches	Peripherally	Centrally
Count	**21**	**239**	**116**	**123**
Percentage	8.08%	91.92%	44.62%	47.31%
Mid-size establishments	Outside patches	Within patches	Peripherally	Centrally
Count	**67**	**43**	**29**	**14**
Percentage	60.91%	39.09%	26.36%	12.73%
Large establishments	Outside patches	Within patches	Peripherally	Centrally
Count	**30**	**0**	**0**	**0**
Percentage	100.00%	0.00%	0.00%	0.00%

Table 21. Spatial distribution of different categories of establishment relative to the residential patches

Overall, small-size establishments are located within residential patches, and half of them are centrally located within residential patches, which mainly serve local residents at the level of their neighborhood. A mid-size establishment, by its nature, serves more people than a small one. More than a quarter of mid-size establishments are located within residential patches, though peripherally, serving not only local residents but also potential customers from adjacent residential patches. Most of mid-size establishments and all the large establishments are located outside of residential patches, which implies, upon closer examination, that they serve more than one residential patches.

5.2 Location of Establishments Relative to Thoroughfares and Bus Stops

A similar analysis was conducted that looked at the location of establishments relative to major thoroughfares and bus stops. To recapitulate, a major thoroughfare is defined as a component of the street network such as a boulevard or an expressway, that is granted with a high level of arteriality (connected to street of similar topological level or to a controlled-access highway); which spans over the length of several morphological neighborhood areas that it provides access to; which often crosses first order barriers (such as railways, canals, etc.), and which tends to be located at the periphery of morphological neighborhood units where it acts as an anti-nodal dividing axis (Gauthier, 2015).

One hundred meter is used as the threshold to mark close proximity of thoroughfares and bus stops from retail establishments selling fresh fruits and vegetables. Among all the establishments in the Island of Montreal, 66.83% are located near a thoroughfare. A majority of establishments of each category are located within 100 meter from a thoroughfare (58.08% of small establishments; 80.91% of mid-size establishments; and 93.33% of large establishments, respectively). These statistics might point to the influence of automobility on locational patterns. The analysis looking at the location relative to bus stops surprised the author. It revealed that a high proportion of establishments of each category are located within 100 m. from a bus stop in the Island of Montreal (89.62% of small establishments; 99.09% of mid-size establishments; 100% of large establishments, respectively).

Global	Near thoroughfare	Not near thoroughfare	Near bus stop	Not near bus stop
Count	**272**	**135**	**378**	**29**
Percentage	66.83%	33.17%	92.87%	7.13%
Small establishments	Near thoroughfare	Not near thoroughfare	Near bus stop	Not near bus stop
Count	**151**	**109**	**233**	**27**
Percentage	58.08%	41.92%	89.62%	10.38%
Mid-size establishments	Near thoroughfare	Not near thoroughfare	Near bus stop	Not near bus stop
Count	**89**	**21**	**109**	**1**
Percentage	80.91%	19.09%	99.09%	0.91%
Large establishments	Near thoroughfare	Not near thoroughfare	Near bus stop	Not near bus stop
Count	**28**	**2**	**30**	**0**
Percentage	93.33%	6.67%	100.00%	0.00%

Table 22. Spatial distribution of different categories of establishment relative to thoroughfares and bus stops

More than half of small establishments, more than 80% of mid-size establishments and more than 90% of large establishments are located near major thoroughfares. As previously mentioned, a thoroughfare tends to be located at the periphery of morphological neighborhood areas, were they often act as dividing axes or morphological boundaries. Their high level of arteriality (high topological status) implies that they are connecting many places together (i.e. morphological neighborhood areas) and that they are often very well connected with the surrounding arterial system. Major thoroughfares carry large loads of traffic and are generally accommodating bus routes. All the mid-size and large establishments and about 90% of small establishments are accessible by bus. Many small establishments that are not near thoroughfares but within residential patches might be located on the local commercial streets, where they are accessible by foot at local level as well as by bus.

5.3 Assessing Characters of Urban Tissues within the Establishment Catchment Areas

The research aimed at better understanding the local conditions in which the different categories of establishments could be found. In so doing, it wished to unveil the tissue conditions to which the establishments are "responding," and to measure some characters of the urban form that could help explain their presence. To allow for comparison, the geographical area considered for analysis is the 750m. pedestrian shed as previously defined. Furthermore, considering the overarching interest in the research for the question of physical accessibility to fresh food, the characters of the form retained for analysis are those that influence the number of dwellings within reach (or conversely, the number of dwellings that are granted access to an establishment). Two interrelated sets of conditions in the residential tissues influence the said number of dwellings that are accessible within pedestrian sheds. Those are the residential density and the street network configuration (or topology). As far as density is concerned, it is easy to conceive that detached single-family houses on large lots produce a lower residential density than a compact tissue of multi-family residential buildings. The impact of street topology may seem more elusive, but simply stated, a tightly meshed street grid (produced by small urban blocks) offers more path opportunities than a system made of loops and cul-de-sacs.

Table 23 outlines descriptive statistics pertaining to the pedestrian sheds of the three categories of establishments in relation to residential density and street network connectivity. Residential density is expressed in number of dwellings per hectare. More specifically, gross densities are expressed in number of dwellings per hectare. Net densities are expressed in number of dwelling per hectare of residential lots (to the exclusion of streets, parks and lots accommodating non-residential land-uses). Street network connectivity (a topological character of the form) is expressed by number of intersections per hectare, as well as by the ratio of edge to node (i.e. the total number of street segments divided by the total number of intersections) within the pedestrian shed area. Small size establishments are located in high residential density areas on average, which is attested by the highest averages of gross density and net density. Large size establishments, conversely are located in low residential density areas. The conditions of street network connectivity are more intricate and will be explained later with sample of pedestrian sheds illustrating distribution according to street network connectivity index (expressed in total number of street segments / total number of nodes).

		Number of dwellings	Residential density variables			Street network connectivity variables		
			Percentage of ped shed area filled by residential lots	Number of dwellings/ ha (gross density)	Number of dwellings/ ha of residential lots (net density)	Percentage of theoretical circle area filled by ped shed area	Total street segments /total nodes	Number of nodes/ ha
Small EST. n = 260	Mean	**5416.61**	**46.60**	**56.92**	**127.04**	**52.77**	**2.03**	**0.704**
	Min	0	0	0	0	25.04	1.55	0.147
	Max	14192	79.63	144.76	465.26	63.70	2.43	1.210
	S Dev	2573.24	10.42	24.55	67.03	7.67	0.16	0.170
Mid-size EST. n = 110	Mean	**3464.84**	**43.72**	**39.09**	**93.15**	**46.88**	**1.99**	**0.663**
	Min	0	0	0	0	16.56	1.64	0.070
	Max	12866	86.59	135.23	447.82	62.31	3.25	1.104
	S Dev	2452.93	13.13	23.12	62.37	10.43	0.20	0.179
Large EST. n = 30	Mean	**1581.40**	**25.17**	**22.81**	**89.92**	**35.05**	**2.05**	**0.548**
	Min	0	0	0	0	10.35	1.62	0.170
	Max	5526	54.03	59.83	303.77	58.25	2.46	1.103
	S Dev	1484.92	17.42	17.52	66.42	12.39	0.19	0.238

Table 23. Statistics of 750 m. ped sheds of different categories of establishments

Figure 28 and 29 show a representative sample and summarize the findings of the analysis of the tissue conditions observed within the pedestrian sheds of the three categories of establishments. The classifications of gross density (in dwellings / hectare) and street connectivity index (in total segments / total nodes) are according to natural breakdown.

Figure 28 illustrates that a plurality (36%) of small establishment pedestrian sheds are displaying gross residential densities of 69 to 110 dwellings/ha. By comparison, 42% of mid-size establishment pedestrian sheds have densities of 22 to 44 dwellings/ha., and 47% of large size establishment pedestrian sheds have densities ranging from 0 to 22 dwellings/ha, no large size establishment pedestrian shed has high gross densities. Lower gross densities affect mostly large establishments and a significant proportion of mid-size. The latter conditions are attributable in part to the fact that all large establishments and 60.91% of mid-size establishments are located outside the patches.

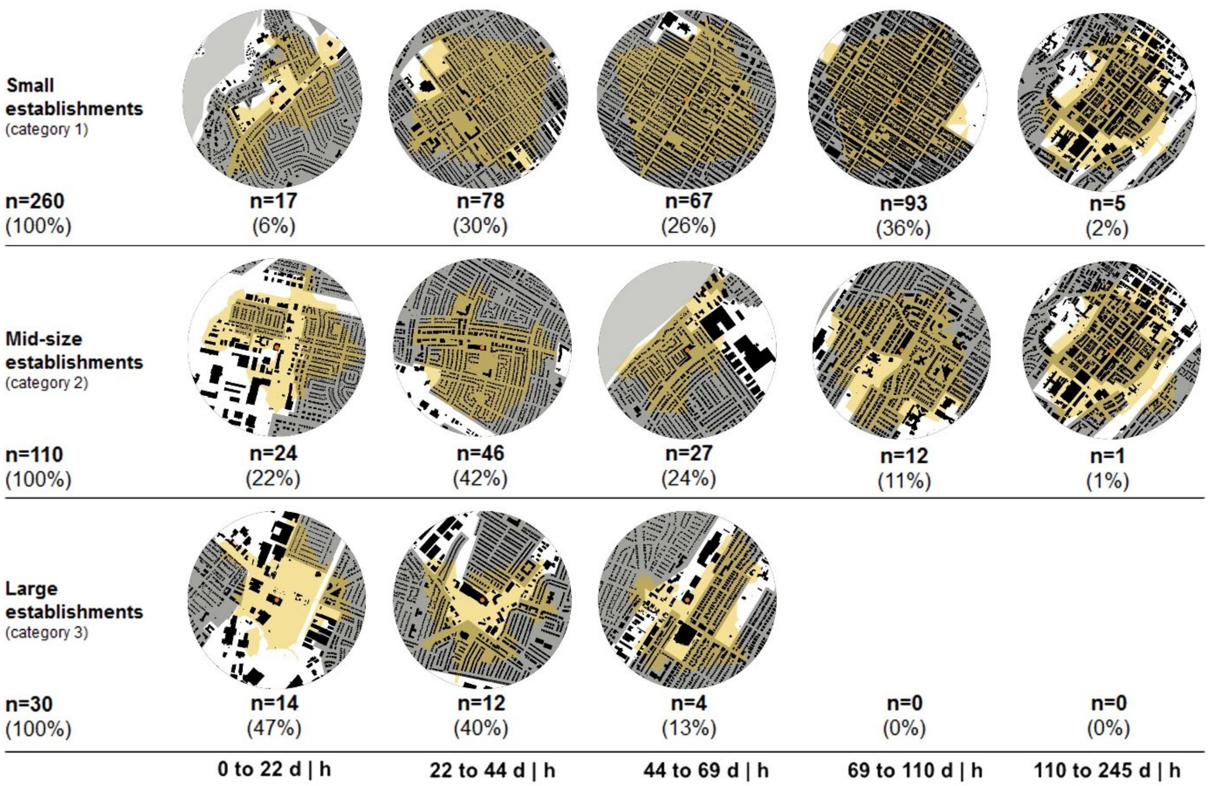

Figure 28. Sample of pedestrian sheds illustrating distribution according to gross residential densities (in dwelling/ha. Categories according to natural breakdown)

Figure 29 shows how the pedestrian sheds of the three categories of establishments do compare in terms of street network connectivity (i.e. total street segments/ total nodes). According to the American Planning Association (2006) *Street Connectivity Standards Ordinance*, a network connectivity index of 1.4 is the minimum desirable, whereas an index of 1.6 or more is preferable. A tight meshing such as in a grid could produce an index of more than 2 (Héran, 2011).

According to the said APA standards, the pedestrian sheds of all categories of establishments are ranking very high in terms of connectivity. The high indexes observed for large establishments pedestrian sheds are to be considered with caution, as a limited number of street intersections, though; combined with a few streets segments produce a high figure. A significant proportion of large size establishments do locate in such places, which explains the large establishment pedestrian sheds have highest ratio of edge to node average among three categories of size (Table 23). In such circumstances, it is preferable to use this indicator in conjunction with the number of intersections per hectare.

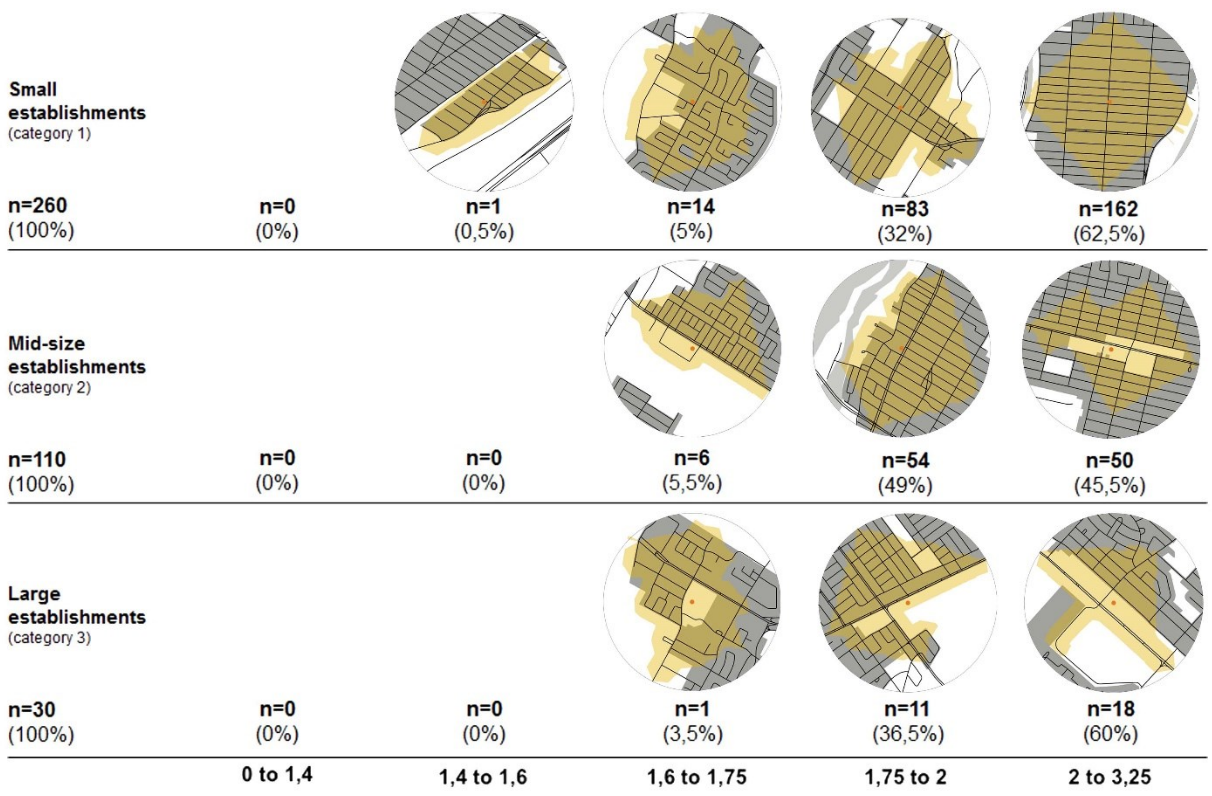

Figure 29. Sample of pedestrian sheds illustrating distribution according to street network connectivity index (in total segments/total nodes. Categories according to America Planning Association, 2006)

Figure 30 illustrates that 38.5% of small establishment pedestrian sheds and 31.8% of mid-size establishment pedestrian sheds are displaying between 0.5792 to 0.7232 intersections per hectare, and 40% of large establishments are displaying between 0.3933 to 0.5791 intersections per hectare. Compared with small and mid-size establishments, large establishments tend to be located in places of less number of intersections per hectare.

Small establishments (category 1) **n=260** (100%)	**n=5** (1.9%)	**n=52** (20%)	**n=100** **(38.5%)**	**n=70** **(26.9%)**	**n=33** **(12.7%)**
Mid-size establishments (category 2) **n=110** (100%)	**n=8** (7.3%)	**n=27** (24.5%)	**n=35** **(31.8%)**	**n=30** **(27.3%)**	**n=10** (9.1%)
Large establishments (category 3) **n=30** (100%)	**n=7** (23.3%)	**n=12** **(40%)**	**n=5** 16.7%)	**n=3** (10%)	**n=3** (10%)
	0.0696 to 0.3932	**0.3933 to 0.5791**	**0.5792 to 0.7232**	**0.7233 to 0.8995**	**0.8996 to 1.2101**

Figure 30. Pedestrian shed distribution relative to street network connectivity index (in number of intersections per hectare. Categories according to natural breakdown)

Combining the two street network connectivity variables, small establishments are located in places of higher street connectivity with more number of intersection per hectare and more street segments per intersection. Mid-size establishments are located in places of intermediate connectivity places with similar number of intersections per hectare but less segments per intersection. Comparing with small and mid-size of establishments, large establishments are located in lower-connectivity places with a high number of segments per intersection but less intersection per hectare, which proves the situation that a significant proportion of large establishments locate in circumstances of limited number of street intersections but a few street segments, producing high indexes in total segments/ total nodes.

5.4 Conclusion

This chapter contrasts establishment distribution patterns. The “availability” of food differs greatly between neighborhood areas, as some residential patches have no establishments in them, whereas others have many. Additionally, the fact that a significant number of establishments are located outside of the residential patches per se, raises related questions pertaining to accessibility. The fact that a number of establishments are located between two patches suggests for instance that these stores serve both. Large establishments do locate outside and serve more than one neighborhood area. Mid-size establishments tend as well to locate outside or at the periphery of residential areas, serving two or more patches. The distributions of large and mid-size establishments relative to thoroughfares, cohere to some extent to their position relative to morphological neighborhood areas (MNAs), as thoroughfares tend to be located at the periphery of MNAs where they often act as anti-nodal dividing axes, or “boundaries”. More generally, areas with higher residential densities and better street connectivity are more likely to be serviced by establishments.

Chapter 6 Morphological Neighborhood Areas

In the previous chapter, the spatial distribution of establishments in relation to 341 morphological neighborhood areas (MNAs) was considered. Shifting the perspective to focus on the MNAs rather than on the individual establishments, and their respective catchment areas, allow to investigate further the conditions at the neighborhood level that could help explain not only the presence or absence of establishments, but also the level of access, or "intensity" of service offered. In addition to the four residential density and network connectivity variables, two indicators were developed to assess the level of access to establishments in residential patches: 1. the coverage level (i.e. the percentage of a residential patch serviced or "covered" by pedestrian sheds), and; 2. the service level within residential patches (expressed as the sum of all pedestrian shed areas divided up by the total area of a residential patch) . The latter indicator allows to account the cases where more than one establishment serve the same area, that is: when the pedestrian sheds "overlap" in a residential patch. Figure 31 exemplifies the coverage level and service level of a residential patch (Figure 31 c is the case of coverage level, Figure 31 d is the case of service level). In addition to morphological variables, the average household income was also considered in this chapter as a control variable, in order to examine whether and how income correlates with presence or absence, and level of access to establishments. Such a control helps adding confidence to the results of morphological analysis. All these variables allowed for a correlation analysis.

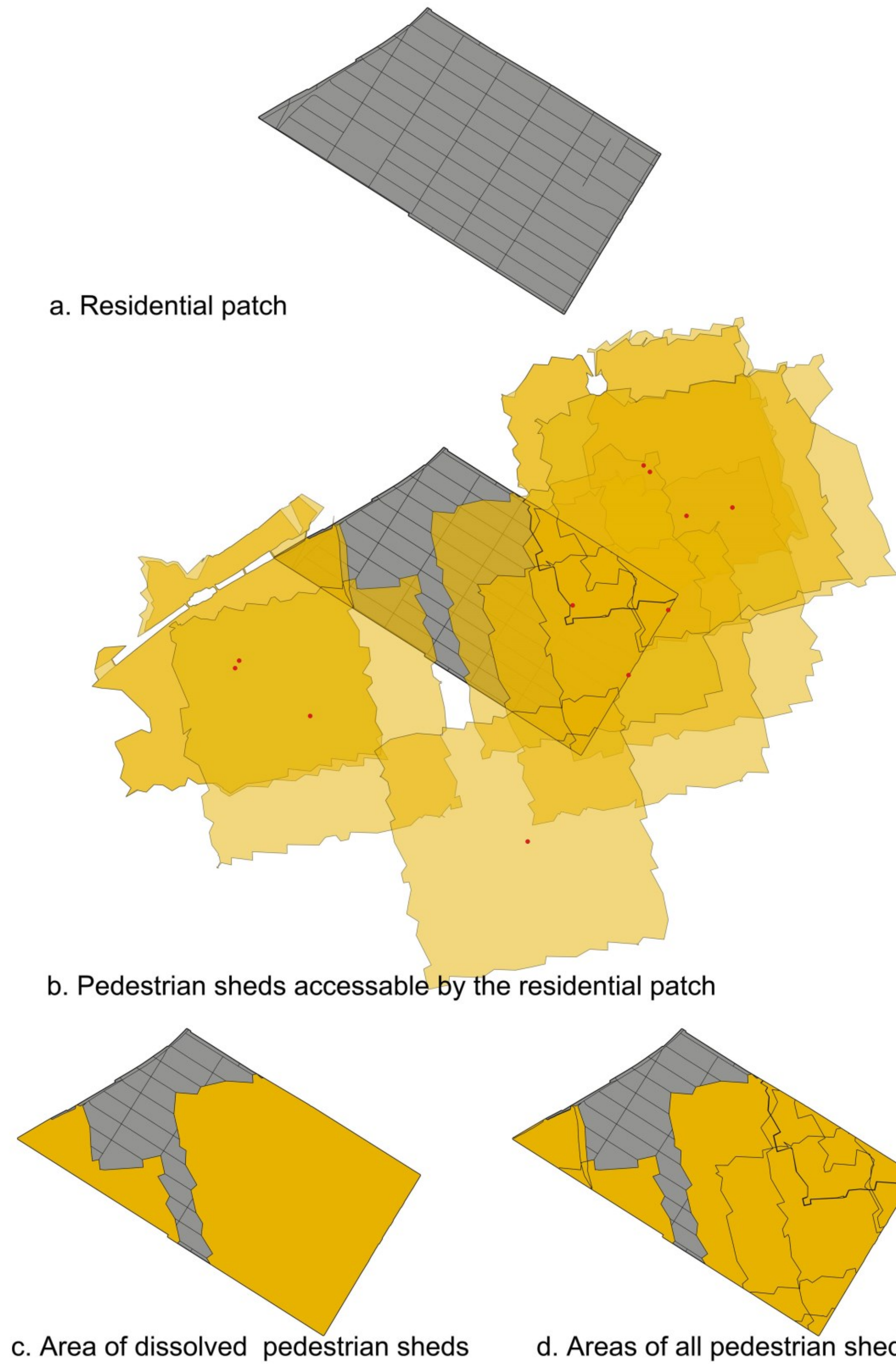

Figure 31. Example of a coverage level and service level of a residential patch

6.1 Quantitative Analysis of Morphological Neighborhood Areas

The global area of the residential patches serviced by establishments (i.e. covered by their catchment areas) within walking distance on the Island account to 49.80% of the total area. Yet, some patches have no coverage, while the best granted ones have a coverage level of 100%. Such global level of coverage corresponds to 73.87% of the total number of dwellings on the Island (or 648068 on 877319), with percentages ranging from 0.13% to 100% at the individual patch level. The higher percentage of dwelling than percentage of land coverage, implies that areas with higher residential densities are better granted with establishments. The higher levels are found in areas that display inner-city conditions. In such environments, only a small proportion of residential tissues fall outside of pedestrian sheds. The lower levels of coverage are observed in post WWII suburbs, in which only a small proportion of the residential tissues are within pedestrian sheds. The service level for its part, range from zero, in the absence of an establishment, to 14.13, where the total area of overlapping pedestrian sheds is more than fourteen times the area of the morphological neighborhood area serviced.

	Number of dwellings	Residential density variables		Street connectivity variables		Annual average household income (CAD)	Coverage level (%)	Service level
		Number of dwellings/ha (gross density)	Number of dwellings/ha of residential lots (net density)	Total street segments/ total nodes	Number of nodes/ha			
Mean	**2577.12**	**37.83**	**65.37**	**1.76**	**0.847**	**68483**	**42.76**	**0.95**
Min	5	0.36	0.40	0	0	0	0.00	0
Max	23508	240.46	564.92	3.00	2.247	244654	100.00	14.13
S Dev	3216.79	30.42	59.58	0.29	0.316	38240	37.78	1.41
Percentage of the total residential patch area covered by pedestrian sheds								**49.80%**
Percentage of dwellings in residential tissues that serviced by establishments								**73.87%**

Table 24. Statistics of residential patches (n = 341)

Figure 32 visually shows the spatial distribution of different "levels" of gross densities in the residential patches in the island of Montreal. The gross density categories are according to natural breakdown. In general, the residential patches in inner city have higher residential densities than those in post WWII suburban area in both extremities of the Island.

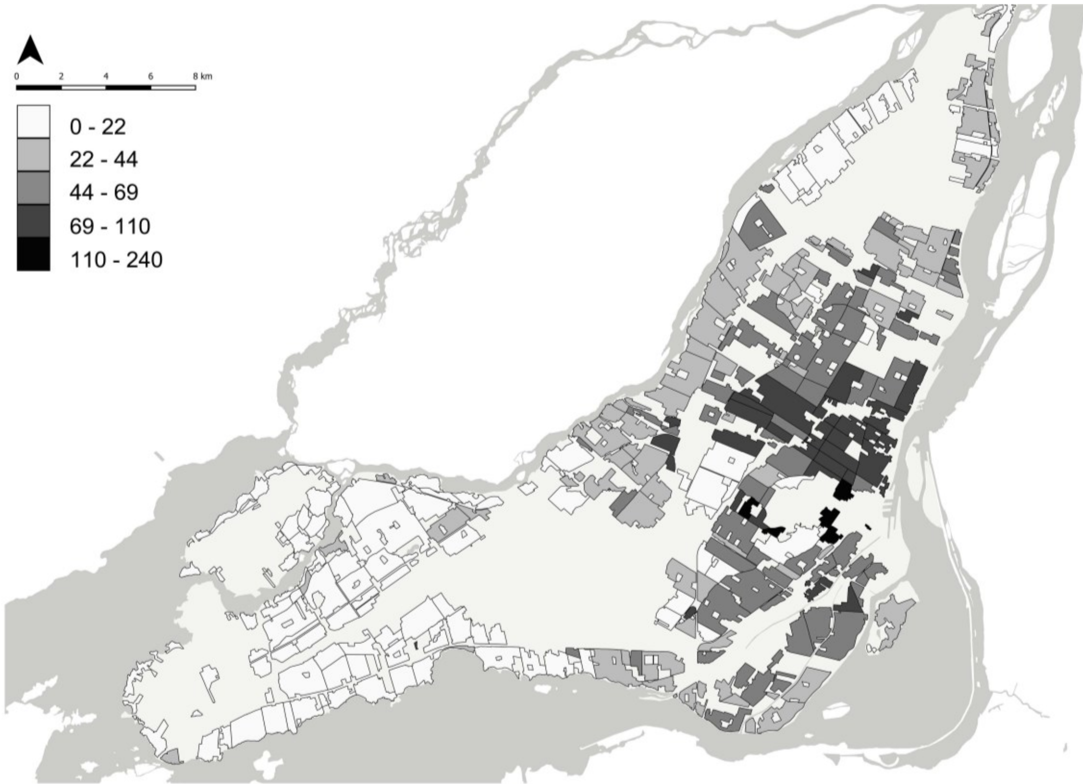

Figure 32. Gross density "levels" of residential patches (in dwelling/ha. Categories are according to natural breakdown)

Figure 33 shows the distribution of different "levels" of street network connectivity (expressed in total number of street segments/ total number of nodes) of residential patches. Though the inner city street network connectivity is better than that of suburban area in general, the street network connectivity difference between inner city and suburban area is not as marked as differences in residential density. The category of smallest connectivity index values (≤ 1.4) contains very few residential patches. Even though inner city areas display higher connectivity than post WWII suburbs overall, the contrast is not as sharp as with densities.

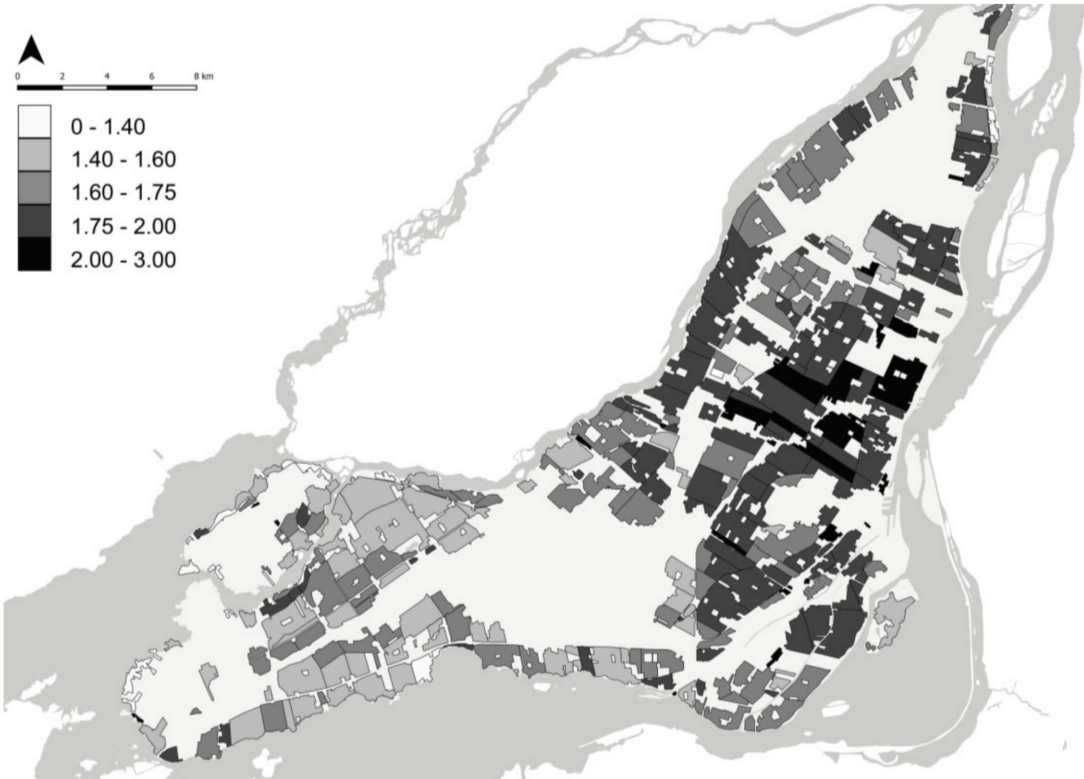

Figure 33. Connectivity "levels" of residential patches (in total segments/total nodes, categories according to America Planning Association, 2006, same with Figure 28)

Figure 34 shows the distribution of different categories of service levels of residential patches (service level is expressed as total area of pedestrian sheds/ area of residential patch). The residential patches in inner city have higher service levels than those in suburban area. Most of the residential patches in category of smallest service levels (≤ 0.71) are low-density suburban environments.

According to the mapping of the results in Figures 32 - 34, preliminary relationships between residential density, street network connectivity, and service level are found. The three variables is likely to display positive correlations, especially between residential density and service level.

Figure 34. Service "levels" of residential patches (Categories according to natural break down)

6.2 Correlation Analyses

In this section, correlation analyses between variables pertaining to coverage level, service level, residential density and street network connectivity, as well as annual household income and average year are conducted. Some researchers suggest that income is correlated with disparities in food access. In the United States in particular, food deserts have been found mostly in socioeconomically disadvantaged areas. In Canada, the situation appears to be more contrasted. Assessing in accessibility to food by foot correlates with income allows to determine if Montreal conforms to the situation observed where food deserts prevail, or not.

Figure 35 illustrates the correlations between variables in all the residential patches (n = 341) in the Island of Montreal. The preliminary results show that both density variable and connectivity variables are positively correlated with retail coverage level and retail service level. Gross and net densities in particular are strongly correlated with coverage level and service level. Number of street segments per node has weak correlation with coverage and service levels, number of nodes per hectare has weak correlation with coverage level but almost no correlation with service level. The service level and coverage level are strongly positively correlated (r = 0.701), which suggests that in morphological neighborhood areas with high coverage, pedestrian shed tend to “overlap” a lot, that is to say, those with larger percentage of residential tissue covered are those that tend to offer “multiple options” of establishments selling fresh food. Gross and net density display near perfect correlation (r = 0.976), since these variables measure very similar conditions.

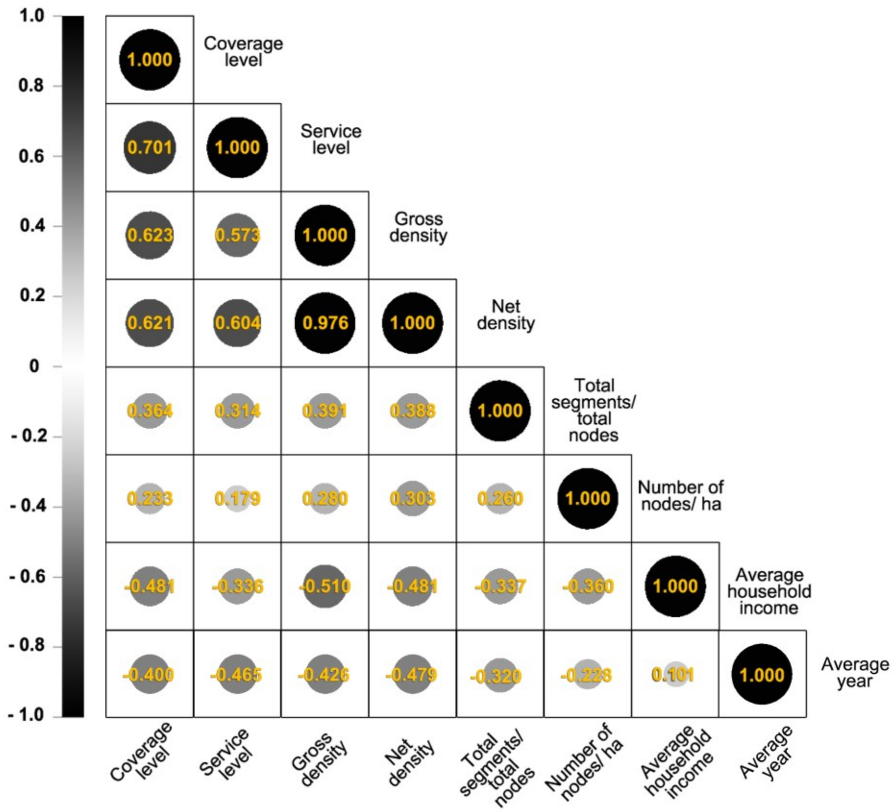

Figure 35. Correlation coefficients (Global, N = 341)

6.2.1 Controlling for Average Household Income

Figure 35 shows that household income is negatively correlated with both residential density and street network connectivity variables, which is an evidence of high-income residents tends to live in low residential density areas (i.e. residential tissues made of attached or detached houses) and more likely to be travelled by car. Income is moderately negatively correlated (r = -0.481) with coverage level and weakly negatively correlated (r = -0.336) with service level. These findings imply that residents with lower income levels have better access to fresh food at a walking distance than people of higher means. This tends to accredit the interpretation to the effect that food desert is not a significant problem in Montreal.

Density and connectivity correlate positively, while income does correlate negatively with the fresh food establishments' presence (coverage) and level of service. Correlation evidently does not equal to causation. In order to strengthen the interpretation that morphological conditions might indeed explain levels of coverage and service, income was controlled in the following correlation analyses. Residential patches were classified into five categories by a natural break down of household income. Since the latest household income data is from 2006 profile of dissemination areas, four residential patches that were built after then do not have income information and were excluded from the correlation analyses of categories. In patches corresponding to the categories of "extremely low" income (n = 8) and "extremely high" income (n=13), the income showed correlated, though negatively, with level of coverage and level of service. Such results suggest that income might be a factor explaining the absence or low presence or service levels. In the patches corresponding to each of the three remaining categories of "mid-low" income (N = 143), "medium" income (N = 96) and "mid-high" income (N = 77), the income is weakly or not correlated with level of coverage and level of service. Such results suggest that in these patches the income is not a factor that could explain the presence of establishments. Patches corresponding to "extremely high" and "extremely low" income levels were excluded from the second iteration of the correlation analysis focusing on morphological variables. The patches corresponding to the "mid-low", "medium" and "mid-high" income levels respectively display an array of morphological conditions.

Re-running the correlation analysis for patches of each of these groups increases the level of confidence that the results actually measure the impact of morphological features (pertaining to density and connectivity) on the presence and level of service offered by establishments selling fresh fruits and vegetables. Figures 36 - 38 illustrates the correlations between the variables in residential patches of three categories of income.

The results show that both density variables and connectivity variables are still positively correlated with retail coverage level and retail service level in each category. Gross and net densities in particular are strongly correlated with coverage level and service level in category of medium income, and are moderately correlated in categories of mid-low and mid-high income. Number of street segments per node has a weak correlation with coverage and service levels in categories of medium and mid-high incomes, almost has no correlation in category of mid-low income. Number of nodes per hectare has no correlation with coverage and service levels in each category. The service level and coverage level are moderately positively correlated (r = 0.578) in category of mid-low income, and strongly positively correlated (r = 0.710) in category of medium income, and perfectly positively correlated (r = 0.873) in category of mid-high income. Gross and net densities display near perfect correlation (r = 0.949, 0.974, 0.987) in each category.

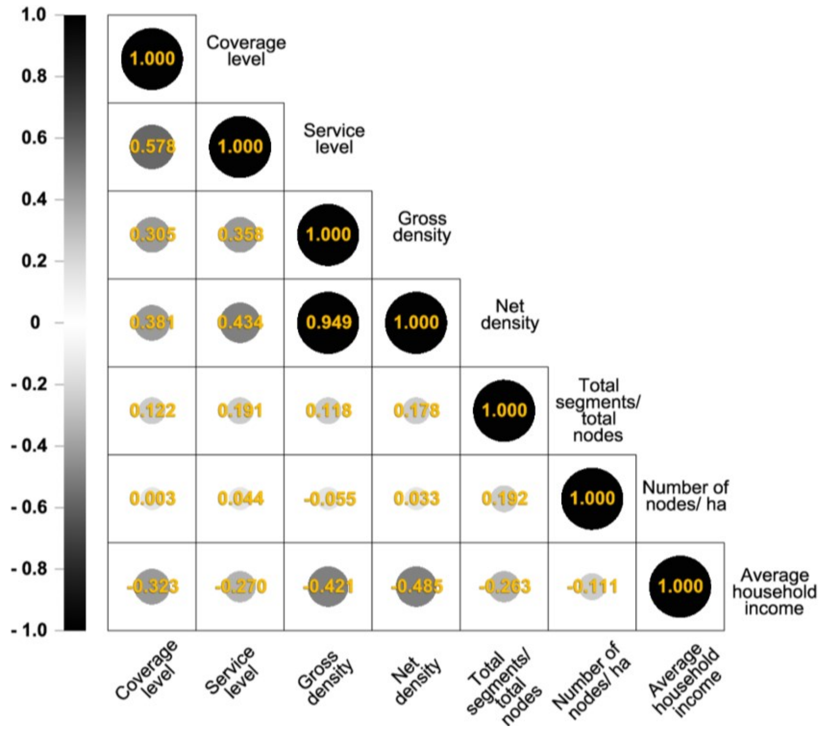

Figure 36. Correlation Coefficients (mid-low income, N =143)

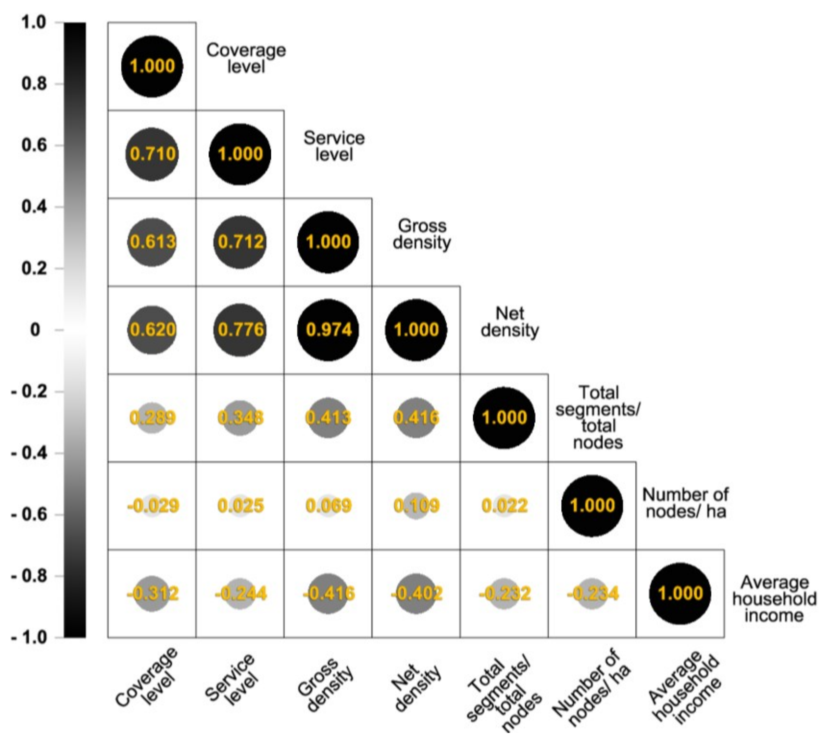

Figure 37. Correlation Coefficients (medium income, N =96)

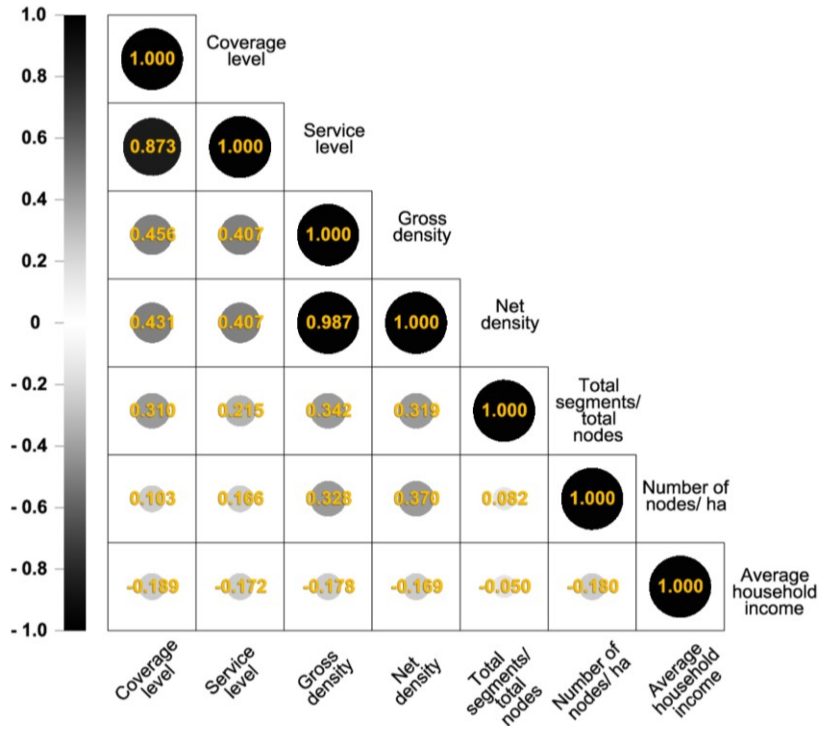

Figure 38. Correlation Coefficients (mid-high income, N =77)

6.2.2 Controlling for Average Year of Lots

Another control variable that demonstrated useful for the research is the year of urbanization of the Morphological Neighborhood Area. Québec cadastral system records the date of creation of each cadastral lot. The system was established in late 19th century (and rolled out on a city by city and neighborhood by neighborhood basis). All previously existing lot were then attributed a creation date corresponding to the creation of the *cadastre* in their sector, all subsequently created lot were attributed their actual date of creation. Though the data have limitations, this dating system is acceptable for the purposes of this research. The average year of lot creation within the residential patch is negatively correlated with both residential density and street network connectivity variables (Figure 35). These negative correlations demonstrate that earlier residential tissues tend to have higher residential density and better street network connectivity than more recent ones, which is evidence that early residential tissues are more walkable, while more recent residential tissues are predicated on automobility. Furthermore, average year is moderately negatively correlated ($r = -0.400$) with coverage level and moderately negatively correlated ($r = -0.465$) with service level. These findings imply that residents living in residential areas urbanized earlier have better access to fresh food at a walking distance than people live in in more recent residential areas. Again, in order to strengthen the interpretation that morphological conditions might indeed explain levels of coverage and service, average year of patches was then controlled in the following correlation analyses.

Figure 32 and 33 showed that inner city areas offer better conditions than suburban areas in terms of residential density, street network connectivity and service level. Figure 39 presents a map, which classifies of residential patches based on average year of creation of their lots. It is useful to remember that before the 1870's, the city was compact and essentially travelled by foot for daily errands. Horse-drawn streetcars were introduced in the 1860's that were replaced by an electrified version starting in the early 1890's. Streetcar remained a major mode of transportation until the end of WWII. In the 1950's, the system was dismantled and streetcar routes became bus routes. Though gaining in popularity from the 1930's onward, the use of individual automobile really generalized after WWII, in parallel to a rapid development of the suburbs. The 1960's saw a rapid development of major control access highways in the Island of Montreal (as well as the construction of a new Metro in the city center. Figure 39 illustrates how early residential patches (i.e. whose average year span from origin to 1945) are mostly located in what could be termed the “inner city” with several exceptions of small patches scantily distributed in the Island. Residential patches of “intermediate” average year of creation (i.e. from 1946 to 1960) are mainly located in proximity to inner city area, or in suburbs created along the shores. More recently urbanized residential patches (i.e. average year from 1961 to present) are located in outer suburbs, in areas made easily accessible by control-access highways, as the city spread further and further. Comparing Figure 39 and Figure 34, the distribution of residential patches of different years and the distribution of different service levels are similar, which supports the above-mentioned result of negative correlation between year and access to fresh food. Table 25 shows the mean value of each variable in the three category of average year. All variables have highest mean values in the category of early average year and lowest mean values in the category of late.

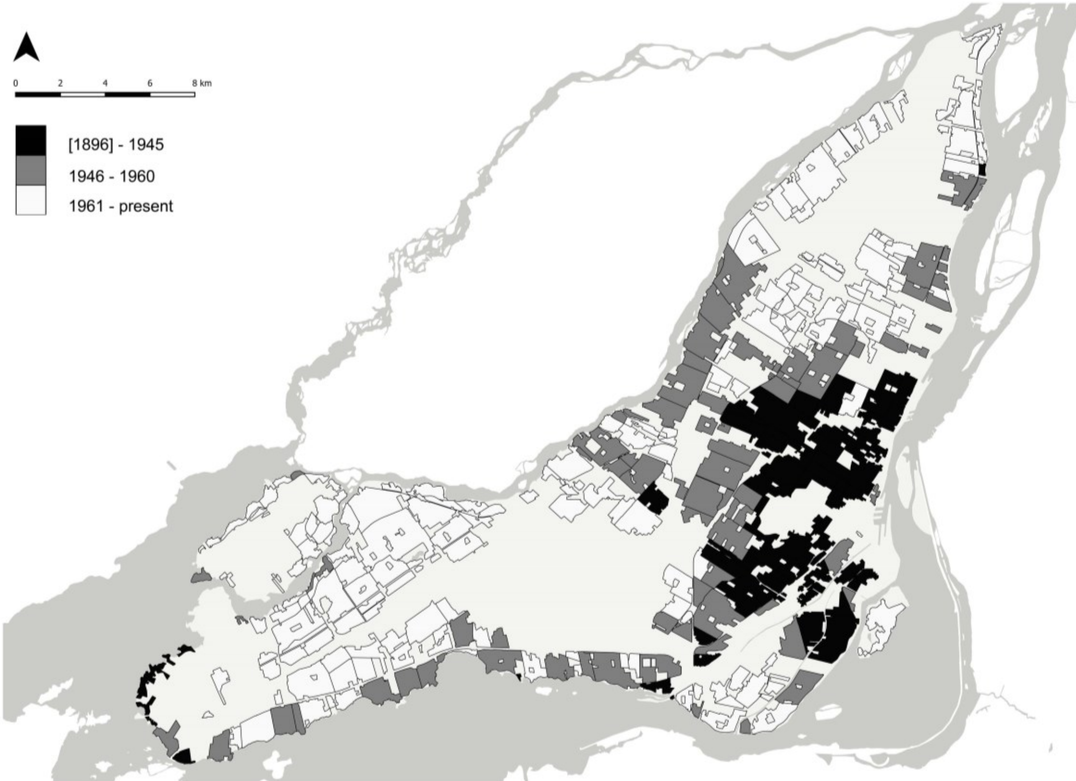

Figure 39. Categories of average year of residential patches

Average year	Residential density variables		Street connectivity variables		Coverage level	Service level
	Average gross density	Average net density	Average number of nodes/ ha	Average number of segments/ node		
Early [1896] - 1945	63.66	119.66	0.9297	1.92	68.40%	2.04
Intermediate 1946 - 1960	36.15	65.17	0.9187	1.78	46.91%	1.08
Late 1961 - present	28.34	43.92	0.7819	1.68	30.69%	0.46

Table 25. The mean values of all the variable in three categories of average year

Re-running the correlation analysis for patches of each of these groups of average years increases the level of confidence that the results actually measure the impact of morphological features (pertaining to density and connectivity) on the presence and level of service offered by establishments selling fresh fruits and vegetables. Figures 40 - 42 illustrates the correlations between the variables in residential patches of three categories of average year.

The results illustrate that using the three time frames origin to 1945, 1946 to 1960, and 1961 to now, allows to control for average year of urbanization, as in each category, the average year does not correlate with other variables (to the exception of a weak correlation between year and coverage level in the origin to 1945 category). Yet, both density variables as well as connectivity variables are positively correlated with retail coverage level and retail service level in each time category. Gross density in particular is strongly correlated with coverage level in category of intermediate average year, and is moderately correlated in categories of early and late average year. Net density is moderately correlated in each category. Number of street segments per node has a weak correlation with coverage and service levels in categories of intermediate and late average year, and has no correlation in category of early average year. Number of nodes per hectare has no correlation with coverage level and service level in category of intermediate average year, has weak correlation in category of late average year, and has weak correlation with coverage level but no correlation with service level in category of early average year. The service level and coverage level are moderately positively correlated ($r = 0.424, 0.597$) in categories of early and intermediate average year, and perfectly positively correlated ($r = 0.932$) in category of late average year. Gross and net densities display near perfect correlation ($r = 0.968, 0.986, 0.985$) in each category.

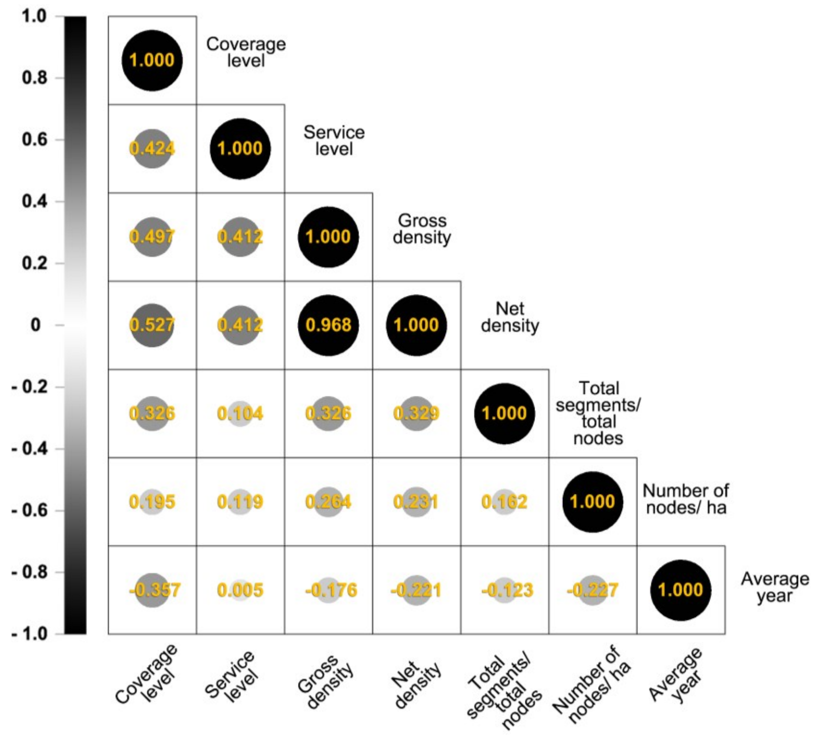

Figure 40. Correlation Coefficients (origin to 1945, N =73)

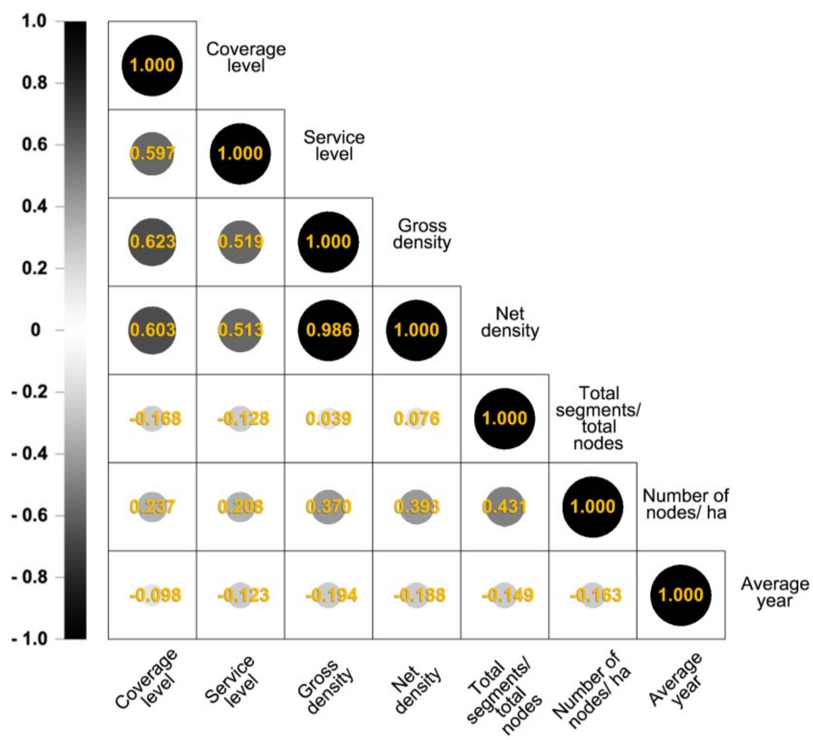

Figure 41. Correlation Coefficients (1946 to 1960, N =84)

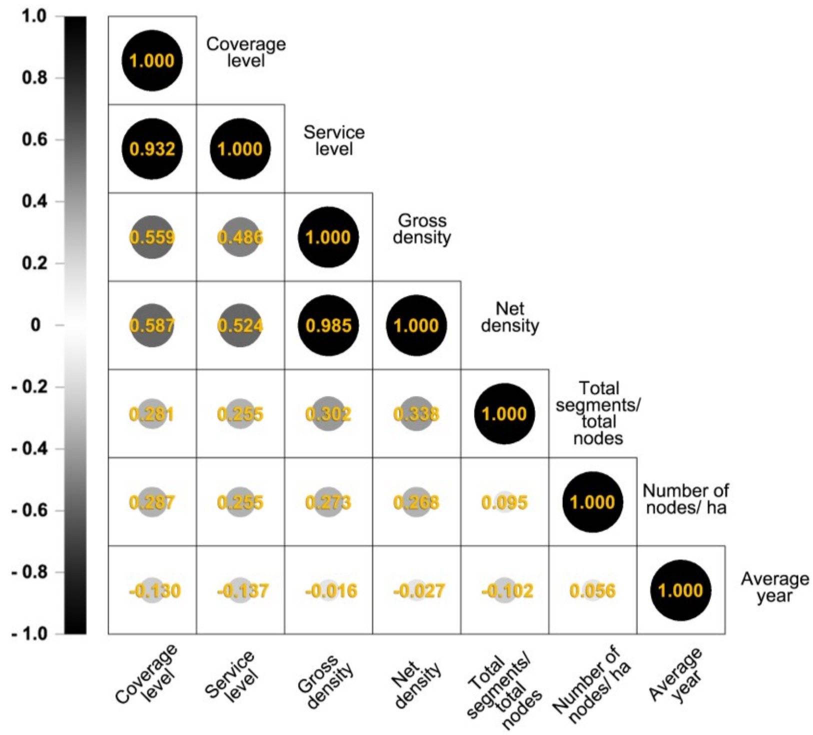

Figure 42. Correlation Coefficients (1961 to present, N =184)

The correlation analyses in patches corresponding to the three categories of income and three categories of average year have the similar results and findings with the global correlation analysis in all residential patches. When controlling for income and year, we can more confidently say that morphological variables paly a role in food access and service. In particular, residential density significantly affects both coverage and service levels.

6.3 Regression Analyses

Since it has been demonstrated that residential density is the most significant variable impacting the presence or absence, and level of access of morphological neighborhood areas, a deeper exploration of the relationship between residential density and service level is conducted in this section. Figure 43 is the scatter diagram between gross density (independent variable) and service level (dependent variable), and Figure 44 is the scatter diagram between net density (independent variable) and service level (dependent variable). Overall, the trends of the points in the two diagrams both perform linear regression relationship.

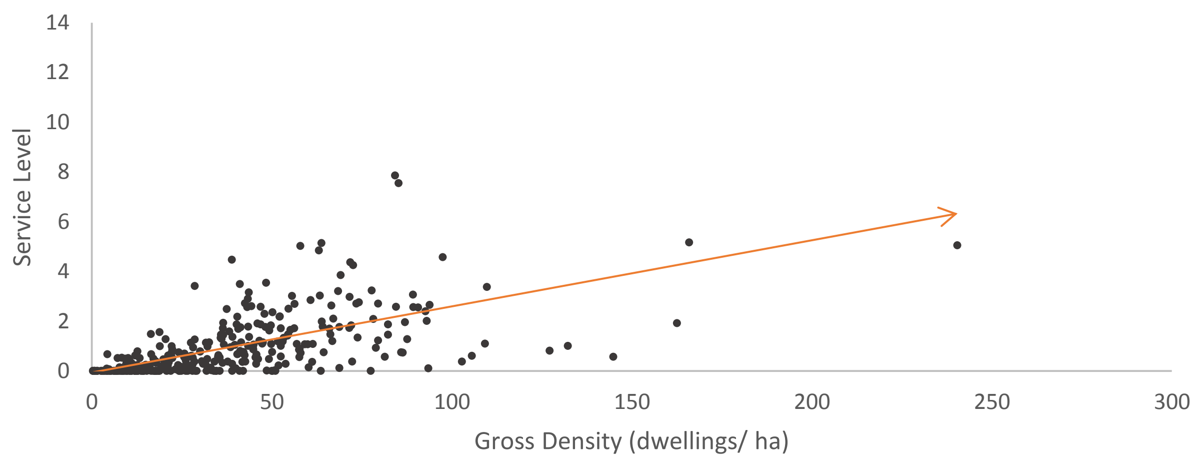

Figure 43. Scatter diagram between gross density and service level

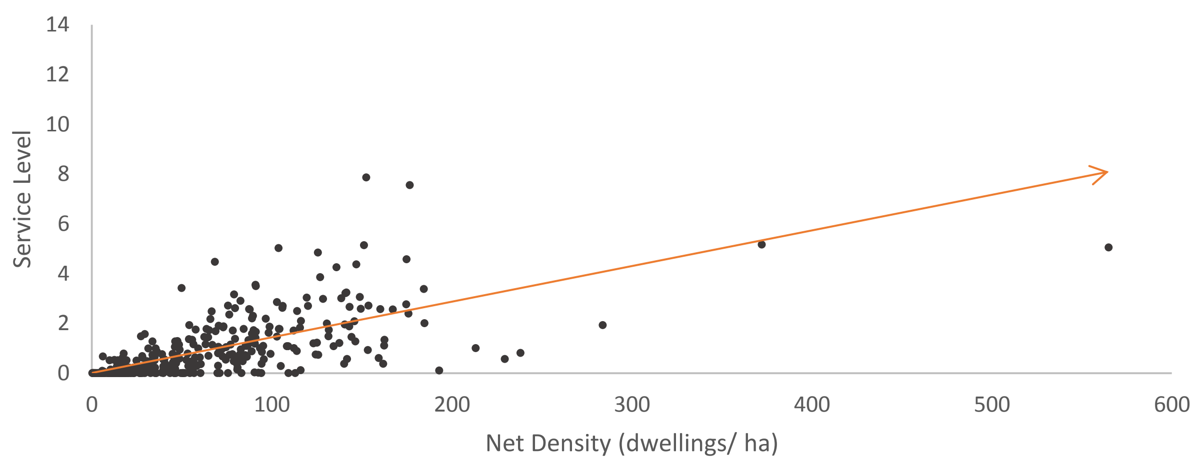

Figure 44. Scatter diagram between net density and service level

Regression models are used to test the relationship between service level (dependent variable) and residential density (independent variable). From the output (Table 26), the R square is 0.3282, indicating that about 32.82% of the variation of the service level (dependent variable) can be explained by gross density (independent variable) in the regression model. The R square is 0.3652, indicating that about 36.52% of the variation of the service level (dependent variable) can be explained by net density (independent variable) in the regression model (Table 27).

Regression Statistics	
Multiple R	0.572915352
R Square	0.328232
Adjusted R Square	0.326250384
Standard Error	115.9446487
Observations	341

Table 26. Regression statistics output (service level and gross density)

Regression Statistics	
Multiple R	0.604352
R Square	0.365241
Adjusted R Square	0.363369
Standard Error	1.127056
Observations	341

Table 27. Regression statistics output (service level and net density)

Regression analyses between dependent and independent variables were conducted to find the equation of a line that best fits the data. As said that the equation of a bivariate linear regression relationship is supposed to be (Holt, Sweet, Grace-Martin, 2011, p. 167):

$$Y = a + b * X$$

Where a is the intercept, b is the slope, X is gross density (or net density), Y is service level.

Table 28 shows the results of regression analysis between service level and gross density. In this case, the intercept coefficient is – 0.0579, the slope (gross density coefficient) is 0.0266. The resulting equation is:

$$Y = -0.0579 + 0.0266 * X$$

Where X is gross density, Y is service level.

Table 29 shows the results of regression analysis between service level and net density. In this case, the intercept coefficient is 0.0116, the slope (net density coefficient) is 0.0143. The resulting equation is:

$$Y = 0.0116 + 0.0143 * X$$

where X is net density, Y is service level.

Explained in section 3.3, p-value is used to measure the significance association between dependent variable and each independent variable to determine whether this regression equation is satisfied. When p-value ≤ 0.05, the association is significant and estimated regression equation is satisfied, otherwise not. In this case, the regression equations are satisfied as the p-value of gross density coefficient is 3.89E-31, and the p-value of net density coefficient is 2.48E-35, which are far less than 0.05.

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.0579	0.100187	-0.57796	0.563676	-0.25497	0.139162
Gross density	0.026563	0.002064	12.87006	3.89E-31	0.022504	0.030623

Table 28. Estimated regression equation output (service level and gross density)

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.011597	0.090607	0.127992	0.898231	-0.16663	0.189819
Net density	0.014308	0.001024	13.96642	2.48E-35	0.012293	0.016323

Table 29. Estimated regression equation output (net level and gross density)

To find the thresholds values of independent variables that result in a morphological neighborhood area having good level of access or multiple options of establishments selling fresh food, 1 was assumed as the value of Y (service level) that represents a good level of access. A service level equals or greater than 1 may account for two situations: 1. 100 % of a residential patch area is covered by pedestrian sheds, which means the residential patch is totally serviced; 2. the residential patch is serviced by more than one establishment. The gross density value and net density value that correspond to a service level value of 1 are 39.77 (dwellings/ ha) and 69.12 (dwellings/ha). In other words, when a residential patch reaches a gross density of 39.77 (dwellings/ ha) or reaches a net density of 69.12 (dwellings/ha), it is much more likely that all the residents can access fresh food retail service by foot, and can in particular have multiple choices of fresh food retail stores within a 750-meter walking distance from their home.

6.4 Conclusion

Levels of household income do correlate negatively with food access and level of service in the case of the Island of Montreal. In other words, being less economically privileged increases the odds that one has access to fresh fruits and vegetables at a walking distance in Montreal. Furthermore, the levels of coverage and levels of service, as measured, implies that such access is actually available to the said populations in their respective neighborhoods. The differences between inner city and suburban conditions are reflected in both residential density and street network connectivity. Accordingly, the accessibility to fresh food retail establishments by foot varies from inner city to suburban areas. When controlling for income and year, the correlation between morphological conditions and access to fresh food is strong, in particular the residential density. Though the estimated regression equation is not ideal (i.e. doesn't fit all the points very well), the scatter diagram points to thresholds values of residential density as a valuable reference. In a nutshell, hitting a gross density of 39.77 dwellings/ ha or a net density of 69.12 dwellings/ ha of residential lots translate into a morphological neighborhood area that has good level of access, i.e. multiple options of establishments selling fresh food at a walking distance for most of the population.

Chapter 7 Accessibility to Fresh Food Retail Establishments

This chapter relates to the previous two chapters and discusses the impacts of location and context on accessibility by different transportation modes. Furthermore, considering the overarching interest in the research for the question of physical accessibility to fresh food, the characters of the form retained for analysis are those that influence the number of dwellings within reach (or conversely, the number of dwellings that are granted access to an establishment). In previous chapter, the availability of fresh food was measured using indicators coverage level and service level.

In this chapter, the superposition of the catchments of different modes of transportation to the residential patches allows to delineate more specifically the residential areas on the Island of Montreal – i.e. the residential lots, – that are serviced by establishments accessible by active and collective transportation (by bus here), and from there, to calculate the total number of dwellings affected.

7.1 Access by Active Modes of Transportation

- Walking

Figure 45 illustrates the combined walkable catchments superimposed on the residential patches. From Table 30, the number of residential patches serviced by at least one establishment within a 750 m. walking distance (i.e. a 10-minute walk or so) is 246, out of 341 (i.e. 72.14%). The combined areas of the residential patches serviced by establishments within walking distance on the Island account to 49.80% of the total area. Yet, some patches have no coverage, while the best granted one has a coverage level of 100%. Such a level of coverage translates into 73.87% of the total number of dwellings on the Island (or 648068 on 877319), with percentages ranging from 0.65% to 100% at the individual patch level. The higher levels are found in areas that display inner-city conditions. In such an environment, only a small proportion of residential tissues fall outside of walkable catchments. The lower levels are observed in post WWII suburbs, in which only a small proportion of the residential tissues are within pedestrian sheds. This difference between inner-city and suburban conditions is also a portrait of coverage level of residential patches. Figure 46 shows the distribution of different categories of coverage levels (the percentage of a residential patch serviced or “covered” by walkable catchments) of residential patches. The residential patches in inner city have higher coverage levels than those in suburbs.

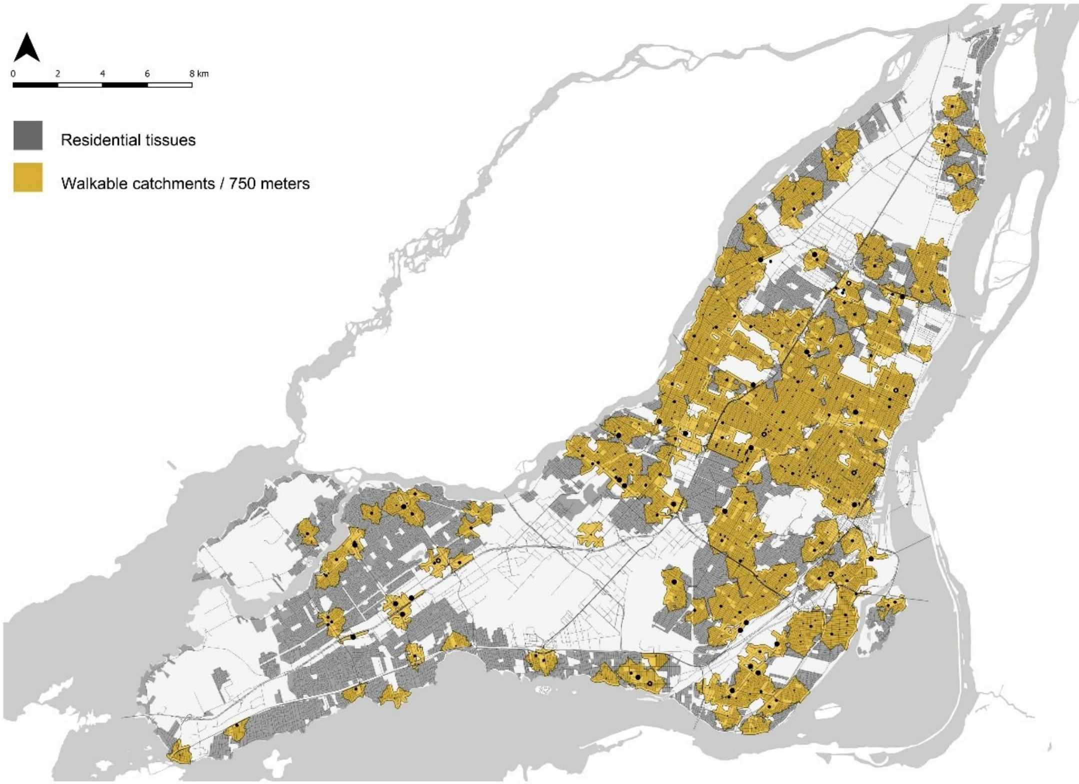

Figure 45. Combined 750m. walkable catchment areas and residential patches

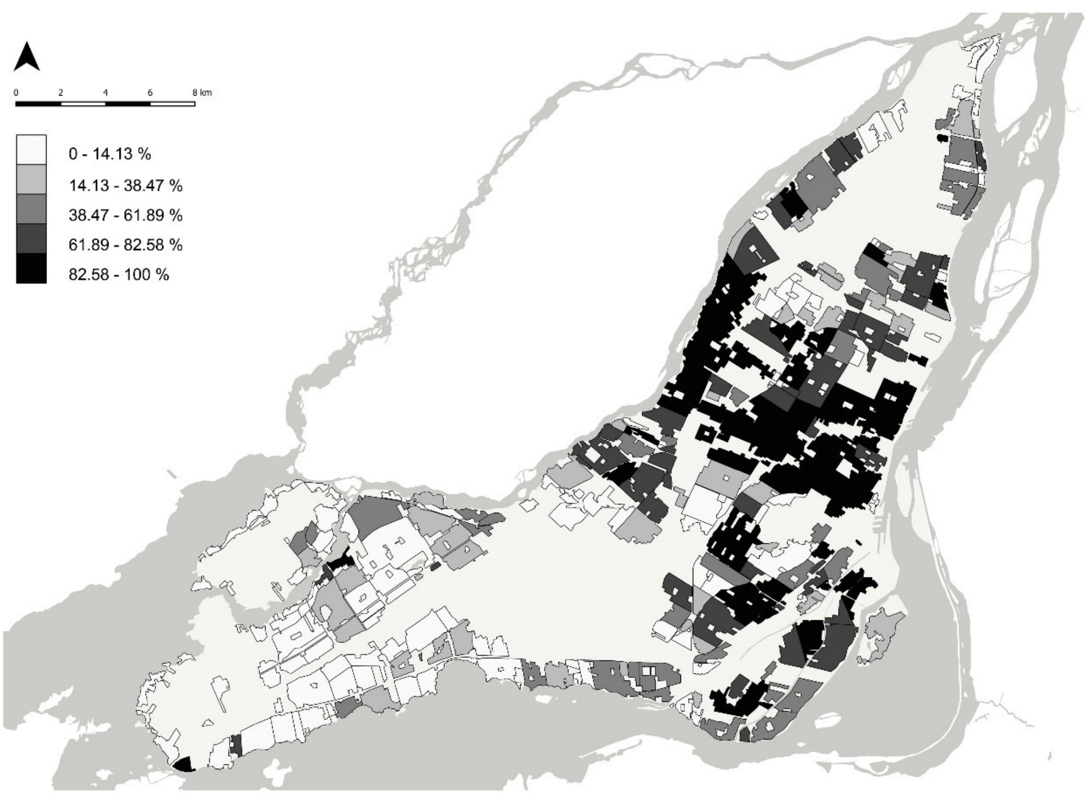

Figure 46. Coverage "levels" of residential patches accessible by foot (Categories according to natural break down)

- Cycling

Figure 47 illustrates the combined “cyclable” catchments superimposed on the residential patches. From Table 30, the number of residential patches serviced by at least one establishment within a 2200 m. cycling distance (i.e. a 10-minute ride or so) is 309, out of 341 (i.e. 90.62%). The combined areas of the residential patches serviced by establishments within “cyclable” distance on the Island account to 90.11% of the total area. Yet, a small portion of patches have no coverage, while more than half of the patches have a coverage level of 100%. Such a level of coverage translates into 97.30% of the total number of dwellings on the Island (or 853659 on 877319), with percentages ranging from 0.32% to 100% at the individual patch level. The differences between inner-city and suburban conditions are small in this case. Figure 48 shows the distribution of different categories of coverage levels (the percentage of a residential patch serviced or “covered” by “cyclable” catchments) of residential patches. The residential patches in inner city and suburb both have high levels of coverage.

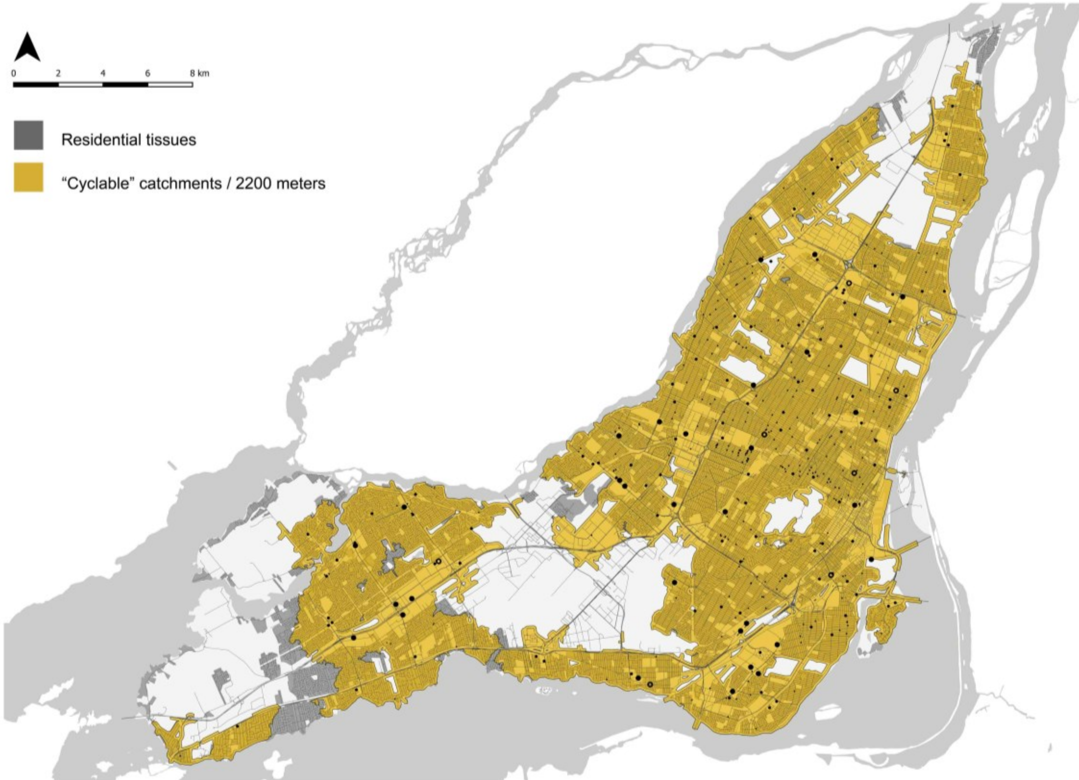

Figure 47. Combined 2200m. "cyclable" catchment areas and residential patches

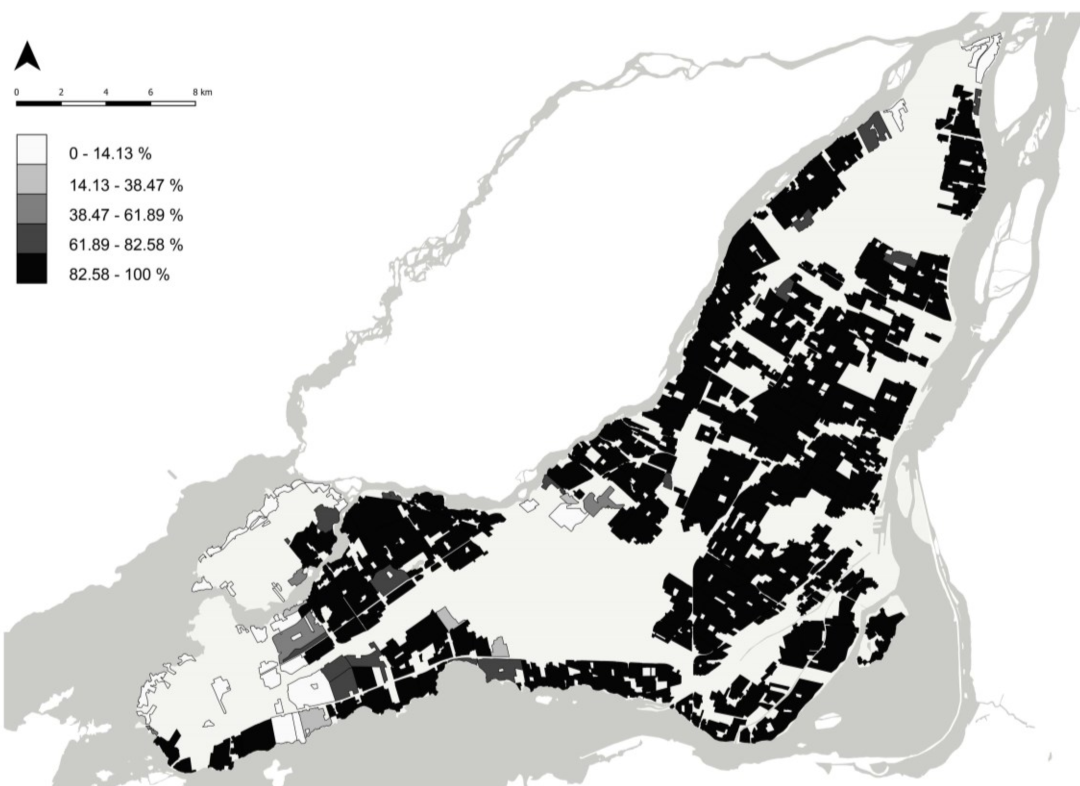

Figure 48. Coverage "levels" of residential patches accessible by bicycle (Categories are same with Figure 45)

7.2 Access by Collective Modes of Transportation

Figure 49 illustrates the combined “combo” catchments (equivalent to a 10-minute combination of walking and bus ride) superimposed on the residential patches. From Table 30, the number of residential patches that have access to at least one establishment by bus and walking is 293, out of 341 (i.e. 85.92%). The combined areas of the residential patches accessible by the “combo” mode on the Island account to 59.87% of the total area. Such a level of coverage translates into 81.41% of the total number of dwellings on the Island (or 714193 on 877319), with percentages ranging from 1.22% to 100% at the individual patch level. The higher levels are found in areas that display inner-city conditions. In such an environment, only a small proportion of residential tissues fall outside of “combo” catchments. The lower levels are observed in post WWII suburbs, in which only a modest or a small proportion of the residential tissues falls within combo catchments. Figure 50 shows the distribution of different categories of coverage levels of residential patches (i.e. the percentage of a residential patch serviced or “covered” by combo catchments). The residential patches in inner city have higher coverage levels than those in suburbs.

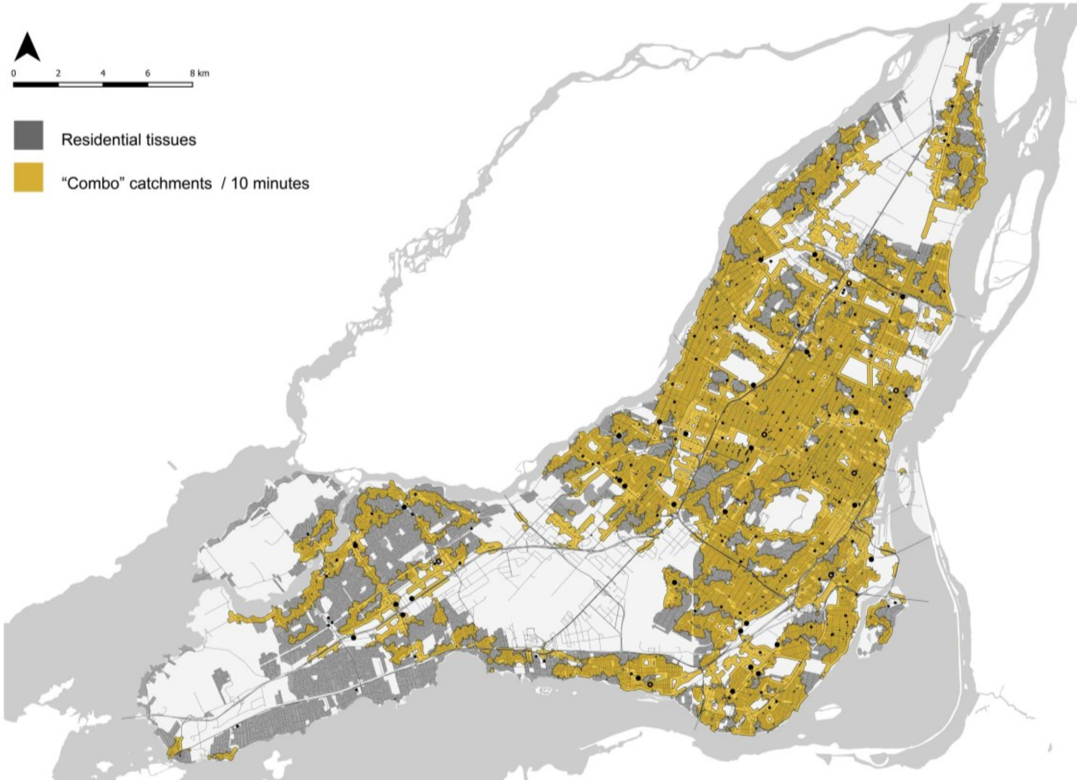

Figure 49. Combined “combo” catchment areas and residential patches

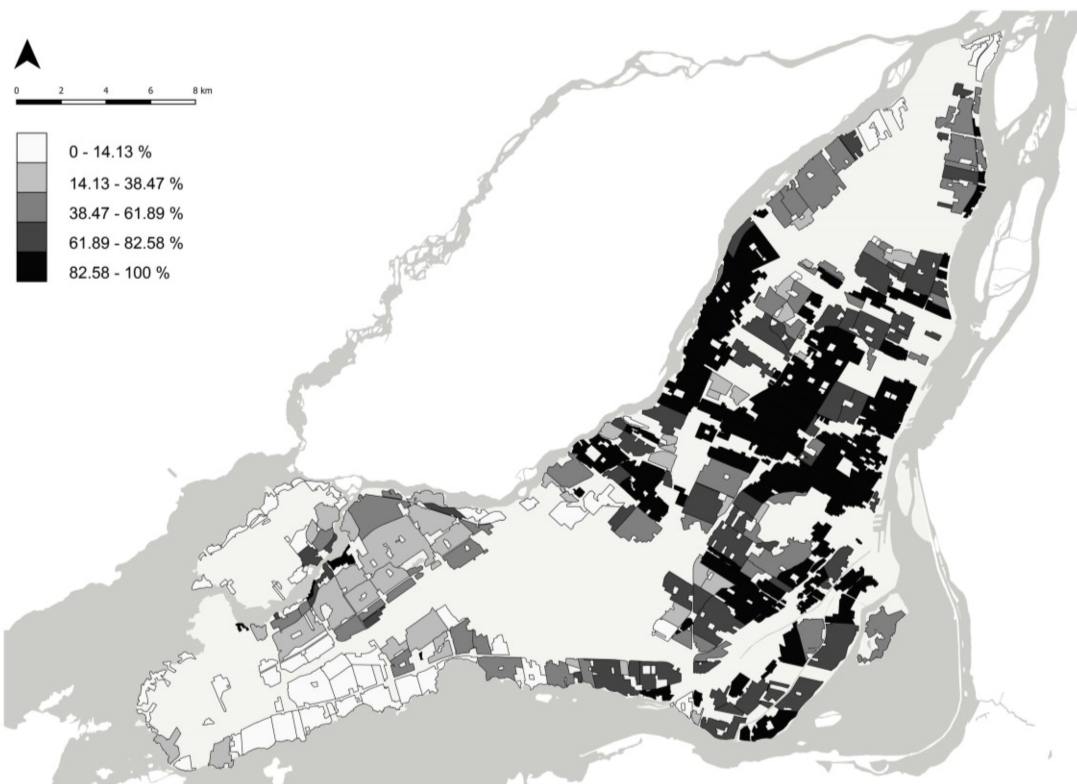

Figure 50. Coverage "levels" of residential patches accessible by walking and bus (Categories are same with Figure 45)

“Combo” catchments and walkable catchments are dissolved in order to represent the catchment area which corresponds to a 10-minute walk or to a 10-minute combination of walking and bus ride. Figure 51 illustrates the combined ““combo” + walking” catchments superimposed on the residential patches. As indicated in Table 30, the number of residential patches that have access to at least one establishment by bus or by foot is 300, out of 341 (i.e. 87.98%). The combined area of the residential patches that are accessed by establishments by walking or “walking + bus combo” on the Island accounts to 68.83% of the total area. Such a level of coverage translates into 88.85% of the total number of dwellings on the Island (or 779527 on 877319), with percentages ranging from 0.65% to 100% at the individual patch level. The higher levels are found in areas that display inner-city conditions. In such an environment, only a small proportion of residential tissues fall outside of walking and “combo” catchments. The lower levels are observed in post WWII suburbs, in which only a small proportion of the residential tissues are within combo catchments. Though the accessibility varies between inner-city and suburban conditions still exists, the difference is less significant than by walking only. Access to the bus service improves the accessibility to fresh food by 15% when considering the number of household. Such a gain is essentially made in post WWII suburbs.

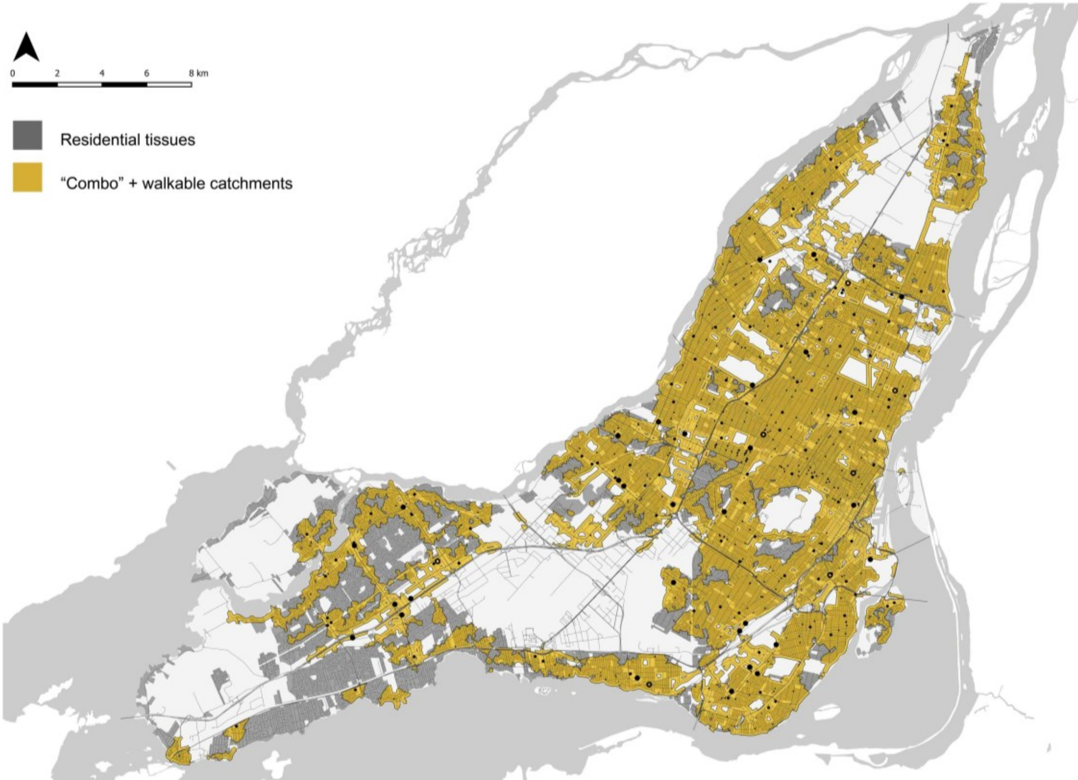

Figure 51. Combined "combo"+ walkable catchment areas and residential patches

Catchments	Number of residential patches serviced	Percentage	Total coverage area of residential patches by catchments / ha	Percentage	Total number of dwellings within reach	Percentage
Walkable	246	**72.14**	11711.014	**49.80**	648068	**73.87**
Cyclable	309	**90.62**	21189.8007	**90.11**	853659	**97.30**
Combo	293	**85.92**	14080.3188	**59.87**	714193	**81.41**
Combo + walking	300	**87.98**	16186.6665	**68.83**	779527	**88.85**
Residential patches	341	100	23516.7843	100	877319	100

Table 30. Characters of affected residential tissues

Chapter 8 Conclusion

8.1 A taxonomy of key findings

A taxonomy (Appendix B) is produced, which presents key results based on five categories of service levels within residential patches. The categories are according to natural breakdown, and expressed as: high, intermediate high, intermediate, intermediate low and low. The spatial distribution of residential patches in the five categories of service level was shown in Figure 34 (p. 113).

- Category of high service level

In the category of high service level, there is only one residential patch with a low household income (32,638 CAD). The average year of creation of lots is 1949. This single residential patch has the highest service level at 14.13, and is almost totally covered by 750 m. pedestrian sheds. Since the combined ped-sheds of establishments represent 14 times the residential patch area, residents have numerous options of fresh food retail establishments at a walking distance. This commercial offer is by small establishments, mostly located within the patch per se. The residential patch contains 1.48% (13,011 out of 877,319) of dwellings in the Island of Montreal in a high residential density environment (i.e. a gross density of 94.07 and a net density of 178.13). Within 10 minutes by walking, almost all the dwellings in the residential patch are serviced by small establishments, while 1.27% of dwellings are also serviced by mid-size establishments and 32.3% are serviced by large establishments. Further, almost all the dwellings in the residential patch are serviced by establishments regardless of size by either walking, “combo” mode, or cycling within 10 minutes.

- Category of intermediate-high service level

In the category of intermediate-high service level, there are 11 residential patches with a relative low average household income (44,244 CAD). The average year of creation of lots in these residential patches is 1918, which means that the residential areas were created before the automobile era. A relatively high average service level of 5.29 and a relatively high average coverage level of 88.35% imply that residents in these areas are serviced by multiple fresh food stores. These residential patches contain 6.74% of dwellings in the Island of Montreal (59,102 out of 877,319) in high residential density environments (i.e. an average gross density of 94.7 and an average net density of 197.61). These residential patches also display best street network connectivity, reflected by the highest average number of intersections per hectare (1.1002) and the highest average number of segments per intersection (2.01). Within 10 minutes by walking, almost all (99.08%) the dwellings in the residential patches are serviced by small establishments. Further, a majority (61.05%) of dwellings are serviced by mid-size establishments, while only 7.07% are serviced by large establishments. All the dwellings in the residential patch are serviced by establishments, regardless of size by walking, “combo” mode, or cycling within 10 minutes.

- Category of intermediate service level

In the category of intermediate service level, there are 37 residential patches with a relatively low average household income (46,471 CAD). These residential areas were also created before automobile era as the average year of creation of lots is 1939. An average service level of 2.75 and a high average coverage level of 91.88% imply that the typical residents in these areas have more than one choice of fresh food store at a walking distance. The residential patches contain 25.6% (224,4566 out of 877,319) of the dwellings of the Island of Montreal, in residential environments of intermediate density (i.e. an average gross density of 62.98 and an average net density of 115.56). These residential patches display good street network connectivity, reflected by a high average number of intersections per hectare (0.923) and a high average number of segments per intersection (1.93). Within 10 minutes by walking, a vast majority of (87.72%) the dwellings in the residential patches can be serviced by small establishments, while more than half (54.92%) of the dwellings are serviced by mid-size establishments, and only 10.86% are serviced by large establishments. A vast majority of dwellings are serviced by walking or by "combo" mode (i.e. 97.42% by walking and 93.11% by "combo") within 10 minutes. When combining walking and "combo" mode, almost all the dwellings are serviced by establishments. Using bicycle, all the dwellings can access an establishment within 10 minutes.

- Category of intermediate-low service level

In the category of intermediate-low service level, there are 89 residential patches with an average household income of 51,306 CAD. These residential areas were generally created since the spreading of automobility, but just before the era inaugurated in the 1960's by the construction of control access highways. The average year of creation of lots is 1958. An average service level of 1.28 and an average coverage level of 79.36% point out that a majority of residents in these areas can access an establishment selling fresh food. The residential patches contain 36.14% (31,7082 out of 877,319) of dwellings in the Island of Montreal. Those are located in intermediate residential density environments (i.e. an average gross density of 52.54 and an average net density of 91.59). These residential patches have 0.9008 intersections per hectare and 1.85 segments per intersection on average. Within 10 minutes by walking, 60% of the dwellings in the residential patches are serviced by small establishments, while 46.46% of the dwellings can be serviced by mid-size establishments, and only 7.63% are serviced by large establishments. Within 10 minutes, 87.11% of dwellings in the residential patch are serviced at a walking distance regardless of the size of establishments, and 82.76% are serviced by "combo" mode. Combining walking and "combo", 95.81% of the dwellings are serviced by establishments. Using bicycle, almost all the dwellings can access an establishment within 10 minutes.

- Category of low service level

About 60% (204 out of 341) of the residential patches in the Island of Montreal are in the category of low service level. These residential patches have a high average household income of 81,516 CAD, and are in areas created most recently, as the average year of this category is 1968. An average service level of 0.17 and an average coverage level of 15.01% imply that only a small proportion of residents in these areas can reach an establishment selling fresh food within 10 minutes by foot. Though representing a majority of the residential patches (60%), these contain only 30.04% (263,558 out of 877,319) of dwellings in the Island of Montreal. Accordingly, those patches are characterized by low residential densities (i.e. an average gross density of 23.43 and an average net density of 37). These residential patches display the lowest street network connectivity, reflected by a relatively low average number of intersections per hectare (0.7966) and the lowest average number of segments per intersection (1.67). By walking, only 20.94% of dwellings are serviced establishments within 10 minutes (8.47% serviced by small, 12.62% serviced by mid-size, 1.58% serviced by large, respectively). Yet, 47.24% of dwellings in the residential patch are serviced within 10 minutes by "combo" mode. Combining walking and "combo", 52.88% of the dwellings are serviced, a number that was a surprise for this researcher. By cycling, 76.93% of the dwellings can access an establishment within 10 minutes.

8.2 General Conclusion

This paper did posit that some physical and spatial properties of the built environment inform both the spatial distribution of different types of establishments and their respective conditions of accessibility. However, the relationships between the retail 'landscape' and the broader urban landscape are more intricate than they might appear at first stance. Different periods of development have produced differing urban forms, each partly determined by a privileged mode of locomotion (by foot, by streetcar or by car). In some areas of the city, the location of establishments and their accessibility are the direct consequences of preordained development models that have assigned specific locations to stores (through zoning) and favored a mode of access predicated on automobility. In other areas, developed prior to the automobile hegemony, inherited urban forms present conditions that are more amenable to walking, while displaying higher residential densities. Yet, these conditions alone do not guarantee the presence of retail establishments, as in the case of food deserts, nor do they determine their exact location. Other factors can intervene. Merchants can decide for instance to locate their store based on the assumption that customers will use their automobile, irrespective of the availability of other transportation options.

Retail distribution patterns might hence be attributable to different sets of considerations, such as: inherent qualities and properties of the form; to “inertia” and the subsistence of old patterns; to locational logics dictated by extraneous considerations such as economic perspectives or retail practices, and finally, to a combination of such factors. Yet, retail establishments are deployed in built environments that display characteristics that could be assessed by analysis. Consequently, some of the rules governing their spatial distribution could be unveiled. This paper explored the objective conditions in the spatial system of the city that are associated with the presence (or absence) of different categories of retail establishments selling fresh fruits and vegetables, as well as the impacts of such locational patterns on accessibility by foot.

Morphological analyses results show that in densely built neighborhoods from pre-automobile times, small establishments prevail, that tend to be centrally located and accessible by foot. The presence of establishments and the level of service is positively correlated with morphological characters. Though positively correlated to both residential density and street network connectivity, establishments respond to the former more than they respond to the latter. Large establishments are found outside of neighborhood areas and in more recently urbanized low-density built environments. They are poorly accessible by foot (as expected), but since they are located between morphological residential areas, they serve at least two neighborhoods. Yet, all establishments (!) are located nearby public transit (PT) stops (which constituted a surprise), as a consequence that accessibility increases significantly when considering "combo" trips. Mid-size establishments are found in varying locations and morphological contexts, but 60% of them are also located outside of neighborhood areas. They respond strongly to local conditions (density and connectivity) and are highly associated to thoroughfares and public transit, which are determinant to their location. Significant positive correlation between residential densities and retail coverage combined with high disparities in residential densities across morphological neighborhood areas explains that while 50.2% of residential tissues are not serviced at a 10-minute walking distance (750 m.), only 26.13% of the dwellings in the Island fall in that situation. At the neighborhood level, when a gross residential density of 39.77 dwellings/ha or a net residential density 69.12 dwellings/ ha are reached, the level of service increases significantly. It is not only that all or almost all dwellings within the neighborhood area serviced are at a walking distance, but that the residents/ customers have multiple options of fresh food stores. Only 9.89% of residential tissues in the Island are not serviced at a 10-minute cycling distance (2200 m.). The "cyclable" catchments on a 2200 m. (10 minutes) biking distance – which constituted another surprise of this research. The un-serviced residential tissues are those that have low residential densities, so that only 2.7% of the dwellings in the Island fall in that situation.

59.87% of residential tissues are serviced in a 10-minute journey combining walking and bus. Only 18.59% of dwellings are not serviced by this combination of modes of transportation. Finally, only 31.17% of residential tissues are not serviced when residents/ customers accept either walking or combination of “bus + walking”, only 11.15% of dwellings are not service in this situation.

The discussion that precedes was made possible based on a fairly detailed analysis of the morphological conditions found both at the local level (in morphological neighbourhood areas and within pedestrian catchment areas for instance) as well as at the global, or pan-Island level (e.g. the position of establishments relative to residential patches or major thoroughfares). This stands in sharp contrast from the analyses conducted in chapter 4. Compared with the map of residential patches in terms of service level, visually, the map of establishment count per one-kilometer quadrat presents a similar distribution pattern (Figure 52). Though rigorous, those quantitative spatial distribution analyses did not allow speaking of the context that could explain or inform the actual spatial distribution patterns observed and quantified. For, the “relative position” of the establishments is what often appears to be more meaningful: first, their position relative to each other, but then also, their position relative to the residential areas that they are meant to serve, as well as their position relative to major access route and bus stops and routes. Such are aspects that a morphological approach has allowed to address. Furthermore, it seemed very important to try to assess the local conditions (i.e. urban tissue conditions) to which the different categories of establishments seemed to be responding to. None of the geographical reference units delineated predominantly residential areas but the morphological neighbourhood area does. Morphological neighbourhood areas as a unit of reference, not only allows speaking the location of establishments but also allows assessing accessibility to establishments from every dwelling in residential areas. When controlling for demographic (income) and historical (inherited retail landscape) condition, being able to identify factors that appear to favour the presence of establishments accessible by foot is key to support sustainable planning efforts. The relevance of such an approach also seems more promising than an approach more narrowly focused on ‘food deserts’ for instance for the development of evidence-based policy.

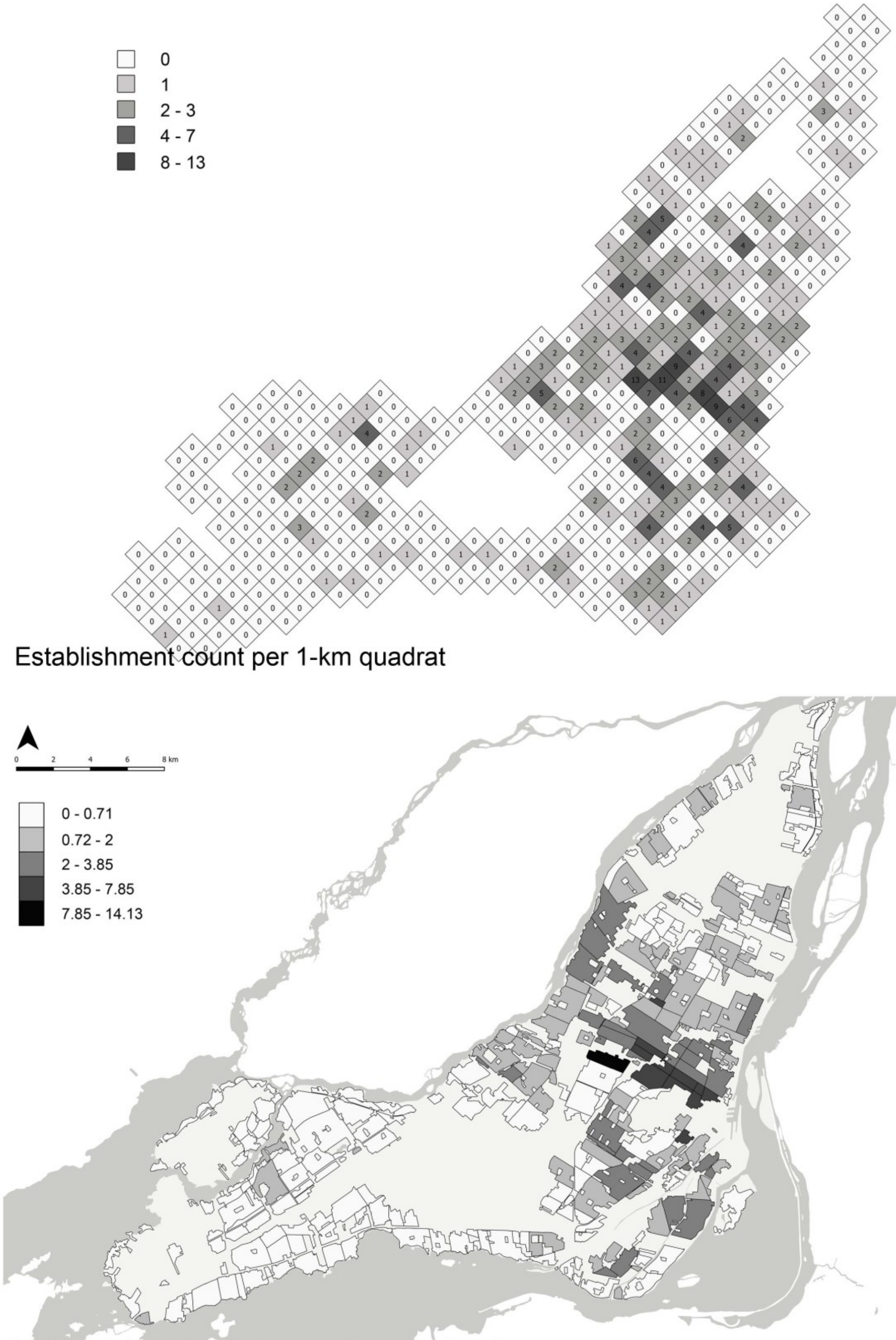

Figure 52. A comparison between the map of establishment count per 1-km quadrat and the map of residential patches in terms of service level

8.3 Limitations, Future Research and Policy Implications

This research discussed the relationship between urban form and accessibility to fresh food in Montreal. A new framework was applied to approach the spatial distribution of fresh food retail establishments, their surrounding built environments and their accessibility by different modes of transportation. This research has produced important findings that are worth to study in more details, as well as suggesting areas of interest for future research and development:

1. Other measures of the urban form could be scrutinized and their impacts on the spatial distribution of fresh food retail establishments and accessibility to fresh food can be assessed.
2. The method of walkable, “cyclable”, and “combo” catchments used to measure accessibility to fresh food retail establishments by different modes of transportation in this study can be applied to other facilities and amenities, e.g. measuring the accessibility to hospitals, schools, pharmacies, parks, sport facilities, etc.
3. This research inquired on the spatial distribution of fresh food retail establishments in relation to transportation networks and the built environment in the case of the Island of Montreal. While the research approach can be applied to the study of larger area (i.e. Montreal’s metropolitan area) or the study of other cities (e.g. Quebec City).
4. When analyzing the accessibility to fresh food retail establishments by bus (i.e. “public transit + walking), the total travel time for grocery shopping purpose was set as 10 minutes to correspond to an equal time to the study of by walking and cycling. Using the same set travel

time to study the accessibility to fresh food has the merit to compare the accessibility by different modes of transportation. However, the time of 10 minutes (750 m. walking distance and 2200 m. cycling distance) used in the study of accessibility by walking and cycling were according to pre-existing studies (Larsen, El-Geneidy and Yasmin, 2010), while there is no research about the travel distance/time that people are willing to consider specifically for grocery shopping in Montreal. Therefore, future studies on accessibility to fresh food retail or other facilities can use surveys on this in order to produce more specific data on food shopping. Furthermore, surveys could investigate the actual shopping practices by customers of different type of establishments, and from different morphological areas of the city.

5. In this study, when analyzing the accessibility to fresh food retail establishments by collective modes of transportation, metro and train were not considered as the distance and time from the outside of the station to the platform (and the other way round) where people actually wait for the train is considerable in relation to a total travel time (of 10 minutes). However, when studying accessibility to certain facilities or amenities, for example, hospitals, the set time could be great enough to overlook the time spent inside the metro stations or train stations. At this situation, travel by metro and train should be considered.
6. This research looks at the accessibility to establishments selling fresh fruits and vegetables but does not consider the shopping practices of people. Future research could look at the relation between objective condition of accessibility (as measured in this study) and people's perspectives and shopping practices. Another line of enquiry could also consider the

availability of food nearby working places. The methods developed in this research to analyze transportation that combine walking and transit could serve such a purpose; by considering “trip chains” from home to work that include food shopping opportunities.

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Appendix A Centrographic Statistics

The following section summarizes the depiction of these methods by O'Sullivan and Unwin (2010).

The first measure of central tendency is mean center, also called center of gravity or centroid, which provides a single point summary measure for the location of a set of points (distribution). In other words, the center of a point pattern is the point whose coordinates are the average (or mean) of the corresponding coordinates of all the points in this pattern. The coordinates of mean center is given by the following formulae:

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n}$$

$$\bar{Y} = \frac{\sum_{i=1}^{n} y_i}{n}$$

Where x_i and y_i are the coordinates for point i, $\{\bar{X}, \bar{Y}\}$ represents the mean center for the points, and n is equal to the total number of points.

Centroid is the second measure of central tendency, which should be used with polygons or a polygon shape by a set of points. The centroid of a plane polygon is the center of gravity or balancing point of the polygon or all the points in the shape. If calculating the centroid of a polygon that composed of straight line segments between nodes, centroid can equal to mean center (mean X, mean Y), but if calculating the centroid of a bounding box of a polygon or nodes, the centroid is normally at a different position, even may not be inside its polygon.

Another measure of centrality is weighted mean center. It is produced by weighting each X and Y coordinate by another variable, the variable can be any characteristic of the point pattern, or for centroid derived from a polygon, it can be weighted by any characteristic of the polygon. The coordinates of weighted mean center is given as:

$$\bar{X}_w = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}$$

$$\bar{Y}_w = \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i}$$

Where x_i and y_i are the coordinates for point i, $\{\bar{X}, \bar{Y}\}$ represents the mean center for the points, n is equal to the total number of points, and w_i is the variable.

Then, the last basic measure of centrality is median center, which is "a location representing the shortest total distance to all other features in a study area. The location of a single x,y coordinate value that represents the median x-coordinated value and the median y-coordinate value for all features in a study area (GIS Dictionary, 2016)." In a point pattern, the median center is the point that minimizes sum of distance between itself and all other points. However, there is no direct solution to determine a median center, it can only be determined approximately. There may be even more than one median center that would minimized the distance to all the points in the pattern.

The basic measures of dispersion are standard distance and standard deviational ellipse, they are obviously based on standard deviation. Standard deviation is "a statistical measure of the spread of values from their mean, calculated as the square root of the sum of the squared deviations from the mean value, divided by the number of elements minus one. The standard deviation for a distribution is the square root of the variance (GIS Dictionary, 2016)". The formulae for standard deviation of single variable is given as:

$$s_x = \sqrt{\sum_{i=1}^{n} \frac{(x_i - \bar{X})^2}{n-1}}$$

$$s_y = \sqrt{\sum_{i=1}^{n} \frac{(y_i - \bar{Y})^2}{n-1}}$$

Where x_i and y_i are the coordinates for point i, $\{\bar{X}, \bar{Y}\}$ represents the mean center for the points, and n is equal to the total number of points.

Standard distance deviation represents the standard deviation of distance of each point form the mean center. A summary circle can be plotted for the point pattern by this measure, the circle centered at mean center $(\bar{X}, \bar{Y})$ with standard distance radius *d*, given as:

$$d = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{X})^2 + \sum_{i=1}^{n}(y_i - \bar{Y})^2}{n}}$$

Where x_i and y_i are the coordinates for point i, $\{\bar{X}, \bar{Y}\}$ represents the mean center for the points, and n is equal to the total number of points.

Although standard distance deviation is a good single measure of dispersion of the incidents around the mean center, it does not show the directional bias of the data. While standard deviational ellipse gives dispersion in two dimensions, so it can capture the shape of distribution. There are three parameters in standard deviational ellipse, angle of rotation, dispersion along major axis, and dispersion along minor axis. The major axis shows the direction of maximum spread of the distribution of points. The minor axis is perpendicular to major axis and shows the minimum spread. Standard deviational ellipse is given as (ArcGIS Desktop 9.3 Help):

$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{X})^2}{n}}$$

$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{Y})^2}{n}}$$

Where x_i and y_i are the coordinates for point i, $\{\bar{X}, \bar{Y}\}$ represents the mean center for the points, and n is equal to the total number of points.

The angle of rotation is calculated as:

$$\tan\theta = \frac{\mathrm{A} + \mathrm{B}}{\mathrm{C}}$$

$$\mathrm{A} = \left(\sum_{i=1}^{n} \tilde{x}_i^{\,2} - \sum_{i=1}^{n} \tilde{y}_i^{\,2}\right)$$

$$\mathrm{B} = \sqrt{\left(\sum_{i=1}^{n} \tilde{x}_i^{\,2} - \sum_{i=1}^{n} \tilde{y}_i^{\,2}\right)^2 + 4\left(\sum_{i=1}^{n} \tilde{x}_i \tilde{y}_i\right)^2}$$

$$\mathrm{C} = 2\sum_{i=1}^{n} \tilde{x}_i \tilde{y}_i$$

Where $\tilde{x}_i$ and $\tilde{y}_i$ are the deviations of the xy-cordiantes from the mean center.

The standard deviations for the x-axis and y-axis are:

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n}(\tilde{x}_i \cos\theta - \tilde{y}_i \sin\theta)^2}{n}}$$

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{n}(\tilde{x}_i \sin\theta - \tilde{y}_i \cos\theta)^2}{n}}$$

Where $\tilde{x}_i$ and $\tilde{y}_i$ are the deviations of the xy-cordiantes from the mean center.

Appendix B Taxonomy of Morphological Neighborhood Area

Level of service	Number of patches	Percentage of patches	Number of dwellings	Percentage of dwellings	Average service level (by foot)	Average coverage level (by foot)	Average percentage of dwellings w. access by foot	Average gross density	Average net density	Average number of nodes/ ha	Average number of segments/ node	Average percentage of dwellings serviced by small-size EST. (by foot)	Average percentage of dwellings serviced by mid-size EST. (by foot)	Average percentage of dwellings serviced by large - size EST. (by foot)	Average percentage of dwell. w. access by "combo" (i.e. walking + bus)	Average percentage of dwell. w. access by "combo" +walking	Average percentage of dwell. w. access by cycling	Average year *	Average annual household income (CAD)
High (7.85 - 14.13)	1	0.29%	13011	1.48%	14.13	99.29%	99.98%	94.07	178.13	0.7808	1.93	99.98%	1.27%	32.30%	99.71%	99.98%	99.98%	1949	32638
Intermediate-high (3.85 - 7.85)	11	3.23%	59102	6.74%	5.29	88.35%	99.08%	94.7	197.61	1.1002	2.01	99.08%	61.05%	7.07%	99.06%	100.00%	100.00%	1918	44244
Intermediate (2 - 3.85)	37	10.85%	224566	25.60%	2.75	91.88%	97.42%	62.98	115.56	0.923	1.93	87.72%	54.92%	10.86%	93.11%	99.56%	99.99%	1939	46471
Intermediate-low (0.72 - 2)	89	26.10%	317082	36.14%	1.28	79.36%	87.11%	52.54	91.59	0.9008	1.85	60%	46.46%	7.63%	82.76%	95.81%	99.54%	1958	51306
low (0 - 0.71)	203	59.53%	263558	30.04%	0.17	15.01%	20.94%	23.43	37	0.7966	1.67	8.47%	12.62%	1.58%	47.24%	52.88%	76.93%	1968	81516
	N = 341	100%	N = 877319	100%	Commercial service to patches			Morphological conditions				(nature of) Commercial offering			Accessibility by alternate modes			Control	
	* year = year of creation of cadastral lot (First cadastral plan was created in late 19th century, it did record all pre-existing lots. The official cadastre records all initial lots and all those created since.)																		