AMERICAN UNIVERSITY OF BEIRUT

PANDEMIC-SENSITIVE LIVABILITY INDICATORS AT THE NEIGHBORHOOD SCALE: THE CASE OF MONTREAL

by
SARA MOHAMMAD RADWAN EL KHATIB

A thesis
submitted in partial fulfillment of the requirements
for the degree of Master of Urban Planning and Policy
to the Department of Architecture and Design
of the Maroun Semaan Faculty of Engineering and Architecture
at the American University of Beirut

Beirut, Lebanon
January 2021

AMERICAN UNIVERSITY OF BEIRUT

PANDEMIC-SENSITIVE LIVABILITY INDICATORS AT THE NEIGHBORHOOD SCALE: THE CASE OF MONTREAL

by
SARA MOHAMMAD RADWAN EL KHATIB

Approved by:

____

Dr. Ramzi Farhat, Assistant Professor Advisor
Department of Architecture and Design

____

Dr Ibrahim Alameddine
Department of Civil Engineering Member of Committee

____

Dr Serge Yazigi
Department of Architecture and Design Member of Committee

Date of thesis defense: January 28, 2021

AMERICAN UNIVERSITY OF BEIRUT

THESIS RELEASE FORM

Student Name:	El Khatib	Sara	Mohammad Radwan
	Last	First	Middle

I authorize the American University of Beirut, to: (a) reproduce hard or electronic copies of my thesis; (b) include such copies in the archives and digital repositories of the University; and (c) make freely available such copies to third parties for research or educational purposes:

- ☑ As of the date of submission
- ☐ One year from the date of submission of my thesis.
- ☐ Two years from the date of submission of my thesis.
- ☐ Three years from the date of submission of my thesis.

______________________________ February 8, 2021____

Signature Date

ACKNOWLEDGEMENTS

First, I would like to express my deepest gratitude to Ramzi Farhat for helping me navigate this journey of writing a thesis during what was arguably the hardest year to us AUB Students. It has been a wonderful experience working with him and I learned so much which I will carry through to my future endeavors.

Thank you to the committee, Dr Ibrahim Alameddine and Dr Serge Yazigi for their valuable insight, your comments have strengthened my approach as a researcher. I am also especially grateful to this wonderful, little department which has exposed me to so much not just as a student but as a person, my life has truly been enriched. Studying this major at AUB has been one of the best decisions of my life.

Mom, Dad, I hope I always make you proud of me and that you keep me as your favorite child, thank you for supporting me no matter what. To Omar, I cannot begin to express my deepest appreciation and adoration for your unwavering support for these years, and your deft skills on Microsoft Word. I also want to thank my loved ones who were there to listen to my complaints on this difficult journey: Odette, Mary, Karim, Bassil and Assil. And finally, a special mention to my partners in crime in this major, Ranime and Dina I literally could not have done it without you or our zoom sessions.

Also, I want to acknowledge this difficult time that has befallen us current graduates, especially in Lebanon. So here is praying for a better future for us and our families, uninhibited by the challenges of the present.

ABSTRACT
OF THE THESIS OF

Sara Mohammad Radwan El Khatib for Master of Urban Planning and Policy
Major: Urban Planning and Policy

Title: Pandemic-Sensitive Livability Indicators at The Neighborhood Scale: The Case Of Montreal

The COVID-19 pandemic has made life closer to home and brought at the forefront the importance of urban livability on the scale of the neighborhood. This thesis presents and index that could be used to assess neighborhood livability using data on urban form, housing, green space, amenities, mobility, employment, and education. The index is tested on the city of Montreal, Quebec and presents different weighting methods which are sensitive to local dynamics and city-wide lockdowns. The index employs the use of GIS to map and compute metrics of livability on the spatial scale, and presents a final map of livability scores per neighborhood.

Neighborhood livability in Montreal conforms to overall socio-spatial trends which are interrelated and exist as a result of history, politics and planning. This thesis attempts to explore the entry points into addressing livability beyond the pandemic by using the index to find neighborhoods which need to be intervened on, and through what metrics.

Further research will need to be conducted to propose suitable interventions of planning or policy in the city of Montreal, depending on the local context, the needs of residents and the ongoing challenges of the pandemic in order to maintain livability in the new normal.

TABLE OF CONTENTS

ILLUSTRATIONS

Figure

TABLES

Table

CHAPTER I

INTRODUCTION

A. Introduction

With economic, social, and natural challenges abound, planning for livability in cities continues to be a prime professional concern. More recently, this issue has been thrown into sharp relief with the onset of the Covid-19 pandemic, especially if we consider the fact that almost 95 percent of the epicenters of the outbreak have been in urban areas (UN-Habitat, 2020). As cities around the world have launched campaigns to battle the outbreaks, we have started to learn more about the spatial scales at which policy initiatives are more effective. There is a growing consensus that action at the city level is of uneven effectiveness, with some neighborhoods disproportionately bearing burdens compared to others within the same city, such as enclaves of poverty and of color.

Neighborhoods are also the most important unit of the city today because the pandemic has literally pushed life closer to home, with remote working and learning being the norm, travel restrictions, and sporadic curfews. For instance, In the first few weeks of the lockdown, Parisians’ outings were restricted to 1 hour, within 1km from their homes. More drastically, the government of Dubai required residents to stay home 24/7 for three weeks with the only exceptions being local trips to purchase essentials and that they applied for a permit, providing information on exact destination, arrival time and license plate information. Even 12 months into the pandemic, countries like

Lebanon and Canada continue to battle with the highest levels of spread by imposing strict lockdowns and restrictions.

For these reasons, the neighborhood is ever more important in re-evaluating livability in the age of COVID-19. Livability is also best legible on the scale of the neighborhood where there is homogeneity in the urban fabric, a homogeneity that allows researchers to draw more generalizable results and recommend specific tangible policies. Since managing Covid-19 is an inherently socio-spatial issue, and so is the practice of livability, the importance of livability on the neighborhood scale reflects the goal of achieving a humane and inclusive socio-spatial environment. In this sense, the objective of this thesis is to create an index to assess overall neighborhood livability and specifically so an index that is sensitive to the challenges posed by pandemics such as Covid-19.

Livability is an "ensemble concept" (Myers, 1988; Andrews, 2001), and refers to a combination of factors, that together form a certain quality of life. These factors include the built and natural environments, social cohesion, economic prosperity, equity, culture, inclusion, and educational opportunity. For example, Appleyard et al (1981) defined livable streets as "those that encouraged residents to commune with one another and identify streets as part of their home territory." As it was broadened to reference districts and urban areas, the concept of livability was ultimately understood to combine factors which yield more than the sum of their individual parts (Ellis and Roberts, 2016). The importance of livability on the neighborhood scale reflects the goal of achieving a humane and inclusive socio-spatial environment. This is grounded in a calculus of economic efficiency, but also an appreciation of the fundamental importance of the social spaces of everyday life for general well-being (Zielenic, 2018). A similar phenomenon is observed by Richard Florida in his theory on the creative class, where built environment and human capital factors are inherently self-reinforcing (Florida, 2005).

Livability is also highly contextual. Geography and other meteorological conditions change the approach in achieving livability, so does culture, class, gender, and age. Furthermore, it is important to note a livable neighborhood cannot fully exist in isolation, and the connectivity of many livable neighborhoods with each other is what creates common value in livability. The foundation of livability lies in a place's resilience, which allows it to persist despite economic and social shocks. The Covid-19 pandemic has been testing the resilience of communities all around the world on many levels. Economies have crashed, real estate markets were for the most part frozen, and the economic ripples have been felt in all corners of the world. Liabilities of neighborhoods designed around tenets of good planning such as compact and smart growth were exposed, supply chains were upended, and small businesses teetered on the edge of closure, all while traditional aspects of community life and social cohesion were strained. This research will learn how these forces played out in the urban laboratory that is the neighborhood and incorporate these lessons into a livability framework and index. The different indices presented by this thesis will explore the intersection of traditional livability metrics and pandemic sensitive indicators. The indices will be created using different methods in the literature and compared to understand the strengths and weaknesses of each index. A comparison will also be made between neighborhood livability and the actual spread of COVID-19 to explore the dynamics taking place on the city scale.

B. Case Study

This thesis studies livability on the case of Montreal, Canada. Montreal is internationally recognized as a livable city and has ranked 20th in Mercers Livability Index (Mercer, 2019) and 20th in the Economist Intelligence unit (EIU, 2019). Furthermore, it has a diverse urban fabric ranging from dense historic cores to high rise downtowns, row housing and typical suburban development. And most importantly, it had a plethora of open-source data that could be used to apply the index presented by this thesis.

C. Research Significance

The significance of this research is that it could present new insight to the definition and experience of neighborhood livability, both in normal times and during the pandemic, that could be built on in future research and allow for more standardized assessments. This research will also provide a reference for the current debates on the future of urbanism and the problematics that have come to light during this pandemic. Furthermore, the index will identify disparities and opportunities in neighborhoods that become a starting point for highly contextual and relevant urban planning, policy, and design interventions.

D. Methodology

To answer my research questions, I will adopt a mixed-method approach that combines qualitative and quantitative techniques, while leaning more towards quantitative research. The purpose of this approach is “more than simply collecting and analyzing both kinds of data;” rather, it involves the “use of both approaches in tandem so that the overall strength is greater than either qualitative or quantitative research" (Creswell, 2009). The research methodology is as follows:

1. A review of the scholarship on livability indices, health, and sustainable development (secondary research). This will be accomplished through analyzing academic peer reviewed articles in the literature review, specifically focusing on the definition and the framework employed in defining and measuring livability, health, sustainable development, and other urban quality indicators.
2. A review and analysis of existing and in-use livability indices (quantitative). This research will focus specifically on the methodology of measuring livability in order to compare how different indices define, measure and manipulate data into indicators and how these are combined, weighted and possibly mapped on the urban scale.
3. A review of current healthcare, planning and governance policy on pandemic mitigation from select cities (qualitative). This is specified using the search terms "urban" and "pandemic," or "urban planning" and "COVID-19," or "livability, urban" and "COVID-19." The goal is to find academic research that can provide insight on the important metrics of urban life using case studies from NY, China, USA, Italy and more.
4. Finally, the outcome is a GIS-based index which incorporates the above findings into an intuitive framework which can assess livability on the scale of the neighborhood. GIS, internet surveys and social media have proven to be beneficial additions to traditional, time consuming

qualitative research (Harvey & Aultman-Hall, 2016) and this is growing in importance as more research becomes big data oriented. For the application of the GIS model in Montreal, I will employ the use of publicly available government data on land use and GIS shapefiles, from *donnesquebec*.com. For household data I will use the 2016 Canadian Census (Stat Can, 2016). And For other geographical data I will use publicly available data from Open Street Maps.

Figure 1 below presents a visual representation of the methodology to be used in this thesis.

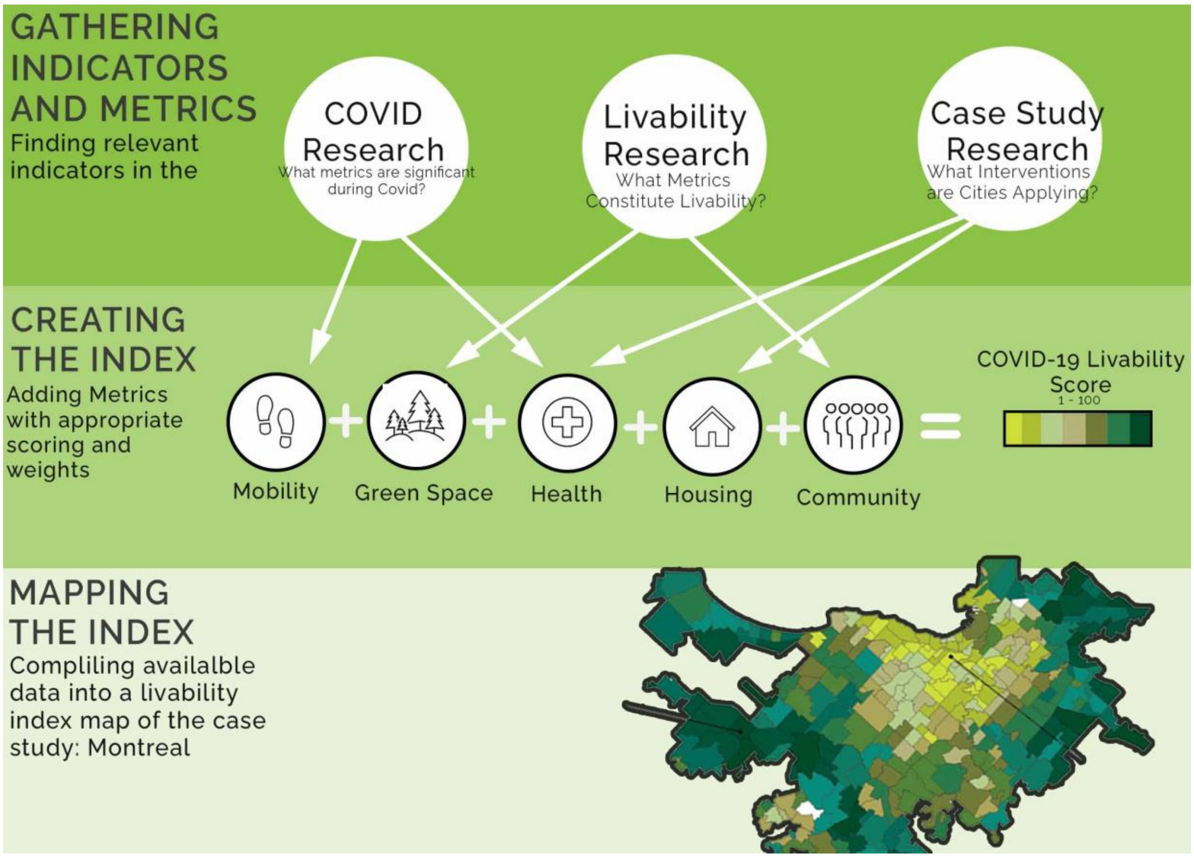

Figure 1: Methodology Diagram

E. Thesis Structure

The thesis is comprised of five chapters. The first, the introduction, includes the general scope of the thesis, the case profile, and the methodology. Chapter 2 presents a thorough overview of two main categories used in the literature review: a general research on livability and research on urbanization and COVID-19. The chapter concludes with a finalized list of indicators relevant to livability and to COVID-19. Chapter 3 presents the detailed steps and calculations used to find the score of each neighborhood on each indicator and an explanation as to the method employed for each indicator. Chapter 4 combines the aforementioned indicators in 3 different weighting schemes in order to find the final livability score of each neighborhood. This chapter also contains an analysis of the dynamics taking place on the scale of the city and provides insight as to how livability is impacted by forces beyond the index. Chapter 5 summarizes the findings and the issues facing Montreal's neighborhoods and highlights opportunities for future research.

CHAPTER II

LITERATURE REVIEW

The literature review is twofold. First, it aims at understanding the roles and examples of indices in the urban field. Second, it aims at understanding how the pandemic is challenging the status-quo of cities around the world, and ultimately reconciling traditional measures of livability with the new normal of this and future pandemics to be able to assess the livability of neighborhoods during pandemics such as COVID-19.

A. Livability Indices

Historically, indices have been used to measure specific metrics that change with time, two examples being the Gender Gap Index and the Dow Jones Industrial Average. Indices are used to combine groups of data in order to create a more legible 'total' that is useful in describing phenomenon of a certain field. Numerous indices and measurement tools were developed over the last three decades to rank cities according to the quality of the built environment, amenities, and opportunities afforded to their residents and visitors. Measures of safety climate, transportation, infrastructure, healthcare, public policies and services, business environment, cost of living, recreational amenities, education, housing, gross domestic product (GDP) per capita, sanitation, culture, air quality, and natural capital have been incorporated into quantitative models to compare and rank cities. Qualitative aspects such as lifestyle, well-being, happiness, tolerance, have also been used to benchmark urban livability.

Most indices are based on academic research, but there are also a handful of private sector-led initiatives that measure city or community livability as a service, sold either to governments, policy makers or to other companies. The following section discusses the types of livability indices using select examples and then categorizes the literature in a detailed table for reference.

1. Comprehensive Indices

Comprehensive indices tend to be produced by private firms and are catered to creating yearly reports of livability worldwide earmarked for sale as a consulting service, or even to the public and the sector of academia. The most comprehensive livability index to date is the *Economist Intelligence Unit (EIU) Livability Inde*x which rates cities yearly on a livability scale from 0 (intolerable) to 100 (ideal). The index takes a variety of indicators in each of five categories, as seen in the table, to formulate a score. Examples include traveler satisfaction, corruption, social and religious tolerance under the culture and environment category (Kashef, 2015). Figure 2 below shows that the higher performing cities tend to have comparable scores in most categories.

The ten most liveable cities

Country	City	Rank	Overall Rating (100=ideal)	Stability	Healthcare	Culture & Environment	Education	Infrastructure
Austria	Vienna	1	99.1	100	100	96.3	100	100
Australia	Melbourne	2	98.4	95	100	98.6	100	100
Australia	Sydney	3	98.1	95	100	97.2	100	100
Japan	Osaka	4	97.7	100	100	93.5	100	96.4
Canada	Calgary	5	97.5	100	100	90	100	100
Canada	Vancouver	6	97.3	95	100	100	100	92.9
Canada	Toronto	7	97.2	100	100	97.2	100	89.3
Japan	Tokyo	7	97.2	100	100	94.4	100	92.9
Denmark	Copenhagen	9	96.8	95	95.8	95.4	100	100
Australia	Adelaide	10	96.6	95	100	94.2	100	96.4

Figure 2: Ten most livable cities (EIU,2019)

2. Issue Specific Indices

While comprehensive indices are common, a few issue-specific ones have gained notoriety within their field. *Walk Score* is a very well-known index that measures the walkability of any address using a point system and decay function based on distance from addresses to amenities. It can be found in most real estate websites in the global north as a measure of the neighborhood's vitality and appeal. In fact, there is research which uses walk score to assess the changes in home values (Cortright, 2009). The simplicity of this index has made it integral in the real estate sector and largely influences consumer choice in selecting neighborhoods for potential residence (Walkscore,2020). Another well-known, issue-specific index is *LEED ND*, a green neighborhood rating system which rates neighborhoods on a point system based on the tenets of sustainable development (LEED ND). This is one of the most widespread building ratings used by developers and cities as a measure of progress to more sustainable development.

3. Demographic-centered indices

Some indices are structured around the needs of a particular demographic. Examples include the *AARP Livability Index*, meant to score places as peer the needs of the geriatric population and appraises seven broad categories of community: housing, neighborhood, transportation, environment, health, engagement, and opportunity with a focus on ageing communities, and then ranks communities against the U.S. median in as many as nine subcategories for each. Each category contains 4-9 metrics and 2-5 policies. Policies capture political will and steps communities are taking in pursuit of livability. Each metric is scored from 0-100 and the scores are averaged out and equally weighed to obtain a one score result out of 100. The index extracts information from more than 50 sources, including federal data from the American Community Survey and the major agencies-transportation, housing, environmental protection and AARP's own survey research and expert analysis (AARP,2018).

4. Human resource indices

Some indices are used solely in the private sector for human resource purposes. The *Mercer Quality of Living Index* is used by large multinational companies that to compensate mobile employees fairly depending on where they live. It compares 500 cities based on 39 factors in 10 categories. The total index is based on consumer goods, economic environment, housing, medical and health considerations natural environment, political and social environment, public services and transport, recreation, schools and education, and socio-cultural environment. (Mercer, 2020). New York City is given a baseline score of 100 and other cities are rated in comparison.

5. Development Consulting indices

Other indices are geared towards informing policy and design investments in specific locations. *Place Score*, developed by a Prop-Tech startup based in Australia, coined the term place experience, and created tools to measure it. It gathers online and face-to-face survey data as well as observational studies from the people and packages this data into one of five products. This is also the idea behind the *Care Factor* which, assessed community livability in Heidelberg Germany before and during COVID-19 based on 50 care factors extracted from surveys (Legge, 2020). As per their literature, their purpose is to “empower everyone, everywhere to have their say in the decisions that affect everyday places” (Legge, 20202)

6. Summary

The following table is a summary and classification of the above indices and more, their scale, focus, and data, and whether they are designed by academic bodies, commercial enterprises, non-profit organizations, or governmental agencies.

Name and Source	**Scale**	**Focus and Field**	**Methods (Qualitative (QL/ Quantitative(QL) / Both)**
EIU Livability Index **(EIU, 2019)**	City	Livability / Commercial	Both. Uses 40 livability indicators in five weighted categories: stability (25%), healthcare (20%), culture and environment (25%), education (10%) and infrastructure (20%). Data collection and measurement tools include raw quantitative data public opinion surveys, and interviews with a broad spectrum of professionals, city officials, and urbanites.
Walk Score (Walkscore, 2020)	Neighborhood	Transportation / Commercial	QT. Spatial analysis: Measures distances between amenities, residence, and other locations using decaying scoring functions.
LEED ND **(LEED ND, 2014)**	Neighborhood	Sustainability/ Commercial	QT- Point system that assesses the neighborhoods’ smart location and linkage (SLL), b) neighborhood pattern and design (NPD), and c) green infrastructure and buildings (GIB).
AARP Livability Index (AARP, 2018)	Neighborhood	Livability / Non-Profit	QT. Public census data in housing, neighborhood, transportation, environment, health, engagement, and opportunity with a focus on ageing communities.
Place Score (Legge,2020)	Neighborhood	Livability / Commercial	QL, very contextual, uses online and face to face survey data as well as observational studies from the residents in the community
Mercer Quality of Living **(Mercer, 2020)**	City	Livability/ Commercial	QT- the total index is based on consumer goods, economic environment, housing, medical and health considerations natural environment, political and social environment, public services and transport, recreation, schools and education, and socio-cultural environment
Sustainable neighborhoods Happiness Index (Cloutier,	Neighborhood	Sustainability / Academic	QT- water management, energy management, urban design, food management, business & economic development, waste management, buildings & infrastructure, transportation, and community governance.

Jambeck, & Scott, 2014)			
Premature mortality study Toronto (Awuor & Melles, 2019)	Neighborhood	Health / Academic	QT- statistically and spatially examined six environmental variables (ultrafine particles, carcinogenic and non-carcinogenic pollutants, pollution released to air, tree cover, and walkability index), six health service indicators (number health providers, breast, colorectal and cervical cancer screening uptake rates, student nutrition program uptake rates, and healthy food index), and eight socioeconomic indicators (total income, Gini-coefficient, two age categories – below and above 40 years, proportion of females to males, visible minorities, indigenous peoples, education, less than grade 9)
CODAS Fuzzy (Karasan, Bolturk, & Kahraman, 2019)	Neighborhood	Livability/ Academic	Qualitative surveys analyzed with statistical and mathematical methods which employ the use of fuzzy logic which accurately give quantification to qualitative human surveys
The Livable Urban Landscape: **(Fu, Yu, & Zhang, 2019)**	City	Urban Form / Academic	QT- GIS and Remote Sensing technologies to generate a set of urban livability evaluating indicators via extracted land use information on Convenience, Amenity, Health and Safety e.g. Density of transit, distance to intersections.
Neighborhood Equity Index Toronto (City of Toronto, 2014)	Neighborhood	Livability (Equity) / Governmental	QT- Measures Economic Opportunities (Unemployment, low income, social assistance), Social Development (HS Graduation, Marginalization, Post-secondary completion) Participation in decision making (voting rate) Physical surroundings (Meeting places, walkability, healthy food stores, green space), Healthy Lives (Premature Mortality, Mental Health, Preventable Hospitalization, Diabetes)
Designing Healthy Neighborhoods- Detroit **(Wineman et al., 2014)**	Neighborhood	Health / Academic	QT- Studied Urban form in relation to self-reported health and demographic data
Area Vibes (2020)	City/ Neighborhood	Livability / Commercial	QT- national level census data in the US and user review
Cali Healthy Places Index **(Maizlish et al., 2019)**	Neighborhood	Health / Non-Profit	QT- mapped relationships between public health data in correlation to eight thematic groups: Economics, Education, Healthcare access, Housing, Neighborhood Conditions, Clean Environment, Social Environment and Transportation.
Healthy Livable Cities Index AUO/RMIT **(AUO, 2020)**	City/ Neighborhood	Livability / Academic	QT- Eight years of research combines nine indicators of livability associated with health and wellbeing: walkability, social infrastructure, transport, food, alcohol, public open space, employment, and housing. Uses GIS, census data and policies to map livability across Australia's 21 largest cities.

Table 1: Livability Literature Review

B. Detailed Livability Metrics Discussion

Indices uses different indicators to assess their definition of livability. This is also heavily dependent on the research objective, researchers' agendas, data availability and target audience. Furthermore, various approaches to standardization, normalization, and weighting of the indicators can alter the magnitude and effect the indicator has on the final index. These are decisions that researchers need to take into consideration based on their objectives and well-established research standards. The following discusses approaches to indicator and metric specification as they appear in the following indices: Stanislav & Chin's (2019) Evaluating Livability; Fu, Yu, & Zhangs (2019) Livable Urban Landscape; LEED Neighborhood Development; Australian Urban Observatory Healthy Livable Cites; California Healthy Places Index; Toronto Neighborhood Equity Index; and the Sustainable Neighborhoods Index. Metrics were then compared to the data available in Montreal and feasible to apply remotely to select the final indicators for the index. The detailed tables of each index in the literature review can be found in the appendix for reference.

1. Urban Form

Most of the indicators are focused on urban form as aspects of urban form are easy to measure and relatively stable over time. Most indicators also consider mixed use, compact neighborhood centers as essential to livability (AUO, 2020; City of Toronto, 2014; Fu, Yu, & Zhang, 2019; LEED ND; Maizlish et al., 2019), and negatively assess sprawl (Cloutier, Jambeck, & Scott, 2014). The Livable Urban Landscape index focuses heavily on spatial indicators and also weighs negatively the distance to primary roads and road intersections (Fu, Yu, & Zhang, 2019).

2. Mobility

Multiple forms of mobility are needed to connect the different users of the neighborhood, and this is reflected in the indicators. For example, it is stated that walkable street blocks should be around 200-300m, as this increases the number of intersections between blocks making it easily navigable on foot between locations (AUO, 2020; Fu, Yu, & Zhang, 2019). If block lengths were longer, then there would be a longer detour required to reach a location at the other side of the block, or neighborhood, making it less feasible to make the trip on foot. In the same logic, cul-de-sacs also inhibit walking within the neighborhood especially for those who live at the end of a cul-de-sac (AUO, 2020). Other measures of soft mobility oriented urban development include sidewalks, assessed as a complete network with sufficient widths to serve pedestrians (LEED ND, 2014; AUO, 2020; Stanislav & Chin, 2019). Bike lanes are also important to livability and should be separated from cars in high traffic volume area (AUO, 2020; Fu, Yu, & Zhang, 2019). Lastly, public transportation should be convenient, consistent, and efficient (AUO, 2020; Fu, Yu, & Zhang, 2019; Stanislav & Chin, 2019; Cloutier, Jambeck, & Scott, 2014; LEED ND, 2014).

3. Housing

Housing varies significantly even within the neighborhood, but it can still be accounted for using larger trends, when the data is available. In the literature, indicators on housing are mostly focused in two categories: the physical and the social aspect. Physical housing indicators include housing density, housing diversity; the type of the housing structure such as single family, multi-family units or apartment complexes; and whether the housing is owner-occupied or renter-occupied (Stanislav & Chin, 2019).

Social indicators on the household level include household size, household income, social assistance, and education levels (City of Toronto, 2014; Stanislav & Chin, 2019). It is important to note that these indicators are difficult to measure because there is no optimum level to set for each one. For example, the simple fact that there are more owner-occupied units compared to renter occupied units does not imply that an area is less livable. The indices that used these indicators used them mostly to assess social vulnerability as opposed to livability.

4. Amenities

There are specific amenities important to livability which are not as general as mixed use, and these include supermarkets, community centers and even elder care. Supermarkets are especially important because they provide access to food and daily essentials (AUO, 2020; City of Toronto, 2014; Mazilish et al., 2019; LEED ND, 2014). Supermarkets should optimally be within walking distance from residence, defined as 400-500m. Community centers provide services for local residents and are the smallest unit at which residents can communicate their needs to city officials and neighborhood representatives. Furthermore, they provide flexible safe for community gatherings, events, and meetings (AUO, 2020; LEED ND, 2020). Lastly, elder care is important in many communities to mitigate social isolation experienced by seniors and to allow older residents to age in place, if they choose to (AUO, 2020).

5. Employment

Livable neighborhoods harbor three main activities: work, live and play. Work, or employment opportunities cannot be controlled for each resident but can be facilitated by zoning commercial and mixed areas within neighborhoods and providing incentives for businesses to locate in these neighborhoods. The California Healthy Places Index defines this as employment density, which represents the combined jobs of retail, entertainment, and educational uses per acre in a development (Mazilish et al., 2019). Other indicators assess this as travel time to work, with the logic that the less overall travel time, the more jobs are located in the direct neighborhoods (Stanislav & Chin, 2019). Similarly, the Australian Urban Observatory measures employment proximity as the percentage of people working within the same census data (AUO, 2020).

6. Education

Access to education in the literature is specified as physical proximity from educational institutions. LEED ND requires that at least 50% of households are within 1600m from a dwelling, while the Australia Urban Observatory aims for 100% between 1600m. Stanislav and Chin set the threshold of 1km to educational facilities. However, these indicators do not take into account other barriers to entry such as the price of tuition, acceptance rate, competition, capacity or overall education quality. This is an important indicator which cannot be assessed in depth the scale of an index and should be studied alone since schools do play a deciding role for families if choosing where to live and for students who travel for universities in large quantities.

7. Open and Green Space

These indicators are very important in almost all indices since they measure access to nature and large space for recreation and sports which contribute positively to wellbeing. LEED ND measures access to public space within 400m from homes as well as the provision of street trees every 12m along at least 60% of the block length (LEED ND, 2014). AUO measures access as % of dwellings 400m from a park and the California Healthy Places Index takes it one step farther by measuring the % of people living within 500m of a park or open space at least larger than 1acre. Also, they take tree canopy score as a population weighted percentage in order to account for density (Maizlish et al., 2019). The Livable Urban Landscape Index considers a radius of 500m for parks and squares and a vegetation coverage of 35%.

The Toronto Neighborhood Equity Index measures the average amount of green space (incl. parks and public areas) per km2 in a 1km circular buffer from each residential block in the neighborhood. The Sustainable Neighborhood Index, alternatively, takes qualitative and quantitative measures. The latter is defined as the percentage of green space from total land area and the former an assessment of the city's efforts to sustain and improve the quantity and quality (for example, proximity and usability) of green spaces, and its tree planting policy (1 = below expectations; 2 = meets expectations;3 = exceeds expectations).

8. Health

Livable neighborhoods optimally contribute to individual livability and longevity, and this is reflected in the literature review. The Toronto Neighborhood Equity Index measures diabetes and mental health, whereas LEED ND directly regulates noise and air pollution. Since pollution is not stable some indices have linked metrics of traffic congestion, a known contributor to both noise and air pollution (Cloutier, Jambeck, & Scott, 2014). Other indicators use proxies for health such as the distance to manufacturing facilities and noisy open markets (Fu, Yu, & Zhang, 2019). There is not much consensus between the indicators on the role of the neighborhood in assessing physical health as it is highly variable between populations, age groups and neighborhoods.

C. Scholarship on Cities and COVID-19

This next section discusses the available scholarship so far during the pandemic as of October 2020, and extracts from the research indicators relevant to neighborhood livability during COVID-19. To assess urban livability during pandemics such as COVID-19, there needs to be an understanding of what forces drive the spread of infectious disease in urban areas, how do neighborhoods adapt to lockdowns, and what are the possible solutions that have been adopted by cities. These findings would inform metrics and ultimately policy and planning decisions that maintain or improve livability. The current pandemic is profoundly changing urban livability on many fronts. At the time of writing this thesis, nine months has elapsed since the onset of the COVID-19 pandemic. The scholarship that has investigated in its various impacts and can be organized into 4 main themes: Urban Density, Open Spaces, Urban Health, and Urban Food Systems.

1. Urban Density

In the first few months of the pandemic, density was purported to be a prime factor in the spread of the pandemic in cities. In fact, some built on these assumptions to argue that the post-war trend of low density, single family housing as is popular in North American and Australia was vindicated after all (Altaf, 2020). However, enough data has been collected which proves that density per se was not the main culprit, and that crowding was (Hamidi et al., 2020; Altaf, 2020).

The question then is, if more than 95 percent of outbreaks have been in cities (UN,2020) and since cities are characterized by the intensity of their urbanization and economies, how is density not to blame? The reason that dense megacities had the first and largest outbreaks is because of historical geopolitical and economic dynamics which put them at the frontline of exposure COVID-19. Cities in these 'megaregions' are defined by their high connectivity through travel, trade and employment (Adler, Florida & Hartt, 2020). This connectivity has led to better established transportation infrastructure and frequency of service which furthers the spread of disease between and throughout megaregions and their suburbs.

Early in 2020, the New York Metro Area became the center of the outbreak in the United States. NY is part of the Boston-New York-Washington mega-region, the largest in North America, and is serviced by the Acela train, the only high-speed train in North America. Similarly, in China, high-capacity train networks were responsible for up to 95% of the spread of cases out of Wuhan and infections spread first between mega-regions linked to the most frequent and serviced destination (Zhao, 2020). This finding is worrying to policy makers since disease can take hold in mega-regions before a sufficient health care response is established. The argument against the negative effect of density is furthered if we examine that in dense hyper-urbanized Hong Kong, Seoul and Taipei, robust and widespread interventions such as social distancing, mask wearing, and contact tracing were successful in flattening the curve of cases and deaths.

If density is not the main contributor to spread of COVID-19 in cities, then what is? Hamidi, Sabouri and Ewing conducted a comprehensive data driven analysis of the factors that were correlated with the spread of COVID-19 and found that connectivity mattered more than density. In fact, after controlling for metropolitan area population, socio-economic backgrounds, and health care infrastructure in the U.S counties, they found COVID-19 mortality rates were lower in denser counties due to better healthcare and stricter adherence to social distancing guidelines in dense counties (Hamidi et al, 2020). Other research also found that the people more likely to get infected typically had a lower level of education, and worked as essential workers who were more likely to live in crowded households (Altaf, 2020). Similarly, in rural areas testing and healthcare access are both lower, which leads to the unchecked spread of COVID-19 and increased death tolls (Zhang, 2020).

Since density does not explain spread, and connectivity explains how early and how quick disease spread between cities, what are the characteristics of cities that are correlated with the concentration of COVID-19? Researchers Maroko, Nash and Pavilonis compared New York and Chicago, two cities with similar population densities and urban fabrics and found that hot spots in both cities had significantly larger household sizes compared to cold spots (NYC: 3.0 people per household in hot spots and 2.1 in cold spots; CHI: 2.8 people per household in hot spots and 2.0 in cold spots). And these hotspots were in neighborhoods that were significantly less dense. The proportion of housing units with more than one occupant per room was not significantly different (0.39 and 0.36 in NYC and CHI, respectively) between hot and cold spots. Specifically, in CHI the hot spots were majority black (83%). Hot spots in both cities were not central neighborhoods and relied on public transit (Maroko, Nash, & Pavilonis, 2020).

When it comes to density and disease, connectivity explains how fast and how aggressive community spread starts but the adherence to health guidelines and the vulnerability of some populations dictates the spread and concentration of COVID-19 within urban areas. In many urban areas around the world, especially dense cities that have grown without proper planning, adhering to health guidelines is extremely difficult. In four cities in India (Mumbai, Delhi, Kolkata, Chennai), a COVID vulnerability index identifies how unplanned population density, dilapidated residence, lack of personal rooms and exclusive household access to water and sanitation puts people at higher risk (Mishra, Gayen, & Haque, 2020). Simply because social distancing is impossible when bathrooms and kitchens are shared by dozens, personal space is nonexistent.

2. Urban Health

Evidently, COVID-19 is directly affecting health, and especially those older with preexisting health conditions such as diabetes and obesity. Unfortunately, COVID-19 is also profoundly impacting health in other ways. Lockdowns have exacerbated social isolation and degraded mental health outcomes amongst the poor and isolated (Amerio et al., 2020). Not everyone's lockdown has been the same. For example, some people have had to lockdown in places where they have chosen to sacrifice personal space to afford to be in a vibrant downtown where they spend the majority of the day out in the city for work and play. Students also crowded in dorms to attend universities far from home. Workers migrated and crowded in group housing environments to save enough money to send back to their family. Specifically, isolation in small spaces with non-pleasant views increased depressive symptoms and worsened performance for working from home during lockdown, as per a study from Italy (Amerio et al., 2020).

COVID-19 is also indirectly affecting the health of urban residents. For the majority, teleworking, and the decrease in usual routine activities such as sports, and social activities, has led to a shift to a more sedentary lifestyle. It is well documented that sedentary lifestyles increase the likelihood of non-communicable disease (Adlakha & Sallis, 2020). In fact, residents of walkable, high-density mixed-use and pedestrian-oriented communities are usually more physically active than those in lower density communities and have lower risk of obesity, diabetes, and heart disease which are also significant risk factors for COVID-19 mortality (Adlakha & Sallis, 2020).

COVID-19 has not only reduced the need to get around the city, but it has also negatively changed the perception on the safety of usually crowded public transit and thus, the automobile has become a more attractive as a safe, and socially distant mode of transport during the pandemic, increasing previously downward trends of care ownership (Stevenson et al, 2016). Although transportation by car exposes drivers to less exposure since most automobile trips are solo, there are negative externalities to auto-centric transport such as lung disease from air pollution, non-communicable disease due inactivity, higher stress while driving and the significant risk of injury/death (Stevenson et al, 2016). Furthermore, automobile-oriented development patterns are inequitable to those who chose not to own a car, cannot afford to have a car, the disabled, and the elderly.

Walking remains a safe and active mode of mobility during the pandemic. This is not just because of ease of movement, but because it also has many mental and physical benefits given that it is taking place in pleasant areas with less air pollution and it is a mode accessible to all. Similarly, biking is touted as a safe and active way to get around more efficiently than walking. Biking has seen a renaissance during this pandemic, especially during the stricter closures in the first few months which limited car traffic on the roads. Although that initial surge has tapered off there are interesting trends in biking around cities which imply that biking is here to stay. More children and typical ‘non bike advocates’ are biking around their neighborhood more. A recent survey in Toronto found that 84 percent of respondents were in favor of the construction of supported bike lanes and 85 percent wanted the city to do more to protect vulnerable road users (Doucet & Mazumder, 2020).

Another Canadian study on the activity of youth during the pandemic identified two trends: a cluster of youth that maintained activity outdoors and those that significantly decreased time spend outdoors (Mitra et al, 2016). Low density neighborhoods far away from highways, as well as high density neighborhoods with park access were both associated with increased outdoor activities. Youth and children face particularly unique challenges during this pandemic since they have been limited to remote learning and have suffered from decreased social contacts. This can have profound effects on physical activity and development patterns. From an urban perspective, this study shows that neighborhoods with lower car traffic, higher perceived road safety, and with access to parks are more conductive to maintaining activity among the youth.

Most importantly, forms of active mobility are safe: Infectious disease researchers have found that the likelihood of infection from a passerby while walking, running, or biking is very low due to the brief exposure and the outdoor environment which limit viral load exposure (Rasmussen, 2020). According to Angela Rasmussen, “the risk of infection is much higher when different conditions are met” Those risk factors include:

- Being indoors in an enclosed space with others
- In close physical proximity (less than 2m) for a prolonged period (at minimum15 minutes) outside
- Not wearing a mask and being around those not wearing masks

During this pandemic, active mobility and recreation while wearing a mask and being socially distant is a safe and recommended activity during this pandemic since the risks are outweighed by the mental and physical health benefits.

3. Public Realm

Open spaces, streets, parks, public squares, and even malls are central to the allure of urban spaces and in the beginning of the pandemic, they emptied out almost overnight. This shift in our perception of the public realm sparked intense debate over the future of the public realm (Honey-Rosés et al., 2020). Will less people use these spaces? Will we change what we do in public? What does this mean for how our cities will be planned in the future? Perhaps the pandemic will temporarily change our practices yet leave our values and approaches unchanged in the future, some surmised (Honey-Rosés et al., 2020).

It is early to foretell the impact the pandemic will have on public spaces, but one thing is for sure, when they are open, communities are flocking to them. Parks have witnessed an increase of use during the pandemic as they are a safe mode of recreation and social distancing in the outdoors (Lennon, 2020). Specifically, residents are flocking to their smaller neighborhood parks as opposed to larger urban parks at the city level, however this is not the case for the elderly and health compromised who may not feel safe to access public space given their high-risk status. This is also not true for residents of underfunded, neglected neighborhoods who have limited access to open space, which is well maintained, well-lit and safe. Open spaces within the city are necessary to ensure social distancing outdoors as well as to provide mental and health benefits to residents while allowing the urban fabric to accommodate varied uses from all age groups and socio-demographic backgrounds (Kasinitz, 2020).

To achieve this during this pandemic, public space will need to be used at significantly lower capacities. Ironically, this vision of empty and huge plazas was celebrated during the midcentury modernist era which sought to substitute overcrowding with wide open boulevards for air and light. This movement was a common design response after the Spanish flu of 1918-19 and the spread of other communicable disease in cities historically (Kasinitz, 2020).

What if some cities do not have enough space for social distancing while moving or using the public sphere? Rhoads et al. focused specifically on the linear public realm of the sidewalk, an often-neglected piece of infrastructure when compared to parks and plazas. They produced a model which assessed sidewalk width adequacy for social distancing in ten of the most traditionally “walkable” cities and found most cities fail to meet the social distancing minimum width requirement of 3 to 5 meters (for two passerby’s including street furniture and building clearance). To solve this, they designed an open streets heuristic which can intuitively select streets for pedestrianization based on the lowest decrease in travel time (Rhoads et al, 2020). Their model shows that improving soft mobility while maintaining social distancing is possible without an overhaul of existing infrastructure.

4. Food Security

The COVID-19 pandemic has exacerbated food insecurity in urban centers because of the distribution in the food supply chain (Lal, 2020) especially in the first few months. This led to a shortage of food supplies in supermarkets and a wastage of food earmarked for the service sectors. Furthermore, the inability of migrant workers to work during the harvesting season also decreased the amount of food entering the supply chain. Lal advocates for an increase in the application of home gardening and urban agriculture programs within urban areas not only for food security but also for the provisioning of ecosystem services such as water quality, air quality, heath etc.

However, food security in urban areas goes further than just ensuring supply chains are well-functioning and supplemented with local food production. Food deserts have been also aggravated during the pandemic (Meyherson, 2020). A food desert is an area (or neighborhood) that does not have access to any fresh food grocer or supermarket within its vicinity. According to the USDA, in 2015, 12.8% of the population lived in “low income and low access areas” where people live more than a mile from a supermarket in urban areas, or 10 miles in rural areas (Meyherson, 2020). Accessibility has also dropped due to stringent lockdowns and the decrease in service of public transportation due to the pandemic and this mostly affects lower income economies. One of the largest food distribution warehouses in the world is located in Hunts Point, a neighborhood in the Bronx, NewYork. In a bitter twist of events, The Bronx is also a food desert (Meyherson, 2020). Food environment should be assessed on the neighborhood scale and take into consideration local capacity for food production to ensure resilience and community health.

5. Dynamics of Urban Transmission & Susceptibility to COVID-19

The indicators that this thesis presents lend themselves either to livability or susceptibility. Indicators of livability assess quality of life in a neighborhood whereas indicators of susceptibility assess the innate characteristics of a neighborhood which increase its susceptibility such as concentrations of elderly, lower income, health compromised etc.

A livable neighborhood may be highly susceptible to the spread and mortality of COVID-19. An example of which is a dense inner-city neighborhood with bustling sidewalks and public transportation, crowded restaurants and socializing. One can expect COVID-19 to go rampant under such conditions. Vulnerability to disease is thus sometimes at odds with the level of land use mix, social collaboration, and density needed to achieve a sustainable and livable community which benefits people's mental and overall health. Although this thesis argues that livable neighborhoods are essential for wellbeing during the pandemic, it is important to understand the risk factors which increase urban susceptibility and would call for different interventions and policies. A study on community susceptibility and resiliency to COVID-19 of US counties (Peters, 2020) found seven main susceptibility factors to COVID-19 after an analysis of 3079 counties.

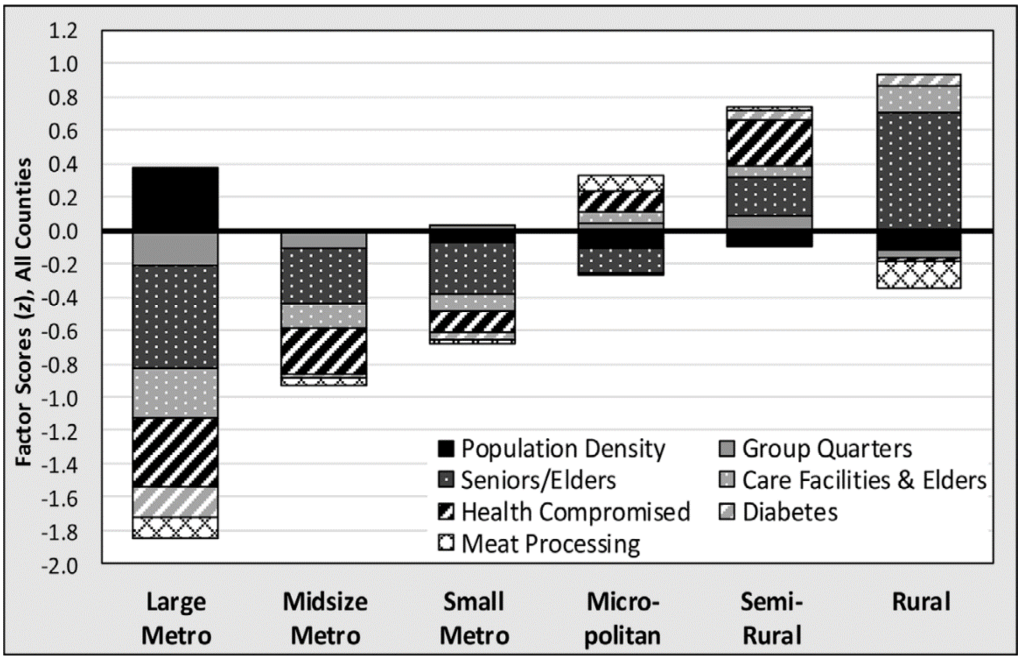

Figure 3: Susceptibility Factors (Peters, 2020)

Figure 3 shows the proportion of each of the seven risk factors affecting counties on the urban-rural spectrum. Non-metropolitan counties are more susceptible to COVID-19 than metro counties due to larger populations of elderly, health compromised and vulnerable care facilities. On the other hand, large metros are less vulnerable (negative z-scores) due to their overall younger and healthier populations but experience increased risk correlated with overall population density. This means that when outbreaks take place, they are less fatal due to the younger population but could infect more people in total compared to an outbreak in a rural county. In fact, rural counties have the highest share of 'very high risk' with over 10% of rural counties exposed to very high risk of susceptibility to COVID-19 (Peters, 2020).

The risk factors in and of themselves represent different environmental and demographic factors which differ between locations. These may differ significantly between region and more so, countries. For instance, it is not the mere existence of a care facility that would make a neighborhood vulnerable or unlivable, these risk factors simply identify where extra precautions may be needed to prevent new outbreaks or extinguish existing. According to these risk factors, a highly resilient place would have only young populations with impeccable health, low enough density yet with access to medical facilities and no group quarters or meat processing plants. This is not feasible, and it is not the intention of this thesis to promote such formats of settlement. A compromise must be made according to the local situation of the virus and the maximum tolerance of risk a region is willing to endure. The approach to creating livable neighborhood is similar, balancing vulnerability to COVID-19 while maintaining as maximum levels of livability not only during the pandemic and after.

6. Lessons learned: final list of indicators

The following table presents the final list of indicators to be used in constructing the index in the next chapter. The indicators were grouped by their categories in a similar method to previous indices mentioned in the literature review and the consultation of the committee members. This list represents the theoretical list which was constructed based on the literature review. Some indicators and grouped were slightly redefined to fit the available data as will be discussed in the next chapter.

Legend		Existing livability indicators
		Existing indicators which are important during COVID-19
		New COVID-19 livability indicators

Group		Indicator	Metric
Urban Form		Walkable Street Blocks	% ‘walkable’ street blocks < 240m in length
		Mixed Use Neighborhood Centers	% HH within 400m of non-residential land use
		Cul de sac	% streets terminating in a cul de sac
		Sidewalk Width	pedestrian only width (m)
		Bike Lanes	length of bike lanes within neighborhood (m)
		Highway proximity	% households more than 500m from a highway
		Open/Slow Pedestrian Street	% residential land use within 400m of a open/slow pedestrian street
Housing		Housing Diversity	Simpson’s diversity index for number of bedroom diversity
		Household Condition	% of Households that do not need major repair
		Household Density	Number of People/ HH
		Housing Affordability	%households that spend less than 30% of total income on housing
		Housing View	represented by tree cover
Amenities		Access to centers	% HH within 1600m of community centers
		Supermarkets	% residential land use within 400m
		Elder Care Facilities	% of total elder care facilities within neighborhood
Employment		Employment Density	Combined employment density for retail, entertainment, and educational uses (jobs/acre)
		Employment Proximity	% of people working within the same neighborhood
Education		Elementary and Secondary School	% of households within 1600m
Open and Public Space		Park Access	% Households living within 500 m of a park, beach, or open space greater than 1 acre
		Tree Canopy	Tree Canopy % with 40% considered max optimal level.
Health		Noise Pollution	Neighborhoods with acceptable levels of noise pollution <70dB LAeq

		Air Pollution	Neighborhood with acceptable levels of air pollution PM2.5 < 25
		Medical Facilities	Decaying score based on trip length (Paez et al. 2010)
		Urban Agriculture	% households within 1km of community garden
		Diabetes	% households with diabetics
		Obesity	% households with obesity

Table 2: Theoretical List of Indicators

CHAPTER III

CASE PROFILE

Montreal is the second largest city in Canada after Toronto, and the largest city in the Province of Quebec. Founded in 1642, as Ville-Marie, it was later named Montreal after the Mount Royal, the triple-peaked hill in the center of the island. The city began as a French missionary settlement but soon became a trading hub for fur and agriculture given its prime location on the St. Lawrence river, which provided access to the Great Lakes and the rest of the American Continent for trade and transport. Montreal has a diverse urban fabric which portrays its rich history. The old port, part of the Ville Marie borough, was the initial French settlement in the 17th century and boasts gridded cobblestone streets with brick and stone three-story houses. Today Ville Marie, the downtown, juxtaposes the old port with skyscrapers and wide boulevards nestled by the southern side of Mount Royal. The surrender of Montreal in 1760 marked the end of New France and the beginning of British colonial rule. Most of the expansion of the city took place under British colonial rule during the early 19th Century.

During this time, growth in Montreal exploded with the building of rows of triplex housing blocks with the now iconic external staircases. Many units can be incorporated into a triplex while maintaining access to the street, light and in the lower apartments, and front yards. Most triplexes have three floors and two apartments on each floor, with a similar price of a traditional single-family home. This configuration provided an economic boost to the generations of Montreal immigrants who bought these homes, lived in one apartment, and rented the remaining apartments to other immigrants, contributing to the layering of different cultures and socio-economic groups early on (Dewolf, 2020). As a result, neighborhoods were diverse and were very conductive to street life, diversity, and connectivity (DeWolf, 2020). This holds true to this day where Little Portugal, Little Italy, and China Towns mesh in a homogenous urban fabric.

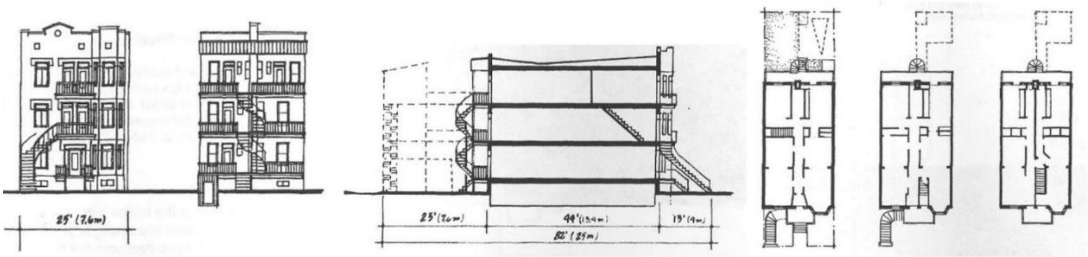

Figure 4: Plans of Plex Housing in Montreal (Dewolf, 2020)

The Island of Montreal, also known as the agglomeration of Montreal, is not all under the same political jurisdiction. The Ville de Montreal, the city itself, extends over 19 boroughs. After a brief merger in 2002, other boroughs de-merged from the city in 2006 into independent towns and cities. These are predominantly anglophone suburb communities in the West of the island who desired some independence from the primarily Francophone city. The most prominent difference between the towns and the city is the change in the typology of urban development, Westmount for instance is an affluent suburban neighborhood within the center of the downtown, as well as Mont-Royal which was designed on the tenets of Garden City and City Beautiful Movement in contrast with the adjacent high-density mid-rise apartment complexes of Cote de Neige and the row-plex housing of Outremont (Town of Mont Royal, 2020).

Montreal was chosen as a case study for this thesis due to its diverse urban fabric, eclectic population, its reputation for lively neighborhoods (as discussed later in the thesis) and most importantly, data availability. Montreal as a city is highly livable on the world stage, and in 2019 ranked 20 and 21 worldwide in the EIU Livability index and the Mercer Index respectively. It is also considerably more affordable than the other large cities in Canada and has a concentration of reputable higher education institutions in both French and English that attract talent and business from around the world. The city also actively worked towards improving the cityscape for livable outcomes. In the Montreal Master Plan, the seven goals encompass creating diverse and complete living environments, showcase the city's natural and built heritage and health environment and create dynamic employment areas within a prestigious city center. All of these are connected by efficient and sustainable transportation networks (Montreal Master Plan, 2002). Figure 5 below labels the boroughs and towns of the agglomeration of Montreal, and their geographic limits.

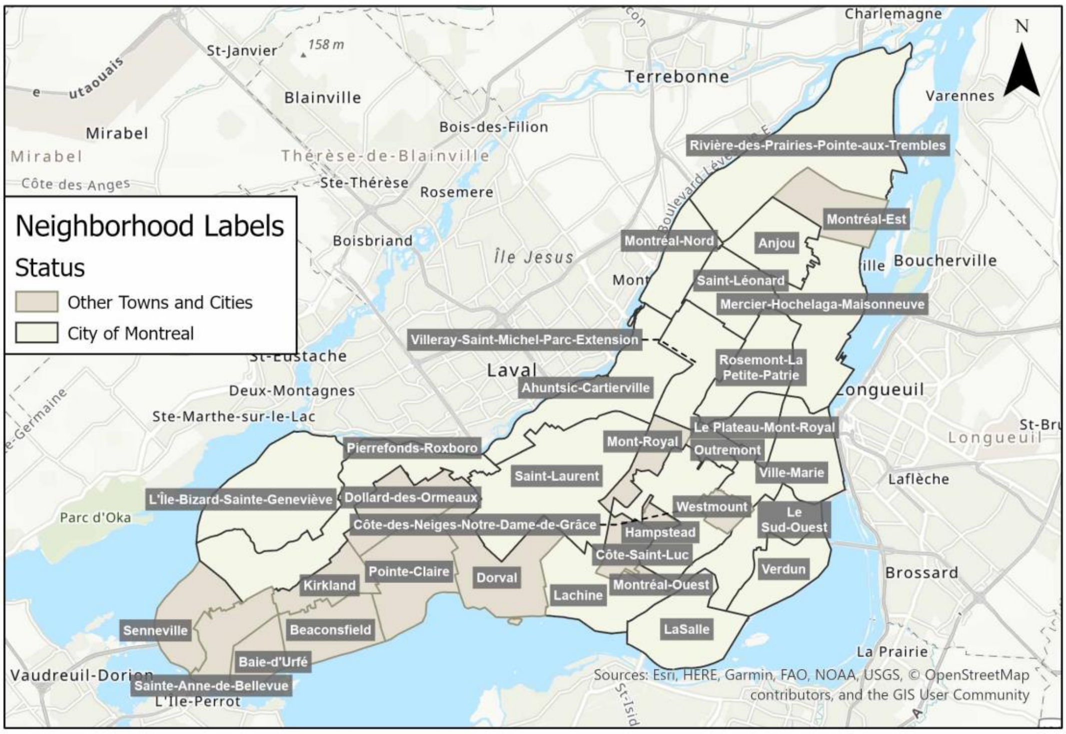

Figure 5: Neighborhood Labels and Jurisdiction

A. Research design

This thesis studies the entire island of Montreal including towns that may be jurisdictionally separate, since there is more diversity in urban form and in other metrics that provides the index with more relevant comparisons. Furthermore, the towns and the city are strongly interconnected through jobs, recreation, infrastructure and even services. Studying the city by itself would not give a complete view of the dynamics of urban living within the Island. The rest of the chapter presents the methods and results of the indicators and metrics used to calculate the index of livability on the scale of the island agglomeration of Montreal.

All the data obtained was open-sourced, as detailed within each section. GIS and Land Use Data was sourced from donnesquebec.com, the open data portal of Quebec.

Data on Housing and Employment was extracted from the 2016 Canadian Census, and datapoints on amenities were extracted from Open Street Maps.

The metrics were defined in a way that most would not need normalization or any extra standardization. For example, the metrics that consider a percentage of households within a certain distance are designed so that 100% is optimal and the highest possible value whereas 0% is the lowest possible indicator. In this case, normalization is not necessary since the data fits between the 0-100% score of the final index. For other indicators like Tree Canopy, Min-Max normalization is performed since there is consensus in the research on which number is the optimal percentage. Indicators that have no measure of an “optimal” are omitted from the final index and used later in the discussion to compare the livability index to the demographics. Examples include the data on managerial workers, knowledge workers, percent diabetics, percent obese, percent elderly and percent poverty. These metrics should not be graded on the bases that a certain number is optimal because there is no consensus on what percent of elderly in a neighborhood is ‘too much’.

The revised list of indicators below reflects only metrics which are measurable and objective and fitting with the data. A new group, ‘mobility’ is introduced since the data sets available are mobility specific. Cul de Sacs and walkable street blocks were removed since they are accounted for within the Walk Score indicator. ‘Housing view’ is difficult to generalize on a neighborhood level and so the tree canopy was considered as an important proxy since it provides a measure of street trees which contribute positively to mental and physical health (Amerio et al., 2020). Human demographic indicators such as occupation type, age and health were taken out of the final index since they cannot be categorized as ‘good’ or ‘bad’ but they were discussed in the literature review in order to highlight important metrics during COVID-19.

Group		Indicator	Metric
Urban Form		Mixed Use Neighborhood Centers	% HH within 400m of non-residential land use
		Sidewalk Width	pedestrian only width (m)
		Highway proximity	% households more than 500m from a highway
		Shared Street	% residential land use within 400m of a open/slow pedestrian street
Mobility		UrbanTransit	% Transit Score
		Walkability	%Walk Score
		Bike Lanes	%Bike Score
Housing		Housing Diversity	Simpson’s diversity index for number of bedroom diversity
		Household Condition	% of Households that do not need major repair
		Housing Affordability	%households that spend less than 30% of total income on housing
		Housing Suitability	% Dwellings considered uncrowded by Canadaian
Amenities		Access to centers	% HH within 1600m of community centers
		Supermarkets	% residential land use within 400m
		Elder Care Facilities	% of total elder care facilities within neighborhood
Open and Public Space		Park Access	% Households living within 500 m of a park, beach, or open space greater than 1 acre
		Tree Canopy	Tree Canopy % with 40% considered max optimal level.
Health		Noise Pollution	Neighborhoods with acceptable levels of noise pollution <70dB LAeq
		Air Pollution	Neighborhood with acceptable levels of NO2. Proxy Highway Proximity
		Medical Facilities	Decaying score based on trip length (Paez et al. 2010)
		Urban Agriculture	% households within 1km of community garden
Employment		Employment Density	Score by commute times availbe on each census tract
Education		Elementary and Secondary School	% of households within 1600m

Table 3: Final List of Indicators

B. Indicator Calculation

1. Urban Form

a. Mixed Use

Mixed-use neighborhoods are imperative to resilience and livability and the mix of uses has been identified in livability indices before the pandemic (LEED ND, 2014; AUO, 2020; Stanislav and Chin, 2019). Furthermore, the pandemic has revealed the mixed-use neighborhood as the model of urban recovery of many cities around the world: Paris plans on becoming 15-minute city; Melbourne is aiming for a 20-minute city; and nearby Singapore is planning for 20- minute towns in a 45-minute city. The goal is to put accessibility to live, eat, work, and play within a 15-minute radius – to create lively decentralized (yet connected) neighborhoods while reducing reliance on private automobile trips. Interestingly, the pandemic might make this more possible. With most people teleworking, there are less daily long commutes between residential suburbs and commercial downtowns and therefore less need for residents to leave their vicinity daily. However, this is inherently not possible in every neighborhood as historically commuter, suburban neighborhoods were designed for just that - commuting- and are not within the walking distance of 400m to any non-residential land use. The mixed use indicator is calculated as the percentage of residential land use within 400m of mixed use.

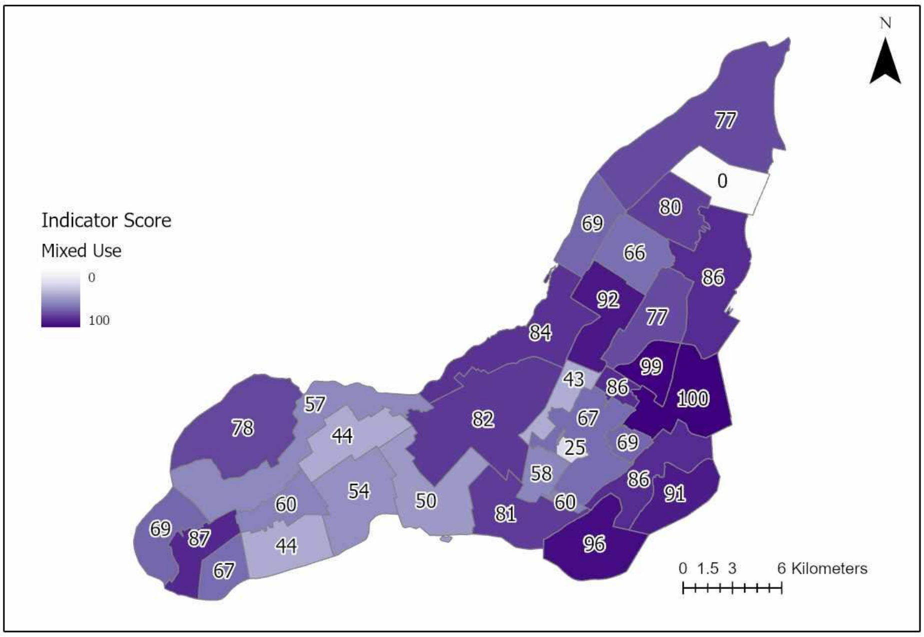

Figure 6: Mixed Use Score Map

Prominent outliers are Montreal Est, with a score of 0 and Hampstead with a score of 25. The former is a zoned as an industrial area on the land use map of Montreal and the latter is a small purely residential town. Unsurprisingly, the low-density west island does not facilitate the economics needed to support mixed use land use.

b. <u>Sidewalk Width</u>

Sidewalk width is a crucial element of neighborhood livability during a pandemic. According to the researchers at the University of Manitoba, the risk of catching the virus by walking past someone on the sidewalk is extremely low (Coombs, 2020). However, sidewalk widths that meet the minimum standard of social distancing help residents in the neighborhood avoid unnecessary risks while walking on the sidewalk and could reduce fear associated with sidewalk crowding. This ensures a lively streetscape which tends to the needs of residents safely. The minimum width of sidewalks for social distancing is taken as 3m (in the absence of street furniture) for two pedestrians. This is adapted from a study that assessed sidewalk networks in 10 major cities around the world for social distancing (Rhoads, Solé-Ribalta, González, & Borge-Holthoefer, 2020).

The first step to calculating the index score for sidewalk social distancing was to find the average width of the sidewalk polygons. The polygons are available from the City of Montreal's open data platform, donneesquebec.ca. Since sidewalk polygons are mostly rectangles with significantly long lengths compared to width, width can be calculated by dividing double the area by the perimeter of the polygon (Rhoads, Solé-Ribalta, González, & Borge-Holthoefer, 2020).

$$w = \frac{2A}{P}$$

The calculations were done in GIS using the field calculator. The polygons that met the threshold of 3m were selected and the total length of sidewalks by neighborhood was calculated. The index score was calculated by finding the length of sidewalks that meet the 3m threshold as a percentage of the total sidewalk length per neighborhood. This normalizes the value per neighborhood and the value is not distorted by the original length and number of sidewalks which differ between neighborhoods.

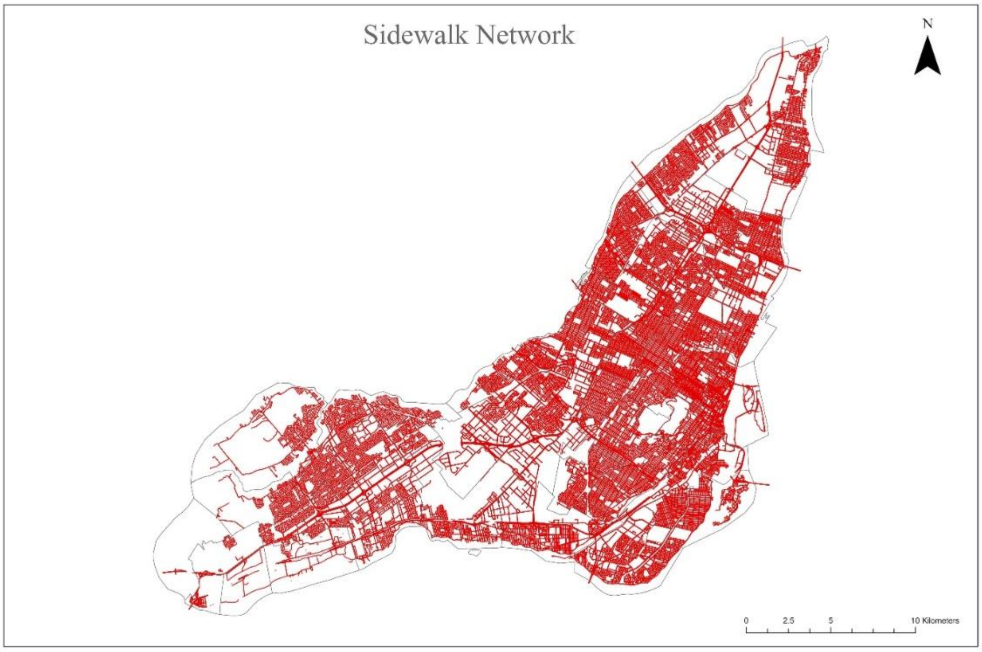

Figure 7: Sidewalk network Montreal

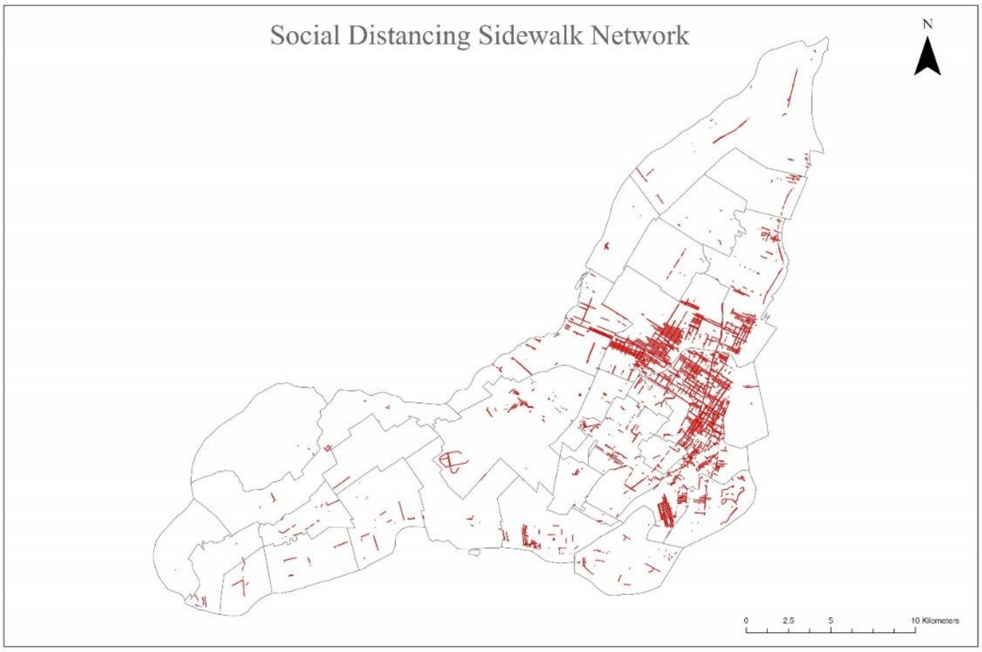

Figure 8: Sidewalk network at 3m threshold

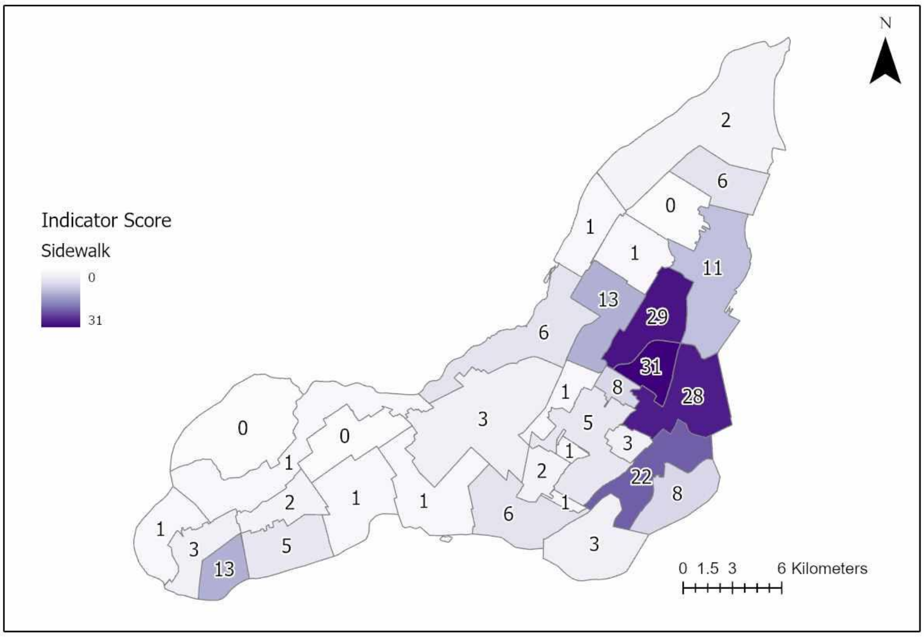

Figure 9: Sidewalk Score Map

Figure 9 shows the index score out of 100. Most neighborhood sidewalk networks fail to meet the 3m requirement. Even the most pedestrian friendly neighborhood scores only 30%. For comparison, the entirety of the sidewalks in Paris meets the 50% mark.

c. <u>Shared Streets</u>

Large cities like Paris and London closed parks at the beginning of the pandemic due to fears of crowding, which inadvertently led to crowding in smaller neighborhood parks. When those got too busy as well, people started using the streets. However, leisure activities are not possible on all streets, which led to the demand for more pedestrian open space outside of a park. The pandemic instigated the creation of slow, shared, and open streets all around major cities in the world. Oakland, California made headlines when it announced that 10% of its streets will be closed to cars. Paris ditched curbside parking for bike lanes and wider streets. New York closed 100 miles of streets to cars and opened them for the people. In the global south, Bogota and Mexico City also did the same (TransAlt, 2020).

Outdoor recreation and mobility are inherently linear in the case of jogging, walking biking and strolls. Planners may thereby need to give greater priority to the provision of a decentralized yet connected system of green spaces and pathways (Lennon,2020). Montreal was quick to react and added to its existing network of shared and open streets. The city has existing 'green alleys' which are greened and accessible interstitial spaces amidst residential alleys, as well as pedestrianized streets which allow for slow car access and are seasonally closed to cars. Both the green alleys and shared streets shapefile datasets were combined and buffered to calculate area coverage. The shared streets score is calculated as the percentage of residential land use within 400m (extracted from literature review) of a shared pedestrian street or green alley.

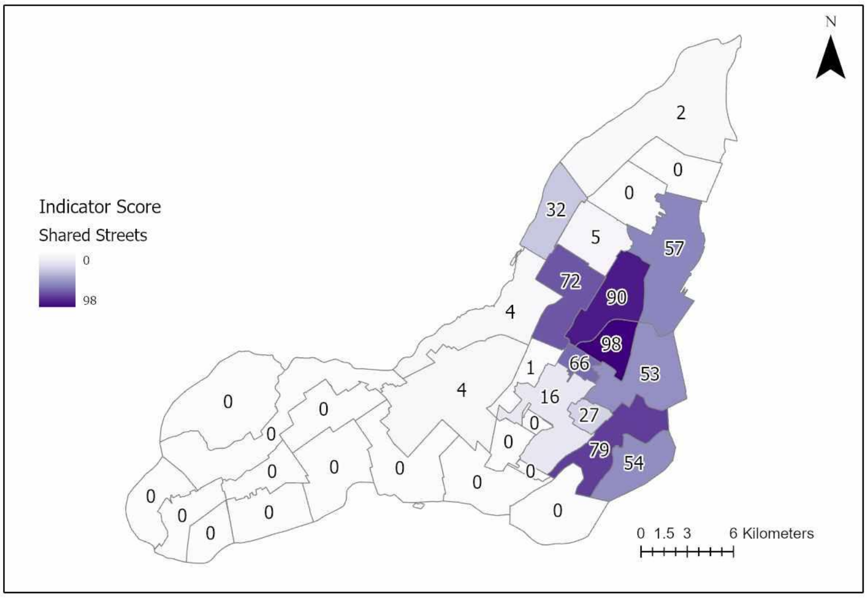

Figure 10: Shared Streets Score Map

One neighborhood's score vastly surpasses the rest: Le Plateau, because it is home to most the city's green alleys. This is because the building typology of the plateau consists of low-rise row apartment blocks and 'plexes' packed along tight street controls. These blocks require ventilation and light in between and it is those intra-building block spaces, which formed from setbacks and building regulation, that became accessible green alleys. This isn't as easy to do in in other neighborhoods such as Ville Marie, the downtown, in which buildings are taller and have larger footprints, and do not create interstitial spaces.

2. Mobility

a. <u>Walkability</u>

This thesis uses Walk Score as a proxy for walkability at the scale of the neighborhood in Montreal. This methodology was also employed by the City of Toronto for calculating their Neighborhood Equity Index (City of Toronto, 2014).

Walk Score uses a patented system to analyze walking routes at each address. Points are awarded on decay function basis where amenities within a 5min walk (400m) are awarded the highest points with no points awarded beyond a 30min walk (2.4km). Walk Score also measures the pedestrian suitability of the urban form using road metrics such as block length and intersection density (Walk Score, 2020). The scores are publicly available for all cities and neighborhoods in North America. The Walk Score was adopted for each neighborhood and town on Montreal Island. For neighborhoods and towns with no discrete data points, Walk Score can automatically calculate the score for any coordinate. Coordinates were also taken on random streets to confirm the accuracy of the summarized neighborhood scores.

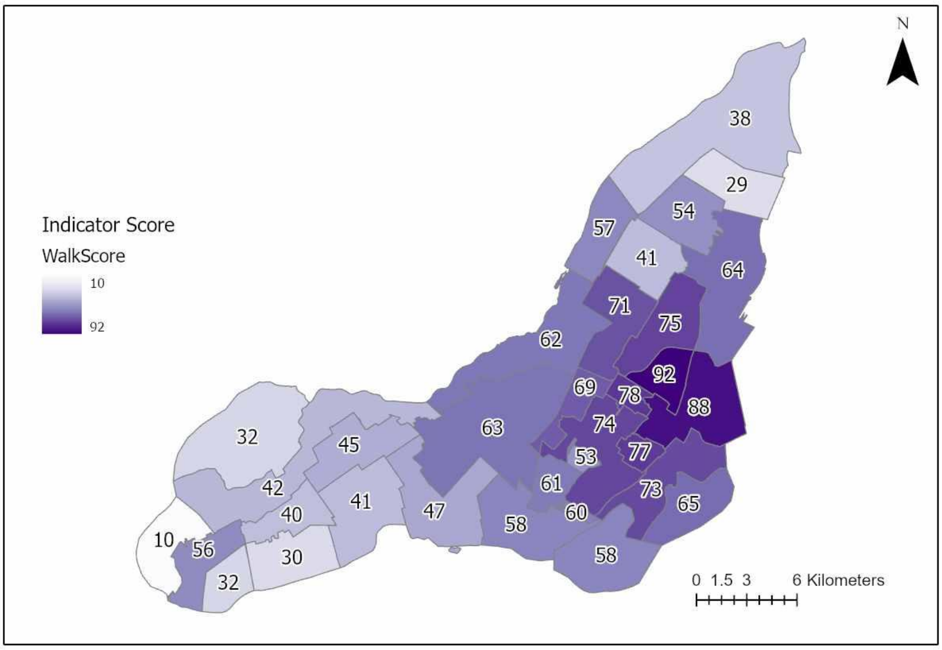

Figure 11: Walk Score Map

Figure 11 shows the highest scoring neighborhoods were Ville Marie, and Le Plateau the densest central districts of the city with strong mixed use and commercial corridors. Both these boroughs existed before the age of the automobile and retained their human scale in urban design which are more walkable.

b. <u>Transit share</u>

The quality of urban transit is one of the most important elements of livable cities (Fu, Yu, & Zhang, 2019; Stanislav & Chin, 2019: LEED ND, 2014). City-wide transit is assessed by route frequency, number, and location of stops and mode of transit rail, bus, tram, metro etc. A neighborhood with good transit would have a variety of transit options with many stops and frequent servicing. Like Walk Score, Transit Score assesses public transit service in neighborhoods of major cities. It calculates a 'usefulness' score defined by distance to the nearest stop on the route, the frequency and the type. It also uses publicly available GTFS format supplied by transit agencies. To normalize the raw scores for each transit route, the index uses a 'perfect score' location as a benchmark. To achieve this, the index averaged the Transit Score of five cities with comprehensive transit data: San Francisco, Chicago, Boston, Portland, Washington, D.C. (Walkscore, 2020).

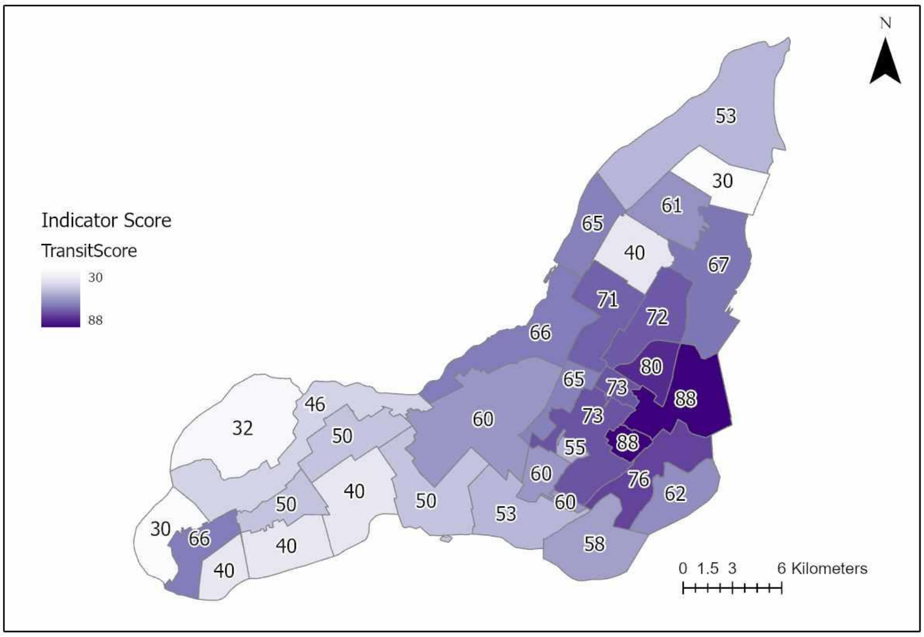

Figure 12: Transit Score Map

Figure 12 shows a similar pattern to Walk Score: the central neighborhoods have better transit options. The slightly further dense residential neighborhoods with mostly commuting working class have a satisfactory transit system in place. The suburbs in the west of the island score significantly lower for public transit since sprawling development does not have the density necessary to support transit on the large scale.

c. Bike-ability

Biking and other forms of soft mobility such as scooters, are essential in cities. They play a role in solving 'last-mile' problems in transit and provide a healthy, efficient, and low impact method of commuting that reaches areas that are too long to reach on foot and might not be as quick to reach by transit. The Bike Score index, also by the company behind Walk Score and Transit Score, is based on four equally weighted components: bike lanes, hills, destination and road connectivity and bike commuting mode share. The index does not focus only on areas with bike infrastructure since low traffic streets with high connectivity already lend themselves very well to biking without the need for separate bike lanes.

Montreal scores highly on Bike Score compared to other forms of mobility because the roads are wide and well-connected and has a good bike sharing infrastructure with separated bike lanes on main arteries in the city, even the suburbs in the west maintain a score above 50.

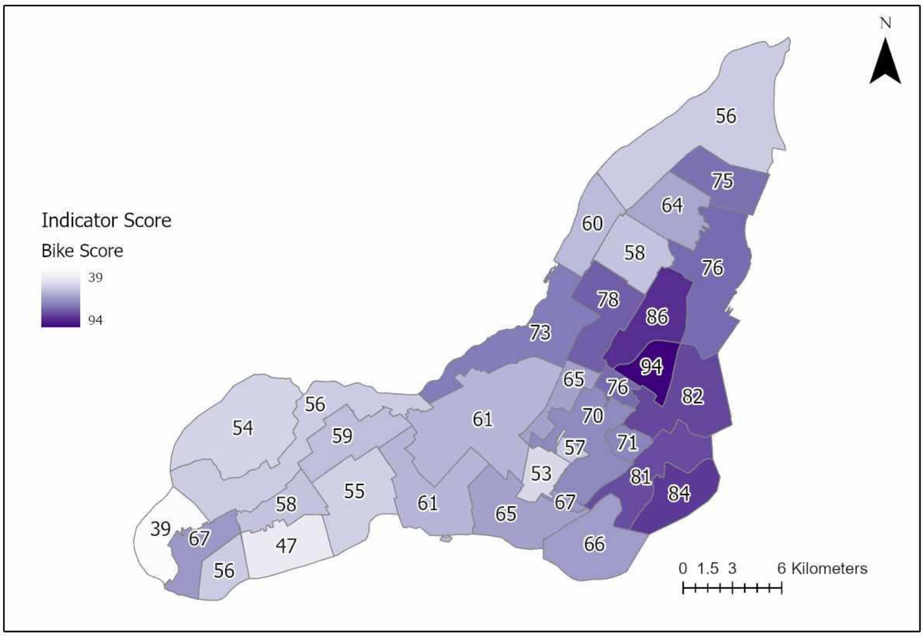

Figure 13: Bike Score Map

3. Housing

a. <u>Housing Suitability</u>

As mentioned in the literature review, crowding and not density is a risk to the spread of COVID -19 (Maroko, Nash, & Pavilonis, 2020). This study considers the indicator housing suitability as a proxy for crowding within the dwelling. As per the National Occupancy Standard in Canada, housing suitability assesses the required number of bedrooms for a household based on the age, sex and relationships among household members (StatCan, 2013). A dwelling is considered suitable if it meets the following criteria:

1. A maximum of two persons per bedroom.
2. Married couple/ partners share a bedroom.

3. Household members over 18 have a separate bedroom.
4. Household members under 18 may share a bedroom if they are from the same sex.
5. Household members below 5 years old may share a bedroom if it decreases total number of bedrooms needed.

This standard differs from the United Nations definition of crowding where three or more persons per room is considered not-suitable (UN, 2017) However, according to the UN, this definition may be lowered or raised for national use since crowding is highly dependent on local factors in addition to age and sex. Canada is a developed country with household sizes on average lower than other developing countries so the housing suitability metric of between 1-2 people per room maximum is a good proxy for crowding especially since this thesis acknowledges that overcrowding per room is detrimental to livability during COVID-19 since according to the CDC, infected individuals infect around 50% of their household (Grijalva et al., 2020). Therefore, having enough room to isolate in the case of exposure is imperative to lessen the spread of COVID-19 within the household and within the community.

The data was extracted from the 2016 Census using the Census Mapper API to select the data at the census tract level. According to Statistics Canada's Illustrated Glossary, a census tract is defined as an area that is small and relatively stable with a population between 2,500 and 8000 and is the smallest unit that will be used to analyze census data. Montreal Island is considered as a census agglomeration and usually referred to as the agglomeration of Montreal. The island contains the Ville de Montreal (The City of Montreal) which is considered a census subdivision as well as towns and cities on the island which are also census subdivisions (StatCan, 2016).

The housing suitability score was calculated by finding the percentage of dwellings which is considered suitable on the level of the census tract. A score of 100 indicates that none of the dwellings are considered unsuitable. Then, the dissolve tool in ArcGIS Pro was used to join census tracts based on the neighborhood they are in and to find the mean of the suitability score. It is important to note that though this method might overgeneralize or undergeneralize scores between blocks in the neighborhood, it provides a basic assessment of overall housing suitability trends of the neighborhoods.

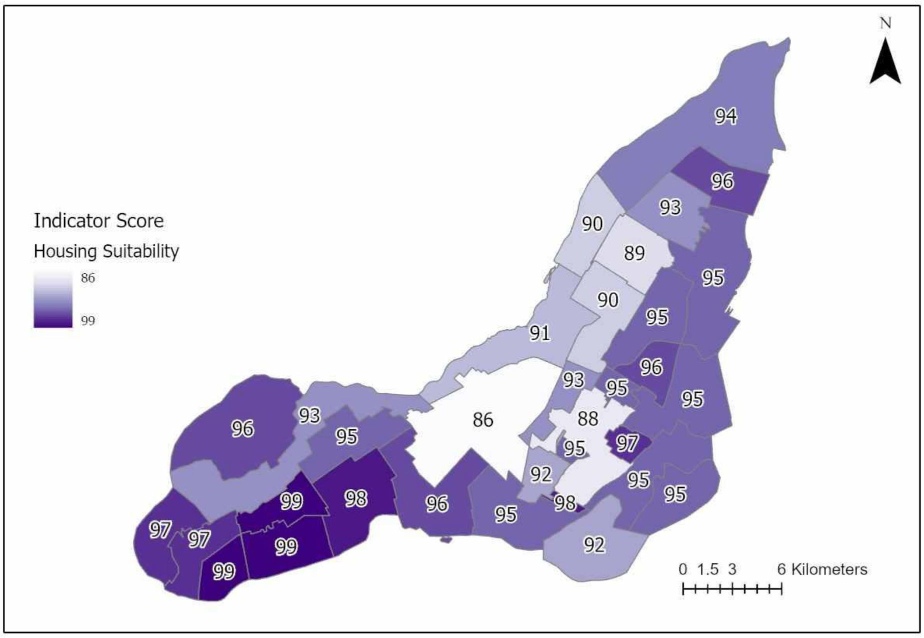

Figure 14: Housing Suitability Score Map

Neighborhoods with higher percentage of unsuitable housing are correlated with higher immigrants, lower average income, and more working-class families (CBC, 2020). Cote des Neige (88) is a dense residential neighborhood habituated mostly by students and immigrants, which may share rooms and contribute to overcrowding within the home. The same is true for Saint Laurent (86) where housing is cheaper ye still close to the jobs in the city.

b. Housing Affordability

Generally, housing affordability is defined as being achieved when expenditure on housing is less than or equal to 30% of income (AUO, 2020). The data on affordability was downloaded using the Census Mapper API, under shelter cost: spending less than 30% of income for owner-tenant households with non-zero income. The table was then merged with the GIS shapefile and dissolved by neighborhood name. Then the percentage of households in affordable housing was calculated by dividing the number of those that spend less than 30% on housing by the total number of households.

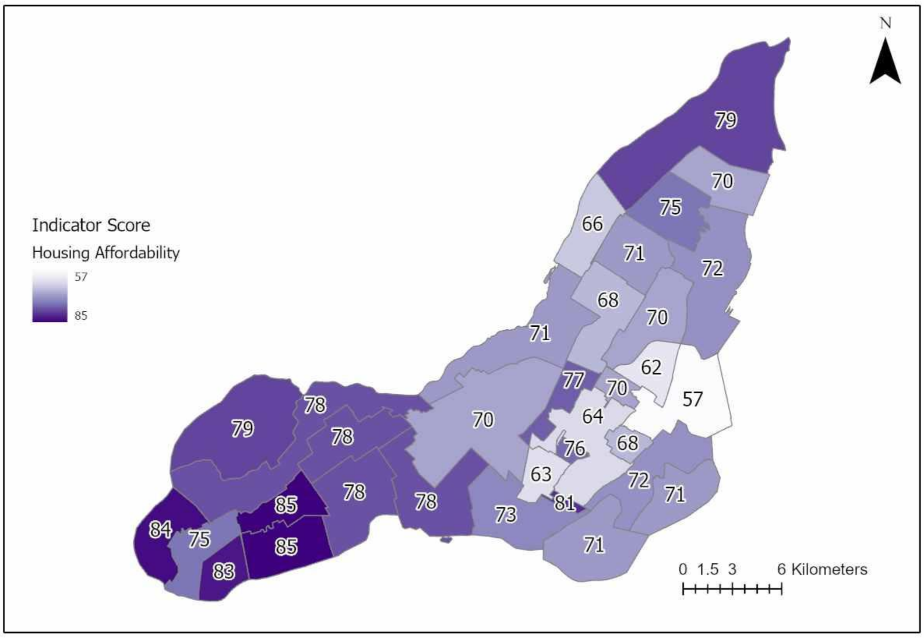

Figure 15: Housing Affordability Score Map

The suburbs on the west of the island score higher because those with higher wages and bigger families concentrate in the suburbs and towards the north of the island where housing prices are cheaper and attract more working-class families. In the central district there are two groups, students, young entrepreneurs, and the creative class who are choosing to spend more on housing to remain downtown and those in the old port of Montreal, the historic touristic neighborhood with exorbitantly high housing prices but that is also home to those of higher income who choose to remain within the city.

c. Dwelling Diversity

Dwelling diversity plays an important role in neighborhood diversity and vitality (Stanislav & Chin, 2019; LEED ND, 2014). The availability of different options of units from studios to larger 4 bedroom and more apartments ensures a diversity in household ages and sizes. A truly diverse neighborhood and livable neighborhood is hospitable to students, young couples, bachelors, and families alike. This is usually difficult to achieve, due to often conflicting needs of different demographics.

The data available in the 2016 Canadian Census is the proportion of households by bedroom number. There are five dwelling types: Studios, 1 Bed, 2 Beds, 3 Beds, 4+ Beds. The Simpson Diversity Index and evenness index were used to calculate scores for diversity. Simpson’s index is mainly used in the field of biology to calculate species diversity and richness within an ecosystem. However, urban planners have employed the index to measure housing and even land-use zoning diversity in cities (Talen, 2005; Byrne& Flaherty, 2004; Corner& Greene, 2015). There are two similar yet slightly different equations to calculate Simpson’s Diversity Index. Lower case n is the total number of dwellings of a particular type and N = Total number of dwellings of all types per neighborhood.

$$D = \sum \frac{n^2}{N^2}$$

$$D = \frac{\sum n(n-1)}{N(N-1)}$$

Theoretically, the scale of Simpson's D is between 0 and 1 where a score of 1 denotes maximum diversity (in the case of 1 per group) and 0 denotes no diversity. One is a theoretical number, and the maximum achievable D is 0.8 with larger numbers. In order to achieve a scale from 0-1 Simpson's Evenness Index - $E = (1/D)/S$ – is used, where S = total number of classes (5 in this case). E ranges between 0-1 and does not need any normalizing and is just multiplied by 100 to get the final score.

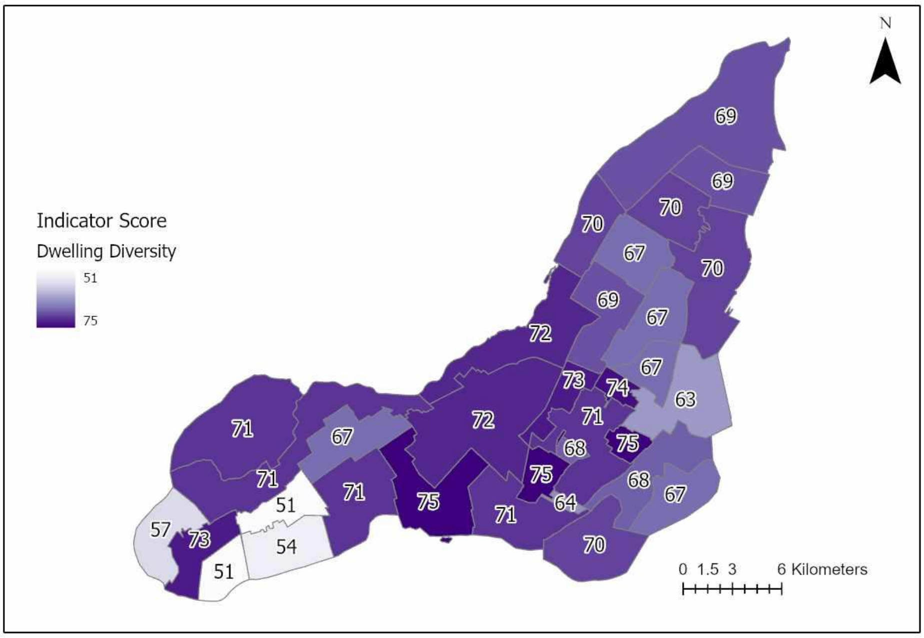

Figure 16: Dwelling Diversity Score Map

The patterns of dwelling diversity on the scale of the island are surprising, the highest diversity is seen in more single-family housing development typologies. This could also be because in the high-density areas with younger populations, there is a significantly larger demand for smaller studios and one-bedroom apartments.

d. Dwelling Condition

Statistics Canada defines dwelling condition as one of three categories: regular maintenance needed, painting or furnace cleaning. Minor Repairs needed, loose tiles or steps. And major repairs needed such as in dwellings with defective plumbing, wiring and structural damage. The index considers good dwelling condition as those without major repairs. The indicator is the percentage of total households that do not need major repair. Where the higher the number, the better the condition.

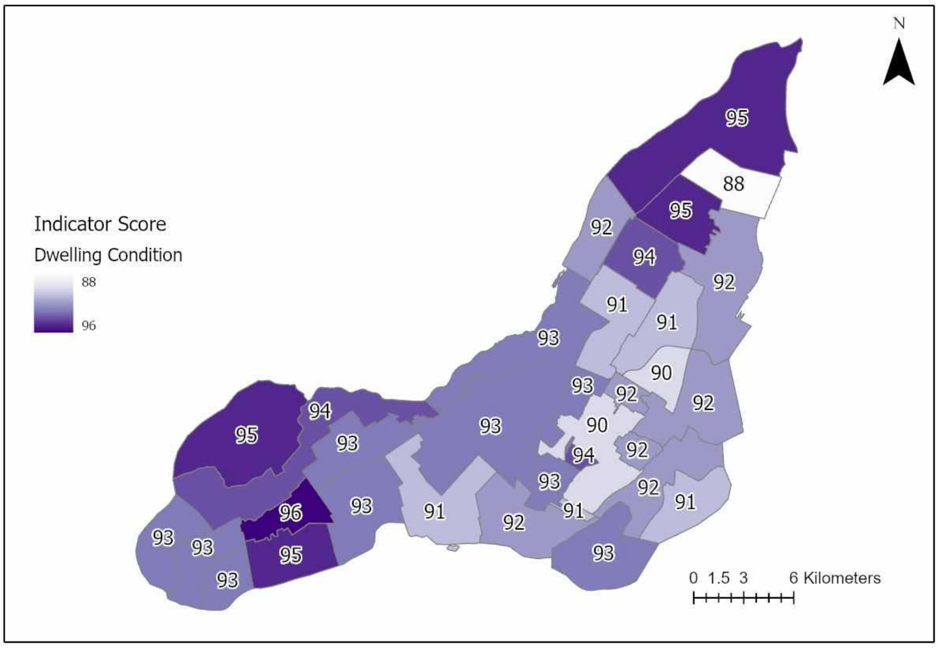

Figure 17: Dwelling Condition Score Map

The lowest results are found in the older neighborhoods where buildings deteriorate with age, as well as more low income and industrial areas where residents and landlords might not prioritize home maintenance.

4. Amenities

a. Supermarket Access Indicator

COVID-19 increased the importance of accessible supermarkets since a majority of people are now working from home and are living more locally. Access to supermarkets is defined as the percent of residential land use of a neighborhood within 400m of a supermarket. The data was exported from Open Street Maps using Overpass Turbo. Two search queries were used: “supermarkets” and “convenience stores”. Open Street Maps defines supermarkets as large mainly food retailers and convenience stores as smaller grocers which sell a limited selection compared to supermarkets. The JSON file was then imported into ArcGIS and buffered 400 m and intersected with the residential land use layer. The score is out of 100 with 100 meaning that 100% of households in the neighborhood have access to a supermarket or convenience store within 400m.

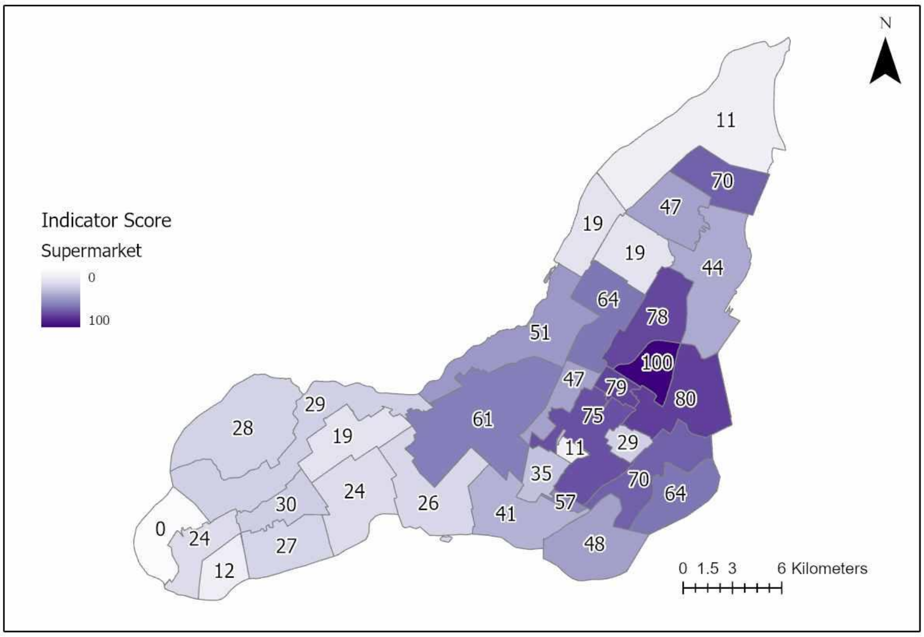

Figure 18: Supermarket Score Map

The scores are consisted with the profiles of the neighborhood with residents of Le Plateau having full access to supermarkets. Access is lower outside the city center and from major roads.

b. Access to Centers

Access to community centers is an important indicator for the strength of community and collaboration in a city (AUO, 2020). The indicator is defined as the percentage of residential areas per neighborhood within 1600m from a community center. This is an acceptable commute for important but less frequent destinations (AUO, 2020). Furthermore, 1600m is a radius that serves a sufficient density of residents, any less would be too little. Similarly, the data was also exported using Overpass Turbo queries for "town hall" and "community center."

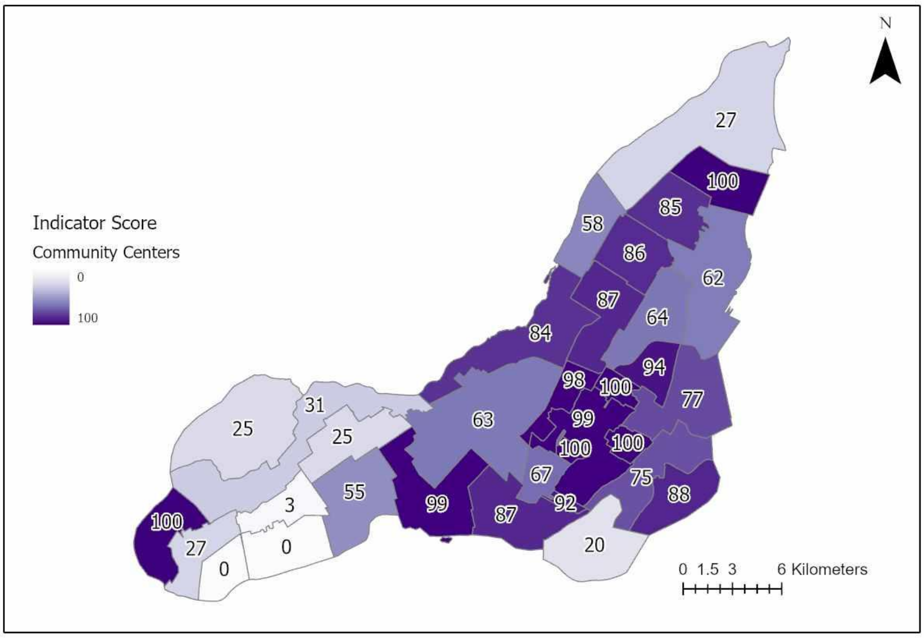

Figure 19: Community Center Score Map

As shown in Figure 19, most neighborhoods are well serviced by community centers especially in the center of the island. LaSalle is an interesting outlier with a score of 20, since there is only one town hall at the edge of the canal this could be a result of residential zoning filling up the neighborhood center.

c. <u>Elderly Facilities</u>

Although the elderly are considered highly vulnerable during the pandemic since there is a concentration of high-risk individuals within a limited indoor space, the ability to age in place remains important (AUO, 2020). This is also an important indicator since the elderly are subject to higher complications due to COVID-19 in comparison to the average population. This does not mean that neighborhoods with more elderly care facilities are more vulnerable. Outbreaks are usually contained within the facility and the staff due to the isolated nature of the facilities. This indicator is added to the index to reflect the ability to age in place and is removed while assessing livability during the pandemic since the elderly are highly vulnerable. The indicator is defined as the percentage of residential areas per neighborhood within 1600m from an assisted living facility for seniors.

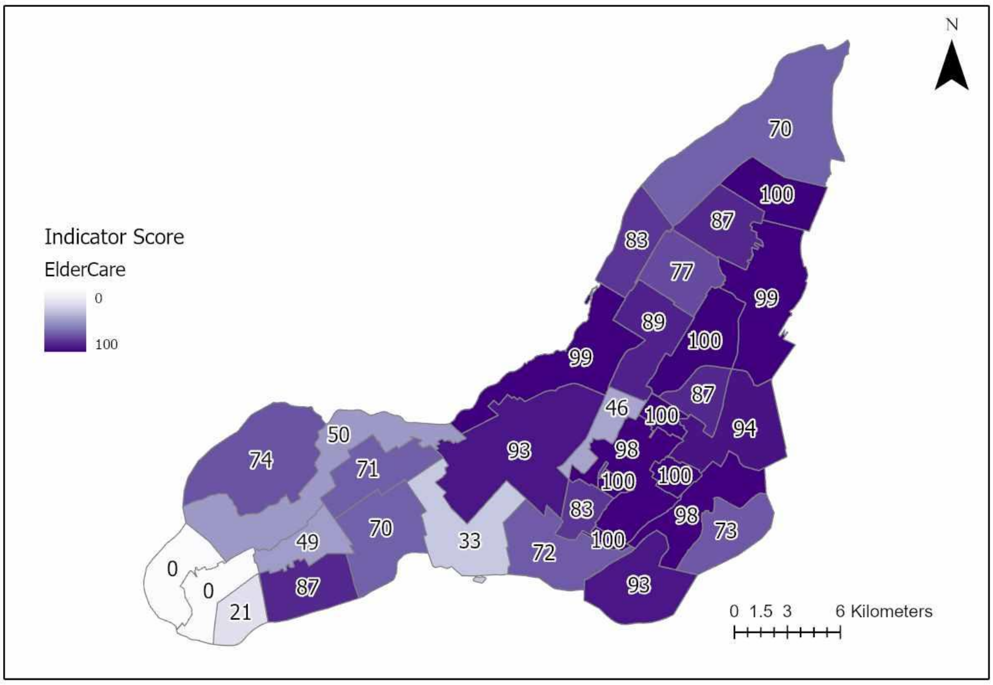

Figure 20: Elder Care Score Map

Elderly facilities are well spread out in the city with the exception of Dorval (33), the airport and industries are located there, and the Town of Mont Royal (46) since it is a private town and may decide not to build elderly care as opposed to residential housing. Senneville (0) and Sainte Anne de Belevue (0) are mostly non-residential and do not have elderly residences.

5. Green Space

a. Tree Canopy

This indicator is used to capture the effect of trees on the population in a neighborhood. Tree cover and other urban greenery contributes significantly to neighborhood livability in a variety of ways. Trees, especially large and mature trees, contribute positively to the environment by filtering pollutants and removing carbon dioxide from the air. They also mitigate the urban heat island effect, flooding, and promote biodiversity. Most importantly, they play a large role in the mental health of residents. A recent study on the pandemic has found that poor quality views (non-green) are strongly associated with moderate and severe depressive symptoms (Amerio et al., 2020). Although this is less important during the winter months when trees in colder areas like Montreal lose their foliage, trees provide significant wind break protection, reducing heating costs (Potyondy, 2013).

Some indices measure tree canopy as population-weighted tree canopy in order to capture the direct benefit of trees to communities, thereby highly scoring areas with high percentage of tree coverage and large populations (Maizlish et al., 2019). This method of scoring was not used in this index in order not to bias the index to neighborhoods with large populations but some tree cover, of which there are many due to the large diversity in the morphology of the city. Instead, only the percentage of tree coverage was used with 40% tree coverage representing a perfect score of 100 in urban areas. This means that neighborhoods with scores of 40% and over score 100 on the index. According to American Forests, a non profit organization with 145 years of experience in forestry, 40% is a baseline standard for urban tree cover in forested regions such as Canada and is the target for the City of Toronto’s 2018 Tree Canopy Study (Romoff, 2018).

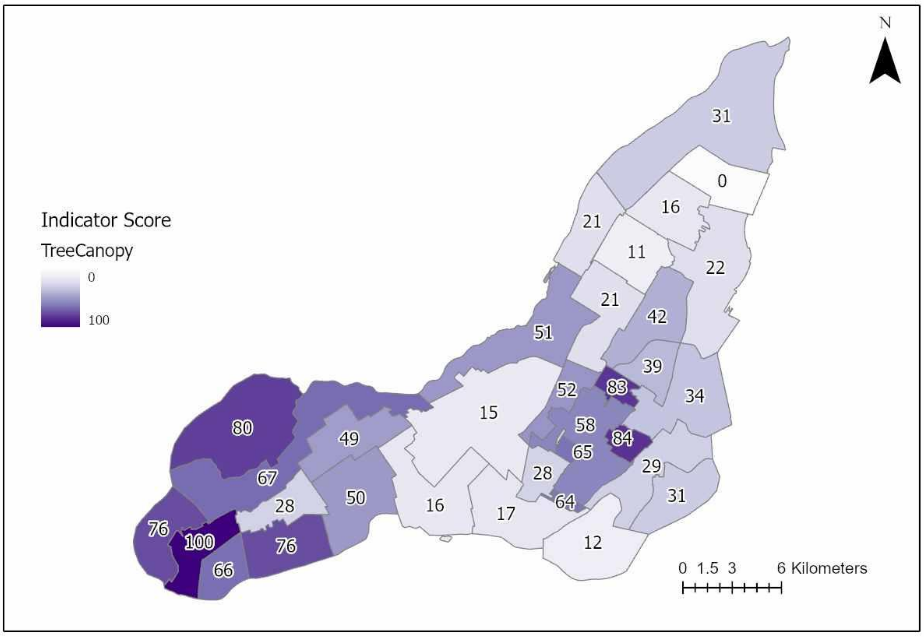

Figure 21: Tree Canopy Score Map

The tree canopy data was available as a shapefile and was intersected with the neighborhood boundary shapefile to classify trees by neighborhood. Finally, the total tree cover area was calculated as a percentage of the total area by neighborhood. The highest scores are found in the areas with lower built density and overall populations towards the west with the exception of Westmount and Outremont, both of which lie on the foothills of the Mont Royal.

b. Access to Parks

Local parks have undergone a renaissance during the pandemic. Around the world they went from being frequented occasionally, to prime urban destinations. In most places, parks remained opened during periods of lockdowns. Access to parks was already an important indicator before the pandemic as well and part of most if not all existing indices (Maizlish et al., 2019; AUO 2020; Fu, Yu, & Zhang, 2019; Stanislav & Chin, 2019; LEED ND, 2014). The indicator selected for the index considers parks and public spaces larger than 1 acre (4047 sqm) since any smaller area would not cater comfortably for larger groups of people with different uses of space.

The park layer is available as a shapefile on the scale of the Ville de Montreal, and not the entire island, so new shapefiles were created of all the parks on the Island of Montreal using the editor tool and an accurate ESRI Basemap. Then, the select tool was used to select only the parks that are greater than 1 acre in area and buffered by 500m, the acceptable walking distance to a park in urban areas. The next step was to erase the buffered area from the island shapefile to get the areas farther than 500m from any park and classified by neighborhood. However, some of these areas were not residential areas, such as the airport. To avoid distorting the final score of the neighborhood, this layer will be intersected with only areas marked residential on the land use map.

A better calculation would be to find the number of individual residential buildings more than 500m from a park. However, since building footprint data is not available on the scale of the whole island, the residential land use is the next best proxy. It is important to note that the residential land use does not include density. For instance, 1 square km in the suburbs not accessible to a park might include only a dozen households, but the same area in a dense neighborhood could include hundreds of households, making larger parks in denser areas more valuable.

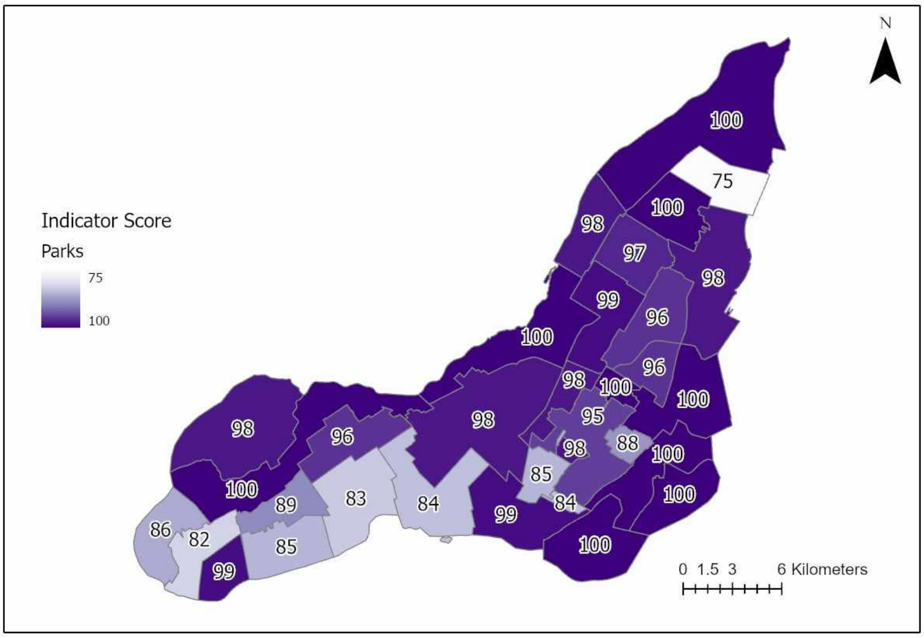

Figure 22: Parks Score Map

Overall, access to parks in Montreal is almost 100%. The lowest scoring neighborhoods are those with more low-density, single-family housing development where it is not feasible to build parks every 500m because of density considerations. The other neighborhoods with almost perfect scores are high density middle class working neighborhoods which have more built density than green space.

6. Heath

a. <u>Urban Agriculture</u>

Local food production is an important indicator for resilience and livability (LEED ND, 2014). Communities with access to common growing areas rely less on the wasteful food supply chains which are prone to destabilization as seen in the early months of the COVID-19 pandemic. Specifically, the pandemic has aggravated risks of severe/extreme food insecurity, with global numbers rising from 135 million in January 2020 to 265 million by the end of 2020 (Lal, 2020). In Montreal, the urban agriculture movement is strong, with initiatives such as VertCite, Lufa Farms, Santropol Roulant, among others. In addition to community gardens, policies also encourage the creation of rooftop greenhouses and other policies which promote home gardening at the household level. This indicator assesses the city-led community gardens available as GIS shapefiles from the city open data website. The urban agriculture score is measured as the percent of residential land use within 1000m of a community garden.

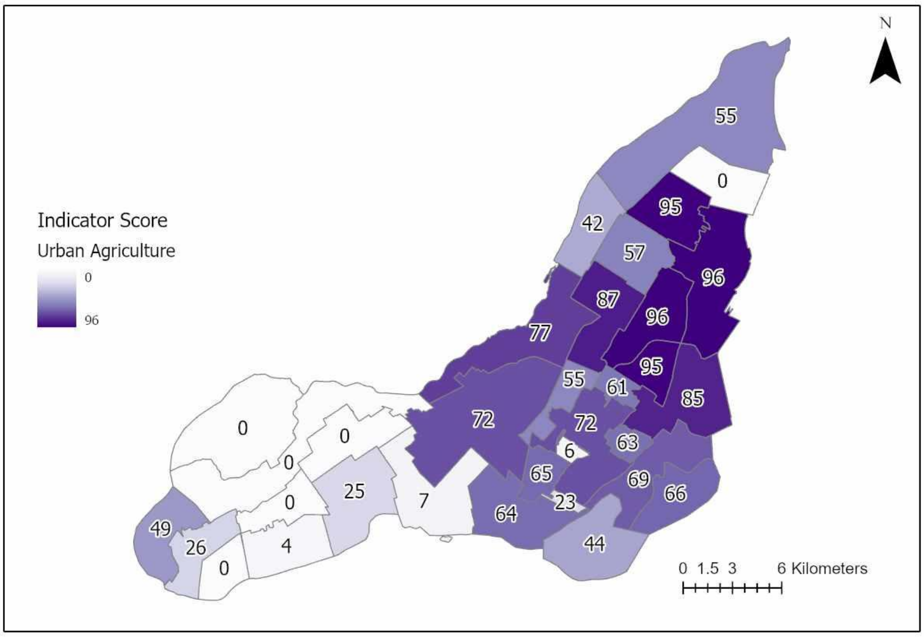

Figure 23: Urban Agriculture Score Map

The highest scores are found within the dense central neighborhoods for which community gardens are easy to access and plenty, there are only two community gardens serving the suburban west island but that is because households there are more likely to come with their own private garden. Overall, accessibility to urban agriculture is high and more likely higher when taking other private initiatives into consideration.

b. Air Pollution

Livability takes on a more literal meaning during COVID-19 when neighborhood environments can directly affect health and therefore chance of mortality from the virus. Mitigating pollution is important now more than ever for short term health and long-term wellbeing.

Major cities that are heavily polluted by nitrogen oxides and particular matter have had high rates of infection and mortality from COVID-19 (Paital and Agrawal, 2020). Due to the high spatial variability of air pollution, it was not possible to obtain a detailed data set for air pollution usable in this index, although there are studies which map out these air pollutants on the scale of the island (Deville Cavellin et al., 2016; Crouse et al., 2009).

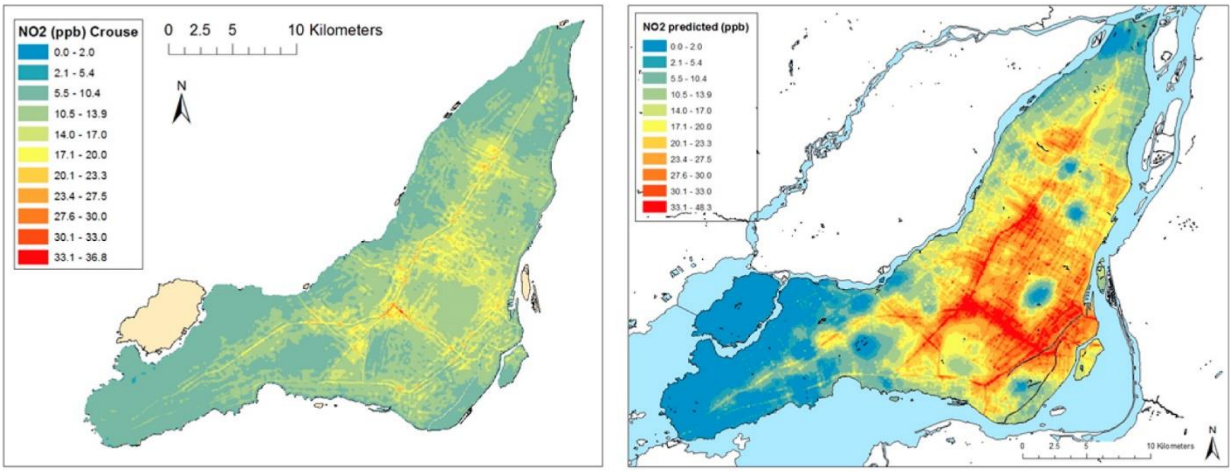

Figure 24: Spatial Variablity of NO2 (Deville Cavellin et al., 2016; Crouse et al., 2009).

Figure 24 shows two different studies side by side. Both studies report different pollution levels between seasons but highlight that the spatial patterns of areas with the highest pollution remain similar and follow roads closely. This is because even when conditions change or traffic decreases, the amount of pollution is always the most around roads. Therefore, the index takes distance within 500m from the highway as a proxy for air pollution. The final scores are not perfectly consistent with the study maps since smaller roads also contribute air pollution and the amount is dependent on the traffic volume on each road. Optimally, it would be more accurate to use the original GIS data created by past research if the data is available.

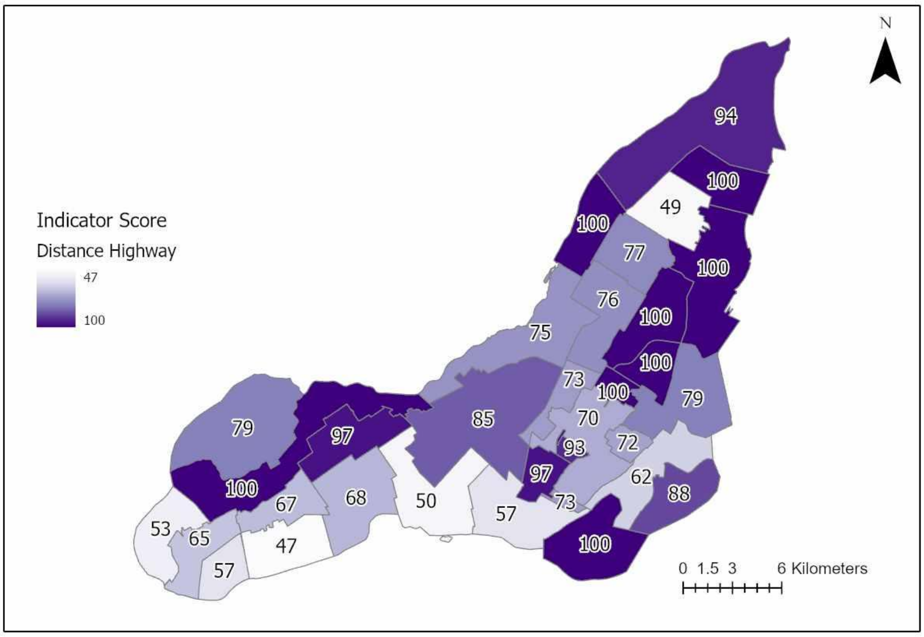

Figure 25: Highway Proximity Score Map

c. <u>Noise Pollution</u>

Noise pollution is the ‘non-silent killer’. Long time noise exposure, which is what most urban residents are exposed to, is tightly linked with premature hearing loss, annoyance, and sleep interruptions. Although not a COVID-19 risk factor, noise pollution is the second most harmful environmental risk factor after air pollution. Annoyance and a degradation in sleep quality also affect day to day mental health and may lower immune function (Dale et al., 2015). In most cases, the most significant spatial indicator of urban noise pollution is proximity to road and rail transportation. Noise scores were calculated by georeferencing a noise pollution map outlining similar scores using shapefiles and combining them and averaging them by neighborhood. There is large spatial variability by street since noise decays quickly over a short distance, but the index gives a general ranking of neighborhoods that experience more pollution compared to others (Ragettli et al., 2018).

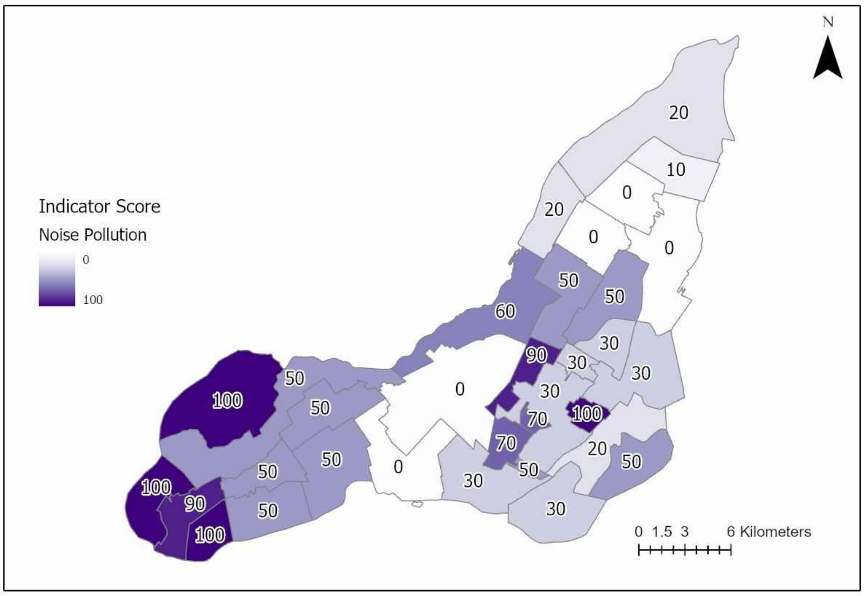

Figure 26: Noise Pollution Score Map

In

Figure 26, higher scores represent less noise pollution. The neighborhoods which score the lowest are close to the airport and industrial areas towards the middel of the island, and near the highway and industrial areas towards the north. In the more central neighborhoods, transportation and construction activities contribute the most to noise pollution. Noise exposure was associated with all socioeconomic indicators, with the strongest correlations found for those that spend over 30% of their income on housing, a metric that represnts affordable housing also used in this thesis.

d. Medical Facilities

Seniors tend to have lower mobility levels and are the most vulnerable during COVID-19. A Montreal study assesses medical accessibility using trip length, concentration of senior populations, car ownership and found that availability of health care facilities in Montreal Island tends to be lower precisely in the areas where seniors are concentrated (Paez et al., 2010). The map data was georeferenced from the study and the data was extracted and averaged by neighborhood to calculate a final score.

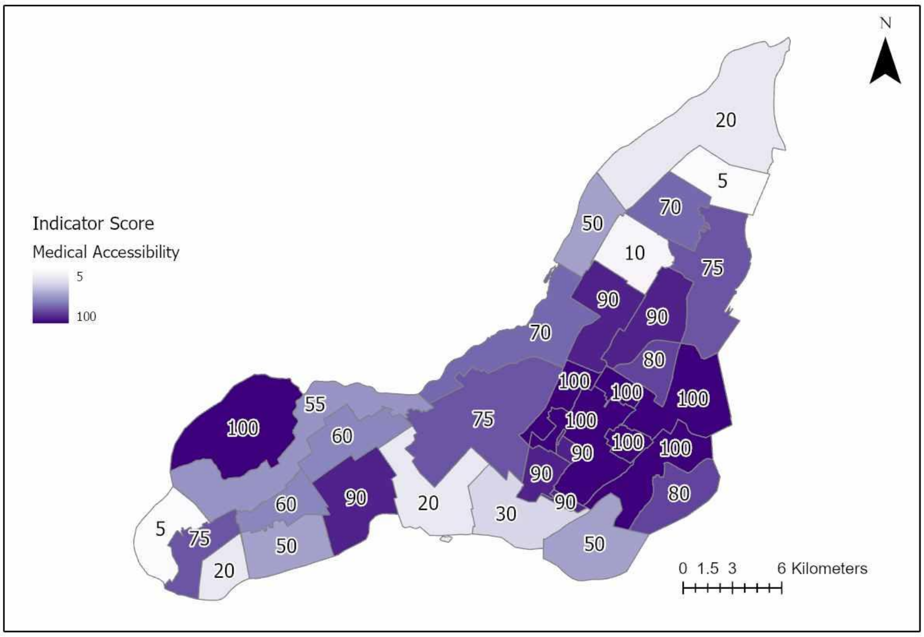

Figure 27: Medical Accessibility Score Map

Figure 27 highlights the inconsistent accessibility on the scale of the island, according to the research this is due to road design, car ownership and the lack of adequate public transit connecting facilities to the elderly who need them most.

7. Education

a. <u>Schools</u>

Schools are an important metric of livable neighborhoods as seen in the literature review; they play a deciding role for families with children when deciding where to live. For the purposes of the this study, school polygon data was exported from Open Street Maps using Overpass Turbo. Using the buffer of 1600m, school access is 100% all over the agglomeration of Montreal, except for Riviere des Prairies.

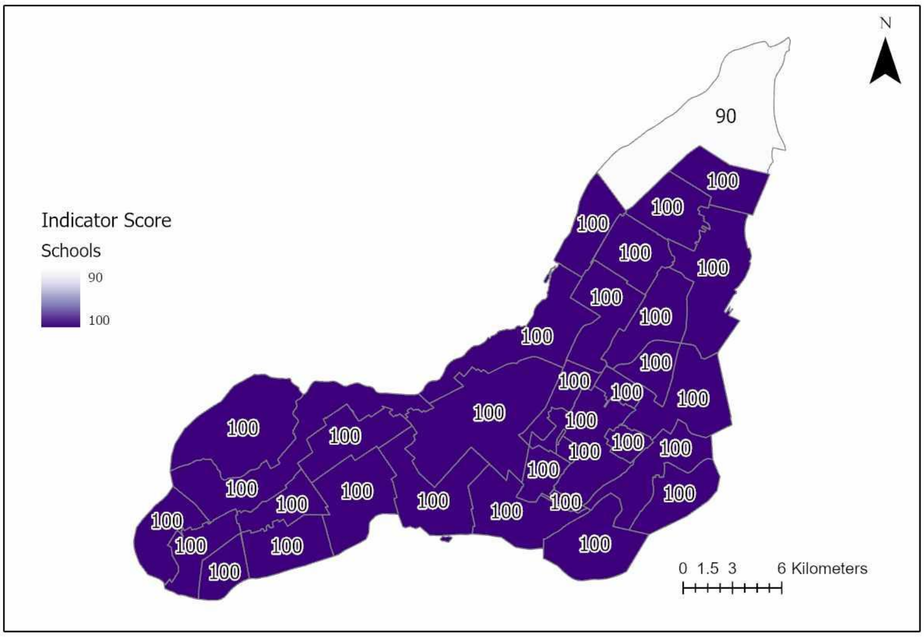

Figure 28: Schools Scores Map

8. Employment

a. Employment Density

As seen in the literature review, job proximity is a good measure of livability because it implies less commute time and more flexibility. Employment density is expressed as jobs/acre and is a good indicator of the live/work mix in a place when the data is readily available. The 2016 Canada Census collects data on commuting duration under 5 groups: less than 15 minutes, between 15-30, 30-45 min, 45-60 min and over 60 min. This data provides insight into the concentration of jobs around one's residence. As noted, this data is a proxy and for the analysis to be truly reflective of employment density, one needs to look at the jobs/acre for each job sector as well as the mode of transportation. The pandemic has truly changed the work/life balance in communities where some sectors hazard the exposure to COVID-19 due to the nature of their work and still commute long distances using shared public transportation, unlike remote workers. These factors are critical to studying the employment section of livability within a city. For this thesis, the data is taken as a weighted average score where each group of commuters receives a different score. The data was extracted from the Census Mapper API and was uploaded onto GIS where the dissolve tool was used to amalgamate all the data per neighborhood. Finally, each neighborhood was scored using the below weights on the number of households within each commuting duration category.

Commuting Duration	Score
Less than 15 minutes	100
15- 29 minutes	75
30- 44 minutes	50
45- 59 minutes	25
60 or more minutes	0

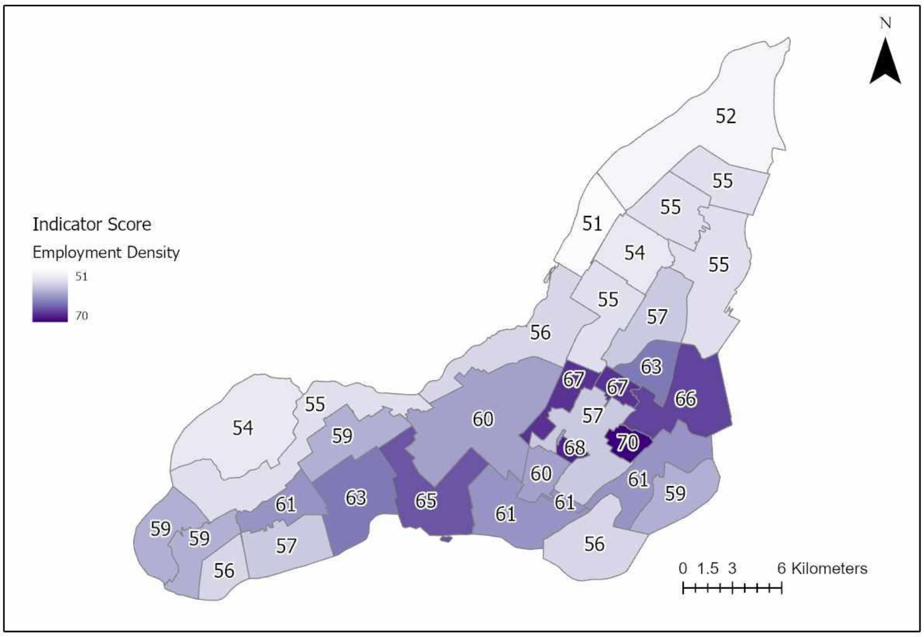

Figure 29: Employment Density Score Map

As per Figure 29, employment tends to be concentrated within the west of the island and the central districts. Although this is not as important during COVID-19 since those who can, telework, but the lower income neighborhoods in the north of the island are more likely to have essential worker positions and have the longest commutes.

CHAPTER IV

INDEX WEIGHTING

Index weighting is perhaps the most important step in creating any index, and there is research solely focused on the methods of weighting (Reckien, 2018). Many methods, qualitative and quantitative, can be used employed, depending on the goal of the index and the type of the data collected. Quantitative methods include variable reduction, variable addition, hierarchal and fuzzy normalization approaches (Reckien, 2018). Qualitative methods include expert analysis, surveys or using weightings from the existing literature. Ultimately, these approaches are important to ascertain the validity of this any similarly constructed index. Unfortunately, expert and resident consultation could not be done due to the difficulty of conducting interviews during the pandemic.

To compensate, the thesis proposes a baseline index and a sensitivity analysis by comparing this baseline index to three other alternative indices. The baseline index is an equal-weighting scheme index at the level of indicator categories. It is compared to three alternatives: a ‘lockdown’ equal-weighting scheme derived from a smaller set of indicators given levels of government restrictions; a ‘reduced dimension’ equal-weighting scheme using interpreted principal components derived from a Principal Component Analysis, and a ‘density-sensitive’ equal weighting scheme that eliminates some indicators that penalize lower density single-family home environments.

A. Baseline, equal-weighting Index

The equal weighing of indicators is a well-established method of creating indices (AARP, 2020; EIU, 2020), especially for data collected using surveys since survey respondents view categories with equal importance (City of Toronto, 2014). This happens because surveys tend to be simply categorized and when being filled, there is no implied sense of hierarchy to the respondent. Even for non-survey data such as this thesis, the equal weighting is simple and does not distort the original data. To apply equal weighting to this livability index, each category was weighted equally to adjust for the varying number of indicators within each category. This is to ensure that many indicators within one group do not skew the total index. For example, there are two indicators under green space and much more under housing and if all indicators themselves were equally weighted, the index score would reflect housing scores more than green space. Furthermore, some indicators are correlated within groups such as transit, bike and walk score and weighing them equally as indicators would over-account for mobility in the total index. This index does not need to be standardized since the original data is on a scale of 0-100.

Category	Weight (%)	Indicator
Urban Form	12.50	Mixed Use
		Sidewalk Width
		Distance Highway
		Shared Streets
Housing	12.50	Dwelling Diversity
		Dwelling Condition
		Housing Suitability
		Housing Affordability
Amenities	12.50	Access to centers
		Supermarkets
		Elder Care
Mobility	12.50	Walk Score
		Transit Score
		Bike Score
Green Space	12.50	Park Access
		Tree Canopy
Health	12.50	Noise Pollution
		Medical Facilities
		Urban Agriculture
Employment	12.50	Employment Density
Education	12.50	Schools
Total	**100.00**	

Table 4: Equal Indicator Weighting

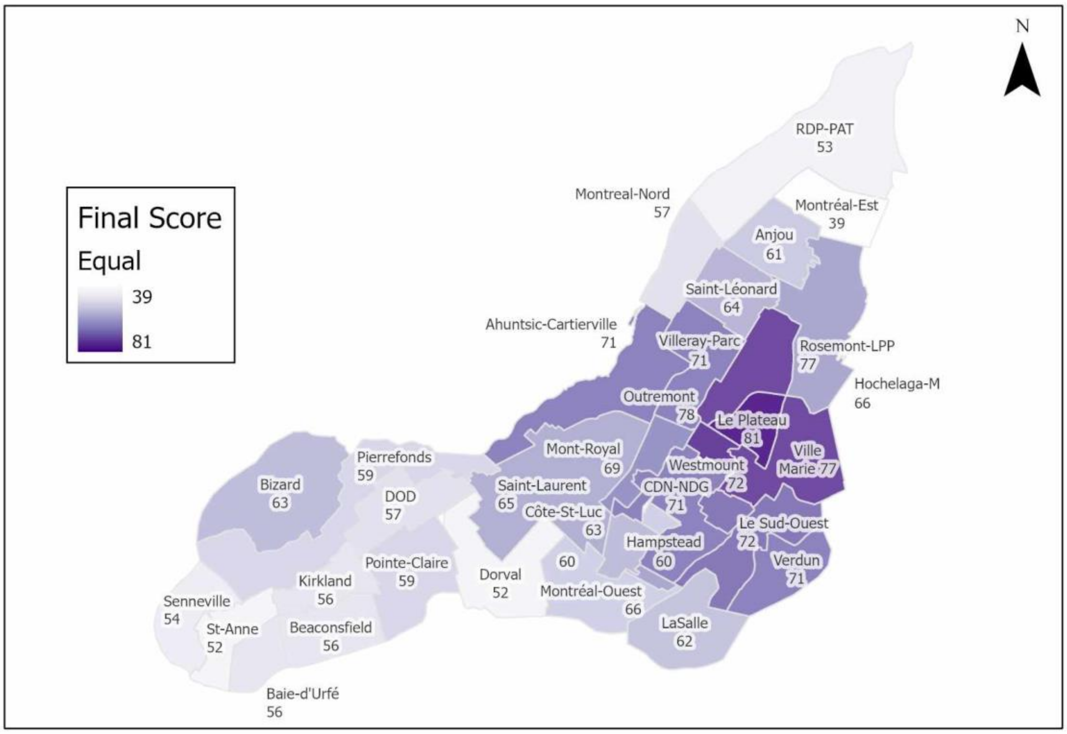

Figure 30: Equal Weighing Livability Score: Baseline Index

As per the baseline index, the livable neighborhoods of Montreal are concentrated around the center of the island, and around the Mont-Royal Mountain, and to a lesser extend the downtown. Le Plateau, Outremont, Rosemont, and parts of Ville Marie have a very similar urban fabric of row houses and dense walkable blocks in addition to the most popular high streets in the island. Le Sud-Ouest and Verdun are the most recent upcoming neighborhoods undergoing urban renewal and an influx of a younger creative class-type crowd. They are also near the downtown and the waterfront of the Lachine Canal to the East.

Westmount, the independent town situated at the base of the mountain, scores highly mostly because of accessibility, housing quality and green space. The rest of the boroughs towards the north and west of the island score lower especially on mobility and accessibility to amenities and mixed-use areas. Montreal Est, a barren industrial area with a small number of dwellings in below average condition, scores the lowest. Next is Dorval, home to the airport and its associated warehouses with very little residential land use. With a similar score, Saint Anne de Bellevue has only a few blocks of residential land use with most of the land being a national park and museums. Detailed Scores of each neighborhood are available in Appendix A for further reference.

Agasay realty	Reason	Moving waldo	Reason	Money sense	Reason	Time out	Reason
Old Port - Ville Marie	Culture and Food	Ville Marie	Parks, Young Professionals, Tourist Attractions and Architecture	Rosemont	Climbing Values	Plateau	Urban Design and Night Life
Plateau	Relaxed, Parks, Bars Food	Outremont	Known for High Quality of Life (For Young Couples)	Pointe Clair	Home Values in Suburb	St Henri - Le Sud Ouest	Bars, Cafes and Market, Waterfront
Le Sud Ouest	Market, Waterfront, Main Street	Rosemont LPP	Parks, Schools, Library	Le Sud Ouest	Location	Villeray	Family Friendly
Lachine	Parks, Waterfront, Museums	Griffintown Le Sud Ouest	Family Condos and Food Scheme			Rosemont	Market, Little Italy, Parks
Westmount	Library, Park, Galleries	Villeray	Green Spaces			CDN	Culture, Diversity
		NDG	Culture, Outdoors				
		Plateau	Top for Students				

Table 5: Neighborhood Rankings Comparison

Some neighborhoods in Montreal score high on international rankings, among other neighborhoods in the world. Verdun was just ranked number 11 in the Top 40 according to Time Out Magazine in 2020, after getting a bump up from number 22 in 2019. According to a resident, “It’s the charm of a very local area in a big city that’s not overrun by the big city” (Time Out, 2020). This year Verdun inaugurated the Jazz Fest Stage and its very own sandy urban beach. Like the other highly livable neighborhoods in Montreal, Verdun boasts a plethora of green space, a growing high street with local businesses, and strong bottom-up community initiatives. In the baseline livability index, Verdun ranks 10th on the list, and its overall score is brought down by its mobility score, access to amenities, lower housing affordability and its employment density. These seem to be metrics that might change in the coming years as possibly more businesses come in and housing prices are driven upwards. In the short term, this is highly dependent on the progression of the pandemic.

B. Lockdown index

The response to COVID-19 in Quebec has varied significantly during the months this thesis was being researched and written. In the summer of 2020 cases were decreasing and stable, and the province was able to enjoy a safe and no-restrictions summer. Towards the beginning of the school year cases began to gradually creep upwards, and it was at this point that the government created a four-level alert rating for COVID-19: green zones, yellow zones, orange zones, and red zones. In mid-September 2020, Montreal downgraded from green to yellow and then to orange a week later. In mid-October, Montreal was in the red. Each tier is associated with gradually more restrictive regulations. Green is business as usual with masks, distancing, and timid capacity restrictions. Whereas, red zone restrictions closed restaurants, gyms, places of worship, community centers, and in extreme cases, all non-essential stores were ordered to close (Government of Quebec, 2020). As of Jan 11th 2021, the government imposed an 8pm curfew for four weeks to flatten the curve in the rise in cases.

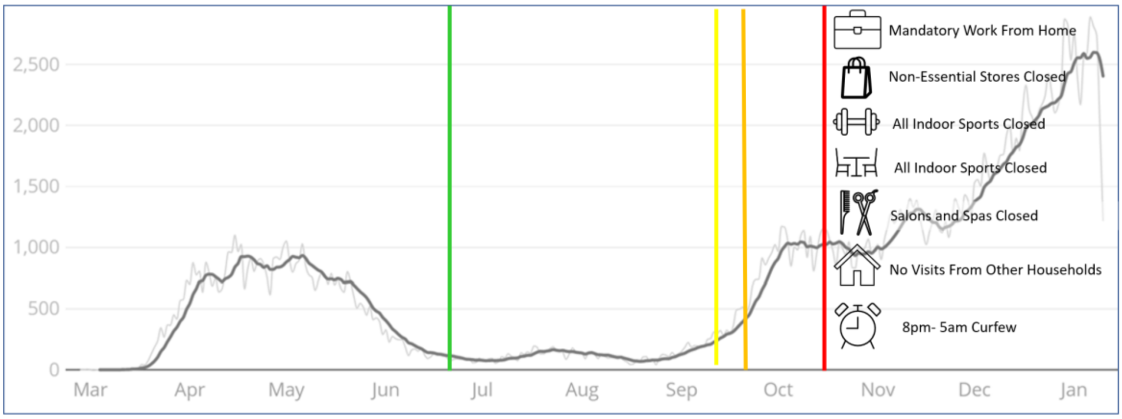

Figure 31: Cases and Restrictions (Sante Montreal, 2020)

This is the inspiration for creating another version of the index, the Lockdown Index, where metrics that represented services and facilities no longer accessible or relevant during lockdown were omitted from the index. This index would correspond to the red zone restrictions as per the regulations of the Province of Quebec. In a red-zone lockdown the indicators removed were schools, community centers, senior residences, and mixed use. In Quebec, schools remained open even in red zones but closed during extreme lockdowns and in the case of an outbreak. However, since school accessibility scores are perfect for all the neighborhoods, it would not change the respective neighborhood ranking when omitted.

Community centers and senior residences are inaccessible and vulnerable during high community transmission, and COVID-19 has ravaged long term homes. In a recent outbreak, over eighty elderly residents were sickened in the same home (CTV News, 2020). Lastly, the mixed-use indicator was also omitted because most businesses on high streets such as restaurants, bars, clothing stores, and furniture stores have been deemed non-essential and have been closed during peak community transmission. Supermarkets are separately accounted for in the index and that indicator represents accessibility to essential goods and services.

Category	Group Weight	Indicators	Indicator Weight
Urban Form	16.67	Mixed Use	0.00
		Sidewalk	5.56
		Highway Proximity	5.56
		Shared Streets	5.56
Housing	16.67	Dwelling Diversity	4.17
		Dwelling Condition	4.17
		Housing Suitability	4.17
		Housing Affordability	4.17
Amenities	16.67	Supermarkets	16.67
		Community Centers	0.00
		Elder Care	0.00
Mobility	16.67	Walk Score	5.56
		Transit Score	5.56
		Bike Score	5.56
Green Space	16.67	Park Access	8.34
		Tree Canopy	8.34
Health	16.67	Noise Pollution	5.56
		Medical Accessibility	5.56
		Urban Agriculture	5.56
Employment	0.00	Employment Density	0.00
Education	0.00	Schools	0.00
Total	**100.0**		**100.0**

Table 6: Lockdown Indicator Weightings

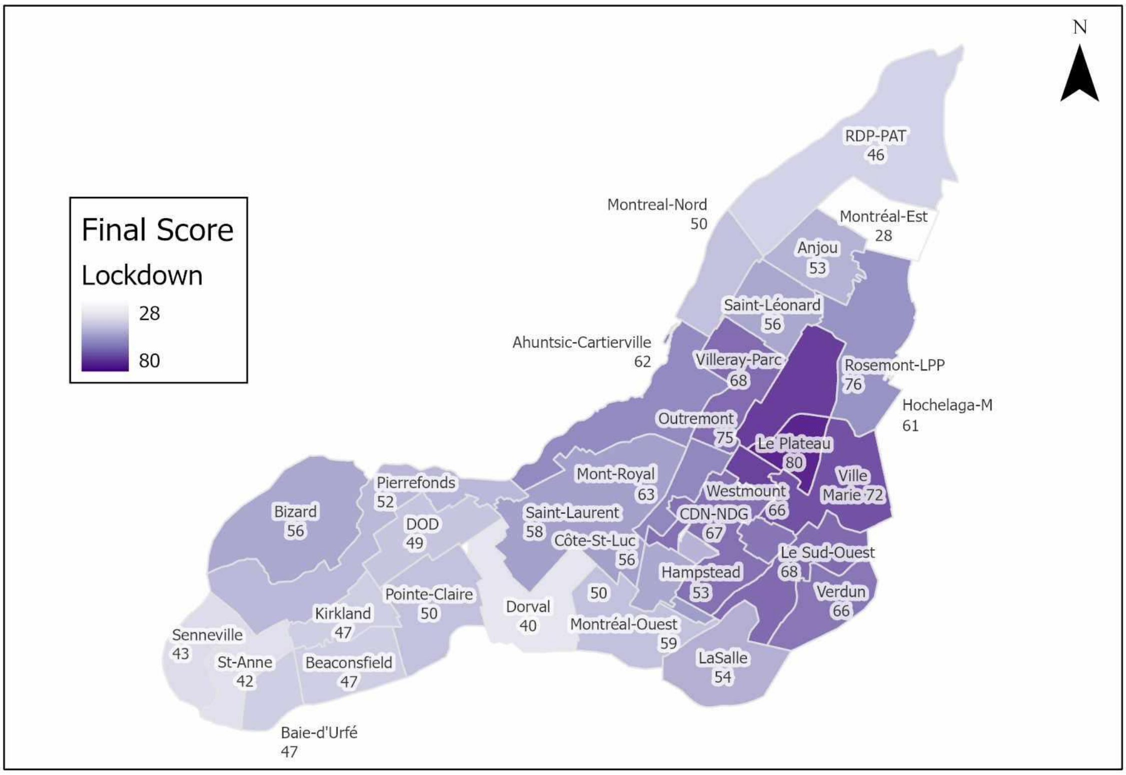

Figure 32: Lockdown Livability Index Scores

Baseline		Lockdown	
Neighborhood	Score	Neighborhood	Score
Le Plateau-Mont-Royal	81	Le Plateau-Mont-Royal	80
Outremont	78	Rosemont-La Petite-Patrie	76
Rosemont-La Petite-Patrie	77	Outremont	75
Ville-Marie	77	Ville-Marie	72
Le Sud-Ouest	72	Le Sud-Ouest	68
Westmount	72	Villeray-Saint-Michel-Parc-Extension	68
Villeray-Saint-Michel-Parc-Extension	71	Côte-des-Neiges-Notre-Dame-de-Grâce	67
Ahuntsic-Cartierville	71	Westmount	66
Côte-des-Neiges-Notre-Dame-de-Grâce	71	Verdun	66
Verdun	71	Mont-Royal	63
Mont-Royal	69	Ahuntsic-Cartierville	62
Mercier-Hochelaga-Maisonneuve	66	Mercier-Hochelaga-Maisonneuve	61
Montréal-Ouest	66	Montréal-Ouest	59
Saint-Laurent	65	Saint-Laurent	58
Saint-Léonard	64	Saint-Léonard	56
Côte-Saint-Luc	63	Côte-Saint-Luc	56
L'Île-Bizard-Sainte-Geneviève	63	L'Île-Bizard-Sainte-Geneviève	56
LaSalle	62	LaSalle	54
Anjou	61	Anjou	53
Hampstead	60	Hampstead	53
Lachine	60	Pierrefonds-Roxboro	52
Pierrefonds-Roxboro	59	Lachine	50
Pointe-Claire	59	Montréal-Nord	50
Montréal-Nord	57	Pointe-Claire	50
Dollard-des-Ormeaux	57	Dollard-des-Ormeaux	49
Kirkland	56	Baie-d'Urfé	47
Baie-d'Urfé	56	Beaconsfield	47
Beaconsfield	56	Kirkland	47
Senneville	54	Rivière-des-Prairies-Pointe-aux-Trembles	46
Rivière-des-Prairies-Pointe-aux-Trembles	53	Senneville	43
Sainte-Anne-de-Bellevue	52	Sainte-Anne-de-Bellevue	42
Dorval	52	Dorval	40
Montréal-Est	39	Montréal-Est	28

Table 7: Baseline Vs Lockdown

Interestingly, the same neighborhoods occupy the top five ranking in the baseline, equally weighted index, and the lockdown index. These neighborhoods score consistently high in all categories so even the removal of key indicators such as mixed use, employment, schools, centers, and elderly care did not have much effect on the overall rankings. Some neighborhoods switched rankings, for example Rosemont overtook Outremont in the lockdown index because it scores higher for shared streets and sidewalk width.

C. Reduced Dimension Index

Principal Component Analysis (PCA) is a statistical technique used to extract a smaller number of dimensions (Principal Components, or PCs) from the variables under consideration. PCA is useful in identifying statistically, which components can be used in a reduced-dimension index depending on much they contribute to the total variance. In this sense, it is a tool for data reduction, since only a few a PCs are chosen for further inclusion in the modified index (City of Toronto, 2014; Reckien, 2018; Fu, Yu, & Zhang, 2019). Using PCA, the total number of possibly correlated indicators is substituted for by a shorter list of unitless, uncorrelated (orthogonal) components (Reckien, 2018). It falls unto the researcher to interpret the meaning of these components in terms of concepts consistent with notions of livability.

A graphic analysis of the correlation between the variables is useful to visualize the results of the correlations between the variables. The spherical projection of the correlation matrix below shows the correlation between the indicators. Most of the indicators cluster together on the right sphere. Transit Score, Bike Score, and Walk Score are highly correlated because they represent metrics which are similar:

interconnected streets with wide sidewalks and short block lengths around high density areas which lend themselves well to public transit. These same areas are more likely to have better access to supermarkets and medical facilities as well as well-planned shared streets and community gardens.

On the left sphere, the tree canopy indicator and noise pollution are almost perfectly correlated. In fact, this is corroborated by a study of noise pollution in Montreal which found that total greenery as measured through a NDVI (normalized difference vegetation index) was the most significant predictor for low noise pollution levels in a Land Use Regression Model (Ragettli et al., 2016). These same neighborhoods also tend to have more affordable and suitable housing since they are suburban neighborhoods with overall higher income.

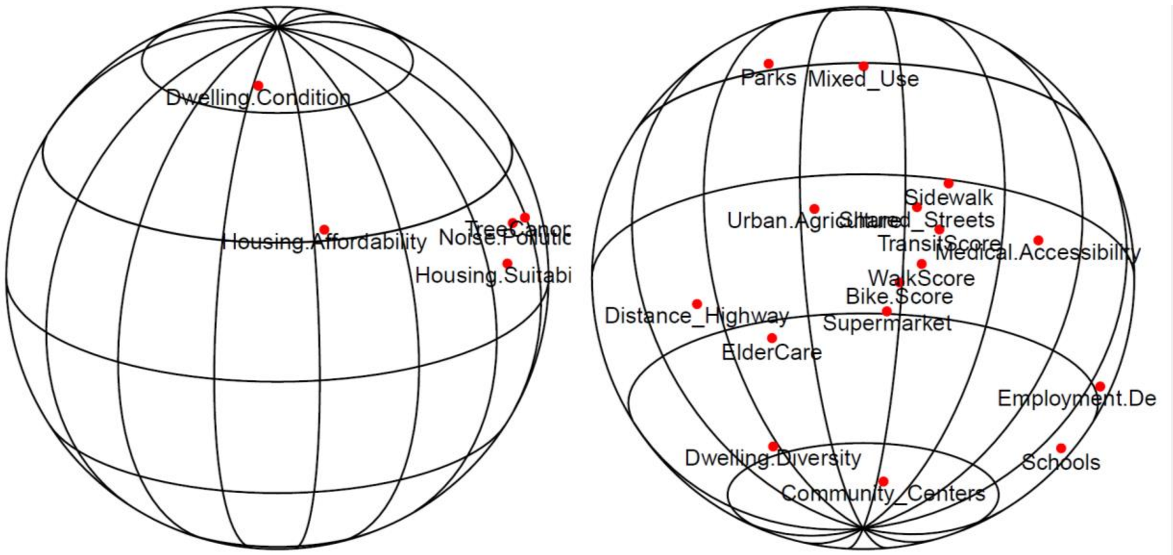

Figure 33: PCA Correlation

PCA extracts components from this correlation. The results of the PCA analysis are summarized in Table 8. The values within the table are loading factors, or the contribution of each indicator to the component. The magnitude of the loading factors signifies larger influence in the data, and the sign signifies the direction of correlation between indicators. Each component represents a pattern of correlation in the data, beginning with the largest to the smallest. In this study, the first 4 PCs accounted for 70% of the variance in the data, and the first 7 for 85%.

Components can be interpreted given the indicators contributing to each components the most (largest weights). For example, Walk Score and Bike Score were two of the higher weights in PC1. PC1 can accordingly be interpreted as neighborhoods with good multi-modal mobility. Tree Canopy and Noise Pollution were two of the higher weights in PC2. PC2 can, accordingly, be interpreted as neighborhoods with superior ecology. Mixed Use and Commercial Centers were two of the higher weights in PC3. PC3 can also here be interpreted as mixed-use neighborhoods. Dwelling diversity and sidewalks were two of the higher weights in PC4. Accordingly, PC4 can be interpreted as dense neighborhoods. If, in the future, metrics can be developed to capture these livability concepts directly, then an indicator can be developed with fewer resources expended that is currently required as per the indictor list in the baseline index.

Indicator	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Proportion Of Variance	0.3835	0.1344	0.1041	0.08748	0.05833	0.04477	0.04117
Cumulative Proportion	0.3835	0.5179	0.6220	0.70951	0.76784	0.81260	0.85378
Eigen Value	2.8379	1.6798	1.4788	1.3554	1.10678	0.96958	0.92985
Walkscore	-0.3269282	0.1222624	-0.03339	0.126898	-0.00562	0.007377	-0.09869
Transitscore	-0.2975617	0.1500103	-0.10843	0.150726	-0.05579	-0.10476	-0.13123
Bike.Score	-0.312189	0.0715124	0.009716	-0.20919	0.080077	-0.07372	0.016344
Mixed_Use	-0.1871809	0.000706	-0.44948	0.034869	-0.27761	-0.06963	0.180104
Shared_Streets	-0.2835128	0.1007645	-0.15073	-0.24261	0.076936	-0.08102	0.067023
Sidewalk	-0.2399652	0.1448277	-0.18202	-0.40193	0.043299	-0.03521	0.026401
Supermarket	-0.2993826	0.0447705	0.071418	-0.19249	0.053908	0.142076	-0.02545
Eldercare	-0.2213243	-0.137234	0.102794	0.060707	0.325848	0.293178	-0.39081
Community_Centers	-0.1818681	0.0351517	0.399218	0.097158	-0.33741	-0.18002	-0.02798
Parks	-0.1404707	-0.164228	-0.42309	0.183055	-0.02171	0.160934	-0.01799
Treecanopy	0.0974444	0.4390717	-0.12193	0.218902	0.152072	-0.13326	0.207847
Distance_Highway	-0.1399692	-0.18461	0.032868	0.07396	0.668474	-0.13127	0.214156
Noise.Pollution	0.12767421	0.4125725	-0.10949	0.178755	0.104058	-0.0952	0.385029
Urban.Agriculture	-0.2799334	-0.089429	-0.14412	0.053647	-0.32676	-0.12112	0.013621
Medical.Accessibility	-0.2005013	0.2917207	-0.07125	0.319134	0.196689	0.244101	-0.11942
Schools	-0.0507216	0.232389	0.227026	-0.04459	-0.15711	0.737949	0.351253
Housing.Suitability	0.14025111	0.3811354	-0.02721	-0.33025	0.135426	-0.19014	-0.25755
Dwelling.Condition	0.19923502	-0.033799	-0.38694	0.274097	-0.01461	0.185292	-0.32258
Dwelling.Diversity	-0.1503233	-0.118728	0.252624	0.451484	0.022761	-0.25695	0.126901
Housing.Affordability	0.29752592	0.0897294	-0.10506	-0.08036	-0.01608	0.017579	-0.21069
Employment.Density	-0.0753917	0.4056146	0.210878	0.159912	-0.10909	-0.0821	-0.4179

Table 8: PCA Results

Once way to use PCA is to derive an index with an equal weighting of a number of PCs that explains an acceptable percentage of the variance. Another less statistically robust, but more practical approach is to identify the indicator with the highest loading (weighting) on each PC from the chosen PCs, and choosing it to stand for that PC in an equal-weighting scheme of the reduced set of indicators. For this analysis, the second approach was used. This leaves the final index with 7 indicators as opposed to 21. This is also an equal weights indicator where each of the 7 indicators were simply added and averaged to find the scores for each neighborhood. These are:

1. Walk Score
2. Tree Canopy
3. Mixed Use
4. Dwelling Diversity
5. Distance Highway
6. Schools
7. Employment Density

Baseline Index Scores		Reduced Index Scores	
Le Plateau-Mont-Royal	81	Outremont	84
Outremont	78	Westmount	82
Rosemont-La Petite-Patrie	**77**	Le Plateau-Mont-Royal	79
Ville-Marie	77	Ville-Marie	75
Le Sud-Ouest	72	Côte-des-Neiges-Notre-Dame-de-Grâce	75
Westmount	72	Ahuntsic-Cartierville	73
Villeray-Saint-Michel-Parc-Extension	71	Mont-Royal	72
Ahuntsic-Cartierville	71	**Saint-Laurent**	**72**
Côte-des-Neiges-Notre-Dame-de-Grâce	71	Montréal-Ouest	72
Verdun	71	Verdun	72
Mont-Royal	69	Villeray-Saint-Michel-Parc-Extension	71
Mercier-Hochelaga-Maisonneuve	66	Le Sud-Ouest	70
Montréal-Ouest	66	**Rosemont-La Petite-Patrie**	**69**
Saint-Laurent	**65**	Hampstead	68
Saint-Léonard	64	Lachine	68
Côte-Saint-Luc	63	Senneville	67
L'Île-Bizard-Sainte-Geneviève	63	Anjou	66
LaSalle	62	Mercier-Hochelaga-Maisonneuve	66
Anjou	61	Saint-Léonard	65
Hampstead	60	**Dorval**	**65**
Lachine	60	Côte-Saint-Luc	64
Pierrefonds-Roxboro	59	L'Île-Bizard-Sainte-Geneviève	63
Pointe-Claire	59	Pointe-Claire	62
Montréal-Nord	57	Montréal-Nord	61
Dollard-des-Ormeaux	57	**Sainte-Anne-de-Bellevue**	**61**
Kirkland	**56**	Pierrefonds-Roxboro	60
Baie-d'Urfé	56	LaSalle	59
Beaconsfield	56	Dollard-des-Ormeaux	56
Senneville	54	Rivière-des-Prairies-Pointe-aux-Trembles	55
Rivière-des-Prairies-Pointe-aux-Trembles	53	Baie-d'Urfé	53
Sainte-Anne-de-Bellevue	**52**	Beaconsfield	52
Dorval	**52**	**Montréal-Est**	**50**
Montréal-Est	**39**	**Kirkland**	**49**

Table 9: Baseline Vs Reduced

As shown in Table 9 the overall rankings are similar but rearranged. Some outliers, in bold, are significantly reranked in the reduced-dimension index such as Montreal Est and Kirkland. The reduced index is a credible method to rapidly assess neighborhood livability in the absence of a complete data set as required by the baseline index presented in this thesis. However, the reduced index may over or under-rank some neighborhoods. Montreal Est as a neighborhood that needs further analysis for well-tailored policy interventions. Also, one can argue that Kirkland is significantly more livable in most aspects especially if one takes into consideration other socio-economic factors.

Alternatively, the literature on livability uses PCA to find of indicator weightings (City of Toronto, 2014; Reckien, 2018; Fu, Yu, & Zhang, 2019). In the Neighborhood Equity Index, PCA was used on 140 neighborhoods, using indicators that are interrelated and biased in the same direction, i.e. neighborhoods that have higher unemployment also have lower graduation levels, lower access to healthy food and are more dilapidated and so on. In the end, they kept all 15 indicators and used the PCA method to deduce individual weights for the original indicators using a methodology that weighs each indicator in relation to the contribution of each PC to the total variance and the contribution of indicator to that PC. This method of extracting weightings from the PCA was not used in this study, as it is only useful when, as stated, indicators that are interrelated and biased in the same direction.

D. Density-Sensitive Index

The purpose of this section is to add an element of sensitivity to the discussion. Expert solicitation traditionally would have provided more robust validation to the method of weighting of the index. This alternative tweaks the index to suit the context, and specifically so as not to penalize less-dense neighborhoods on metrics can be compensated for by the qualities of these neighborhoods. The original index is created with the assumption that all areas should have access to parks, wide sidewalks, and community gardens, and although these elements are important to livability, they are less so in the suburbs where most homes have their own backyard and where there is no crowding on the sidewalks. This index does not include the 3 indicators of parks, gardens, and sidewalks, in order to test the sensitivity of the index to less-dense neighborhoods which might have different needs to livability than traditional central neighborhoods. The other metrics remain equally-weighted.

As seen in Table 10 below, only a few neighborhoods saw significant re-ranking from the modified index. Hampstead's ranking increased the most with a jump of 10 points and a significant jump in ranking. Hampstead is a very small town independent from the jurisdiction of Montreal yet still central, with high accessibility to amenities and an average transportation score. Since it is zoned differently and is comprised of winding roads and cul-de-sac's, narrow sidewalks, and no community gardens, it scored significantly better on this alternate index.

This is captured in the language the neighborhood uses to describe itself. As stated on their website, "the founders of the Town of Hampstead envisioned a community where residents could be safeguarded from the chaotic mixture of residential, commercial and industrial zoning. This original vision was laid out in a plan adopted by the provisional council of 1913-1914. The plan was based on a model for development that became popular towards the end of the 19th century. This model was known as the "Garden City" concept." (Town of Hampstead, 2020).

Similarly, Westmount scores 9 points higher, now occupying 2nd Place, Montreal Ouest scores 5 points higher, and L'Île-Bizard-Sainte-Geneviève 6. There is a rearrangement of the top neighborhoods due to Westmount's and Outremont overtaking Le Plateau, and this is because Plateau scored significantly higher in the indicators that were not included. The rest of the west island suburbs only rise slightly, which was surprising since this was index designed to test the sensitivity of these neighborhoods to an index that more favors sprawl-typology development. Except for a few outliers, most of the rankings remained similar to the original index, therefore it can be concluded that the original index is sensitive to the different urban typologies and does not significantly penalize suburban boroughs.

Baseline Index Scores		**Density Sensitive Scores**	
Le Plateau-Mont-Royal	81	Outremont	81
Outremont	78	**Westmount**	**81**
Rosemont-La Petite-Patrie	77	Le Plateau-Mont-Royal	77
Ville-Marie	77	Rosemont-La Petite-Patrie	75
Le Sud-Ouest	72	Ville-Marie	74
Westmount	**72**	Côte-des-Neiges-Notre-Dame-de-Grâce	72
Villeray-Saint-Michel-Parc-Extension	71	**Montréal-Ouest**	**71**
Ahuntsic-Cartierville	71	Mont-Royal	71
Côte-des-Neiges-Notre-Dame-de-Grâce	71	Le Sud-Ouest	71
Verdun	71	**Hampstead**	**70**
Mont-Royal	69	Verdun	70
Mercier-Hochelaga-Maisonneuve	66	Villeray-Saint-Michel-Parc-Extension	70
Montréal-Ouest	**66**	Saint-Laurent	70
Saint-Laurent	65	**L'Île-Bizard-Sainte-Geneviève**	**69**
Saint-Léonard	64	Ahuntsic-Cartierville	69
Côte-Saint-Luc	63	Côte-Saint-Luc	65
L'Île-Bizard-Sainte-Geneviève	**63**	Mercier-Hochelaga-Maisonneuve	64
LaSalle	62	Pointe-Claire	63
Anjou	61	Pierrefonds-Roxboro	62
Hampstead	60	Saint-Léonard	60
Lachine	60	Dollard-des-Ormeaux	60
Pierrefonds-Roxboro	59	Beaconsfield	59
Pointe-Claire	59	Senneville	59

Montréal-Nord	57	LaSalle	59
Dollard-des-Ormeaux	57	Montréal-Nord	58
Kirkland	56	Anjou	58
Baie-d'Urfé	56	Lachine	58
Beaconsfield	56	Baie-d'Urfé	57
Senneville	54	Kirkland	56
Rivière-des-Prairies-Pointe-aux-Trembles	53	Rivière-des-Prairies-Pointe-aux-Trembles	52
Sainte-Anne-de-Bellevue	52	Dorval	52
Dorval	52	Sainte-Anne-de-Bellevue	51
Montréal-Est	**39**	**Montréal-Est**	48

Table 10: Baseline Vs Density Sensitive

To summarize, a comparison of the baseline index and the lockdown index shows that the same neighborhoods occupy the top five ranking in both. It can be concluded that the baseline index is reasonably sensitive to lockdown conditions. Comparing the baseline index to the reduced-dimension index, the overall rankings are similar but rearranged, while some outliers are significantly reranked. It can be concluded that for the neighborhoods with the most typical fabric, the reduced index is a good alternative in the case data collection is a significant hurdle. More neighborhoods saw significant re-ranking in the density-sensitive index, again as compared to the baseline. While not all the movement is intuitive, further research and especially so on local validation of the social and cultural practices that compensate for penalizing indicators is necessary.

E. Livability scores and the incidence of COVID-19

The indicator developed above, in its different variants, builds on the general literature on urban planning and the course of the COVID pandemic. While this thesis cannot speak to the question of how neighborhood livability can predict the spread of disease, it is interesting to examine some of the correlations, even if they are a onetime snapshot of the course of the pandemic in the different neighborhoods.

Figure 34 shows the relationship between livability, as calculated by the lockdown index, and the case rate per 100,000 residents as of January 15, as derived from Sante Montreal. The data shows that the less livable neighborhoods, as per this study, have been the hardest hit by the pandemic. The most prominent example is Montreal Nord that holds the 23rd place out of 33 (Lockdown livability:59/100) and has seen the largest outbreaks during the entire 10 months of the pandemic. According to a CBC data analysis, the strongest correlation between the cases per 100,000 residents is the percentage of non-white residents in addition to the concentration of healthcare and frontline workers in unsuitable housing (Rocha, Shingler and Montpetit, 2020). In fact, even housing affordability is low in Montreal Nord (66/100) considering the low livability score and this speaks to the argument that more people might be cramming into smaller spaces to be able to afford housing.

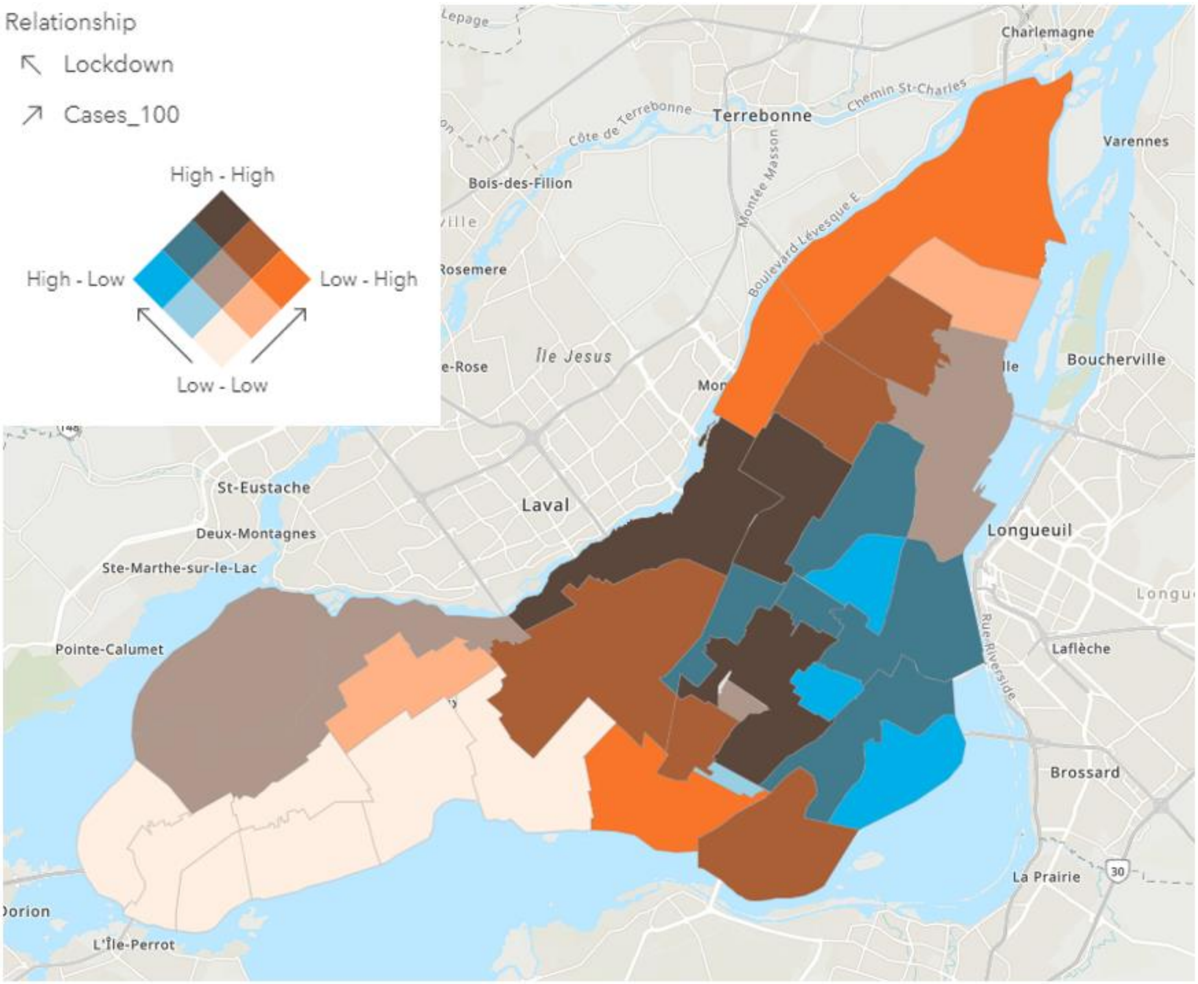

Figure 34: Lockdown Livability Vs Cases

This combination of higher level of exposure and the risk of spread in close quarters has predisposed some communities, especially the low-income minorities, to bear the brunt of the cases in the island. These findings support the argument that it is the unsuitable housing conditions as opposed to overall built density that facilities the spread of COVID-19. Cote des Neiges on the other hand is a livable neighborhood, 9th out of 33, but has a high percentage of front-line workers and the highest interhousehold crowding as exemplified with a score of 88/100 in housing suitability, the lowest score between the boroughs. Similarly, Ahunistic Carterville scores highly on overall lockdown livability (67) but is also experiencing community transmission.

Another similar case is Montreal Est (score on lockdown index 28/100, 4155 cases per 100,000, outbreak rank 12/33) which has a high density of cases considering that the residential part of the neighborhood is only a few streets wide. Statistics Canada data on occupation shows that more than 70% of residents of Montreal Est are essential workers in retail, construction, manufacturing, health care services and education (Stat Can, 2016) which are the sectors experiencing outbreaks during this pandemic (Feith, 2020). Inter-household and community transmission may go unchecked especially in small tightly knit communities.

The systemic vulnerability in these hot spots cannot be solved merely by improving neighborhood livability, and public health measures need to be taken on the household level to make sure that those on the front lines of the virus are less likely to spread it to their families and communities. As noted, this is just one snapshot, and it cannot be definitively concluded that less livable neighborhoods are more prone to COVID-19 and it is not the intention of the research to present it as such. This analysis is just a comparison of two data sets on the city to attempt to explore patterns that might not have been visible separately. Furthermore, in depth field research by public health authorities should be done in neighborhoods of high contagion to assess the dynamics behind the higher spread in some neighborhoods compared to others.

CHAPTER V

CONCLUSION

This thesis has presented a livability index which can be retrofitted to assess livability during COVID-19. This index provides a starting point to identify the strength, weaknesses, opportunities, and challenges experienced by neighborhoods both during normal times and pandemics. In fact, livability will be even more important after this pandemic where the new normal may be much closer to home. Based on the findings of this research, urban interventions should be tailored depending on the vulnerabilities and needs of neighborhoods and local residents. The needs of people during lockdown vary significantly based on age, job roles and other socio-economic factors and more detailed field work should be done to explore the extent of the issues highlighted by the index and to understand the underlying perception towards these issues. Furthermore, the second wave of COVID-19 in Montreal is taking place during the coldest months of year which decreases the use of outdoor parks, bike lanes and walking due to heavy snowfall and icy-conditions therefore, the indoor environment may take precedent over the neighborhood conditions. This is slightly accounted for in the index, but conditions vary significantly between homes and would need to be further researched to determine the role of overall indoor conditions on livability.

For the most part, the most livable neighborhoods according to the baseline index developed herein correspond to existing rankings. This consensus may not necessarily apply to lockdown conditions, however. Residents may have had different opinions based on their experience of lockdown livability in their neighborhoods. Interviewing residents in different neighborhoods was not possible due to COVID-19 restrictions but is very promising for further research into livability during pandemics such as the current one. However, the index is not sensitive to identifying neighborhoods that are undergoing change and upgrading. For example, some neighborhoods like Pointe Claire have been classified by some real estate experts as 'up and coming' neighborhoods in the future based on real estate prices, culture and desirability (Money Sense, 2020) but Point Claire does not score as highly on the index. The livability index does well at capturing existing dynamics rather than potential, but an understanding of potential livable neighborhoods could help bring about policy and planning recommendations instead of ad hoc interventions. This is an area that could be further researched based on historical trends, policies and other dynamics that have created livable neighborhoods in the past.

One important takeaway from the study, given varying scores on the index, is that a more localized approach is needed to maintaining levels of neighborhood livability to support neighborhood vitality, businesses, and residents' mental health. For example, and as concerns local businesses, strict blanket lockdowns have closed thousands of Canadian businesses and threatened many more (Kovac, 2021). Small businesses are especially important to neighborhood vitality and livability, which attracts people and investments into larger development and infrastructure over the long run. In Canada, only short to mid-term solutions were employed to mitigate the effect of the blanket lockdown in the beginning of the Spring. These include direct financial support, tax exemptions, and facilities to upgrade businesses' online presence to engage and connect to the residents.

Yet in spite of this, small businesses in Canada are under major threat as the second wave continues (Kovac, 2021). Cities like Bilbao, Yokohama, Lisbon, and

Seattle established forms of urgent consultancy services to support entrepreneurs and small retailers during the pandemic. But when cases began to creep up in the Fall, Chief Public Health Officer, Dr Theresa Tam, was wary of another blanket lockdown, and advocated for the harnessing of data to find and contain local outbreaks instead of closing entire cities (CBC, 2020). Yet, a few months later, Montreal was once again under a brutal blanket lockdown due to the spread of local outbreaks into the community as well as the inability of residents to maintain a reduced number of contacts during prolonged lockdowns. Possible strategies include leveraging digital tools and big data to minimize the duration and extent of blanket lockdowns to minimize the financial and mental burden on communities and maintain livability.

A. Other considerations for future research

Another important consideration, for future research, is that vulnerable populations need targeted policies to improve their quality of life and adaptability. Vulnerable populations include immigrant workers, front line workers, the homeless, the elderly, the at-risk and even the unemployed. City and neighborhood scale strategies should focus on food, shelter, education, and job opportunities as a basis of a long-term recovery after COVID-19. Cities in particular, are well positioned to provide this support directly. For example, Nantes in France is transforming interstitial spaces to grow food primarily for vulnerable populations. Rotterdam, in the Netherlands is investing in education for children and the homeless. New Orleans, otherwise, is providing direct cash injections to immigrant workers.

For some indicators, the variance in how neighborhoods score is large, which singles them out for policy intervention. The creation of suitable and affordable housing, for example, is not only required to address the spread of pandemics in cities but will improve neighborhood livability. Policies to deal with the pandemic short-term can include reallocating space in empty hotels, and other short-term rentals. Longer term, Vienna for example is planning to build 1000 high quality and affordable apartments within the city in to-be-designed pedestrian friendly areas. Mexico City is investing USD 1 billion to redevelop 13 urban transit corridors through home improvement and new social housing, while creating jobs to support the economy in the meantime. Liverpool plans on renovating thousands of homes in the most deprived neighborhoods in addition to new modular homes and community centers (OECD, 2020). In Montreal, Saint Laurent issued a record high number of building permits in 2020 (DCN News Services, 2020) with developments focused on transit, and some affordable housing. This is an opportunity for urban planners and the public health sector to collaborate in understanding the systemic disadvantages that residents of these neighborhoods experience, and how this can be solved based on the local opportunities and amenities in the neighborhood.

After a year of living with COVID-19 and some World Health Organization officials speculating the possibility that COVID-19 might become endemic, cities need to focus on strategies for long-term recovery and resilience. At the forefront of many cities long term recovery agenda is smart and sustainable growth (OECD, 2020), which prioritizes transit-oriented development specifically sustainable urban mobility. Bogota, Milan and Paris are pursuing some of the most ambitious policies in reallocating tens of kilometers of roadway from cars to pedestrians and cyclists (OECD, 2020). As this research shows, most neighborhoods in Montreal failed to meet the sufficient requirement for sidewalk widths sufficient for social distancing. Although the city closed off many streets to car traffic in the spring and summer, more permanent strategies should be implemented to improve walkability for a post-COVID-19 world, especially during harsh Canadian winters. Further challenges for the city of Montreal

Most urbanists seem to agree that the urban life will change, in some ways, due to COVID-19. The Montreal Gazette, a local newspaper, published an article interviewing expert urbanists on the future of life in Montreal. They surmise that the longer the virus circulates within the community, the more cities might change to accommodate and that the pandemic will cause a collective 'hangover' in the city (Scott, 2021). Some trends are easier to predict. Working from home for example is a trend likely to persist after the pandemic is over (Scott, 2021). This will affect the reduce the need for Montreal's large downtown with its stock of office buildings as more people work from home. And these mobile residents are also leaving small condos, which previously provided accessibility to work and leisure, for more space outside the downtown. Condo listings jumped 141% in the months between April and August 2020 compared to 2019 (Scott. 2021), but these numbers are expected to drop as the vaccination levels increase and restrictions are eased in cities. Until then, the trend of leaving small condos for larger homes in the suburbs is strong in Montreal and with that come different urban challenges that could reshape traditional planning for neighborhood livability.

Transportation has also experienced almost catastrophic declines in ridership, almost 35% compared to pre-COVID levels. The drop in Montreal's mass transit ridership makes maintaining regular schedules and maintenance costly for the city, undermining the benefits of public transport, and making it more expensive and less convenient for all riders, especially those who have no choice except using public transit or their commute to work. However, it is imperative to rethink public transit at the local scale, as harsh weather conditions make walking and cycling difficult in the winter months.

Furthermore, the retail sector has also taken a hit by COVID-19, with 26% of downtown businesses vacant as of August 2020 (Scott, 2021). However, in the meantime this could have allowed local shops in smaller high streets to thrive and may help in increasing livability through a spreading of mixed use evenly around the city. Now, the city is faced with a challenge of mitigating the economic fallout of jobs closing within the city which could trickle down and increase unemployment especially for service sector employees, students and part time workers which have been impacted by the pandemic the most.

In conclusion, the fact that COVID-19 has brought life much closer to home changes the way the neighborhood is experienced, at least temporarily, and the study is intended to provide insights into possible points of entry into making the city more livable and resilient one neighborhood at a time. Livable neighborhoods are created through dynamics that over time upgrade the physical environment, attract businesses, talent and provide attractive amenities and COVID-19 has threatened this model of development. The index provided by this research is one tool to capture and model the dynamics forming neighborhoods over time and provide insight on the course of action needed.

In Montreal, it is not yet clear what the future will be like, but that is expected since cities are complex linkages that are formed over decades rather than months. Having said that, further research could focus on comparing different urban design, planning and policy interventions on the neighborhood scale and assessing their impact on livability. This could provide a comparative view of many possible scenarios that can be tailored to the needs of the neighborhood. Most importantly, residents need to be consulted to determine what suits their definition of livability, since livability is an ensemble concept that changes depending on who you ask, and when.

APPENDIX A

DETAILED INDICATOR LITERATURE REVIEW

LEED ND: Neighborhood Development

LEED ND is applied during the design and planning phase of the project so that the project could be developed exactly to its specific requirements. Points are allocated based on the indicator and on that basis, the rating is awarded. LEED ND prioritize smart location above all, in addition to land use diversity and compact development to ensure the development is human scaled.

Indicator	Metric
Compact Development	>12 DU per acre for residential buildings within walking distance of transit
Mixed Use Neighborhood Centers	N of dwellings within 400m of non-residential land use
Reduced Parking Footprint	Max: 0% front facing off street parking to 20% surface parking on the rear or side
Walkable Street	Continuous sidewalks or equivalent all-weather routes for walking are provided along both sides of 90% of the circulation network block length within the project
Transit Facilities	Provide year-round, from at least one central point in the project to other major transit facilities or to other destinations, such as a retail or employment center, with service no less frequent than 45 daily weekday trips and 30 daily weekend trips
Access to Civic and Public Spaces	Locate 90% of planned and existing dwelling units and nonresidential use entrances within a ¼ mile (400 meters) walk of at least one civic and passive use space.
Access to Recreation Facilities	Locate the project so that a publicly accessible outdoor recreation facility at least 1 acre (0.4 hectares) in area, or a publicly accessible indoor recreational facility of at least 25,000 square feet (2325 square meters), lies within a ½-mile (800-meter) walking distance of 90% of new and existing dwelling units and nonresidential use entrances.
Community Outreach and Involvement	conduct a design charrette or interactive workshop of at least two days that is open to the public and includes, at a minimum, participation by a representative group of nearby property owners, residents, business owners, and workers in the preparation of conceptual project plans and drawings.
Local Food Production	Dedicate permanent and viable growing space or related facilities (such as greenhouses) within the project as specified
Tree Lined and Shaded Streets	Provide trees at intervals of no more than 50 feet (12 meters) (exempting driveways) along at least 60% of the total existing and planned block length within the project

Neighborhood Schools	locate or design the project such that at least 50% of the dwelling units are within a ½-mile (800-meter) walking distance of the functional building entry of an existing or new elementary or middle school or within a 1-mile (1600-meter) walking distance of the functional building entry of an existing or new high school.

Healthy Livable Cites: Australian Urban Observatory

A large-scale multidisciplinary undertaking by NGOs and Universities, that mostly relied on publicly available and census data for the indicators. The consortium tracks more indicators on their interactive website related to social demographics, alcohol consumption, walkability, and employment opportunities (AUO, 2020)

Indicator	Metric
Street Connectivity	no. of 3+ way intersections
Street Blocks	% ‘walkable’ street blocks <240 m length
Cul De Sac	% streets terminating in a cul de sac
Footpath	% of the road network with a footpath
Employment Proximity	% of people working within the same (census) area
Access to Centers	% dwellings <1600m of an activity center
Housing Diversity	% small residential lots < 350 m sq
Density	number of dwellings per hectare
Access to Open Space	High % dwellings <400m walking distance to any park

Livable Urban Landscape

The study extracts fifteen individual land use indicators from topographic maps and remote sensing imagery. A principal analysis-based approach was used to build an urban livability index with the fifteen indicators (Fu, Yu, & Zhang, 2019). The indicators are mostly calculated using Euclidean distance. It does not take into consideration the road network, walking around blocks, highways or other barriers that exist in the urban fabric.

Livable Urban Landscape: Changchun China	Indicator	Metric
Convenience	density of urban transit lines	4 km/km2 density of transit lines
	urban transit stations	Within 300m
	urban center	Within 8810m
	commercial facilities	Within 1km
	medical facilities	Within 1km
	recreation facilities	Within 1km
	elementary & secondary schools	Within 1km
Amenity	vegetation coverage	Over 35% of Area
	parks & squares	Within 500m
Education	Universities and research institutes	Within 1km
Health	Primary Roads	More than 200m
	Manufacturing facilities	More than 500m
	Noisy Open Markets	More than 250m
Safety	Road Intersections	More than 350m
	Toxic chemical facilities or gas stations	More than 250m

California Healthy Places Index

The Index focuses on indicators which measure public health and socio-economic demographics of the population of California such as level of education, health insurance, and income. Although those are relevant indicators, they do not define a neighborhoods livability and could be related to other confounding factors. Therefore, this research looks at the neighborhood design elements of this index. (Maizlish et al., 2019)

California Healthy Places Index	Indicator	Metric
Neighborhood design	Park access	Percentage of the population living within 1⁄2 -mile of a park, beach, or open space greater than 1 acre
	Tree canopy	Population-weighted percentage of the census tract area with tree canopy (% tree canopy)
	Supermarkets	Percentage of the urban and small-town population residing less than 1/2 mile from a supermarket
	Employment density	Combined employment density for retail, entertainment, and educational uses (jobs/acre)

Toronto Neighborhood Equity Index

This index focuses less on social demographics and more on the outcomes of inequities. The authors chose not to map vulnerable populations such as minority group youths that are unemployed but instead mapped the outcome, unemployment. This way neighborhoods are not classified by the profile of the resident but by the measurable universal outcomes that are inequitably spread throughout the city. (City of Toronto, 2014)

Toronto Neighborhood Equity Index	Indicator	Metric
Physical Surroundings	Community Places for Meeting	Average number of meeting places within a 10 min. walking distance measured from each residential block in the neighborhoods (incl. libraries, recreation facilities, places of worship).
	Walkability	WalkScore.com- Between 0 and 100
	Healthy Food Stores	The average number of healthier food stores within a 10-minute walking distance from each residential block in a neighborhood.
	Green Space	Average amount of green space (incl. parks and public areas) per km2 in a 1 km circular buffer from each residential block in the neighborhood.
Other Final Indicators	Unemployment Rate	Number of unemployed persons age 15+.
	Low Income	Percentage of persons living below the after-tax low-income measure.
	Social Assistance	Percentage of persons who are recipients of Ontario Works, persons on ODSP participating in OW employment programs and non-OW persons receiving assistance with medical items.
	High School Graduation	Composite measure of four indicators predicting the rate of youth graduation from high school (2006-2011).
	Mental Health	Percentage of those age 20+ reporting very good or excellent mental health.
	Diabetes	Age and sex adjusted number of persons age 20+ with diabetes per 100 population.
	Voting	Percent of eligible voters who voted in the last municipal election.

Evaluating Livability (Stanislav & Chin, 2019)

the index uses a small sample qualitative approach as opposed to remote sensing or publicly available census data. It focuses on initial perceptions of residents on two separate cities one following new urbanism and another traditional suburban development. However, the list of indicators is consistent with previous research and useful to use in smaller scale comparisons of livability in two different locations since the data availability and type might not be the same or available.

Evaluating Livability – Stanislav & Chin	Indicator	Metric
Demographics	Population	American Community Survey
	Household Size	Mean value of respondents
	household income	Median -
	age	Median -
Housing	housing units	Total number of Units
	Owner occupied units	% of Respondents
	Renter occupied units	% of Respondents
	Single-family units (detached)	% of Respondents
	Attached & multi-family units	% of Respondents
	Median housing value	$
Transportation	Travel time to work	minutes
	Drove Alone	% of Respondents
	Carpooled	% of Respondents
	Public Transit and Walking	% of Respondents
	Worked at home	% of Respondents
Density	Developed area	acreage
	Population density	per developed acre
	Housing density	per developed acre

Sustainable Neighborhoods Index

Incorporates expert assessment feedback with quantitative metrics on key indicators. The result is a comprehensive index that is both accurate and human centered. Furthermore, policies and approaches are also part of the assessment to capture the role of urban governance in livability. This method of measuring indicators is also useful for more contextually sensitive feedback and where data is not available.

	Indicator	Metric
Urban Density	green space	Green Space as % of total land area (%) Planning Department; US
	population density	Population density (person/mi2) US Census Bureau
	green space	Assessment of a city's efforts to sustain and improve the quantity and quality (for example, proximity and usability) of green spaces, and its tree planting policy (1 = below expectations; 2 = meets expectations;3 = exceeds expectations)
	sprawl	Assessment of how rigorously a city promotes containment of urban sprawl and reuse of brownfield areas (1 = below expectations; 2 = meets expectations; 3 = exceeds expectations)
Buildings	energy audit	Assessment of whether a city requires energy audits and whether energy regulations require that new buildings satisfy energy efficiency standards (1-3)
	retrofitting buildings	Assessment of a city's incentives for retrofitting buildings to improve energy efficiency and how widely it promotes energy efficiency in homes and offices (1-3)
Transportation	public transit	Share of workers traveling by public transit, bike or foot (%)
	public transit length	Length of public transit (mi/mi2)
	car use	Annual vehicle revenue miles (miles/person)
	public transit density	Maximum public transit vehicles available per square mile (vehicles/mi2)
	commute time	Average commute time from residence to work (minutes)
	public transit promotion	Assessment of how extensively the city promotes public transportation and offers incentives for less carbon-intensive travel (1-3)
	congestion	Assessment of a city's efforts to reduce congestion
Urban Design	green space	Green Space as % of total land area (%) Planning Department; US
	population density	Population density (person/mi2) US Census Bureau
	green space	Assessment of a city's efforts to sustain and improve the quantity and quality (for example, proximity and usability) of green spaces, and its tree planting policy (1 = below expectations; 2 = meets expectations;3 = exceeds expectations)

	sprawl	Assessment of how rigorously a city promotes containment of urban sprawl and reuse of brownfield areas (1 = below expectations; 2 = meets expectations; 3 = exceeds expectations)

REFERENCES

AARP livability index. (2018). Retrieved from https://livabilityindex.aarp.org/how-are-livability-scores-determined

Adlakha, D., & Sallis, J. F. (2020). Activity-friendly neighbourhoods can benefit non-communicable and infectious diseases. Cities & Health, , 1-5. doi:10.1080/23748834.2020.1783479

Adler, P., Florida, R., & Hartt, M. (2020). Mega regions and pandemics. Tijdschrift Voor Economische En Sociale Geografie, 111(3), 465-481. doi:10.1111/tesg.12449

Air pollution by NO2 and PM2.5 explains COVID-19 infection severity by overexpression of angiotensin-converting enzyme 2 in respiratory cells: A review. (2020). Environmental Chemistry Letters, , 1-18. doi:10.1007/s10311-020-01091-w

Altaf, A. (2020). COVID-19 and population density: A methodological note. Economic and Political Weekly,

Amerio, A., Brambilla, A., Morganti, A., Aguglia, A., Bianchi, D., Santi, F., . . . Capolongo, S. (2020a). COVID-19 lockdown: Housing built environment’s effects on mental health. International Journal of Environmental Research and Public Health, 17(16), 5973. doi:10.3390/ijerph17165973

Amerio, A., Brambilla, A., Morganti, A., Aguglia, A., Bianchi, D., Santi, F., . . . Capolongo, S. (2020b). COVID-19 lockdown: Housing built environment’s effects on mental health. International Journal of Environmental Research and Public Health, 17(16), 5973. doi:10.3390/ijerph17165973

Appleyard, D., Gerson, M. S., & Lintell, M. (1981). Livable streets University of California Press. Retrieved from https://books.google.com.lb/books?id=pfreUQKD_4QC

AreaVibesInc. (2020). Area vibes methodology. Retrieved from https://www.areavibes.com/methodology/

Awuor, L., & Melles, S. (2019). The influence of environmental and health indicators on premature mortality: An empirical analysis of the city of toronto's 140 neighborhoods. Health & Place, 58, 102155. doi:10.1016/j.healthplace.2019.102155

Byrne, J., & Flaherty, J. (2004). Measuring diversity in australian residential property. Retrieved from https://www.researchgate.net/publication/242525177_Measuring_Diversity_in_Australian_Residential_Property

City of Toronto. (2014). Tsns 2020 neighbourhood equity index . ().Social Policy and Analysis. Retrieved from https://www.toronto.ca/wp-content/uploads/2017/11/97eb-TSNS-2020-NEI-equity-index-methodology-research-report-backgroundfile-67350.pdf

Cloutier, S., Jambeck, J., & Scott, N. (2014). The sustainable neighborhoods for happiness index (SNHI): A metric for assessing a community's sustainability and potential influence on happiness. Ecological Indicators, 40, 147-152. doi:10.1016/j.ecolind.2014.01.012

Comer, D., & Greene, J. S. (2015). The development and application of a land use diversity index for oklahoma city, OK. Applied Geography (Sevenoaks), 60, 46-57. doi:10.1016/j.apgeog.2015.02.015

Creswell, J. W. (2009). Research design: Qualitative, quantitative, and mixed methods approaches (3rd ed.). Los Angeles: SAGE.

Crouse, D. L., Goldberg, M. S., & Ross, N. A. (2009). A prediction-based approach to modelling temporal and spatial variability of traffic-related air pollution in montreal, canada. Atmospheric Environment, 43(32), 5075-5084. doi:https://doi.org/10.1016/j.atmosenv.2009.06.040

Deville Cavellin, L., Weichenthal, S., Tack, R., Ragettli, M. S., Smargiassi, A., & Hatzopoulou, M. (2016). Investigating the use of portable air pollution sensors to capture the spatial variability of traffic-related air pollution. Environmental Science & Technology, 50(1), 313-320. doi:10.1021/acs.est.5b04235

Dewolf, C. (2005, April 20,). Getting to know the plex. Maisonneuve, Retrieved from https://maisonneuve.org/article/2005/04/20/getting-know-plex/

Doucet, B., & Mazumder, R. (2020, November). COVID-19 cyclists: Expanding bike lane network can lead to more inclusive cities. The Conversation Retrieved from https://theconversation.com/covid-19-cyclists-expanding-bike-lane-network-can-lead-to-more-inclusive-cities-144343

Feith, J. (2020, Dec 9,). Quebec workplace COVID outbreaks outpacing those in schools and care centers. Montreal Gazette, Retrieved from https://montrealgazette.com/news/local-news/quebec-workplace-covid-outbreaks-outpacing-those-in-schools-and-care-centres

Fu, B., Yu, D., & Zhang, Y. (2019). The livable urban landscape: GIS and remote sensing extracted land use assessment for urban livability in changchun proper, china. Land use Policy, 87, 104048. doi:10.1016/j.landusepol.2019.104048

Grijalva, C. G., Rolfes, M. A., Zhu, Y., McLean, H. Q., Hanson, K. E., Belongia, E. A., . . . Talbot, H. K. (2020). Transmission of SARS-COV-2 infections in households--tennessee and wisconsin, april-september 2020. Atlanta: U.S. Government Printing Office. doi:10.15585/mmwr.mm6944e1

Gyulai, L. (2021). No easy explanation for why COVID cases are higher in montreal's east end. Retrieved from https://montrealgazette.com/news/local-news/no-easy-explanation-for-why-covid-cases-are-higher-in-montreals-east-end

Hamidi, S., Sabouri, S., & Ewing, R. (2020). Does density aggravate the COVID-19 pandemic?: Early findings and lessons for planners. Journal of the American Planning Association, 86(4), 495-509. doi:10.1080/01944363.2020.1777891

Harvey, C., & Aultman-Hall, L. (2016). Measuring urban streetscapes for livability: A review of approaches. The Professional Geographer, 68(1), 149-158. doi:10.1080/00330124.2015.1065546

Honey-Rosés, J., Anguelovski, I., Chireh, V. K., Daher, C., Konijnendijk van den Bosch, Cecil, Litt, J. S., . . . Nieuwenhuijsen, M. J. (2020). The impact of COVID-19 on public space: An early review of the emerging questions – design, perceptions and inequities. Cities & Health, , 1-17. doi:10.1080/23748834.2020.1780074

Kadi, N., & Khelfaoui, M. (2020). Population density, a factor in the spread of COVID-19 in algeria: Statistic study. Bulletin of the National Research Centre, 44(1), 138. doi:10.1186/s42269-020-00393-x

Karasan, A., Bolturk, E., & Kahraman, C. (2019). An integrated methodology using neutrosophic CODAS & fuzzy inference system: Assessment of livability index of urban districts. Journal of Intelligent & Fuzzy Systems, 36(6), 5443-5455. doi:10.3233/jifs-181322

Karwarcki, J. P. (2020). The results are in: Verdun is montreal's coolest neighborhood. Retrieved from https://www.timeout.com/montreal/news/the-results-are-in-verdun-is-montreals-coolest-neighbourhood-100720

Kashef, M. (2016). Urban livability across disciplinary and professional boundaries. 中国建筑与土木工程前沿：英文版, 5(2), 239-253. doi:10.1016/j.foar.2016.03.003

Kasinitz, P. (2020). Rending the “Cosmopolitan canopy”: COVID–19 and urban public space. City & Community, 19(3), 489-495. doi:10.1111/cico.12516

Lal, R. (2020a). Home gardening and urban agriculture for advancing food and nutritional security in response to the COVID-19 pandemic. Food Security, 12(4), 871-876. doi:10.1007/s12571-020-01058-3

Lal, R. (2020b). Home gardening and urban agriculture for advancing food and nutritional security in response to the COVID-19 pandemic. Food Security, 12(4), 871-876. doi:10.1007/s12571-020-01058-3

Laurent, L. (2020, September 15,). France and spain fail the coronavirus test. Bloomberg Retrieved from https://www.bloomberg.com/opinion/articles/2020-09-15/coronavirus-spain-france-and-the-u-k-fail-the-test-and-trace-test

LEED reference guide for neighborhood development (2014).

Lefebvre, H. (1991). The production of space. Oxford: B. Blackwell.

Legge, K. (2020). The impact of covid 19 on community livability. Retrieved from https://www.unissu.com/proptech-resources/the-impact-of-covid-19-on-community-livability

Lennon, M. (2020a). Green space and the compact city: Planning issues for a ‘new normal’. Cities & Health, , 1-4. doi:10.1080/23748834.2020.1778843

Lennon, M. (2020b). Green space and the compact city: Planning issues for a ‘new normal’. Cities & Health, , 1-4. doi:10.1080/23748834.2020.1778843

Maizlish, N., Delaney, T., Dowling, H., Chapman, D. A., Sabo, R., Woolf, S., . . . Snellings, L. (2019a). California healthy places index: Frames matter. Public Health Reports (1974), 134(4), 354-362. doi:10.1177/0033354919849882

Maizlish, N., Delaney, T., Dowling, H., Chapman, D. A., Sabo, R., Woolf, S., . . . Snellings, L. (2019b). California healthy places index: Frames matter. Public Health Reports (1974), 134(4), 354-362. doi:10.1177/0033354919849882

Maroko, A. R., Nash, D., & Pavilonis, B. T. (2020). COVID-19 and inequity: A comparative spatial analysis of new york city and chicago hot spots. Journal of Urban Health, 97(4), 461-470. doi:10.1007/s11524-020-00468-0

Mercer. (2020). Quality of living 2020, evaluating assignment locations. Retrieved from https://mobilityexchange.mercer.com/Portals/0/Content/PDF/qol-2020-evaluating-assignment-locations.pdf

Meyherson, N. (2020, June 9). Groceries were hard to find for millions, now its getting even worse. Cnn Retrieved from https://www.cnn.com/2020/06/09/business/food-deserts-coronavirus-grocery-stores/index.html

Mishra, S. V., Gayen, A., & Haque, S. M. (2020). COVID-19 and urban vulnerability in india. Habitat International, 103 doi:10.1016/j.habitatint.2020.102230

Mitra, R., Moore, S. A., Gillespie, M., Faulkner, G., Vanderloo, L. M., Chulak-Bozzer, T., . . . Tremblay, M. S. (2020). Healthy movement behaviours in children and youth during the COVID-19 pandemic: Exploring the role of the neighbourhood environment. Health & Place, 65, 102418. doi:10.1016/j.healthplace.2020.102418

Myers, D. (1988). Building knowledge about quality of life for urban planning. Journal of the American Planning Association, 54(3), 347-358. doi:10.1080/01944368808976495

National Association of City Transport Officials. (2013). Urban street design guide Island Press.

Nguyen, Q. C., Huang, Y., Kumar, A., Duan, H., Keralis, J. M., Dwivedi, P., . . . Tasdizen, T. (2020). Using 164 million google street view images to derive built environment predictors of COVID-19 cases. International Journal of Environmental Research and Public Health, 17(17), 1-13. doi:10.3390/ijerph17176359

OECD. (2020). Cities policy responses. (). Retrieved from http://www.oecd.org/coronavirus/policy-responses/cities-policy-responses-fd1053ff/

Peters, D. J. (2020). Community susceptibility and resiliency to COVID-19 across the Rural-Urban continuum in the united states. The Journal of Rural Health, 36(3), 446-456. doi:10.1111/jrh.12477

Potyondy, P. J. (2013). Influence of urban tree canopy on single-family residential structure energy consumption at the community scale in hutchinson, minnesota

Ragettli, M. S., Goudreau, S., Plante, C., Fournier, M., Hatzopoulou, M., Perron, S., & Smargiassi, A. (2016). Statistical modeling of the spatial variability of environmental noise levels in montreal, canada, using noise measurements and land use characteristics. Journal of Exposure Science and Environmental Epidemiology, 26(6), 597-605. doi:10.1038/jes.2015.82

Rasmussen, A. (2020, March). Why you're unlikely to get the coronavirus from runners or cyclists. Retrieved from https://www.vox.com/future-perfect/2020/4/24/21233226/coronavirus-runners-cyclists-airborne-infectious-dose?__c=1

Reckien, D. (2018). What is in an index? construction method, data metric, and weighting scheme determine the outcome of composite social vulnerability indices in new york city. Regional Environmental Change, 18(5), 1439-1451. doi:10.1007/s10113-017-1273-7

Rhoads, D., Solé-Ribalta, A., González, M. C., & Borge-Holthoefer, J. (2020a). Planning for sustainable open streets in pandemic cities.

Rhoads, D., Solé-Ribalta, A., González, M. C., & Borge-Holthoefer, J. (2020b). Planning for sustainable open streets in pandemic cities.

Ruth, M., & Franklin, R. S. (2014). Livability for all? conceptual limits and practical implications. Applied Geography (Sevenoaks), 49, 18-23. doi:10.1016/j.apgeog.2013.09.018

SANTE MONTREAL.Situation of the coronavirus (covid-19) in montréal. Retrieved from https://santemontreal.qc.ca/en/public/coronavirus-covid-19/situation-of-the-coronavirus-covid-19-in-montreal/

Scot, M. (2021, Jan). How will the pandemic reshape montreal? A look at 2021's challenges. Retrieved from https://montrealgazette.com/news/local-news/the-post-covid-city

Shingler, B., Montpetit, J. & Rocha, R. (2020). Montreal's poorest and most racially diverse neighbourhoods hit hardest by COVID-19, data analysis shows. Retrieved from https://www.cbc.ca/news/canada/montreal/race-covid-19-montreal-data-census-1.5607123

Stanislav, A., & Chin, J. T. (2019a). Evaluating livability and perceived values of sustainable neighborhood design: New urbanism and original urban suburbs. Sustainable Cities and Society, 47, 101517. doi:10.1016/j.scs.2019.101517

Stanislav, A., & Chin, J. T. (2019b). Evaluating livability and perceived values of sustainable neighborhood design: New urbanism and original urban suburbs. Sustainable Cities and Society, 47, 101517. doi:10.1016/j.scs.2019.101517

Statistics Canada. (2013). Housing suitability of private household. Retrieved from https://www23.statcan.gc.ca/imdb/p3Var.pl?Function=DEC&Id=100731

Statistics Canada. (2016). Illustrated glossary. Retrieved from https://www150.statcan.gc.ca/n1/pub/92-195-x/92-195-x2016001-eng.htm

Stevenson, M., Thompson, J., de Sá, T. H., Ewing, R., Mohan, D., McClure, R., . . . Woodcock, J. (2016). Land use, transport, and population health: Estimating the health benefits of compact cities. The Lancet (British Edition), 388(10062), 2925-2935. doi:10.1016/S0140-6736(16)30067-8

Stiles, J. (2020, April 10,). The geography of occupations: Some neighborhoods will suffer more than others under COVID-19. Retrieved from https://www.planetizen.com/features/109029-geography-occupations-some-neighborhoods-will-suffer-more-others-under-covid-19

Talen, E. (2005). Land use zoning and human diversity: Exploring the connection. Journal of Urban Planning and Development, 131(4), 214-232. doi:10.1061/(ASCE)0733-9488(2005)131:4(214)

The Economist Intelligence Unit. (2020). The global livability index. Retrieved from https://www.eiu.com/topic/liveability#:~:text=The%20Global%20Liveability%20Index,lifestyle%20in%20140%20cities%20worldwide.

Town of Hampstead. (2020). Our history. Retrieved from https://www.hampstead.qc.ca/discover_hampstead/our_history/

TransAlt. (2020). Op-ed: Here are some cities getting open streets right. Retrieved from https://usa.streetsblog.org/2020/05/01/op-ed-heres-some-cities-getting-open-streets-right/

UN Habitat. (2020). World cities report. (). Retrieved from https://unhabitat.org/sites/default/files/2020/10/wcr_2020_report.pdf

UN-Habitat. (2020). UN-habitat COVID-19 response plan. ().

United Nations. (2017). Principles and recommendations for population and housing censuses, revision 3 UN. doi:10.18356/bb3ea73e-en

Ville de Montreal.Ma carte interactive. Retrieved from https://spectrum.montreal.ca/connect/analyst/mobile/#/main?mapcfg=-%20Verdun

Wagner, F., & Caves, R. W. (2012). Community livability: Issues and approaches to sustaining the well-being of people and communities. Abingdon, Oxon: Routledge. doi:10.4324/9780203148204 Retrieved from

Walk score. (2020). Retrieved from https://www.walkscore.com/methodology.shtml

Wineman, J. D., Marans, R. W., Schulz, A. J., van der Westhuizen, Diaan Louis, Mentz, G. B., & Max, P. (2014). Designing healthy neighborhoods: Contributions of the built environment to physical activity in detroit. Journal of Planning Education and Research, 34(2), 180-189. doi:10.1177/0739456X14531829

Zhang, C. H., & Schwartz, G. G. (2020). Spatial disparities in coronavirus incidence and mortality in the united states: An ecological analysis as of may 2020. The Journal of Rural Health, 36(3), 433-445. doi:10.1111/jrh.12476

Zhao, S., Zhuang, Z., Ran, J., Lin, J., Yang, G., Yang, L., & He, D. (2020). The association between domestic train transportation and novel coronavirus (2019-nCoV) outbreak in china from 2019 to 2020: A data-driven correlational report. Travel Medicine and Infectious Disease, 33, 101568. doi:10.1016/j.tmaid.2020.101568

Zieleniec, A. (2018). Lefebvre's politics of space: Planning the urban as oeuvre. Urban Planning, 3(3), 5-15. doi:10.17645/up.v3i3.1343