Geographical Indicators of the Built Environment and Services Environment Influencing Physical Activity, Diet and Body Weight

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Direction du développement des individus
et des communautés

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WRITTEN BY

Éric Robitaille
Direction du développement des individus et des communautés
Institut national de santé publique du Québec

COORDINATED BY

Johanne Laguë
Direction du développement des individus et des communautés
Institut national de santé publique du Québec

LAYOUT

Souad Ouchelli
Direction du développement des individus et des communautés
Institut national de santé publique du Québec

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Danielle Larouche, M. Sc.
Institut national de santé publique du Québec

Basile Chaix, Ph. D.
UMR-S 707 Inserm - Université Pierre et Marie Curie-Paris 6
Faculté de Médecine Saint-Antoine

Marie-Soleil Cloutier, Ph. D.
Institut national de la recherche scientifique

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Agence de la santé et des services sociaux des Laurentides

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Robert Pampalon, Ph. D.
Institut national de santé publique du Québec

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SUMMARY

Background and Objective

Over the past few years, excess weight has become one of the most troubling public health problems. Globally, organizations such as the World Health Organization (WHO) have described the current situation as epidemic. Factors that can explain this trend are linked to complex interactions between individual characteristics and environmental aspects. The built environment and the services environment are elements that can influence individuals' behaviours, lifestyle habits and body weight. The main objective of this document is to analyze and present various indicators of the built environment and of the services environment. These indicators are constructed from a geographic information system and used in ecological studies that look at issues related to diet, physical activity and body weight.

Methods

We conducted a literature review of 56 studies, published between 2003 and 2009, using indicators developed from geospatial databases. The literature review enabled us to draw up a list of measures to attempt to characterize the built environment and the services environment. More specifically, this document contains six summaries of indicator categories for the built environment and the services environment[1] likely to influence the health and behaviours of individuals:

- Summary 1: Indicators of Land-use Diversity and Density
- Summary 2: Indicators of Road Network Configurations
- Summary 3: Indicators Linked to Nonmotorized Transportation Networks and Public Transit Infrastructures
- Summary 4: Indicators of Urban Environment Design (at the both the street- and site-level)
- Summary 5: Indicators Related to Recreational Infrastructure
- Summary 6: Indicators Related to Food Outlets

Each summary contains a section presenting a justification of the potential impact of these environmental indicators on diet, physical activity or body weight. This section contains elements from the literature, data that is pertinent to Québec and Canada, as well as illustrative figures. For each environmental indicator, the summary also includes a section describing the studies retained and one that sums up the results of these studies. These two sections are followed by the list of indicators used, a section on the databases used to operationalize the various indicators, a comments and limits section, and finally a section on operationalizing indicators for Québec. This latter section includes a list of different databases that could be used to calculate the various indicators and a brief description of the

[1] The services environment includes elements of the built environment where contents can influence an individual's diet and physical activity. In other words, buildings that house these services are part of the built environment but the services offered in these building are not linked conceptually to the built environment. In our document, the services environment includes, on the one hand, elements of the food environment that refer only to geographical access to food outlets and, on the other hand, recreational infrastructures.

databases. Examples of operationalization of the indicators are also presented in most summaries.

Results

The literature review allowed us to observe that most studies found significant associations between the built environment and individuals' behaviours or characteristics. However, the methods and data sources used to develop indicators of the built environment are not consistent. The processes by which we develop indicators for the built environment and services environment should include putting in place tools to study the reliability and validity of these indicators. Nevertheless, several indicators used in various studies could be operationalized in Québec through geospatial databases. These indicators could subsequently be the subject of a portrait of the built environment and the services environment in Québec; they could also be used to study possible links between aspects of these environments and individuals' behaviours (physical activity or diet) or, indirectly, individuals' characteristics (body weight).

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1. INTRODUCTION

Over the past few years, obesity has become one of the most troubling public health problems. Internationally, organizations such as the World Health Organization describe as epidemic the current prevalence rate of people with excess weight (1). According to the most recent data, the prevalence of excess weight in Québec is 48% (obesity: 14%; overweight: 34%) (2). Prevalence has been increasing over the past few years, with the average BMI of Quebecers rising from 24.1 kg/m2 in 1987 to 25.4 kg/m2 in 2005 (2,3). This seemingly minimal increase of 1.3 kg/m2 has resulted in significant weight gain in the population and an increase in the number of people at risk for health problems (including type 2 diabetes, stroke, some cancers, and others). Explanatory factors for this trend can be numerous. Most researchers select four categories of factors: individual, social, behavioural or lifestyle and environmental factors (4, 5). In 2006, Québec introduced the 2006-2012 action plan for the promotion of healthy lifestyle habits and prevention of weight-related problems (Investing for the Future), to make the battle against obesity a priority. This report focuses these efforts on various measures that can be adopted to change environments[2] so as to encourage adoption of healthy lifestyle habits. One of these environments concerns the physical environment defined, on the one hand, by the natural environment and, on the other, by infrastructures linked to the built environment.

To better understand how characteristics of the built or the services environment can influence individuals' health and behaviours, characteristics of these environments have to be documented and measured objectively. The main objective of this report is to present the results of a scientific literature review centred on identifying indicators of the built environment relating to the issue of weight. Some of these indicators could then be used to put together a portrait of the built environment in Québec and its regions. The indicators could also be used to identify determinants of the built environment and of the services environment likely to influence the lifestyle habits of Quebecers. In short, this report is for people interested in the promotion of healthy lifestyle habits and the issue of weight, and the related environmental determinants including the built environment and services environment.

We were largely inspired by a document published by the Institut national de santé publique du Québec (INSPQ) on vulnerability indicators associated with a territory's safety (6). It also follows from prior recent research concentrated on developing a deprivation index (7), social development indicators (8), community development indicators (9), socio-territorial indicators (10), and social and environmental indicators (11). These studies show the importance of the elaboration, over the past decades, of sets of indicators in the fields of research and public administration. Moreover, with the recent development of technologies linked to the geographic information system (GIS)[3] and the compilation of new databases, it is now possible to objectively assess the built environment (13, 14). This process is already underway in Nova Scotia. Indeed, a consortium of Dalhousie University, government agencies and some non-profit organizations was set up as a first step towards identifying

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[2] For example, social and food environments.

[3] Information system designed to enable collection, management, manipulation, analysis, modelling and display of geospatial data to solve problems related to development, management and research (12).

indicators of the built environment likely to influence physical activity among individuals. The indicators selected by the consortium were then integrated into online community databases and will be used to put in place public policies related to the development of a built environment that fosters increased levels of physical activity (15).

More specifically, this document contains six summaries of indicator categories for the built environment and the services environment likely to influence the health and behaviours of individuals:

- Summary 1: Indicators of Land-use Density and Diversity
- Summary 2: Indicators of Road Network Configurations
- Summary 3: Indicators Linked to Nonmotorized Transportation Networks and Public Transit Infrastructures
- Summary 4: Indicators of Urban Environment Design (at both the street- and site-level)
- Summary 5: Indicators Related to Recreational Infrastructures
- Summary 6: Indicators Related to Food Outlets

This list of categories of indicators is based on a methodological review of more than 56 peer-reviewed scientific articles published between 2003 and 2009[4] (Table 1).

[4] We limited our review to this short period of time because most relevant articles that met our selection criteria were published during this period. Wendel Vos et al., 2006, note that most studies (over 80%) attempting to make an association between the built environment and physical activity were published from 2002 on (16).

Table 1 List of Indicators Used in the 56 Articles Reviewed

Indicators	References
Summary 1: Indicators of Land-use Density and Diversity	
Diversity (entropy) index	(17-19)
Number of destinations	(20)
Number of retail shops and churches	(21)
Neighbourhood density	(22)
Residential density	(35)
Net residential density	(23)
Employment or destination density	(24, 25)
Walkability index	(19, 22-24)
Sprawl index	(21, 26)
Summary 2: Indicators of Road Network Configurations	
Intersection density	(23, 24, 27-30)
Proportion of four-way intersections	(27, 31, 32)
Segment/intersection ratio	(39)
Number of intersections	(33, 34)
Gamma index	(30)
Alpha index	(30, 35)
Average block lengths	(22, 27, 31)
Average or median block size	(32)
Average block density	(27, 29, 32)
Proportion of roadways by road type	(30)
Percentage of high-, medium- and low-volume streets	(33)
Total length of roads by type (small roads, local roads)	(30)
Average posted speed limits on road segments	(29)
Maximum speed over a series of road segments	(29)
Summary 3: Indicators Linked to Nonmotorized Transportation Networks and Public Transit Infrastructures	
Proximity of pedestrian walkways and cycling paths	(36)
Access to cycling paths	(37)
Distance to closest trail	(38)
Number of bus lines	(33)
Density of public transit stations	(24, 27, 37)
Distance to nearest transit equipment	(27, 39)

Table 1 List of Indicators Used in the 56 Articles Reviewed (continued)

Indicators	References
Summary 4: Indicators of Urban Environment Design	
Median housing age	(31, 36, 40)
Vegetation index	(41, 42)
Number of trees per length of road	(27)
Number of street lights per length of road	(27)
Total number of speed bumps	(43)
Total number of traffic calming measures	(43)
Total number of pedestrian lights	(43)
Total sidewalk lengths per unit area	(27)
Proportion of street segments with pedestrian crossings	(27)
Proportion of street segments with sidewalks	(27)
Summary 5: Indicators Related to Recreational Infrastructures	
Density or number of infrastructures in a given area[a]	(19, 38, 44-50)
Distance between residence and closest infrastructure	(38, 48, 51-55)
Proportion of land area dedicated to recreational infrastructure	(50, 56)
Summary 6: Indicators Related to Food Outlets	
Distance to closest food outlets	(51, 57-62)
Density or number of outlets in a given area	(18, 25, 35, 57, 60-68)
Average distance to an *n* group of food outlets[b]	(61)

[a] The studies use two methods: within a radius of study participants' homes, or based on spatial units (e.g. neighbourhoods).

[b] Distance to closest food outlet is calculated from the central point of the spatial unit (e.g. census tracts) where study participants live (59, 61) or from the homes or workplaces of participants (51, 57, 60, 62, 63, 66).

Geographical indicator: Definition

The literature on the concept of indicators is quite extensive (69, 70). For this reason, and based on the indicators used in the literature pertaining to connections between the built environment, services environment, diet, physical activity and body weight, we limited ourselves to the definition of geographical indicator.

Firstly, and etymologically, an indicator is used to show something (71). "An indicator translates data and statistics into succinct, clear information. It fosters a better understanding of complex phenomena and can be used by various groups of individuals with different concerns" (72): 2. A geographical indicator reveals information about a phenomenon that has a spatial reference. Like any other indicator, a geographical indicator attempts to represent a concept simply.

Maby (2004) and Desthieux (2004) distinguish two main types of geographical indicators: thematic and spatial. Thematic indicators are defined by the association of a set of values with a geographical object (e.g. proportion of housing units built before 1946 across dissemination areas) (72, 73). These indicators are the best known and most commonly used to produce thematic maps. Examples in the health field include life expectancy, infant mortality rate, and hospitalization rate by cause (69). A spatial indicator provides information on the organization of an object in space. It is used as a basic element in spatial analysis (e.g. distance to closest food outlets).

2. OVERVIEW OF THE VARIOUS METHODS USED TO CHARACTERIZE THE BUILT ENVIRONMENT AND THE SERVICES ENVIRONMENT

According to the literature, there are three different approaches to operationalizing environmental indicators susceptible of influencing an individual's diet, physical activity and body weight (14, 74). One of these approaches is linked to the use of built environment and services environment measures as perceived by individuals. The second approach is based on systematic observations of these environments' characteristics. The third and last method uses geospatial databases and GIS data in order to develop indicators. Data collected from observations or perceived measures can, in some cases, be used to create geographic indicators of the built environment and services environment (74). These approaches are interesting for developing indicators of the built environment that are difficult to operationalize from certain databases. However, indicators derived from these tools seldom allow for operationalization on a territorial scale such as that of Québec. This is why, in our report, we favoured studies using indicators of the built environment and the services environment developed from geospatial data and using GIS-based methods.

3. METHODOLOGY

3.1. CONCEPTUAL SCHEMATIC

To define indicators related to weight issues, we chose the ecological models of Papas et al. (2007) and of Chaix (2009) concerning the possible role of the environment on individuals' behaviours (diet, physical activity) and health (5, 75). Lifestyle habits and body weight partly result from a complex process of interactions between individual and social factors, on the one hand, and environmental factors such as the built environment and the services environment, on the other (Figure 1). Papas et al. (2007) suggest that the built environment represents all the elements built or modified by human beings. The conceptual schematic of this research includes two types of indicators in the built environment: indicators related to access to recreational infrastructures, land use configuration, road network configuration, and urban environment design (e.g. proximity of playgrounds or recreational facilities, street types, sidewalk availability, diversity of land use, density), and indicators related to access to food outlets (e.g. proximity of fast-food restaurants, density of grocery stores).

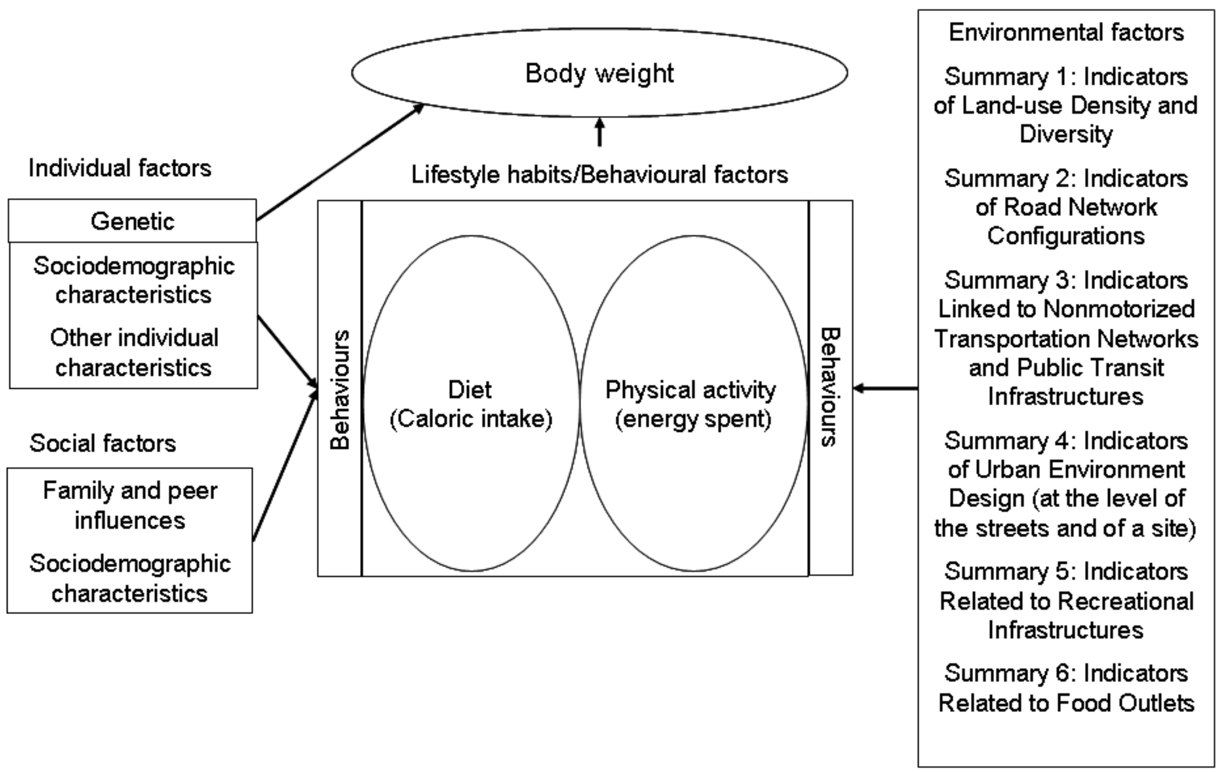

Figure 1: Conceptual Schematic, adapted from Papas et al. (2007), Frank et al. (2003) and Chaix (2009)

Other researchers define the concept of the built environment using elements such as land use configuration, based on the diversity and density of the environment; elements related to the urban form of an area; transport system configuration characterized by access to nonmotorized networks and to public transportation systems; level of connectivity and street width; and urban design of the built environment (17). In this approach, elements related to accessibility to food outlets or of facilities that can promote physical activity (e.g. parks, gyms) are not considered elements of the built environment as suggested by Papas et al. (2007).

A recent literature review makes a distinction between elements inherent in the built environment and in what we may qualify as the services environment. The hypothetical process of the impact of the environment on coronary heart diseases according to Chaix (2009) includes the built environment and the services environment under the concept of neighbourhood environment. The built environment consists of elements such as building appearance and location, the street network, public spaces, design and level of greenness. The services environment includes transportation infrastructures, the food environment, sports facilities and density of destinations.

After reviewing the literature, we chose to distinguish two categories of indicators: indicators related to the built environment and indicators related to the services environment. The indicators related to the built environment attempt to reflect land use configuration, road network configuration, characteristics of the transportation system, and design of the urban environment. These various groups of indicators of the built environment draw on the research of Frank et al. (2003) (17). The services environment includes indicators that attempt to measure aspects of the food environment and recreational facilities.

It is also important to mention that modification of individual behaviours (diet and physical activity) has an impact on body weight as well as on other individual characteristics. For instance, it was demonstrated that physical activity improves health and self-esteem, can reduce body weight, and in the long term can prevent the appearance of chronic illnesses such as cancer or diabetes (76). Needless to say, several articles reviewed in the summaries discuss only possible associations between characteristics of the environment and individual behaviours.

3.2. LITERATURE REVIEW

The summaries included in this report are based on evidence from scientific articles dealing with at least one aspect of the built environment and of the services environment listed in Figure 1. The selection criteria for these articles are as follows: 1) The article should contain a variable related to the participants' condition, namely an individual measure reflecting physical activity, food consumption, or weight and height (body mass index) (Table 2). These variables may be self-reported or measured. 2) The article should also include at least one indicator developed using GIS data or geospatial databases of the built and the services environments.[5] This requirement was introduced to isolate indicators that could potentially be operationalized in Québec using geospatial databases. Indicators of the built environment measured from individuals' perceptions are difficult to implement in large territories. 3) The articles should demonstrate the existence or the absence of a significant association between characteristics of the built environment and characteristics related to study

[5] Several articles were excluded as a result of this requirement, since measured indicators of the environment were operationalized from the participants' perception of this environment or observers related to the studies.

participants (body mass index, diet or physical activity).[6] It is important to consider the word 'association'. The articles reviewed in the summaries demonstrate, in some cases, significant associations between the characteristics of the environment and individual characteristics. However, these associations do not necessarily mean that the observed relationships are causal in nature. In other words, when an article's findings point to a significant association between, for instance, an increase in the density of the built environment and a weak body mass index in the participants, we should not automatically draw the conclusion that a low density of the built environment leads to a decrease in BMI. 4) The articles were published between 2003 and 2009.[7]

Table 2 Variables and Measures Used in the Articles Retained

Individual variables	Measures
Level of physical activity (for transportation, recreation or total)	Frequency (times/week) of walking (transportation, recreation, total)
	Time (minutes/week) spent walking (transportation, recreation, total)
	Average time (minutes/day) spent engaging in intense or moderate physical activity
	Time (minutes/week) spent engaging in recreational physical activity
Diet	Fruit and vegetable consumption (number of portions/day)
	High-fat food consumption index
	Food quality index for pregnant women
	Consumption of sweetened beverages (number/day)
Weight category	BMI[a] (body mass index)

Source: (84).

[a] Weighted status measure index corresponding to the individual's reported weight, in kilograms, over the square of the individual's height, in metres.

With these criteria, a bibliography search was done using various keywords and the browsers provided by PubMed, Medline and Google Scholar. The following keywords were used: *built environment*, *obesity*, *physical activity*, *nutrition*, *health*, *food*, *food security*, *urban planning*, *land-use planning*, *municipal*, *zoning*, *land-use*, *travel*, *transit*, *healthy lifestyle*, *active living*, *active transport*, *walking*, *cycling*, *GIS*, *BMI*, *Physical activity facilities*, *parks*, *accessibility*, *gym*, *objective*, *food environment*, *nutrition environment*, *food access*, *food availability*. The bibliographies of each article found through this search were carefully examined to complete the list of retained articles. The articles reviewed included one or several dimensions of the built environment. Bibliographic searches were also done using

[6] Unless specified otherwise, the term "association" used in this text refers to the results of statistical analyses using multiple variables where indicators of the environment are significantly linked or not to variables related to individual characteristics of the participants (body mass index, diet, physical activity).

[7] For earlier articles, readers can consult many published literature reviews that included articles aimed at measuring the impact of the built environment and the services environment on physical activity, diet or the BMI (5, 77-84).

French-language browsers (e.g. *Érudit*), but none of the studies found met the previously established criteria.

A compilation grid was then established to categorize the retained studies and facilitate writing of various summaries. The grid consists of the following elements: authors and publication dates, subject of the article (food consumption, physical activity, or both), study design (cross-sectional, longitudinal, perceived measures), population studied (sample, country, city), indicators of the built environment, other contextual variables, spatial analysis scale, individual variables not related to consumption, physical activity or body weight, individual variables (body weight, food consumption or physical activity), study findings, and databases used to operationalize the various environment indicators (Appendix 1).

4. RESULTS

For this literature review, we chose 56 studies published between 2003 and 2009. Each study meets the criteria described earlier.

These studies characterize the environment based on indicators that reflect density and diversity of land use (11 studies); connectivity and characteristics of the road network (13 studies); nonmotorized transportation networks and public transit infrastructures (8 studies); urban environment design (10 studies); geographical accessibility to recreational infrastructures (20 studies); and geographical accessibility to food outlets (15 studies) (Table 3). Most of these studies were conducted in the United States (43); the others were carried out in Australia (5), New Zealand (3), Canada (2) and Europe (3). Over 89% of these studies used cross-sectional research designs, that is, they analyzed the influence of the environment on individuals' health and behaviours at a given point in time.

Table 3 Number of Articles Using the Various Indicators

Built environment – Categories of indicators	Number of articles per category
Summary 1: Indicators of Land-use Density and Diversity	11
Summary 2: Indicators of Road Network Configurations	13
Summary 3: Indicators Linked to Nonmotorized Transportation Networks and Public Transit Infrastructures	8
Summary 4: Indicators of Urban Environment Design	10
Services environment	
Summary 5: Indicators related to recreational infrastructures	20
Summary 6: Indicators related to food outlets	15

The spatial scales utilized vary in analyses of possible impacts of the built environment and the services environment on physical activity, diet and body weight. Most researchers use buffers around each survey participant. The buffer zones define a walking environment that can influence behaviours or individuals' characteristics and can vary in distance from 400 metres to 3 kilometres from participants' homes or, in some cases, from schools (50, 67, 85) and place of work (63, 86). Two methods calculate these distances: straight line (20-22, 27, 29-31, 33, 37, 40-44, 46-48, 50, 54, 56, 57, 60-63, 87, 88) or road network (19, 23, 28, 34, 38, 49, 53, 89). Distance based on street network is a better choice since it reflects reality more accurately (Figure 2) (23). The other studies use other types of divisions such as neighbourhoods, census tracts, postal or zip code zones, or counties (18, 24-26, 32, 35, 36, 45, 51, 55, 58, 59, 64-68, 85).

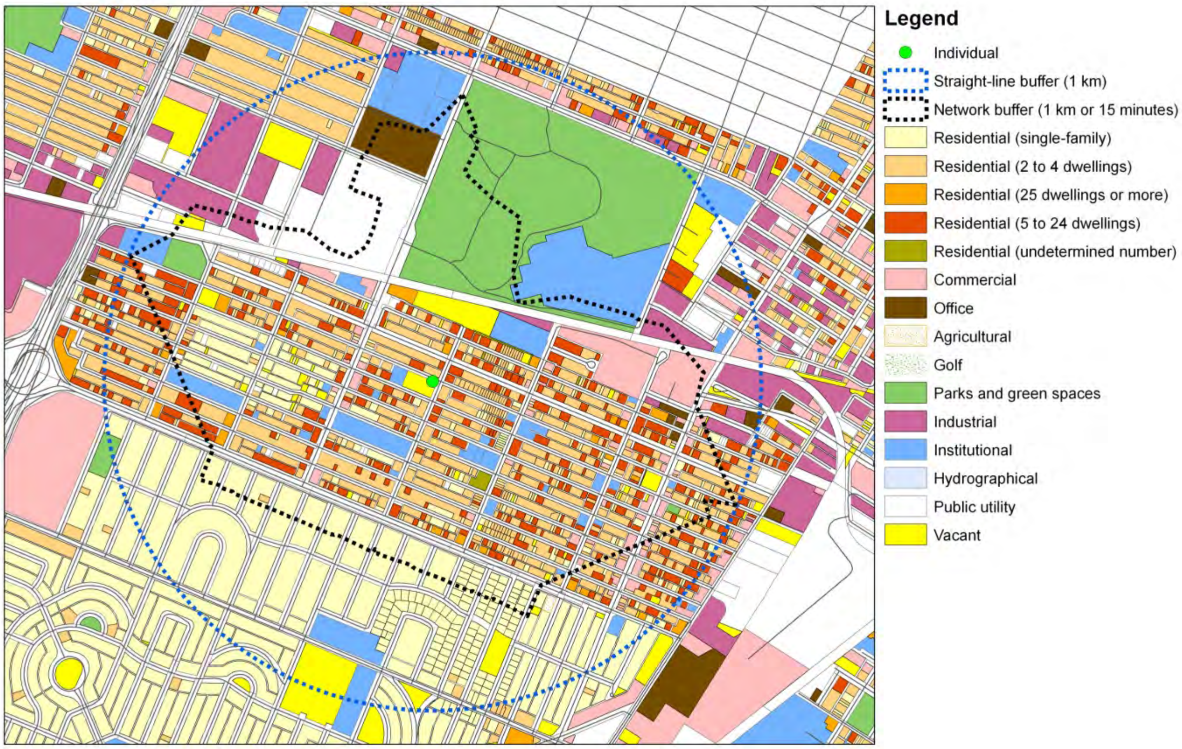

Figure 2: Built Environment of an Individual, adapted from Frank et al., 2005 (90)

5. INDICATORS OF THE BUILT ENVIRONMENT RELATED TO PHYSICAL ACTIVITY

SUMMARY 1: INDICATORS OF LAND-USE DENSITY AND DIVERSITY

Background

A number of researchers have attempted to measure links between characteristics of the built environment, physical activity (recreational or utilitarian), and individuals' health. According to Frank et al. (2003), some aspects of the built environment such as land-use configuration can influence physical activity. They describe land-use configuration using two measures of urban form:[8] diversity and density of the built environment (17). Their hypothesis is that high density and very diverse environments tend to improve accessibility and proximity of sites. Consequently, travel distances individuals must cover to reach their destinations are shorter and can promote physical activity, especially related to transportation.

Land-use diversity refers to the concentration of multifunctionality within an area. The theory suggests that multifunctional environments can improve proximity and reduce travel times between departure sites (e.g. home) and destination sites (e.g. work) and consequently encourage active transportation[9] and physical activity.

Functional diversity can be measured for several spatial scales: building, site, district, and region. The meaning of diversity may vary depending on the spatial scale studied. In buildings, diversity is vertical. In other words, a building can encompass several types of occupancies, such as businesses on the ground floor and housing units on the other floors. On a larger spatial scale such as a site, some real-estate complexes contain multiple occupancy types such as offices, businesses and even residences. Functional diversity measures are applied mainly to neighbourhoods and districts. In addition, districts where the urban layout was built before zoning policies were established exhibit greater diversity. Regional-level diversity can also be measured, and studies employ a measure that demonstrates the balance between employment and residences. The employment/residence ratio can reveal a region’s or municipality’s level of diversity (93).

Several North American metropolitan zones feature high levels of employment or housing homogeneity, which tend to generate lengthy travel between places of residence and places of employment. Such lengthy trips promote the use of motorized modes of transportation. Occasionally, some researchers use the term “bedroom community” to reflect the characteristics of a suburban environment where jobs are few compared to the large number of residences (17, 94).

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[8] Urban form is a concept related to characteristics of the urban fabric. Urban form is often associated with three dimensions of the urban fabric: density, diversity, and design (91). According to the literature on urban environment, an optimal urban form is highly diversified and compact, since urban sprawl increases the impact of urbanization on natural and agricultural areas (92). As for weight issues, a compact and diversified urban form can encourage nonmotorized travel and, consequently, physical activity.

[9] Active transportation involves modes of travel on foot or on bike.

The density of the built environment concerns its compactness. Highly dense environments can promote the use of active modes of transportation because distances to be covered are shorter. Studies on active transportation reveal that highly dense environments can generate numerous trips between origins and destinations. Such considerable numbers of trips imply that they are on average shorter and could facilitate the adoption of active modes of transportation. Even so, in the United States 28% of trips under 1.6 kilometres are made by car (95). The optimal measure for defining density is calculated using the density of destinations such as parks, shopping centres, stores, and workplaces. Most of the studies reviewed use a population density measure. Due to their simplicity and easy operationalization, measures of density are used more often in design planning.

Study Descriptions

Eleven studies were reviewed that aimed to establish links among land-use diversity, density of the built environment, and individual characteristics. Ten of the eleven studies were carried out in the United States and one in Australia. All the studies were conducted in metropolitan contexts, whereas only two studies collected longitudinal individual-level data. Sample sizes varied between 800 and 11 000 individuals. The studies differ in the effects measured on individuals. Among the reviewed studies, seven collated BMI, one used measures of physical activity only, and three measured both BMI and physical activity. The reviewed studies also differ in respondents' age and sex. In fact, six of them focus on adults, two on women, three on children and two on elderly persons.

Finally, three out of the eleven reviewed studies used land-use density and diversity simultaneously as indicators of the built environment. The remaining studies chose either density or diversity.

Study Findings

Several studies reveal significant associations between density and diversity of the built environment and BMI.

Most study findings reveal significant associations between diversity, density of the built environment, and BMI. Frank et al. (2004) observed a strong association between individuals' BMI and land-use diversity, yet no significant relationship between density and BMI (28). Mobley et al. (2006) drew similar conclusions, finding that women living in a built environment with high land-use diversity have a significantly lower BMI than women living in low-diversity districts (18). Finally, Lopez (2007) demonstrated significant associations between density of the built environment and participants' BMI (25). In a study of children, Ewing et al. (2006) observed significant links between increase in density of the built environment and BMI (26). Using a district walkability index, Frank et al. (2007) demonstrated a positive association between land-use diversity and physical activity (23). These study findings suggest that creating an environment which encourages walking (dense and diverse) can increase physical activity and consequently decrease BMI (Table 4).

Some studies, however, failed to find any significant links. Grafova (2008) found no significant link between density of the built environment and risks of overweight in children (35). The author nonetheless draws the conclusion that some characteristics of the environment can be related to childhood overweight, such as density of convenience stores and year of construction of the built environment. Eid et al. (2008) found no significant link between land-use diversity and BMI developments in 6 000 individuals. They concluded that public health officials should not use the built environment or urban sprawl to explain the obesity epidemic (21). Based on longitudinal data from 3 000 children, Ewing et al. (2006) found no significant link between characteristics of the built environment and BMI developments. They claim that these findings can be explained by the sample size, and the effect of latent, that is, non-observable variables, or of certain control variables (socioeconomic) such as children's educational level or age (26) (Table 4).

Significant association between increase in density and diversity of the built environment and increase in physical activity.

Surprisingly, only one investigation looked at physical activity. In Australia, McCormack et al. (2008) demonstrated significant links between proximity and diversity of destinations and utilitarian, but not recreational or intense, physical activity. Nevertheless they concluded that a built environment featuring significant diversity and density can promote walking as a means of utilitarian travel (20) (Table 4).

Two out of three studies revealed significant associations between density and diversity of the built environment, on the one hand, and BMI and physical activity, on the other hand.

Several investigations aimed at measuring the links between characteristics of the built environment, BMI, and physical activity. In this vein, Norman et al. (2006) attempted to measure the impact of the built environment's walkability on BMI and physical activity. Their findings point to the absence of significant associations between walkability, land-use diversity, physical activity and BMI (19). In contrast, Li et al. (2008) noted that the increase in land-use diversity is associated with a significant decrease in the prevalence of obesity.[10] Their evidence also exhibits significantly positive links between land-use diversity and physical activity (24). Based on a sample of persons between the ages of 65 and 97, Berke et al. (2007) demonstrated significant links between the built environment's walkability and actual walking (22). However, this research found no significant links between districts' walkability and respondents' BMI[11] (Table 4).

[10] Measured height and weight data.
[11] Measured height and weight data.

Table 4 Body Mass Index (BMI) and Physical Activity: Summary[a] of Findings on the Association With Density and Diversity of the Built Environment

Indicators	Study Design	Dependent variables	Results[b]
Density and diversity	Cross-sectional: 6 (43, 23, 25, 26, 28, 35) Longitudinal: 2 (21, 26)	BMI	S: 5 studies NS: 3 studies (Longitudinal: NS)
Density and diversity	Cross-sectional: 1 (20) Longitudinal: 0	Physical activity	S: 1 study
Density and diversity	Cross-sectional: 3 (19, 22, 24) Longitudinal: 0	BMI and physical activity	BMI: S: 1 study NS: 2 studies Physical activity: S: 2 studies NS: 1 study

[a] See details in Appendix 1.
[b] S: Significant.
NS: Not significant.

Comments and Study Limitations

Several studies revealed significant links between land-use diversity, density, BMI and physical activity. It is important to note the absence of consensus on the methodology for operationalizing indicators of the built environment. The measures used in the investigations can be somewhat limited. For instance, several studies use residential density as a measure of the built environment. Density of destinations would be a more appropriate measure, but few studies used it. Moreover, the retained studies were conducted in urban settings and the listed measures are difficult to apply in rural contexts (22). Other factors can account for physical activity in these areas, such as increased accessibility to outdoor recreational physical activity sites (96).

Indicators of Diversity and Density of the Built Environment

Diversity of the built environment: As an indicator of diversity, several researchers use an entropy index that reflects the intensity of land-use diversity.

- The entropy index illustrates the diversity of the built environment; the following entropy formula is derived from Cervero and Kockelman, 1997 (91), and is used in several studies (17-19):

$$H2 = \sum_{i=1}^{n} \left[\left(P_{ij} / P_j \right) \ln \left(P_{ij} / P_j \right) \right] / \ln n \qquad \text{Equation 1}$$

Where

n = Number of land-use clusters
P_{ij} *= Number of property assessment units i in zone j*
P_j *= Sum of property assessment units 1 to n in zone j*

H2 varies between 0 and 1:
0: Maximum specialization
1: Maximum diversification

Land-use clusters are determined by researchers and vary from one study to another, the most frequent being residential, institutional, commercial, recreational, and industrial.

- Number of destinations (20)
- Number of businesses and churches (21)

Density of the built environment: Indicators of density in the literature are very diverse; the various density measures chosen by the authors of the studies reviewed are as follows:

- Household density (total number of households in a given area) (22)
- Residential density (number of residents in a given area) (23)
- Net residential density (number of residents in a given residential area) (23)
- Density of workers or destinations (number of employees per given area, intensity of business developments in a given zone; number of potential destinations in a given area) (24, 25)

Databases Used

Various databases are required to calculate these indicators. Databases for indicators of land use differ from databases for indicators of density of the built environment.

Land-use diversity:

Property assessment roll (22-24, 28)
Business directories (21, 24, 25)
Land-use data (19, 21, 23, 24, 28)
Aerial or satellite photographs (21, 23, 24, 28)

Density:

Population census data (18, 19, 25, 35)
Business directories (24, 25)

Operationalization in Québec

Few Québec studies have attempted to establish links between the built environment and physical activity or BMI. However, based on information from the studies reviewed, it is possible to identify a few databases that can be used to operationalize these indicators. Several studies identified in this summary use data from property assessment rolls for their studied territory. Using the property assessment roll as a tool to construct indicators of the built environment offers several advantages. Firstly, property assessment roll databases contain several types of information, such as buildings' main occupancy (e.g. residential, commercial, industrial). This information is often used to calculate indicators of the built environment's diversity. Property assessment rolls can also be used to measure density of the built environment. However, none of the studies identified in this summary used such information to evaluate density. Lastly, property assessment roll databases are generally precise and disseminated into fine spatial scales (property assessment units). These advantages could lead us to use Québec property assessment data to compute land-use diversity and density of the built environment (Figures 3 and 4). Nevertheless, other databases can be used to develop indicators of density of the built environment, such as business directories and population census data.

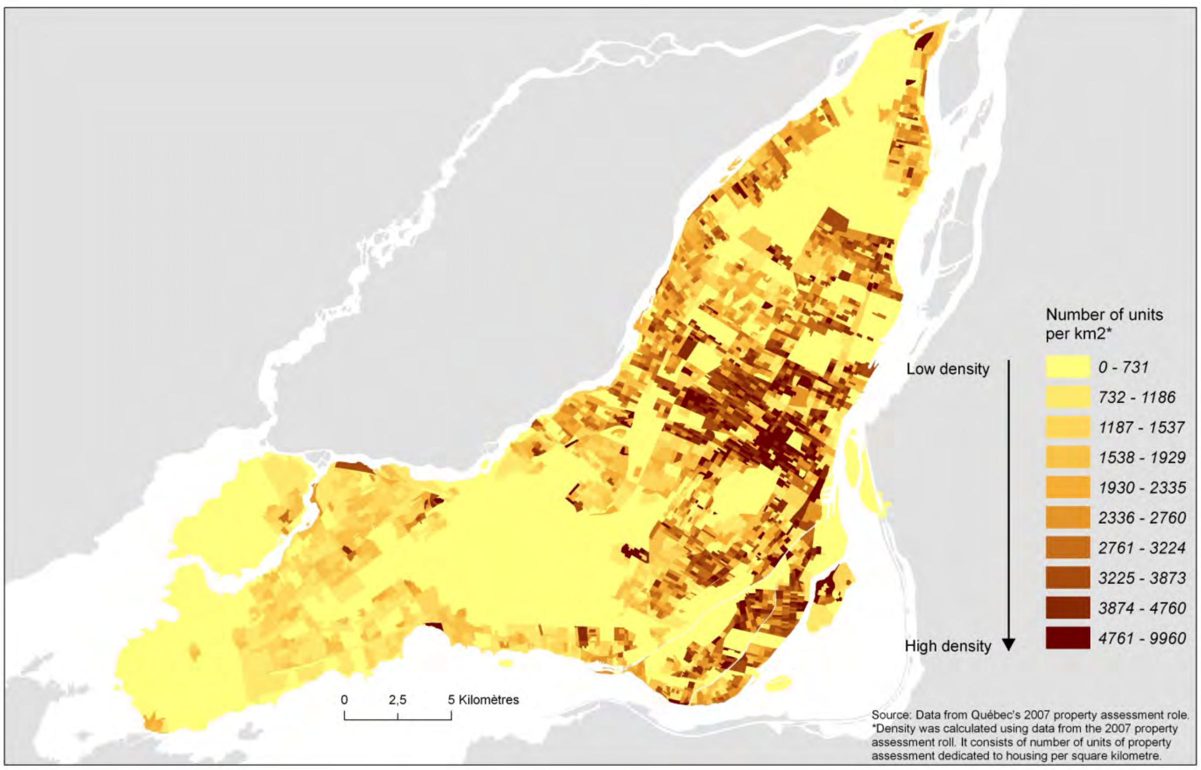

Figure 3: Density of the Built Environment Calculated Using the Property Assessment Roll, Montréal

The theory suggests that highly dense and diverse environments tend to improve accessibility and proximity of destination sites. Consequently, travel distances to be covered could become shorter and encourage physical activity.

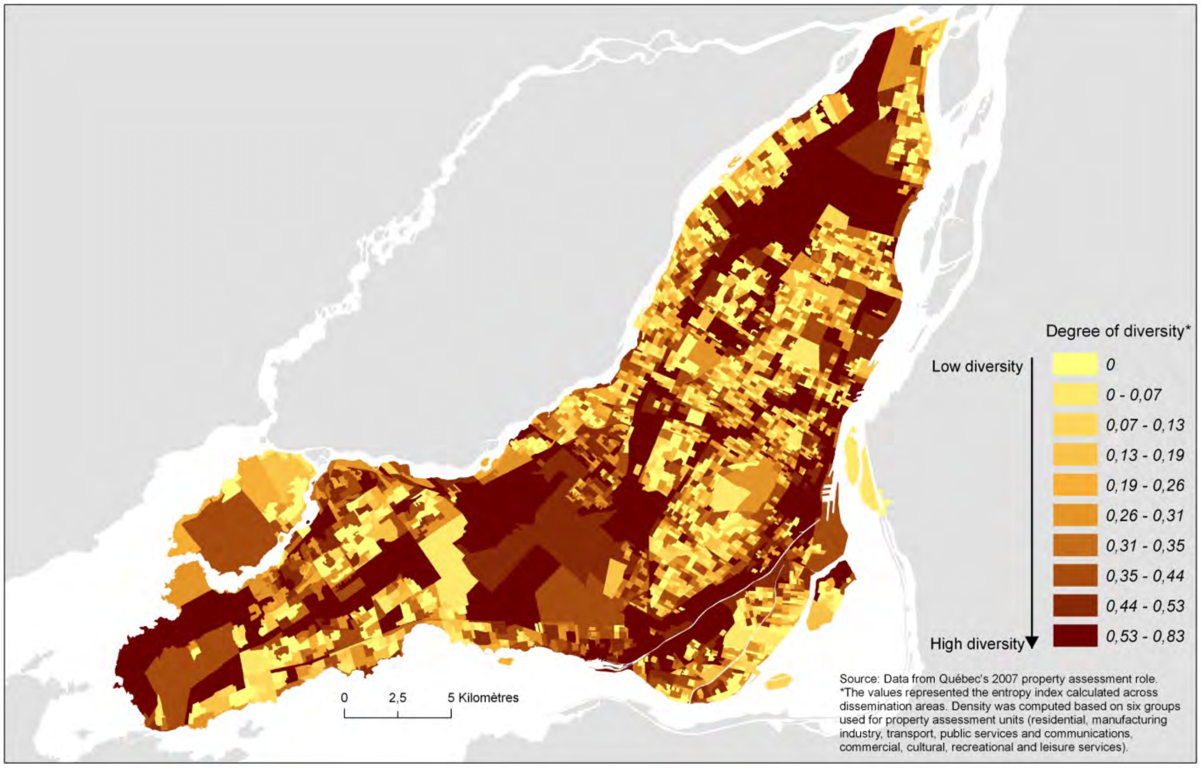

Figure 4: Diversity of the Built Environment (Entropy Index) Calculated Using Property Assessment Roll Data, Montréal

The theory suggests that highly dense and diverse environments tend to improve accessibility and proximity of destination sites. Consequently, travel distances to be covered could become shorter and encourage physical activity.

SUMMARY 2: INDICATORS OF THE ROAD NETWORK CONFIGURATION

Background

Road network configuration is one of the elements that can influence active transportation in individuals (97). According to Frank et al. (2003), the specific elements that can promote active travel within a road network are linked to street configuration, characteristics of networks dedicated specifically to nonmotorized travel, and infrastructures enabling transition between different modes of transportation (17). This summary deals essentially with indicators of the road network's functionality (98). Road network connectivity is one of the most frequently addressed aspects under this topic. Connectivity is determined by the density of street intersections and blocks. The denser the street network is in terms of intersections and blocks, the higher its connectivity will be. In other words, individuals will have easier access to their destinations. This easy access will translate into shorter travel distances or greater choice of itineraries that can be covered using a mode of active transportation. Figure 5 illustrates the impact of a network configuration's level of connectivity on an individual's walking environment.

Network configuration is not linked only to its level of connectivity. Several studies focus also on street characteristics, in particular traffic lane widths. The hypothesis is that residential streets with one traffic lane and low speed limits promote active transportation, as opposed to larger arteries where walking and bicycling is more difficult.

15-minute walking area: 4.1 km^2
Number of road segments: 645
Number of intersections: 327

15-minute walking area: 0.9 km^2
Number of road segments: 66
Number of intersections: 49

Adapted from: Frank et al, 2004 (28).
Data sources: DMTI spatial inc., 2007.

Figure 5: Road Network Connectivity

Less connected networks do not encourage active travel, since they fail to provide individuals with easy access to destinations such as workplaces, places of study or recreational sites.

Study Descriptions

Thirteen studies attempted to establish links between road network configuration and physical activity. Most of these studies were carried out in the United States, only one covered the Auckland region in New Zealand, and none were conducted in Canada. Sample sizes used to identify links between road network configuration and physical activity varied between 100 and more than 30 000 persons. The retained studies analyze associations between the built environment and BMI in two studies, BMI and physical activity in four studies, and only physical activity measures in seven studies. The various measures of physical activity may refer to walking or bicycling to get to places of recreational or utilitarian activities (for example, getting to work). Other studies do not distinguish between recreational and utilitarian walking. Instead, they use only one measure of walking. Samples in the retained studies vary in terms of participants’ age and sex: six focus on adults, three on children or adolescents, and three on elderly persons. Only one study contains an exclusively female sample.

Studies dealing with road network configuration use various spatial scales to determine the built environment susceptible of influencing BMI or individuals' behaviour. Eleven of the thirteen studies determine the built environment based on buffer zones around participants’ place of residence. Buffer areas can vary. The other studies use census-related spatial units. It should be noted that Badland et al. (2008) define the built environment as a buffer zone of shortest itineraries between the respondents’ residence and place of work (86).

Study Findings

Three studies reveal significant associations between indicators of road network configuration and physical activity.

The retained studies focused mainly on road network connectivity and only a few used road traffic intensity. Findings for road network connectivity differ. On the one hand, several studies found no association between street connectivity and physical activity. For example, Oakes et al. (2007) revealed slightly significant and non-significant links between block density and area and the total time spent walking and engaging in physical activity (32). The Forsyth et al. study (2008) of adults, the Wells and Yang study (2008) of women, and the Nagel et al. study (2008) of elderly persons reach similar conclusions (27, 33, 34). Nagel et al. (2008) found no association between street traffic volume and physical activity.

Using similar methods, some studies obtained more significant results. Boer et al. (2007) used a sample of about 30 000 persons in 10 different metropolitan regions in the United States. This study aimed, among other things, at establishing a link between the proportion of four-way intersections and participants' pedestrian trips. A road network where 100% of intersections are four-way is a grid system; it is strongly connected and may promote walking. Evidence shows that participants are more likely to walk in a built environment featuring a high proportion of four-way intersections (31). McGinn et al. (2007) found significantly positive associations between outdoor recreational physical activity, street connectivity and road traffic intensity (29) (Table 5).

The findings of the Badland et al. study (2008) conducted in Auckland, New Zealand, illustrate significant associations between the level of connectivity of the built environment of routes taken to get to work or to school and use of active transportation. In other words, the higher the level of connectivity for the various route environments (residence-work), the more likely workers were to use active transportation as their mode of travel (99) (Table 5).

Some studies reveal significant links between road network configuration and participants' BMI.

Some of the studies reviewed in this summary attempt to establish a link between road network configuration and BMI. For example, in a study involving a sample of 2 482 children between the ages of 5 and 18, Grafova (2008) demonstrated that children living in an environment with a less connected road network did not have significantly greater chances of becoming overweight. However, the author mentions that children living in an environment built after 1969, characterized by numerous dead-end streets and lower connectivity, were more likely to become overweight (35). Frank et al. (2004) demonstrated a significant association between BMI and street connectivity reflected by the density of intersections. However, this association is significant only for Caucasians (28) (Table 5).

Finally, a few investigations attempted to find links between the built environment, physical activity and BMI. Such is the case for Nelson et al. (2006), who examined a nationally representative sample of 20 745 American adolescents. Evidence shows that adolescents living in highly ethnically diverse rural areas have significantly greater chances of being overweight, as opposed to adolescents living in “new suburbia” districts. Adolescent children of “old suburbia” district inhabitants have significantly greater chances of being physically active than adolescents living in “new suburbia.” The classification of districts where adolescents live was determined based on a group of variables associated with aspects of the built environment and socioeconomic characteristics. Variables of the built environment included, among others, elements related to road network connectivity and street types. Rural and suburban environments (old suburbia and new suburbia) feature low connectivity, as opposed to urban environments (inner-city and mixed-race urban areas) (30). Frank et al. (2007) demonstrated a positive association between road network connectivity, physical activity and obesity (23). Berke et al. (2007) concluded that, based on a sample of 936 people aged 65 to 97 in King County, Washington, a neighbourhood’s walkability is significantly associated with actual walking, but not with BMI[12] (22). These findings resemble those obtained by Norman et al. (2006), in a study of 799 adolescents between the ages of 11 and 17 (19)[13] (Table 5).

[12] Measured height and weight data.
[13] Measured height and weight data.

Table 5 Body Mass Index (BMI) and Physical Activity: Summary[a] of the Findings on the Association with Transportation Systems, Road Network Configuration, and the Built Environment

Indicators	Study Design	Dependent variables	Results[b]
Transportation System, Road Network Configuration	Cross-sectional: 2 (28, 35) Longitudinal: 0	BMI	S: 2 studies NS: 0 studies
Transportation System, Road Network Configuration	Cross-sectional: 7 (27, 29, 31-34, 99) Longitudinal: 0	Physical activity	S: 3 studies NS: 4 studies
Transportation System, Road Network Configuration	Cross-sectional: 4 (19, 22, 23, 30) Longitudinal: 0	BMI and physical activity	BMI: S: 2 studies NS: 2 studies Physical activity: S: 4 studies NS: 0 studies

[a] See details in Appendix 1.
[b] S: Significant.
NS: Not significant.

Comments and Study Limitations

As various studies show, there seems to be an association between the level of road network connectivity and physical activity. Several studies demonstrated this association by measuring either only physical activity or respondents' BMI and physical activity within the same study. The association between the level of road network connectivity and BMI appears less clear. All studies analyzed the impact of road network configuration on BMI by means of cross-sectional research estimates. Yet, it is strongly recommended to use longitudinal estimates to establish causal links. Furthermore, most investigations used variables linked to the level of road network connectivity as indicators of the road network configuration. Additional research is required before drawing conclusions on the possible influence of road traffic intensity on individuals' physical activity or BMI.

Indicators of the Road Network Configuration

Several indicators are used to measure characteristics of road networks. The level of road network connectivity is generally calculated based on the number of intersections. Other indicators are linked to the characteristics of street blocks. A road system featuring small blocks seems to increase itinerary options that individuals can choose from to get to their final destination. This large number of itineraries can promote active transportation, because individuals can choose routes where design facilitates travel (e.g. feeling of safety, presence of aesthetically appealing elements, presence of pedestrian infrastructures) (27).

As for indicators related to street width, some investigations use street typology (e.g. highway, artery, local street) (30), road traffic intensity, or speed limit data (29, 33). Intense traffic and high speed limits are usually features of wider streets with many lanes, where active transportation is more difficult. There are many indicators of road network configuration, and no standard method for operationalizing them. The listed studies use different tools to characterize road network configuration in relation to physical activity. Four elements are used to represent road frame features: intersections, segments, blocks, hierarchical road network typology and traffic.

A road network that is highly connected or has strong walkability potential is characterized by numerous intersections. The main measures used are as follows:

- Density of intersections: number of intersections in a given area (23, 24, 27-30)
- Proportion of four-way intersections: number of four-way intersections over the total number of intersections in a given network (27, 31, 32)
- Segment/intersections ratio: number of segments (street portions) over the number of intersections (29)
- Number of intersections (33, 34)
- $\text{Gamma index} = \text{L}/\text{L}_{\text{max}} = L/3(V-2)$
  - where L is the number of segments in a network and V is the number of nodes (intersections). A 0 score means that none of the intersections are connected, a score of 1 means that all possible segments are linked to all of the possible intersections. The Gamma index represents a measure of network connectivity (30)
- $\text{Alpha index} = \dfrac{(\text{L - V}) + 1}{(2V-5)}$
  - where L is the number of segments in a network and V is the number of nodes (intersections). The Alpha index represents the level of possible itineraries included in a given network. A 0 score is defined as a network without itineraries, a score of 1 illustrates a network with a maximum number of itineraries (30, 35)

Some researchers use information on block configuration to assess road network connectivity. Again, there are several measures that reflect road network connectivity using blocks:

- Average block perimeter (22, 27, 31)
- Average or median block area (32)
- Block density (27, 29, 32)

Other indicators of road network features are linked to hierarchical street typology. The street typology within a road network is based on traffic intensity, as well as safety, services and the quality of the environment. There are several classification systems. For example, Marshall (2005) indexed over 73 hierarchical typologies based on various criteria (100). In the retained studies, classification is used as an indicator of traffic intensity for various road frame segments. There are two methods for evaluating segment traffic: use of street typology or use of traffic data. Three investigations use this type of data. Nelson et al. (2006) chose the following street typology: residential or local street with one traffic lane, sidewalks and low speed limits; and wide lane streets where active transportation is more difficult (e.g. highway) (30). McGinn et al. (2007) used speed limit data for each road network segment as well as traffic intensity data (29). Finally, Nagel et al. (2008) used the proportion of high, medium and low traffic volume streets (33).

- Proportion of streets according to a typology (number of streets according to their type over the total number of streets (e.g. small streets, local streets, highways) (30)
- Total length of streets according to type (e.g. small streets, local streets, highways) (30)
- Average speed permitted on road segments (29)
- Maximum speed on total *n* of road segments (29)
- Proportion of high, medium and low traffic volume streets (33)

Databases Used

Although indicators vary greatly, studies use three database types to operationalize indicators of road network configuration. Road network databases are used to operationalize indicators of road frame connectivity and classification. In the case of indicators related to street blocks, census databases are used. Traffic data for the United States is obtained from the Department of Transportation.

Operationalization in Québec

In Québec, there are a few databases that can be used to operationalize various indicators of road network configuration: databases containing information on road frame and on block geometry.

To our knowledge, three databases deal with road networks in Québec:

1. National Highway System (Government of Canada, Natural Resources Canada) (2007)
   The national highway system product is distributed as thirteen sets of provincial and territorial data. It is composed of two linear entities (Road Segment and Ferry Connection Segment) and three point-specific entities (Junction, Blocked Passage and Toll Point) associated with a series of descriptive attributes, such as First House Number, Last House Number, Street Name Body, Place Name, Functional Road Class, Pavement Status, Number Of Lanes, Structure Type, Route Number, Route Name, Exit Number. This file includes the following hierarchical road classification system: 1) Freeway; 2) Expressway/Highway; 3) Arterial; 4) Collector; 5) Local/Street; 6) Local/Strata; 7) Local/Unknown; 8) Alleyway/Lane; 9) Ramp; 10) Resource/Recreation; 11) Rapid Transit; 12) Service Land; and 13) Winter. This database also includes intersections that are classified as follows: 1) Intersection; 2) Dead End; 3) Ferry.
2. DMTI road network (DMTI Spatial Inc.)
   The DMTI road network covers all of Canada. It includes information on street names, address ranges, street ranks, and speed limits for each segment (Figure 6).
3. The Statistics Canada road network
   The Road Network and Geographic Attribute File is a digital representation of the Canadian national road network that contains information on road names, road types, road directions, address ranges, and road ranks. Address ranges are mostly dwelling-based and occur mainly in urban centres of Canada. On each side of road arcs, identification names and codes for the following levels of geography are indicated: province/territory, census subdivision, census metropolitan area, census agglomeration and census tract. The included roads are ranked according to four levels of detail that are suitable for small- and medium-scale cartography. The Road Network and Geographic

Attribute File can provide baseline cartographic features for creating thematic maps based on cartographic boundary files from the 2006 Census.

As for blocks, only one database can operationalize the various indicators of street connectivity: Statistics Canada's block geometry. Dissemination Block Boundary Files portray the dissemination block boundaries for which 2006 Census data are disseminated. A dissemination block is an area bounded on all sides by roads and/or boundaries of standard geographic areas; it is the smallest geographic area for which population and dwelling counts are disseminated. The files include the boundaries of about 478 800 dissemination blocks covering all of Canada.

In Québec, traffic data is not available for the province as a whole. The Ministère des Transports uses model-driven data from origin/destination (OD) studies. OD studies are descriptive and look at characteristics of trips persons make during the business week. In Québec, OD studies are produced for the metropolitan regions of Montréal, Québec, Sherbrooke, and Gatineau/Ottawa.

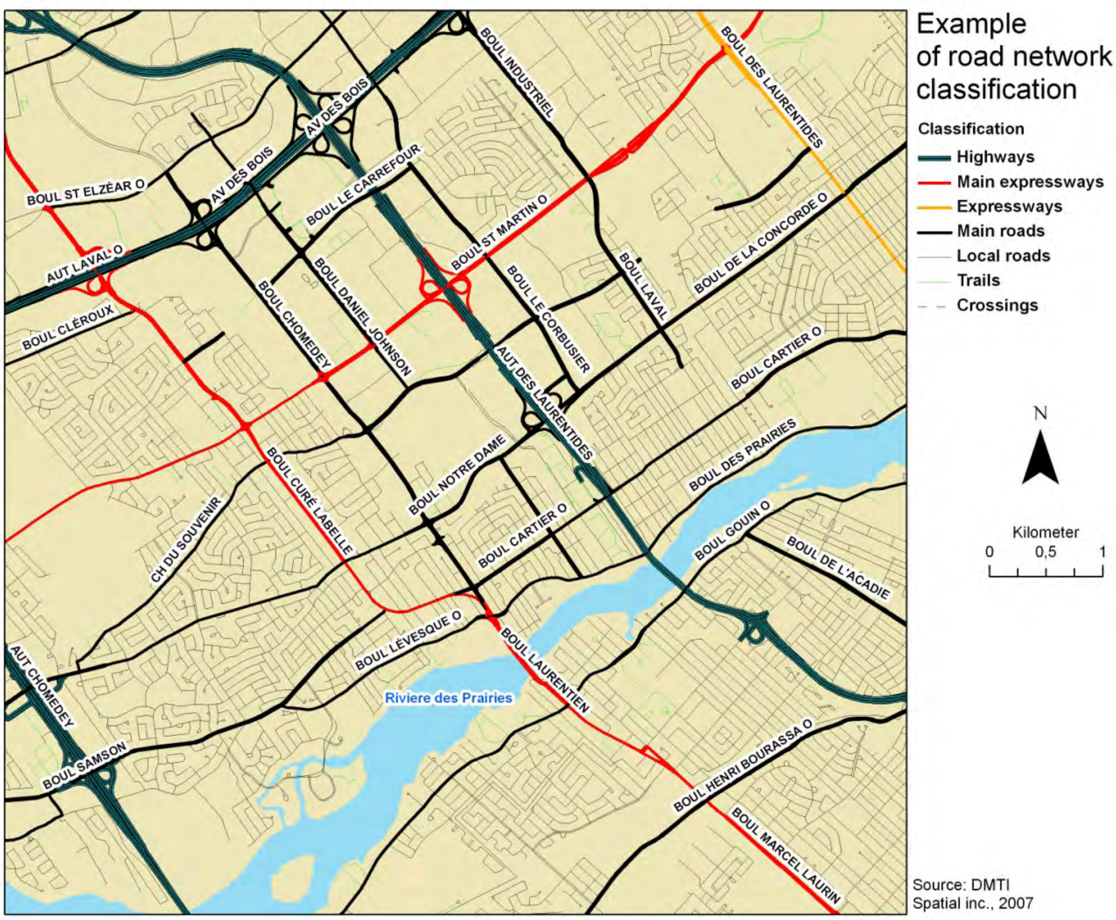

Figure 6: Example of Road Network Classification

Walkability Index and Urban Sprawl Index

Some studies also use indices that attempt to reflect the "walkability" of the built environments under analysis. In an approach based on objective data, the method consists of aggregating a group of indicators of the built environment that encourage physical activity. Some of the studies in the summaries that look at indicators of energy consumption use a synthetical index to characterize the built environment susceptible of influencing individuals' behaviours. This method is used by Frank et al. (2007), Li et al. (2008), Berke et al. (2007), and Norman et al. (2006) (33, 42-44). Frank et al. (2007) used a synthetical index of the built environment's walkability to offset the multicollinearity of the variables linked to the built environment. The walkability index used by Frank et al. (2007), Li et al. (2008), and Norman et al. (2006) contains the following variables: ratio of land area allotted for commercial activities to the overall area of the environment; land-use diversity, residential density, and intersection density. Berke et al. (2007) also used a walkability index for the built environment. Their method involves the evaluation of possible associations between study participants' walking and over 200 variables of the built environment. Evidence shows that 8 out of 200 variables are significantly associated with walking: shortest distance to the grocery store; density of dwellings; number of grocery stores, restaurants and businesses (more than one and several); area of the closest office complex, closest distance to the office complex; and block area in place of residence. These variables are then used to create a walkability score for the built environment.

The urban sprawl index is a measure developed by Ewing et al. (2003), among others. It consists of 22 variables divided into four main groups of components: residential density; district diversity (offices, businesses, residences); road network accessibility; and predominance of downtown over suburban environments in the metropolitan area. This measure of urban sprawl was used on several occasions (26, 101) to demonstrate associations between the built environment and individuals' health or lifestyle. Eid et al. (2008) computed residential sprawl based on the proportion of land area allotted to residential development (21).

SUMMARY 3: INDICATORS LINKED TO NONMOTORIZED TRANSPORTATION NETWORKS AND PUBLIC TRANSIT INFRASTRUCTURES

Background

Evidence shows that moderate-intensity physical activity offers health benefits (76, 102). This moderate-intensity physical activity can be achieved through short trips for utilitarian or recreational purposes. In Europe, it has been demonstrated that approximately 50% of trips were under 5 km and almost 30% were under 1 km long. Nevertheless, in several European countries most of these trips are made by car (103). In the United States, 41% of car trips made in 2001 were under 3.2 kilometres, whereas 28% were under 1.6 kilometres long (95). These are trips that can be made on foot or on bike. In Montréal, data from an origin/destination study demonstrated, according Morency et al. (2007), that motorized trips under 1.6 kilometres long represent over 11.7% (862 000/day) of overall daily trips. The authors further specify that 837 000 of these trips could be made using a mode of active transportation. Translated into physical activity, these 837 000 trips amount to almost 1 156 million walking steps, in other words 2 660 walking steps per person per day (104). Physical activity can be encouraged by characteristics of the built environment, namely increased accessibility to the following two transportation system elements: nonmotorized networks and public transit equipment.

Nonmotorized Networks

Pedestrian trails, pedestrian-only and bicycle-only lanes, as well as bicycle paths are the main nonmotorized transportation network infrastructures. It is hypothesized that the presence of and increased accessibility to such a network can promote physical activity. In rural areas, physical activity would probably occur more frequently in regions where there are natural sites and recreational activities (105). Intense nonmotorized road network development could lead the population to adopt active modes of transportation. The Netherlands and Germany are well-known examples (17, 95). According to data in Pucher et al. (2003), almost 46% of trips in the Netherlands are made on foot or on bike, as opposed to 34% in Germany and 12% in Canada. This high proportion of trips made on bike or on foot, in the Netherlands and in Germany, seems to be associated with characteristics of nonmotorized transportation. Over the last 20 years, several Dutch and German policies promoted nonmotorized network development. For instance, pedestrian-only zones were introduced. Nonmotorized networks for bicycles expanded over the last 20 years, doubling in the Netherlands and tripling in Germany (95).

Public Transit Infrastructures

Like nonmotorized networks, the accessibility to public transit infrastructures can promote physical activity, since most trips made within these infrastructures begin and end with walking or bicycling. In the United States, Besser and Dannenberg (2005) estimated that the average daily walking time for public transit users is 19 minutes (106). Walking and bicycling to get to public transit infrastructures is made easier when they are integrated into the built environment (e.g. metro stations, bus terminals, and bus stops). This is less often the case in suburban areas, where public transit equipment is detached from the built environment and surrounded by incentive-based parking. Engaging in active transportation to get to this public transit equipment is often more difficult.

Study Descriptions

Eight studies assessed the effect of accessibility to nonmotorized networks and public transit equipment on individuals' physical activity. All the studies were conducted in the United States. Sample sizes varied between 100 and over 1 500 participants. Six studies focus on physical activity, and only two on physical activity and BMI. Measures of physical activity are diverse; they may refer to walking or bicycling to take part in recreational or utilitarian activities. Other studies do not make this distinction. The samples in the retained studies vary in terms of participants' age and sex; six studies look at adults, whereas three look at elderly persons. One study targets women and one targets men. None of the retained studies use a sample of children only.

The studies reviewed that deal with accessibility to nonmotorized networks and public transit equipment use various space scales to identify the built environment likely to influence individuals' weight and behaviour. In six out of ten studies, the authors determine the built environment based on buffers around participants' residence. The buffer zones vary between 0.4 kilometres and 3 kilometres. The remaining studies use census-based divisions.

In these studies, indicators of the built environment refer mainly to accessibility to nonmotorized transportation networks and public transit equipment. Nonmotorized transportation networks include pedestrian trails, bicycle trails and bicycle paths. Accessibility is measured using several parameters, including density, distance, and number.

Study Findings

Three out of six studies demonstrate significant associations between accessibility to nonmotorized transportation networks, public transit equipment, and physical activity:

Study findings on the accessibility to nonmotorized transportation networks and on public transit equipment diverge. In a study of an adult sample in Washington state, Moudon et al. (2005) demonstrated that promixity of bicycle paths can promote physical activity (87). They indicated that no previous study had revealed a significant relationship between the presence of bicycle paths and respondents' physical activity. In a study using the same sample, Lee and Moudon (2008) draw the conclusion that accessibility to public transit infrastructures is correlated to intense physical activity (37). Forsyth et al.'s (2008) findings resemble those of the aforementioned study. Nevertheless, the characteristics of the built environment that can be associated with walking for recreational purposes differ from those associated with walking for transportation purposes. Their evidence shows significant positive correlations between walking for transportation purposes and density of public transit equipment. These correlations are negative for recreational walking (Table 6).

Some retained studies found no significant link between accessibility to nonmotorized transportation networks or public transit equipment and physical activity. King et al. (2005) found no significant relationship between proximity of pedestrian trails and physical activity (36). Based on a sample of elderly persons, Nagel et al. (2008) found no significant association between number of bus lines and walking (33). Clifton and Dill's (2005) conclusions challenge the hypothesis that characteristics of the built environment can encourage physical activity. Their evidence showed that access to public transit equipment tended to decrease the number of daily pedestrian trips (39) (Table 6).

Significant links between physical activity and accessibility to public transit equipment, but not significant for BMI:

Two studies attempted to establish links between accessibility to public transit equipment, physical activity, and BMI. Evidence shows that access to public transit equipment tends to promote physical activity. For these two studies, the associations are not significant for BMI-related features of the built environment (22, 24) (Table 6).

Table 6 Body Mass Index (BMI) and Physical Activity: Summary[a] of Findings on the Association with Accessibility to Nonmotorized Transportation Networks and Public Transportation Equipment

Indicators	Study Design	Dependent variables	Results[b]
Indicators related to nonmotorized transportation networks and public transportation equipment	Cross-sectional: 6 (27, 33, 36, 37, 39, 87) Longitudinal: 0	Physical activity	S: 3 studies NS: 3 studies
accessibility to public transportation equipment	Cross-sectional: 2 (19, 20) Longitudinal: 0	BMI and physical activity	BMI: S: 0 studies NS: 2 studies Physical activity: S: 2 studies NS: 0 studies

[a] See details in Appendix 1.
[b] S: Significant.
NS: Not significant.

Comments and Study Limitations

Few studies use objective data to examine the potential effects of accessibility to nonmotorized networks and public transit equipment. Therefore caution should be used when considering these findings. The substantial lack of valid and detailed data on these aspects of the built environment is a major challenge to be overcome in this field of research (87). Few studies were conducted in rural areas. Brownson et al. (2000) reveal, however, the importance of having pedestrian trails in rural areas to promote physical activity, especially among fairly inactive individuals (105). Additional research is required to develop indicators of the environment for rural areas.

Indicators Used

Most studies of links between nonmotorized networks, public transit infrastructures and physical activity use indicators related to data from survey participants' observations or systematic field observations (99). For information concerning nonmotorized networks and public transit equipment, participants had to inform investigators about the presence or absence of pedestrian-only lanes, as well as their proximity to bicycle-only networks, to pedestrian trails, and to public transit (e.g. train stations, metro stations or bus stops). Research that used data from geospatial databases use indicators linked to the distance or presence of these various infrastructures in the participants' residential environment.

Numerous indicators demonstrate aspects of nonmotorized networks and road transportation equipment. The retained studies use various techniques and methods to characterize these aspects of the built environment in relation to physical activity.

Nonmotorized transportation networks:

- Proximity of pedestrian trails and bicycle paths (36)
- Access to bicycle paths (37)
- Distance from the closest trail (38)

Public transit equipment:

- Number of bus lines (33)
- Density of public transit stations (number of bus stops, train stations and metro stations divided by the area) (24, 27, 37)
- Distance from the closest public transit equipment (27, 39)

Databases Used

The databases used to operationalize this data come mostly from entities (municipalities, counties, regional councils) in charge of urban planning in the metropolitan area under study. This is the case for most indicators linked to public transit equipment and nonmotorized transportation infrastructures such as trails and bicycle paths (24, 27, 33, 36-38).

Operationalization in Québec

Few spatially referenced databases can be used to characterize these aspects of the built environment. As for public transit equipment, data from the Agence métropolitaine de transport and various public transit companies and organizations can be used. Other sources of data exist; for instance, the company DMTI Spatial Inc. distributes files that include transportation infrastructures which, in turn, contain some public transit equipment such as train stations or metro stations. These data are available for all of Québec. Nonmotorized networks are also difficult to operationalize, since few databases can reflect these characteristics. The National Topographic Data Base (NTDB) contains information on trails for all of Québec. However, the information contained in this database is not updated very frequently. Moreover, there is little information regarding the source and accuracy of these data. Trails are defined as a narrow path suitable for walking, hiking or bicycling. It is impossible to know for which purpose the trails are designed. Another source of data is useful for geographic representation of trails—DTMI Spatial Inc. However, these files do not contain information on the possible use of the trails included in the database. These trails can be designed for snowmobile or four-wheelers. For the Montréal metropolitan area, the DMTI network includes 11.6 kilometres of trails. Organizations such as Vélo Québec[14] or Fédération québécoise de la marche[15] collect information on nonmotorized networks. This data could be used for developing network accessibility indicators.

[14] Vélo Québec publishes an atlas of Québec's bicycle path network. The most recent edition includes about 8 000 km of paths in 75 municipalities.

[15] The Fédération québécoise de la marche publishes a directory of about 600 walking sites totalling 10 000 km of nonmotorized trails.

SUMMARY 4: INDICATORS OF URBAN ENVIRONMENT DESIGN

Background

The built environment can contribute to the practice of physical activity through the manner in which streets and sites are designed. Frank et al. (2003) focus more specifically on the possible impact of street and setting design on physical activity (17). A study by Day et al. (2006) enhances our understanding of how the design of a street or setting can influence the practice of physical activity (107). The authors of this study note that elements of the built environment (streets and settings) include characteristics that can increase pleasantness and enhance feelings of safety. Urban design layout of a site or street can improve attractiveness and safety and, as a result, encourage physical activity. A street or setting's attractiveness is linked to aesthetic and cosmetic aspects, to the presence of attractions (building architecture, diversity of buildings, open spaces) and comfort (trees, benches). For example, a tree-lined street could improve pedestrian comfort (shade and protection against the wind) and attractiveness of the street (27). An improved sense of security essentially involves elements that can reduce traffic speed (traffic-calming measures, signage, adequate pedestrian crossings) and enhance a sense of safety regarding crime (streetlights, building layout, land use linked to potentially criminal activities, uncivil behaviour).

Street Design

Urban street design refers to the built environment of each street taken individually. A street can be considered dangerous and unattractive and, as a result, will not encourage physical activity. Elements of urban design that can favour or hinder the practice of physical activity on an arterial road include the following: speed limits, lane width, sidewalks, and traffic calming measures. These basic elements are cited in roadway design manuals. The work of Frank et al. (2003) indicates that road design recommendations are geared much more toward walking in Great Britain and Australia compared with the United States (17). Table 7 shows the various parameters used in these countries to develop local roadways in residential neighbourhoods. In addition, we added recommendations for Québec. We also note that the British and Australian manuals include traffic-calming elements, which are not found in the American manual. Moreover, the road widths recommended in Great Britain and Australia are smaller than those indicated in American and Québec recommendations. A street's narrowness can encourage motorists to reduce their speed and can improve pedestrian and cyclist safety. Other aspects of urban street design can foster physical activity, especially those linked to safety (e.g. presence or absence of streetlights, sidewalks).

Table 7 Parameters Used in Some Countries to Develop Local Roadways in Residential Neighbourhoods[a]

Recommendations/ Parameters	Manual, Great Britain	Manual, Australia	Manual, United States	Manual, Canada/Québec
Speed limits	32.19-48.28 km/h Under 32.19 km/h for shared roads	29.93 km/h-39.91 km/h	32.19 km/h-48.28 km/h	30-50 km/h
Road width	3.66 m-5.49 m	5 m-6.49 m	7.92 m standard	6 m-8.5 m
Sidewalks	Usually on both sides; when not necessary (shared roads), obligation to design the road so as to maintain speed at 32.19 km/h	For local roads, at least one side with sidewalks	At least one side with sidewalks	No information:
Traffic calming measures	Narrow roads Chicanes Traffic circle Speed humps Barriers Speed Tables Curb radius reductions	Narrow roads Chicanes Speed humps Traffic circles/Roundabouts Curb radius reduction		Roundabouts Raised crosswalks Raised intersections Rumble strips Speed humps Sidewalk extensions Textured crosswalks Chicanes Curb extensions Street parking Medians Traffic circles

[a] We tried to determine if the Ministère des Transports du Québec had a road design manual similar to those presented in Frank et al.'s study (2003). To our knowledge, the only official ministerial document is the *Manual for setting speed limits on municipal road networks*. The manual does not refer to practices to adopt to introduce traffic calming measures or regulations concerning sidewalks. Another manual published by the Ministère des Transports focuses on the implementation of roundabouts, which are likely to calm traffic. There is also the Canadian Guide to Neighbourhood Traffic Calming published by the Transportation Association of Canada.

Site Design

Urban site design is linked to the following elements: building size, façade design, building orientation, distance to the road, location of parking facilities and design of space between buildings. Layout of these elements at a site can encourage or discourage physical activity. These elements are linked to the appeal and sense of security that emanates from a site's design. Urban site design has a greater impact on pedestrians since they travel at slow speeds and have time to appreciate the built environment. Again according to Frank et al. (2003), site layout in the United States is much more encouraging of motor vehicle use (17). Since the 1950s, building development has been geared toward the use of cars. For example, homes are built to improve connections between place of residence and the street, based on car use (farther from the road, façade that includes a driveway). Development of commercial sites is also oriented toward cars, with large parking lots and locations far from the road. Sometimes it is difficult for pedestrians to venture into these places.

For the past few years, some building promoters have tried to adopt the principles of "new urbanism." Among others, the 27 principles of new urbanism foster the design of streets and buildings that reinforce safe environments and a built environment that is favourable to nonmotorized transportation (108, 109). To maintain a pedestrian-friendly built environment, new urbanism neighbourhoods have narrower streets, numerous trees, shorter distances between buildings and the street, and garages located to the rear of lots (110). In the United States, there are 600 projects that follow these principles. In Québec, these types of projects are few. The "Bois-Franc" real estate project located in the borough of Saint-Laurent in Montréal could meet these principles (111).

Urban design is qualitative by nature. Most studies that have looked at its impact on individual behaviours have opted for measures perceived by participants or observation audits (98). In a review of the literature, McCormack et al. (2004) found only two studies that attempted to measure associations between built environment design and physical activity using GIS data (81). Some studies also followed a quasi-experimental design by evaluating the impact of implementing urban design infrastructures that can encourage physical activity (108, 112).

Study Description

We selected 10 studies published between 2005 and 2008 that included indicators linked to design of the built environment. Most studies were conducted in the United States and one in Australia. Study sample sizes varied from 158 to almost 30 000 individuals. Samples include only adults in four studies, women in one study and children in four studies. Six studies looked at behaviours linked to physical activity. Three studies use BMI data and one uses individual BMI and physical activity data. In six studies, the built environment was determined based on buffers around the sample population's places of residence. Buffer area sizes can vary. Other studies use census spatial data. Site indicators are linked to data on building age and level of urban greening. Data pertaining to roads are linked to safety measures or to the presence or absence of sidewalks.

Study Findings

Significant associations between built-environment design at the site level and physical activity:

Two studies used indicators of site design. Both studies show significant associations between indicators of built environment design and physical activity (walking). Results of King et al.'s (2005) study indicated significant associations between physical activity and living in a neighbourhood with homes built between 1950 and 1969. According to the researchers, these environments are geared toward walking compared with environments built post-1969 (36). Using data on building age, Boer et al. (2007) obtained similar results: study participants living in neighbourhoods built between 1940 and 1949 tended to walk more frequently (31) (Table 8).

Significant associations between built-environment design at the street level and physical activity:

A few studies used indicators of road design (27, 33, 38, 43). Results of Forsyth et al.'s (2008) study are, in part, not significant. The authors had used indicators linked to street trees and street lights along roads (27). Their analyses also indicate significant associations between walking for transport and sidewalk density along roads. Carver et al. (2008) indicate that speed humps in a neighbourhood is associated with boys spending more time engaging in moderate-to-vigorous physical activity. Young girls living in neighbourhoods with two or more pedestrian lights were significantly more likely to make seven or more walking or cycling trips a week than girls in neighbourhoods with fewer pedestrian lights (43). Rutt and Coleman (2005) demonstrated no significant association between time spent walking and indicators of the built environment such as the proportion of sidewalks available along streets (38). The authors point out that most studies using objective data on access to streets including sidewalks have found no association with physical activity. Nagel et al. (2008) found no significant association between percentage of sidewalk coverage and walking (33) (Table 8).

Significant associations between built-environment design at street and site levels and BMI of children:

Two studies use data linked only to participants' BMI. Children compose both studies' samples. Liu et al. (2007) show a significant association between neighbourhood vegetation and childhood overweight (40). Increased neighbourhood vegetation is associated with significant reduced risk of childhood overweight. However, these associations are only significant in higher population density neighbourhoods. Using a subgroup of Liu et al.'s (2007) study, Bell et al. (2008) partly confirm the former's results. They showed that higher neighbourhood greenness was associated with lower odds of children's increasing their BMI scores over two years. However, residential density was not associated with changes in children's BMI scores (41)[16] (Table 8).

Finally, Grafova (2008) used the median year homes were built as an urban design indicator. Results of Grafova's (2008) study show that children living in neighbourhoods where homes were built after 1969 are more likely to be overweight (35).

Significant associations between built-environment design at the site level, physical activity and BMI:

Tilt et al. (2007) also use a measure of neighbourhood greenness. Their research results did not demonstrate a significant association between number of walking trips per month and greenness of the built environment. However, BMI seems significantly lower in neighbourhoods with high accessibility to certain services and high greenness (42) (Table 8).

[16] Height and weight data measured.

Table 8 Body Mass Index (BMI) and Physical Activity: Summary[a] of Findings on Association with Design of the Built Environment

Indicators	Study Design	Dependent variables	Results[b]
Design of the built environment (street and site)	Cross-sectional: 3 (35, 40, 41) Longitudinal: 0	BMI	S: 3 studies NS: 0 studies
Design of the built environment (site)	Cross-sectional: 2 (31.36) Longitudinal: 0	Physical activity	S: 2 studies NS: 0 studies
Design of the built environment (street)	Cross-sectional: 4 (27, 33, 38.43) Longitudinal: 0	Physical activity	S: 2 studies NS: 2 studies
Design of the built environment (street and site)	Cross-sectional: 1 (42) Longitudinal: 0	BMI and physical activity	BMI: S: 1 study NS: 0 studies Physical activity: S: 1 study NS: 0 studies

[a] See details in Appendix 1.
[b] S: Significant.
NS: Not significant.

Comments and Study Limitations

Most studies reviewed in this summary have shown significant associations between elements of built environment design and either physical activity or BMI. Moreover, the measures used are similar from one study to another (year that homes were built and greening index). We must nonetheless exercise caution when interpreting these results since there has been little research done in this area. With the development of GIS and growing accessibility to some municipal databases, there will be a substantial increase in studies on the impact of built environment design on healthy lifestyle habits. There are several studies on possible links between access to services such as parks and open spaces and physical activity. We believe that the greening index is associated with built environment design and not with accessibility of services like parks, beaches and open spaces. The greening index is not only an indicator of the presence of vegetation in parks but it also reflects its presence in the built environment as a whole (e.g. streets, private properties, public spaces).

Indicators of Urban Environment Design

Few studies use databases. One indicator that stems from a database and can characterize built environment design pertains to building age. According to some researchers, homes built before the 1950s are along road networks and are much less car-oriented (31, 35, 36, 43). Neighbourhoods with urban grids characterized by buildings constructed before this period encourage physical activity. Finally, with the significant development of databases and the use of GIS-related technologies, it is possible to assess the presence of urban design elements that could encourage physical activity (e.g. location of street lights, presence of trees, greening index) (27, 40, 41).

The following indicators of built environment design were used in the studies reviewed:

- Median housing age (31, 36)
- Vegetation index (41, 42)
  - Normalized Difference Vegetation Index (NDVI) is a value ranging from -1 to 1. A low NDVI value indicates a site with little vegetation. NDVI is calculated from satellite images using the following formula:

    $$\mathrm{NDVI} = \rho_{\mathrm{nir}} - \rho_{red} / \rho_{\mathrm{nir}} + \rho_{red} \qquad \text{Equation 2}$$

    ρ_{red} and ρ_{nir} are spectral band values in satellite images (red = infrared and nir = near infrared).

    NDVI calculations are based on the principle that green plants absorb radiation in the visible region of the spectrum and reflect radiation in the near-infrared region (113).
- Number of trees per length of road (27)
- Number of street lights per length of road (27)
- Total number of speed humps (43)
- Total number of traffic calming measures (43)
- Total number of pedestrian lights (43)
- Total sidewalk lengths per unit area (27)
- Proportion of street segments with pedestrian crossings (27)
- Proportion of street segments with sidewalks (27)

Databases Used

Databases used in the studies reviewed come from four sources. First, to calculate the number of trees and lights along roads, Forsyth et al. (2008) used aerial photographs (27). To calculate the vegetation index, Tilt et al. (2007), Bell et al. (2008) and Liu et al. (2007) used satellite images (40-42). Census data were used to calculate the median year homes were built. Finally, indicators of traffic calming measures are from authorities in the province of Victoria, Australia (43). To assess the presence or absence of sidewalks along roads, studies used data from aerial photos (27-38). It is important to note that spatial data containing information about roads where there are sidewalks are rare and only a few metropolitan regions have this information. Extracting information from aerial photos can be very time consuming and because the resolution of these photos is sometimes poor, interpretation errors can occur.

Operationalization in Québec

It would be possible to develop two indicators of built environment design in Québec. The first is related to the median year houses were built. Canadian census data could be used to operationalize this indicator. Indeed, one question on the census is about age of dwellings. However, census data include only the year of construction for residential buildings (Figure 7).

The second indicator is related to the level of vegetation in the built environment. It is possible to access Landsat images for the entire province of Québec. These data are available through Geogratis, a Internet portal developed by Natural Resources Canada to provide geospatial data, including satellite images (Figure 8).

To our knowledge, there is no provincial database of the cycling network and road segments with sidewalks.

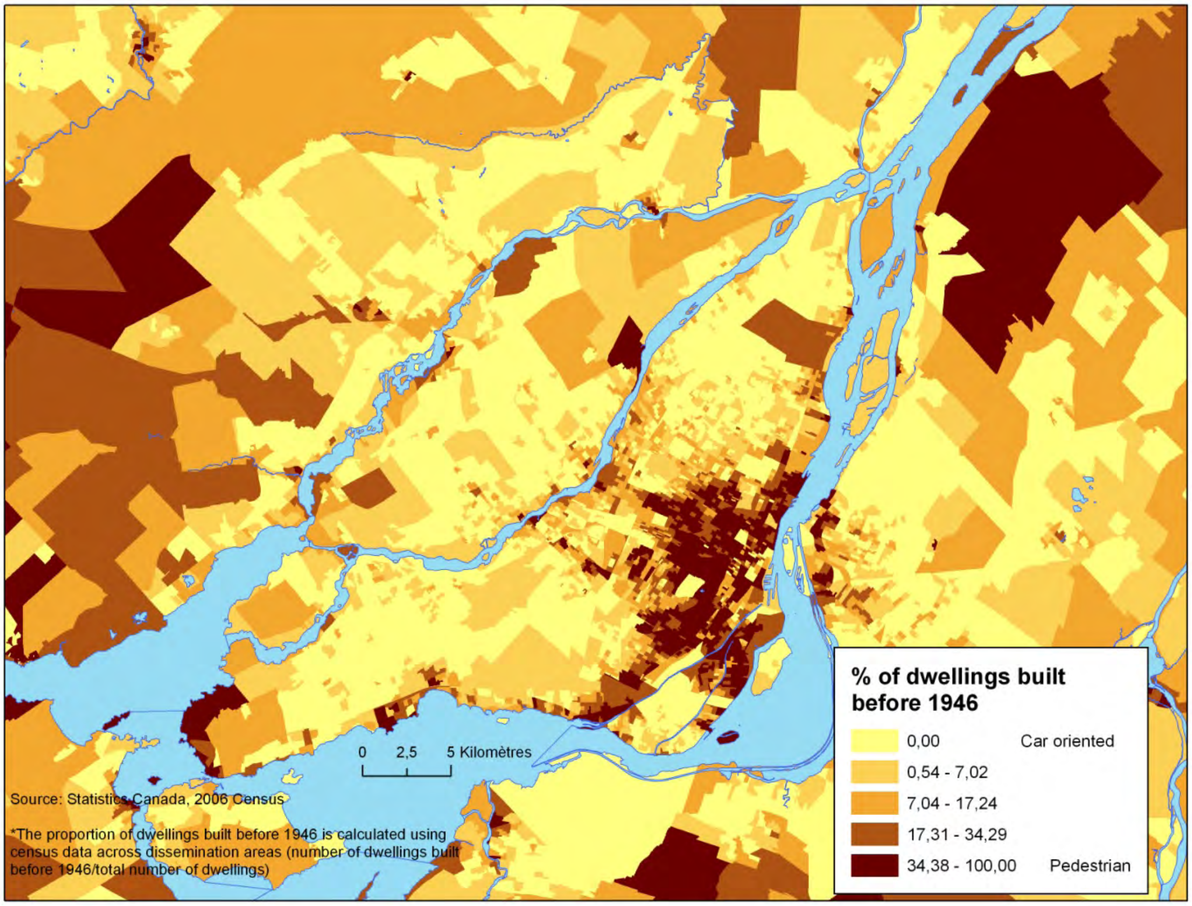

Figure 7: Proportion of Dwellings Built Before 1946

It is hypothesized that the design of urban networks built before the 1950s favours pedestrians.

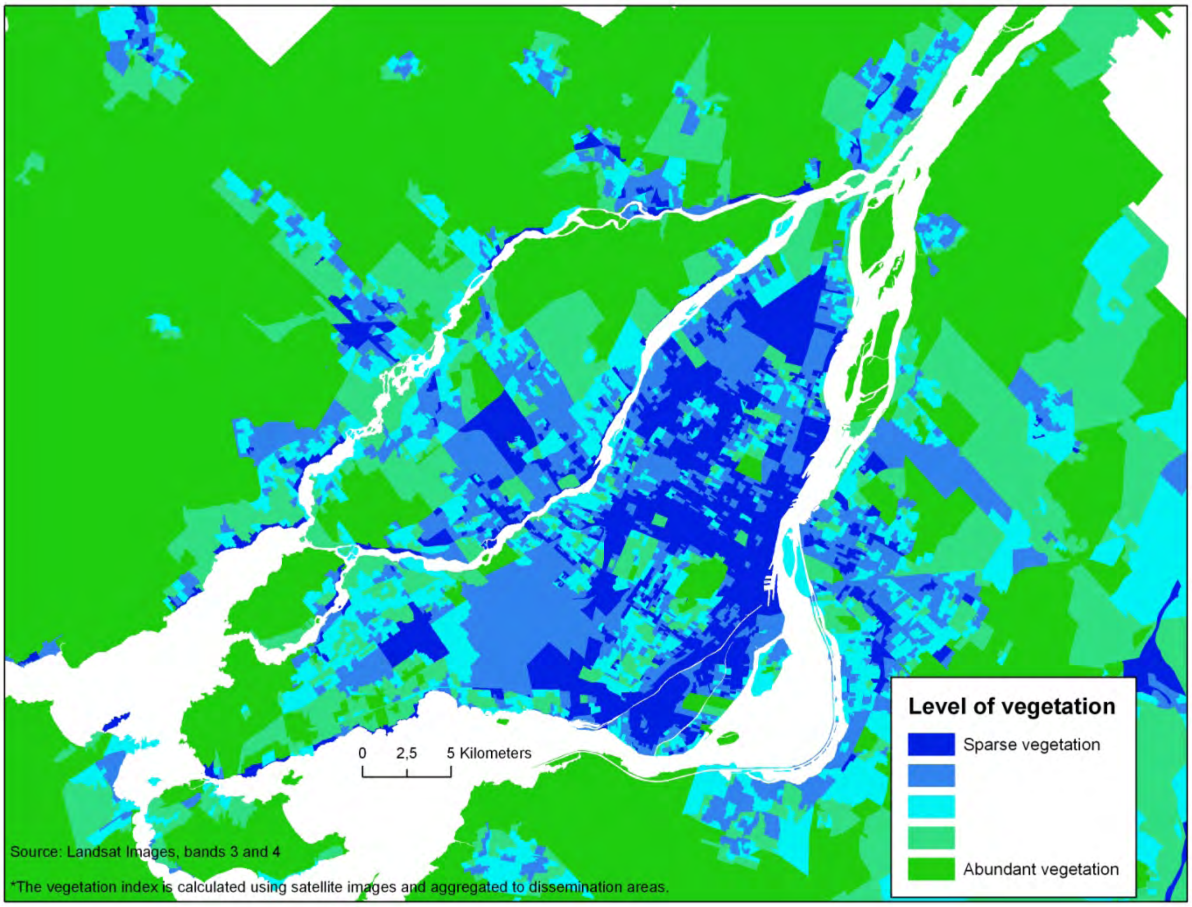

Figure 8: NDVI Variations

It is hypothesized that vegetation could improve the looks of an urban design and the comfort of users and, as a result, encourage physical activity.

6. INDICATORS OF THE SERVICES ENVIRONMENT

The services environment includes indicators mainly related to accessibility of food outlets or recreational infrastructures. Access to both types of services is calculated the same way. Overall, there are four possible measures of distance and several measures of accessibility available to researchers.

The first distance measure is the straight-line distance, that is, the shortest distance between a survey participant's home and a recreational facility or food outlet. This distance is also called Euclidean distance. It is the length of the hypotenuse between point of origin and destination. Another method to calculate the distance between a point of origin and a destination is based on road network characteristics. This measure is called reticular distance (network distance) and, according to several authors, is much more effective since it is closer to reality on the ground (90). Another distance measure is derived from the network distance; not only does it take into consideration the shortest distance between point of origin and destination, but also the time needed to travel this distance (network time). Another distance measure, called Manhattan distance, calculates the distance along two sides of a right-angled triangle, as opposed to along the hypotenuse, the shortest route. This distance measure is optimal for high-density urban areas with a grid-system road layout (Figure 9). Most of the studies we selected for our summaries about the services environment use Euclidean distances; a few use reticular distances.

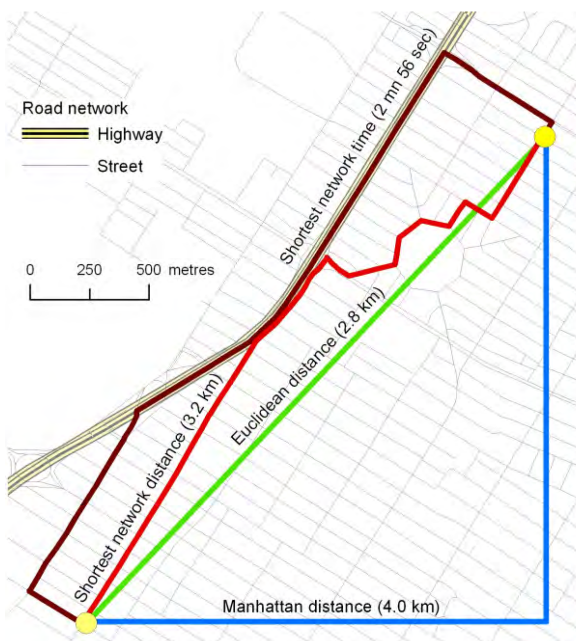

Figure 9: Types of Distance

Source: (114).

The following measures of accessibility were used in the studies reviewed: distance between participant's place of residence and closest recreational facility or food outlet; number of facilities or outlets within a given sector or radius; and average distance between a participant's residence and all facilities or outlets, or n number of facilities or outlets (114-

115) (Table 9). It is important to note that there are other measures of accessibility that we can qualify as a-spatial (affordability, acceptability and convenience) (116) (Table 10).

Table 9 Ways to Conceptualize and Measure Geographical Access to Certain Services

<table>
<tr><td>Conceptualization</td><td>Measures of accessibility</td><td>Formulas</td></tr>
<tr><td>Immediate proximity</td><td>Distance between point of origin and closest destination</td><td>$A_i^a = (\min \lvert d_{ij} \rvert)$
A_i^a = distance between spatial unit[1] i and the closest service
d_{ij} = distance between spatial unit i and service j</td></tr>
<tr><td>Availability in a given area</td><td>Number of infrastructures in a given area (e.g. census sector, neighbourhoods, etc.)</td><td rowspan="2">$A_i^b = \sum_{j \in S} S_j$
A_i^b = average number of services within a radius of n metres or an n number of minutes or in a given area
S = all services
S_j = number of services within a radius of n metres or an n number of minutes from the centre of the spatial unit or in a given area.</td></tr>
<tr><td>Availability in the immediate environment</td><td>Number of infrastructures within a given distance from the point of origin</td></tr>
<tr><td>Average distance to access a variety of destinations</td><td>Average distance between point of origin and n number of destinations</td><td>$A_i^c = \sum_j \frac{d_{ij}}{n}$
A_i^c = average distance between spatial unit i and an n number of services
d_{ij} = distance between spatial unit b and spatial unit and service s
n = number of services included in the analysis</td></tr>
<tr><td>Distance to access all destinations</td><td>Average distance between point of origin and all destinations</td><td>$A_i^d = \sum_j d_{ij}$
A_i^d = average distance between spatial unit i and all services j
d_{ij} = distance between spatial unit i and spatial unit and service j</td></tr>
</table>

1 The point of origin to calculate distances can be the centre of a spatial unit (e.g. neighbourhoods) or a residence.
Adapted from (114).

Table 10 Dimensions of Accessibility

Access dimensions	Definition	
Availability	Availability refers to the number of food outlets or recreational facilities in a given region (Table 9).	Spatial
Spatial accessibility	Spatial accessibility refers to the relationship between location of food outlets or recreational facilities and location of consumers (study participants). This relationship is often expressed as a distance measure (Table 9).	Spatial
Affordability	As its name indicates, this dimension refers to the relationship between price of food or activity and disposable income of consumers for this type of expense.	A-spatial
Acceptability	Acceptability refers to the relationship between consumers' attitude toward characteristics of staff and practices in food outlets or recreational facilities.	A-spatial
Convenience	Convenience refers to the relationship between the adaptation capacity of a recreational facility's or food outlet's organizational structure (opening hours, delivery services, parking), and consumers' ability to accommodate to the structural capacities of these businesses.	A-spatial

Adapted from Penchansky and Thomas, 1981.

SUMMARY 5: INDICATORS RELATED TO RECREATIONAL INFRASTRUCTURES

Background

A study by Poortinga (2006) has shown that a neighbourhood's environmental context which allows individuals to adopt more active lifestyles is linked with ease of access to recreational facilities, parks and green spaces. Similarly, Sallis et al. (2006) note the importance of physical and social contexts in adoption of behaviours that lead to an active lifestyle. Contextual characteristics that can influence these behaviours are linked to the presence of recreational infrastructures such as playing fields, sports clubs and bicycle paths. Potvin et al. (1997) hypothesized that the practice of physical activity in rural areas could be linked to access to recreational facilities (96).

Some studies have shown that when distance between an individual's home and a recreational facility was shorter, use of the facility increased (36, 117, 118). Results of a Canadian study demonstrate a positive association in women between involvement in vigorous physical activity and use of local facilities (119). Conversely, Ross (2000) suggests that some recreational activities such as playing a sport are more often done away from the neighbourhoods where people live (120). Other studies have shown that distance between home and recreational facility could be seen as a barrier to using this facility (121-122). From this perspective, several studies have attempted to show links between physical activity, BMI and access to certain recreational facilities, parks and green spaces.

Study Descriptions

We selected 20 studies published between 2004 and 2008 that included indicators linked to access to recreational facilities (public or private). Over half (13) these studies were conducted in the United States. The others were carried out in Canada (2); Australia and New Zealand (2); and the United Kingdom (3). No study used a longitudinal design. Study sample sizes vary from 58 to almost 20 745 individuals. In all, 12 studies use samples composed of children or adolescents. Among these 12 studies, 2 focus on adolescents. Finally, 8 studies focus on adult samples. The individual behaviours examined are related to BMI in 4 studies, to physical activity in 13 studies, and to physical activity and BMI in 3 studies. Most selected studies attempted to establish associations between access to recreational facilities and either physical activity or BMI, while controlling for other individual variables such as sociodemographic or socioeconomic characteristics of study participants.

Authors identify the built environment likely to influence individual behaviours using buffers that vary from 400 metres to almost 8 kilometres. Several studies use a 1.6-kilometre buffer (1 mile) around participants' homes, which is equal to about a 15-minute walk. Thirteen studies use buffers. Four studies use administrative (neighbourhoods) or statistical divisions to represent the built environment. Other authors do not use buffers or other spatial divisions; their methods are based on calculating access to infrastructures. For instance, some authors calculate the distance between a study participant's home and the closest recreational facility. This distance measure is then used to determine the association between individual behaviours and access to this type of facility. The hypothesis is that the greater the distance between a participant's residence and the recreational facility, the less a participant is likely to use this resource and, as a result, is perhaps less likely to engage in the physical activities offered.

Study Findings

Most of the studies reviewed show significant associations between level of geographical accessibility to recreational infrastructures and physical activity.

Among the studies reviewed, three found no significant association between accessibility to recreational infrastructures and physical activity. For instance, results from the studies of McCormack et al. (2008) and Hillsdon et al. (2006) found non-significant associations between access to green spaces such as parks and recreational or vigorous physical activity (20, 52). Similarly, Panter and Jones (2008) showed that access to recreational facilities (gymnasiums and sports facilities) did not influence levels of physical activity among study participants (53). Another study by Panter et al. (2008) using the same sample qualifies their results. The authors conclude that participants living further from recreational facilities tend to be less physically active. Moreover, they suggest that having a significant number of recreational facilities in a neighbourhood could generate demand for sports activities (89).

At least nine studies reveal significant results. These studies demonstrate that access to recreational infrastructures can foster physical activity. This association proves to be significant in the case of adolescents (44, 46, 49, 85, 88) and children (50, 56). For instance, a Canadian study by Tucker et al. (2009) concludes that greater geographical access to recreational facilities in the built environment is essential to increase youths' levels of physical activity. Diez-Roux et al. (2007) find that adult participants residing in neighbourhoods with a high density of recreational resources were significantly more likely to report engaging in physical activity (45). Lee et al. (2007) explain associations between the participants' and neighbourhoods' socioeconomic status and availability of physical activity and recreational resources (48). Results of this study indicate that women with low socioeconomic status or who live in disadvantaged neighbourhoods may benefit from greater access to physical activity resources (Table 11).

Half of the studies reviewed showed significant associations between access to recreational infrastructures and participants' BMI.

Among the studies reviewed, four attempted to establish an association between accessibility to recreational infrastructures and BMI of participants. Results of two out of four studies are not significant. Burdette and Whitaker (2004) found no significant association between proximity to playgrounds and the risk of child overweight (51).[17] These results are similar to those of Rutt and Coleman (2005), who conducted a study of adults in the region of El Paso, Texas. As a measure of the built environment, they used the shortest distance from each participant's home to the closest recreational facility, as well as the number of facilities within a 4-kilometre radius around each participant's residence (38).

Results of studies by Mobley et al. (2006) and Potwarka et al. (2008) show significant associations between geographical access to recreational infrastructures and participants' BMI. Results of the Mobley et al. (2006) study suggest that participants' BMI is significantly lower by 1.39 kg/m^2 in communities with a high density of fitness facilities (18). In their study, Potwarka et al. (2008) conducted regression analyses which revealed that children with a

[17] Height and weight data measured.

park playground within 1 km of their homes were five time more likely to have a healthy weight (54) (Table 11).

Significant associations between geographical accessibility of recreational infrastructures and physical activity, but not significant for BMI.

Once again, research results concerning links between geographical accessibility of recreational infrastructures and BMI or physical activity are not unanimous. For example, Norman et al. (2006) detected a significantly positive association between proximity to recreational facilities and physical activity in girls but not boys, nor in relation to study participants' BMI (19). These results are slightly more conclusive than those of Witten et al. (2008), which show no significant association between physical activity, BMI and access to recreational facilities, in this case, parks.[18] However, there is a significant relationship between beach access and participants' level of physical activity (55). Finally, results of a study by Gordon-Larsen et al. (2005) indicate that low-income ethnically diverse neighbourhoods were significantly more likely not to have recreational facilities. Consequently, geographical access to this type of infrastructure is lower in these neighbourhoods. This poor access is significantly associated with lower levels of physical activity and greater levels of overweight in adolescents living in these neighbourhoods (47) (Table 11).

Table 11 Body Mass Index (BMI) and Physical Activity: Summary[a] of Findings on Association With Geographical Access To Recreational Infrastructures

Indicators	Study Design	Dependent variables	Results[b]
Geographical access to recreational infrastructures	Cross-sectional: 4 (18, 38, 51.54) Longitudinal: 0	BMI	S: 2 studies NS: 2 studies
Geographical access to recreational infrastructures	Cross-sectional: 13 (20, 44-46, 48-50, 52, 53, 56, 85, 88, 89) Longitudinal: 0	Physical activity	S: 9 studies NS: 4 studies
Geographical access to recreational infrastructures	Cross-sectional: 3 (19, 47, 55) Longitudinal: 0	BMI and physical activity	BMI: S: 1 study NS: 2 studies Physical Activity: S: 2 studies NS: 1 study

[a] See details in Appendix 1.
[b] S: Significant.
NS: Not significant.

Comments and Study Limitations

Some studies seem to find significant associations between geographical access to recreational infrastructures and the practice of physical activity and individuals' BMI. Some authors even suggest that improving geographical access to these recreational infrastructures can encourage physical activity and be connected to the weight of individuals.

[18] Height and weight data measured.

We should, however, exercise caution regarding these results. Indeed, there are several limitations to these studies. First, there is no consensus regarding the methodology employed to measure geographical access to facilities. Apparacio et al. (2008) point out the biases that can be introduced when using different geographical accessibility measures on determinants of health (114). Second, most methods used to measure accessibility are based on participants' place of residence. This option can be valid for children but for adults, it is also important to consider availability of resources around work locations (45).

Indicators Used

The studies reviewed used three indicators of geographical accessibility to recreational facilities:

- Density or number of infrastructures in a given area[19] (19, 38, 44-50)
- Distance between residence and closest infrastructure (38, 48, 51-55)
- Proportion of the land area dedicated to recreational infrastructures (50, 56)

The following recreational facilities were considered in different studies to calculate geographical accessibility:

- Parks and green spaces (20, 38, 44, 45, 47, 50, 52, 54-56, 123)
- Private recreational resources[20] (e.g. gymnasiums/dance studio; martial arts school; exercise centre; swimming pool; golf course; YMCA; bowling alley; tennis court; yoga centre; sports centre) (45, 47-49, 53, 85, 89, 123)
- Public recreational facilities[21] (e.g. playground; soccer field; baseball diamond; basketball court; arena; skating rink; community centre; school; public swimming pool; tennis court) (19, 38, 47, 50, 51, 53, 56, 89)

Databases Used

Different databases are used based on the type of infrastructure:

- Parks and green spaces
- Land use (19, 44, 55)
- Public facilities directories (20, 45, 50, 51, 54)

Private recreational facilities:

- Business directories[22] (19, 20, 38, 45-49, 85, 88)
- Census data (18)

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[19] Two methods are used in these studies: within a radius of study participants' residences or based on spatial units (e.g. neighbourhoods).

[20] Some studies used industry classification system codes to define sport and recreational facilities. For example, Mobley et al. (2006) use nomenclature from the North American Industry Classification System (NAICS) to create a list of exercise and recreational facilities. They use two industry codes: 713910 (*Golf Courses and Country Clubs*) and 713940 (*Fitness and Recreational Sports Centers*).

[21] Some studies indicate the types of infrastructures in playgrounds and others do not.

[22] The Yellow Pages business directory is widely used in research. Other business directories are also used in studies, such as the Infousa.com Web site, and Dun and Bradstreet. Infousa.com and Dun and Bradstreet provide databases that contain information on businesses, their locations and sales figures.

Public recreational facilities:

- Land use (19)
- Public facilities directories (20, 49, 51 53, 54, 88)

Operationalization in Québec

Several different data sources could be used to develop indicators of geographical accessibility to recreational facilities.

Two data sources could reflect the location of parks and green spaces. One is the property assessment roll, which locates the units of assessment for the entire province. The roll contains a predominant unit utilization code. This code is linked to the North American Industry Classification System (NAICS). Parks and green spaces are coded to 7610 (general recreational park) and 7620 (recreational and ornamental park). For example, using this information, it was possible to geolocate 124 property assessment units in the de Lanaudière region listed under the heading "general recreational park" and 252 units under "recreational and ornamental park". It is then possible to calculate the geographical accessibility of these units. Figure 10 shows the results of an example of this type of analysis.

Other data sources can be used to locate parks and green spaces. Canada's National Topographic Data Base (NTDB) is such a source. The topographical contents of the NTDB is very similar to that of the National Topographic System of Canada (NTSC). The NTDB includes information pertaining to parks and green spaces, defined as zones, for instance, a baseball diamond or municipal park where sports and recreational activities take place.

Several databases list private and public recreational infrastructures. For private facilities, one can turn to business directories like those used in the studies reviewed here (Yellow Pages, Infocanada.com, Dun and Bradstreet, and DMTI Spatial Inc.). For example, DMTI Spatial Inc.'s directory uses the Standard Industrial Classification[23] and allows us to obtain a geospatial database for the entire province. Recreational facilities are listed under amusement and recreational services (125). A Canadian study demonstrated that recreational resources are underestimated when business directories are used compared to field observation of these facilities (126). Nonetheless, commercial listings more accurately reflect reality than directories found on the Internet.

These facilities can also be listed using the property assessment roll. Some units of assessment are categorized under the heading "recreational activity". This grouping includes units used for sports activities (golf course, squash, racquetball and tennis court, shooting range, roller-skating, horseback riding, bowling lane, tobogganing, and other sports activities); playgrounds and athletic fields (playground, playing field, general recreational centre, gymnasium and athletic training, other playground and athletic field); swimming (beach, swimming pool); other aquatic activities (marina, access ramp and parking; service

[23] The Standard Industrial Classification (SIC) is a four-digit code established by the American government. The code assigns businesses to industry groups, based on the business's main activity. The code makes it easier to analyze and group data on economic activities. The Classification covers all economic domains: agriculture; forestry; fishing and mines; construction; manufacturing; transport; communications; energy; sales; services; public administration; education; finance; insurance and real estate; health; and recreational activities (124).

station for aquatic equipment, aquatic safety and activity school or club, aquatic show site); activities on ice (arena, curling rink, other activities); extreme sport activities (war game site, flight centre, bungee jumping centre and other extreme sport facilities).

These data should be validated beforehand with regional organizations dedicated to the promotion of physical activities. Organizations such as Unités régionales de loisir et de sport du Québec could contribute to the creation of a provincial directory of recreational facilities. Regional units are non-profit organizations whose mission is to support and promote development of leisure and sport regionally.[24] For example, de Lanaudière recently drew up a comprehensive profile of recreation in the region. This profile includes an inventory of sport and recreational equipment in the various municipalities.[25] The information could be combined with other data to have a complete profile of accessibility to these types of facilities in the province.

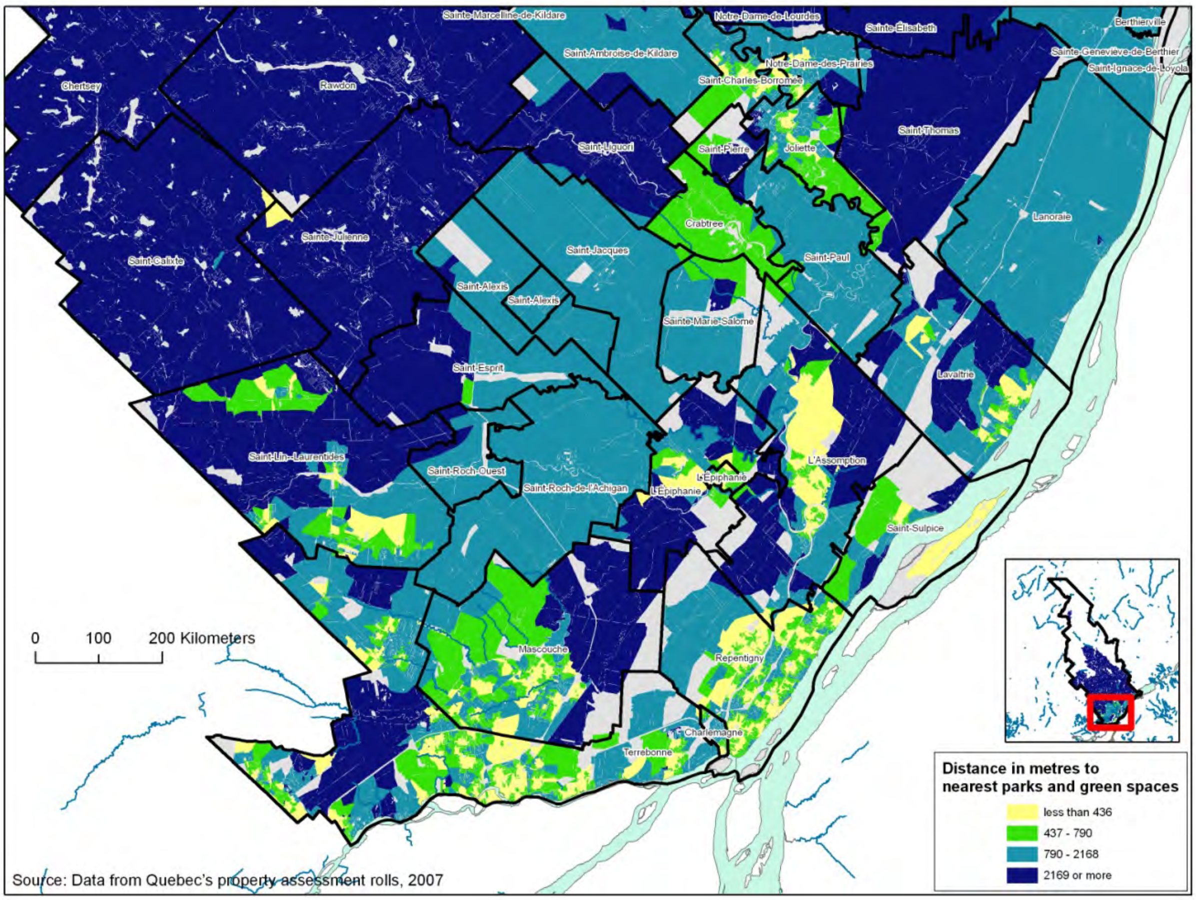

Figure 10: Access to Parks and Green Spaces in South Lanaudière

The hypothesis is that greater accessibility to parks, green spaces, and recreational facilities could encourage physical activity, especially in children.

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24 www.mels.gouv.qc.ca/loisirSport/index.asp?page=regio_unitesRegionales.

25 www.loisir-lanaudiere.qc.ca/portrait2.php.

SUMMARY 6: INDICATORS RELATED TO FOOD OUTLETS

Background

Glanz et al. (2005) indicate that a nutrition environment that can affect health and individual behaviours is divided into four sub-environments: community environment; organizational environment; consumer environment; and information environment. The community nutrition environment is defined by the number and type of food outlets available to the population and the accessibility of these outlets. Access to food outlets can include stores that offer food products for consumption at home (convenience stores, grocery stores and supermarkets) and restaurants (table-service and fast-food restaurants). Some researchers suggest that availability of fruit and vegetables at home is partly linked to the accessibility of outlets that offer these products (127). It is hypothesized that we have greater access to outlets that do not offer foods linked to healthy lifestyle habits (57). For instance, access to fast-food restaurants is an aspect that characterizes an obesogenic environment (128). A few studies have attempted to measure possible links between geographical accessibility of food outlets, eating behaviours and BMI.

Study Descriptions

A total of 15 studies were reviewed for this summary. They used indicators linked to geographical accessibility of food outlets (grocery stores or restaurants). Most studies were conducted in the United States (11). The other studies were carried out in Australia (3) and New Zealand (1). No study included in this summary was conducted in Canada.

To our knowledge, two Canadian studies attempted to establish links between access to food outlets and the health of individuals. The first looked at coronary syndromes (Alter and Eny, 2005) and the second used subjective built environment data (Veugelers et al., 2008). Consequently, they were excluded from our sample of scientific articles (129, 130).

Sample sizes used to measure the impact of geographical accessibility of food outlets on eating habits and BMI vary from 157 to over 714 000 participants. The age and sex of participants distinguish the studies. Six of the studies reviewed had samples composed of children and one of women. Most studies attempted to measure statistical connections between level of accessibility of food outlets and either BMI (10 studies), participants' eating habits (3 studies) or both (2 studies), while controlling for individual sociodemographic variables or for environment (e.g., level of deprivation).

Several studies define the food environment that can influence individuals with administrative and statistical spatial units. Other studies use buffer zones that vary between 800 metres and 2.5 kilometres, a choice that is justified by a person's average walking buffer (almost 1 mile, or 1.6 kilometres, which is about a 15-minute walk), for instance.

Study Findings

Most of the studies show significant associations between access to food outlets and participants' BMI.

For the most part, studies that attempted to measure the impact of geographical accessibility of food outlets on participants' BMI obtained significant results. Only 3 out of 10 studies found no significant association. A few studies demonstrated that increased geographical access to fast-food restaurants is significantly associated with higher risks of prevalence of obesity or overweight and with higher BMI scores among participants (57, 58, 64). For example, Mehta and Chang's (2008) study confirm the hypothesis that exposure to higher fast-food restaurant density is significantly associated with a higher risk of obesity. Similar results have been demonstrated using level of accessibility of convenience stores (35, 67). The studies also conclude that increased geographical access to full-service restaurants and supermarkets or grocery stores is linked to lower obesity and overweight prevalence, as well as to lower BMI (25, 66, 67).

Only three studies found no association between access to food outlets and participants' BMI. (51, 62). One of these studies, by Sturm and Datar (2005), notes density of fast-food restaurants, full-service restaurants, convenience stores and grocery stores is not associated with a significant change in BMI among children followed over a period of three years (68)[26] (Table 12).

Significant associations between access to food outlets and eating habits

In a study of children, Timperio et al. (2007) show that the shorter the distance between home and some food outlets (fast-food restaurants and convenience stores), the lower the likelihood of children consuming fruit daily (60). There was also an association between density of convenience stores and daily consumption of vegetables. Finally, daily consumption of vegetables tends to be higher in children living close to supermarkets. Moore et al (2008) obtained similar results, showing that participants who do not have a supermarket near their homes were 25% to 46% less likely to develop healthy eating habits than participants living in an environment where there are more supermarkets (65). Turrell and Giskes (2008) found no significant association between access to takeaway restaurants and participants' eating habits (61) (Table 12).

Divided results for studies on both BMI and eating habits

Two studies attempted to identify associations between access to food outlets and participants' BMI and eating habits. On one hand, Jeffrey et al.'s (2006) results show that accessibility (from home and work) to fast-food restaurants is not associated with eating in these restaurants or with higher BMI (63). On the other hand, according to Pearce et al. (2007), greater access to fast-food restaurants is significantly associated with consumption of the recommended daily intake of vegetables, as well as with overweight (59)[27] (Table 12).

[26] Height and weight data measured.
[27] Height and weight data measured.

Table 12 Body Mass Index (BMI) and Diet: Summary[a] of Findings on the Association with Geographical Access to Food Outlets

Indicators	Study Design	Dependent variables	Results[b]
Geographical access to food outlets	Cross-sectional: 9 (35, 54, 57, 58, 60, 62, 64, 66-68) Longitudinal: 1	BMI	S: 6 studies NS: 3 studies
Geographical access to food outlets	Cross-sectional: 3 (60, 61, 65) Longitudinal: 0	Diet	S: 2 studies NS: 1 study
Geographical access to food outlets	Cross-sectional: 2 (63, 126) Longitudinal: 0	BMI and diet	BMI: S: 1 study NS: 1 study Diet: S: 1 study NS: 1 study

[a] See details in Appendix 1.
[b] S: Significant.
NS: Not significant.

Comments and Study Limitations

Several studies have demonstrated significant associations between access to food outlets and participants' BMI or eating habits. However, these studies have certain limits. Firstly, further analyses should be conducted to measure the impact of the variety and prices of foods available in these outlets on individuals' BMI and eating habits (57, 58, 60). Indeed, the findings of Sturm and Datar (2005) show a significant association between lower prices for fruit and vegetables and lower gain in BMI in children followed over a three-year period. Secondly, few studies attempt to measure exposure to certain food outlets from a point other than residence. Only three studies measure exposure to food outlets either from participants' workplace or children's school (63, 68).

Indicators Used

- Distance to nearest food outlets[28] (51, 57-62)
- Density or number of outlets in a given area (18, 25, 35, 57, 60-68)
- Average distance to an *n* grouping of food outlets (61)

[28] Distance to nearest food outlets is calculated from the central point of the spatial unit (e.g. census tracts) where study participants live (59, 61) or from the homes or workplaces of participants (51, 57, 60, 62, 63, 66).

The following food outlets were considered to calculate geographical access in different studies [29]:

- Fast-food restaurants (57-60, 64, 67, 68)
- Full-service restaurants (35, 58, 60, 67, 68)
- Takeaway shops (60, 61)
- Convenience stores (35, 60, 67)
- Grocery stores (35, 67, 68)
- Supermarkets (65, 67, 68)
- Greengrocers (60)

Databases Used

Food outlet lists used to calculate geographical accessibility are usually taken from business directories. Directories were obtained from different providers, including Yellow Pages, the American census, Dun and Bradstreet, and InfoUSA. Some studies use directories from local public health authorities or the municipality. According to Simon et al. (2008), directories produced by health authorities are more complete than commercial lists. Results of this study show that 30% more food outlets were listed in the food inspection database than in commercial databases (131). However, the authors of a Canadian study point out that commercial data sources are valuable tools in the evaluation of commercial environments related to eating behaviours (126). By comparing the food environments of some Montréal neighbourhoods chosen according to field observations and commercial business databases, results show 73% agreement between these two sources of information.

Operationalization in Québec

Several databases can list food outlets. It is possible to use business directories like those used in the studies reviewed here (Yellow Pages, Infocanada.com, Dun and Bradstreet, and DMTI Spatial Inc.). For example, DMTI Spatial Inc.'s directory uses the Standard Industrial Classification (SIC) and allows us to obtain a geospatial database for the entire province.

SIC classifies food outlets under 5812 – Eating places (fast-food restaurants and full-service restaurants); 5499 – Miscellaneous food stores (natural food stores, specialized stores (tea, coffee, etc.); 5411 – Grocery stores (convenience stores, grocery stores, supermarkets); 5431 – Fruit and vegetable markets; 5421 – Meat and fish markets; 5441 – Candy, nut and confectionery stores; 5451 – Dairy products stores; 5461 – Retail bakeries. Since the classifications can include a broad variety of businesses, it is possible to find restaurants in the retail bakery category (e.g. Tim Hortons). We could also include retail stores, variety stores (5331) (e.g. Dollarama), and Drug stores and proprietary stores (5912) (e.g. pharmacies).

[29] Two methods were mostly used to identify the different types of food outlets. In some studies, the authors determine the types of food outlets using industrial classification codes (18, 25, 62, 63, 65, 68). For instance, Lopez (2007) uses the North American Industry Classification System (NAICS) nomenclature to select food outlets from a business directory. The codes for fast-food restaurants and grocery stores are 722211 and 445110, respectively. Other studies, especially those related to access to fast-food restaurants, identified these restaurants by chain names (51, 57, 59, 61). This method is also used for supermarkets (60, 62).

This classification does not allow us to distinguish certain businesses that are linked to 'obesogenic' food environments such as fast-food restaurants or convenience stores. Manual classification thus becomes essential to select, among these categories, food outlets that can encourage or discourage healthy lifestyle habits. Restaurant chain names can be used for selection, a method used in several studies.

For this section, a summary analysis of the de Lanaudière region's community food environment was performed using DMTI data. Results of this analysis show that there are 888 restaurants (code 5812) in the region, which represents almost 2 restaurants per 1000 people. In our analysis we included only large fast-food restaurant chains (McDonald's, Burger King, Kentucky Fried Chicken, Pizza Hut, Subway, Tim Hortons, La Belle Province and Dunkin' Donuts (Table 13). Results of this accessibility analysis demonstrate that all the territory within the region of de Lanaudière is on average less than 4.8 kilometres from the nearest outlet of one of the large fast-food restaurant chains selected (Figure 11).

Table 13 Large Fast-food Restaurant Chains, de Lanaudière Region

Name of the chain	Number of outlets
McDonald’s	16
Burger King	3
Kentucky Fried Chicken	3
Pizza Hut	3
Subway	24
Tim Hortons	14
Dunkin’ Donuts	8
La Belle Province	15
Total	86

Source: DMTI Spatial Inc., 2007.
Compilation: INSPQ, 2009.

Some directories use other classification systems. Québec's property assessment roll is one of them. Assessment roll units are classified according to the North American Industry Classification System. Contrary to business directories, it is not possible to select different types of food outlets based on restaurant chain names using data from property assessment rolls. The categories under which restaurants, grocery stores and other food outlets can be listed are numerous, as can be seen in Appendix 2.

Another data source could be used to complete the profile of Québec's food environment. It is linked to a file from the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec that assembles information about food preparation and sale permit holders. This database was used in a Montréal study on access to outlets selling fruit and vegetables (132).

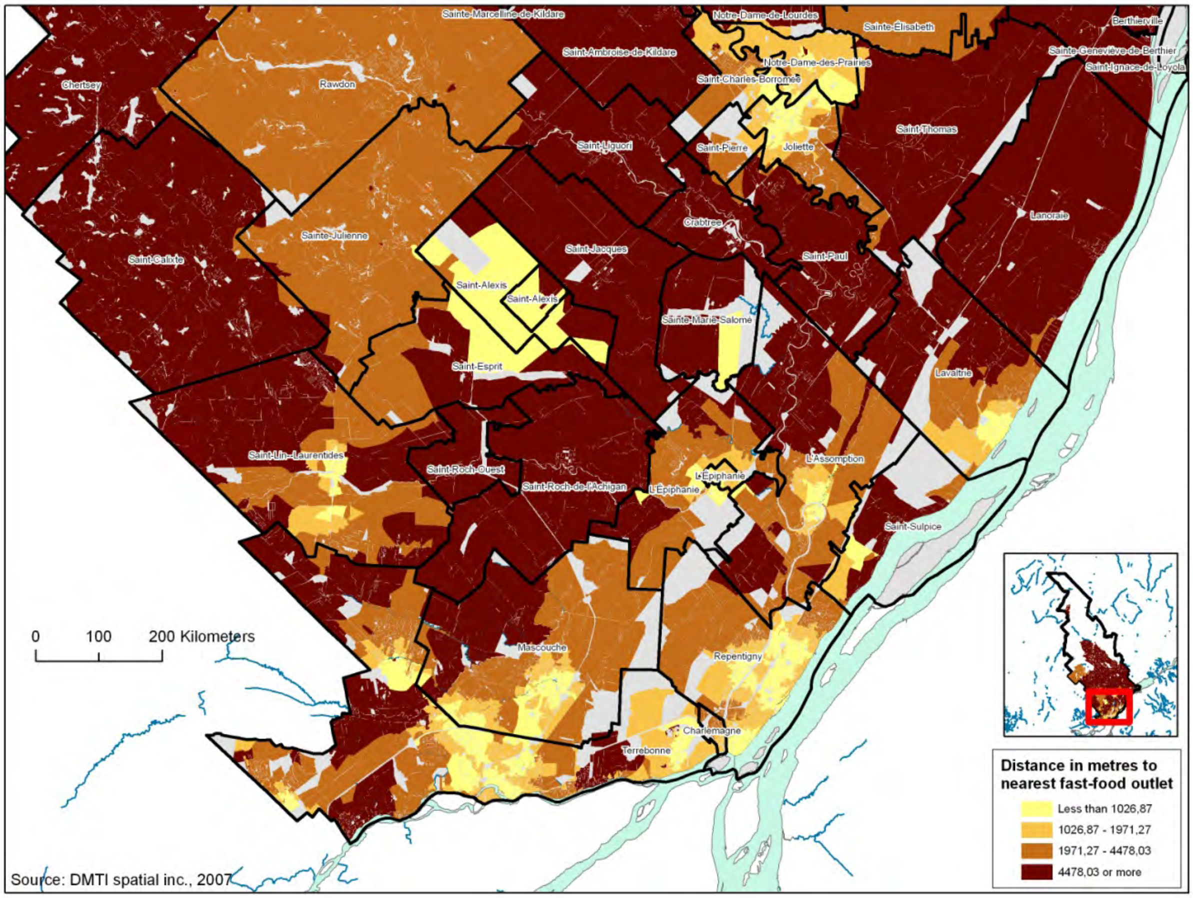

Figure 11: Access to Fast-food Restaurants (Southern Region of de Lanaudière)

It is hypothesized that individuals exposed to a poor-quality food environment (e.g. fast-food restaurants, convenience stores) are more likely to adopt diets that include food items of low nutritional and high caloric value, and to have a higher rate of obesity compared with individuals who live in a "high quality" food environment (e.g. grocery stores, supermarkets, full-service restaurants, greengrocers, public markets).

CONCLUSION

In conclusion, there are increasingly more studies looking at the possible role of the built environment and the services environment on body weight, diet and physical activity. Most of these studies are still in an exploratory stage of the knowledge development process. More specifically, they use geospatial data of the built environment. Yet, this abundance of research poses certain challenges.

Developing indicators for the built environment based on objective measures linked to GIS requires a process to verify the validity and reliability of these data. The validity of data used to develop indicators for the built environment should involve some reflection on the extent to which data is representative of the real world. Most databases used were not conceived with the goal of developing these indicators. The level of accuracy can vary from one database to another and from one region to another. Moreover, information in the databases are often not collected during the same time period as data representing the situation of survey participants. Such discordance can have an impact on study results, especially in settings where the built environment is undergoing rapid changes. It is also desirable that the development of indicators for the built environment using geospatial databases be supported by a variety of data sources. A few studies note that the information contained in these databases could in fact differ. For instance, Simon et al. (2008) demonstrated that there were 30% more outlets in a food inspection database than in a commercial database.

Following an analysis of various articles cited in the Summaries of this document, it seems that researchers used a considerable number of methods and different data sources to operationalize environment indicators. Most indicators identified in the studies are measured using variables that differ from study to study (133). Consequently, it is difficult to verify the reliability of measures developed using geospatial databases. The work of an American team based in the Minneapolis–St. Paul area attempted to remedy this situation by establishing certain protocols for developing indicators of the environment (134, 135). However, only a few studies (27, 32) use these protocols.

The heterogeneous nature of methods used to determine spatial analysis scales is also characteristic of the various studies reviewed. In some studies, the buffer zone is defined as the built environment likely to influence individuals' behaviours and, indirectly, their characteristics. Buffer areas also differ from study to study. The built environment is defined, in some studies, only as the neighbourhoods where participants live. Finally, a few studies attempt to define the built environment not only based on participants' residence but also on place of work or school where participants are registered (63, 99).

Another finding that emerges from analyzing these articles is the divergence in study results. There is no clear consensus concerning the impact of the built environment or the services environment on BMI, physical activity or eating behaviours. Nonetheless, of the 56 articles included in the Summaries, 37 (65%) concluded that there are significant associations between characteristics of the environment and participants' behaviours or BMI. Since this is an emerging field of research, few studies use a longitudinal design. Of the 56 studies included, 6 use longitudinal data. Results of these studies are not conclusive; only 2 studies found significant associations between characteristics of the environment and BMI, eating habits or physical activity. The current state of knowledge development does not allow for inferences to be made concerning the causal effects (136). Moreover a publication bias can increase the proportion of studies with significant, positive results since they are easily publishable.

Of the 28 studies using BMI as a variable characterizing participants, 10 used measured anthropometric data and 18 self-reported data. In the literature, there is an ongoing debate on the validity of data pertaining to self-reported weight and height (137, 138). However, some studies have shown that self-reported data are reliable, due to the strong correlation between these and clinically measured data (139, 140).

Finally, most studies reviewed in the Summaries were conducted in urban areas in the United States. Therefore, it is difficult to determine if these indicators are valid for Québec and for rural areas, or even for small- or medium-sized urban regions (22). Some indicators for land use, road network configuration, transportation system, and build environment design may not apply to rural regions or to small or medium urban areas. Research should be undertaken to identify indicators for the built environment that are valid for rural regions.

Although results of these studies differ, the methods employed to operationalize built environment indicators can be useful to develop indicators appropriate for Québec. The next step of this project will be to operationalize built environment indicators for the province. The Summaries in this document will be the methodological basis for developing these various indicators.

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APPENDIX 1

SYNOPSIS TABLE OF THE STUDIES SELECTED TO ASSEMBLE THE SUMMARY SHEETS

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
Physical activity											
(50)	C, P	Youth, 811 children in grades 7 and 8 London, Ontario	Canada	Land use mix, % of park space; number of recreational facilities (public)		Buffer (straight line) (school and home)	1.6 km and 500 m	Season, sex, grade, ethnicity, family structure, number of people living in the household, parents' education, father's work status, income, lifestyle habits	PA	Significant positive associations between accessibility to sports and recreational facilities and youths' physical activity.	Municipality
(86)	C	Adults (aged 16 and over), 6 476 Auckland, New Zealand	New Zealand	Mixed land use, intersection density, residential density		Environment between residence and place of work (buffer)	1 km	Sex, age, ethnicity, education, income, car owner	PA	Participants who had high street connectivity tended to engage in transport-related physical activity.	Residential rolls
(41)	C, L	Youth, 3 842 children aged 3 to 18 years followed for 24 months. Marion County IN	United States	NDVI, population density		Buffer (straight line and road-based)	1 km	Sex, age, ethnicity, income, health insurance	BMI	Significant relationship between neighbourhood greenness and lower BMI of youth.	Satellite imagery
(31)	C	Adults, 30 025 National Personal Transportation Survey (NPTS) participants 10 metropolitan regions	United States	Mixed land use, intersection density, housing density, block lengths, neighbourhood design (median housing age)		Radius of the centroid of block groups (straight line)	1/4 mile	Education, job status, age, sex, household size, type of household	PA	The probability of walking is higher for participants living in built environments where there is a high proportion of four-way intersections.	Census data, TIGER and InfoUSA business lists

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
(43)	C	Children aged 8-9 years (n = 188) and adolescents aged 13-15 years (n = 346), Children Living in Active Neighbourhoods (CLAN), Melbourne	Australia	Total length of local roads, intersection density, proximity of cul-de-sac, length of walking tracks, number of speed humps, number of traffic lights		Buffer (straight line)	800 m	Not indicated	PA	No significant association between built environment measures and physical activity for children.	
(44)	C	Youth, 1 556 grade 6 girls in the Trial of Activity for Adolescent Girls. Washington, DC, and Baltimore, Maryland; Columbia, South Carolina; Minneapolis, Minnesota	United States	Availability of parks and green spaces	Free lunch (school), % black population, % Hispanic population, % SES index	Buffer (straight line)	1 mile	Ethnicity	PA	Girls who live near several parks are more likely to spend more time doing physical activity outside of school hours.	Local map
(45)	C	Adults, 723 participants. New York City, NY; Baltimore, Md; and Forsyth County, NC	United States	Density of recreational facilities, density of parks and green spaces	Population density, ethnic composition of the neighbourhood	Kernel estimation		Sex, age, ethnicity, income	PA	Results of this study show that participants living in neighbourhoods with a high density of recreational resources reported significantly more physical activity.	Yellow Pages, Internet searches, municipality

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
(46)	C	Youth, 1 556 grade 6 girls in the Trial of Activity for Adolescent Girls. Washington, DC, and Baltimore, Maryland; Columbia, South Carolina; Minneapolis, Minnesota	United States	Availability of recreational facilities	Free lunch (school), SES index, population density, median age of homes	Buffer (straight line)	1 mile	Age, BMI, ethnicity, PA support, after-school transportation	PA	Girls who live near PA facilities engage in significantly more physical activities outside school hours.	Business directories (Smart Pages, InfoUSA)
(21)	L	Adults, 6 000 participants. National	United States	Urban sprawl index, mixed land use		Buffer (straight line)	2 miles	Age, age^2, ethnicity, education, smoking status, marital status, children in the household, income, employment, sex	BMI	Urban sprawl does not cause weight gain.	Land-cover data, census data
(26)	C, L	Youth, National Longitudinal Survey of Youth (NLSY97), 6 760 respondents, 5 815 respondents, 3 667 respondents National	United States	Urban sprawl index (residential density, accessibility)	Safety of neighbourhood (crime)	County		Sex, age, ethnicity, cigarette use, hours worked, education	BMI	Significant association between urban sprawl and risks of overweight among youth. Longitudinal analyses of BMI growth curves show no association with urban sprawl.	

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
(28)	C	Adults, 10 878 participants. Atlanta, Georgia region	United States	Mixed land use, intersection density, residential density		Buffer (network)	1 km	Time spent in car, walking, age, income, education, sex	BMI	Association between BMI and mixed land use, but no significant relationship between density and BMI.	Tax assessment, aerial photography, street network
(23)	C	Adults, 2 056 participants, Strategies for Metropolitan Atlanta's Regional Transportation and Air Quality (SMARTRAQ) Atlanta, Georgia region	United States	Mixed land use, intersection density, residential density		Buffer (network)	1 km	Sex, age, ethnicity, BMI, income, household size, car owner, driver's license, travel behaviour	PA and BMI	Individuals who prefer and live in a walkable neighbourhood walked most (33.9%) and drove 25.8 miles a day on average.	Tax assessment, aerial photography
(47)	C	Youth, 20 745 adolescents, National Longitudinal Study of Adolescent Health, national	United States	Availability of recreational facilities	Population density, education, ethnic minority SES index	Buffer (straight line)	8.05 km	Not indicated	PA and BMI	Increasing number of recreational facilities is associated with reduced risks of overweight and increased physical activity.	Business directories (SIC)
(52)	C	Adults, 4 950 respondents (40 to 70 years old) from the European Prospective Investigation into Cancer and Nutrition (EPIC)	United Kingdom	Road distance between residence and closest green space	Deprivation			Age, sex, education, ethnicity, distance to city boundary	PA	No significant association between access to green spaces such as parks and recreational or higher levels of physical activity.	

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
(48)	C	Adults, 2 672 respondents (25 to 74 years old), 3 interviews 1 (1979-1980), 4 (1984-1985) and 5 (1989-1990) California	United States	Number of recreational resources and distance to recreational resources	SES index	Buffer (straight line)	0.5 mile	Age, ethnicity, marital status, education, income	PA	No significant association between access to recreational resources and physical activity, for women.	Telephone book and Internet searches
(40)	C	Youth, 7 334 children aged 3 to 18 years Marion County IN	United States	NDVI, proximity to fast-food restaurants	SES index	Buffer (straight line)	2 km	Sex, age, income, ethnicity	BMI	Significant associations between increased neighbourhood vegetation and decreased risk for overweight in children. This association is valid for higher population density neighbourhoods.	Satellite imagery
(20)	C	Adults, 1 394 participants.	Australia	Destination mix (all destinations, recreational destinations, utilitarian destinations)	Social disadvantage index	Buffer (straight line)	400 and 500 m	Sex, age, education, number of children, BMI	PA	Strong association of proximity and mix of destinations with utilitarian-type physical activity but not with recreational or vigorous physical activity.	Yellow Pages, telephone books, White Pages, postal service, Department of Transport, and Ministry of Planning

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
(29)	C, P	Adults, 1,270 participants. Forsyth County, NC	United States	Traffic speed, traffic volume, street connectivity		Buffer (straight line)	1 mile	Age, sex, ethnicity	PA	Significant and positive associations between neighbourhood with high street connectivity and physical activity.	Census data, TIGER
(30)	C	Youth, 20 745 adolescents in grades 7 to 12 from the National Longitudinal Study of Adolescent Health, national	United States	Availability of sports and recreational facilities, parks and green spaces, intersection density, alpha index of connectivity, gamma index of connectivity, cyclomatic index of connectivity, road types (small or large)	Education, minority, poverty, housing units, mobility, safety (crime)	Buffer (straight line)	3 km	Ethnicity, education, socioeconomic status, family structure	PA and BMI	Adolescents living in rural areas, or in multi-ethnic areas are significantly more likely to be overweight compared to adolescents living in newer suburban neighbourhoods.	Yellow Pages, Census data, TIGER
(19)	C	Youth, 799 adolescents aged 11 to 17 years San Diego County	United States	Number of recreational facilities, residential density, intersection density, land use mix (residential, institutional, commercial)		Buffer (network)	1 mile	Age, ethnicity, sex, income	PA and BMI	The number of recreational facilities and of parks near participants' residences is positively correlated with girls' physical activity. No significant relationship with BMI was detected.	Yellow Pages, San Diego Association of Governments, US 2000 Census data

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
(32)	C	Adults, 716 participants Twin Cities, Minnesota	United States	Block areas		Block group		Age, health, ethnicity, education, income	PA	No significant association between neighbourhood density and connectivity, and physical activity	Census data
(89)	C	Adults, 401 participants Norwich	United Kingdom	Availability of recreational facilities	Deprivation	Closest facilities		Age, sex, education, income	PA	Participants living far from recreational facilities are significantly less active. However, these participants are just as motivated to engage in a physical activity as those who have these infrasctructues in their neighbourhoods.	Telephone directory, local organizations
(53)	C	Adults, 401 participants Norwich	United Kingdom	Availability of sports and recreational facilities	Deprivation	Closest facility		Age, sex, education, income, dog owner, lifestyle habits	PA	Level of accessibility to these facilities is not associated with physical activity.	Telephone directory, local organizations
(49)	C	Youth, 1 506 girls in grade 12 South Carolina	United States	Number of sports and recreational facilities		Buffer (network)	0.75 mile	BMI, socioeconomic status	PA	Significant association between number of commercial recreational resources and physical activity for adolescent girls.	Internet search, Yellow Pages, local organizations

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
(54)	C	Youth, 108 children aged 2 to 17 years Ontario	Canada	Number of parks, total area of parkland, distance to closest park		Buffer (straight line)	800 m and 1 km	Sex, age, parents' BMI	BMI	The availability of specific facilities in parks is positively and significantly associated with physical activity and healthy weight status among children. Proximity of park space was not associated with healthy weight in children.	Municipal park directory
(85)	C	Youth, two samples 195 702 and 58 876 youth in grades 8, 10 and 12 from the Monitoring the Future (MTF) Survey, national	United States	Density of recreational facilities		Zip codes (school)		Education, ethnicity, parents' education level, mother's work status	PA	Availability to recreational facilities can help increase physical activity levels among adolescents.	D&B MarketPlace software (SIC)
(56)	C	Youth, 32 boys and 27 girls aged 4 to 7 years Erie county, NY	United States	Proportion of neighbourhood area with parks, playgrounds and recreational facilities	Density	Buffer (straight line)	1/2 mile	BMI, ethnicity, SES, lifestyle habits	PA	Positive association between neighbourhoods with significant proportion of park area and physical activity in children.	Property rolls

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
(88)	C, P	Youth, 1 367 6th-grade girls who participated in the Trial of Activity for Adolescent Girls, 6 metropolitan regions	United States	Availability of recreational facilities	SES index	Buffer (straight line)	1 mile	Ethnicity, lifestyle habits	PA	Raising the profile of existing recreational facilities in neighbourhoods may help increase physical activity among adolescent girls.	Business directories, local and regional planning and education organizations
(42)	C, P	Adults, 529 respondents Seattle	United States	NDVI		Buffer (straight line)	0.4 mile	Sex, age, education, income	PA and BMI	No significant association between level of greenness and physical activity and participants' BMI.	Satellite imagery
(34)	L, P	Women, 70 in cross-sectional and 32 in longitudinal sample Georgia, Alabama and Florida	United States	Number of intersections, number of cul-de-sacs, street lengths, population density, employment density, housing density, land-use mix		Buffer (network)	1/4 mile	Age, marital status, household size, number of adults, number of children, BMI, ethnicity	PA	No significant association between street-network connectivity and walking.	Census data, TIGER
(55)	C	Adults, 12 529 participants in the New Zealand Health Survey 2002/3, national	New Zealand	Road distance to the nearest park and beach	Deprivation	Meshblock		Education, social class, social programs, employment, income	PA and BMI	No significant association between access to parks and green spaces, and BMI and participants' physical activity.	Land-cover data

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
(22)	C	Adults, 936 participants aged 65 to 97 years King County, Washington	United States	Walkability index		Buffer (straight line)	1 and 3 km	Sex, age, education, income, living alone, tobacco use, arthritis	PA and BMI	Association between walkability and walking. No association between walkability and BMI.	Assessment rolls
(39)	C, P	Adults, 7 784 participants, Portland	United States	Population density, proportion of territory used for parks		Census tract		Household characteristics, individual characteristics, attitudes and perceptions	PA	Results showed that access to public transportation equipment tended to reduce the number of walking trips per day.	
(27)	C	Adults, 715 participants Twin Cities, Minnesota	United States	Built environment density, intersection density, access to non-motorized transport, design of the built environment, access to the public transit network, land use mix		Buffer (straight line)	200, 400, 800 and 1 600 m	Sex, ethnicity, education, marital status, car owner, age, overall health, household size	PA	No significant association between intersection density and physical activity (recreational and transport). Significant association between elements of non-motorized network and physical activity.	

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
(36)	C	Women, 158 overweight individuals Pennsylvania	United States	Built environment design (median year homes built), proximity to services and facilities	SES index	Block group		Age, ethnicity, marital status, education, employment	PA	Participants living in a neighbourhood with homes built between 1950 and 1969 (a more pedestrian-friendly urban form) and where mixed land use is high are more physically active	State organizations and census data
(37)	C, P	Adults, 608 participants Washington	United States	Intersection density, block size, density of the built environment, land-use mix, nonmotorized transport, access to public transit, design of the built environment		Buffer (straight line)	1 km	Age, sex, income, marital status, car owner, dog owner, lifestyle habits	PA	Utilitarian destinations, such as grocery stores, restaurants, retail stores and convenience stores, were significant correlates of walking and moderate-intensity physical activities.	Tax assessments and regional council
(87)	C, P	Adults, 608 participants, urbanized areas King County, Washington	United States	Destination mix, distance to closest trail		Buffer (straight line)	3 km	Age, age^2, sex, ethnicity, marital status, health, income, lifestyle habits, car owner	PA	Participants' proximity to trails and land-use mix in neighbourhoods where participants live are associated with increased physical activity.	Business directory, tax assessments

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
(33)	C, P	Older adults, 546 households Portland, Oregon	United States	Distance to nearest park, percentage of high-volume streets, percentage of medium-volume streets, percentage of low-volume streets, percentage of sidewalk coverage, number of intersections, number of routes	Poverty	Buffer (straight line)	0.4 and 0.8 km	Sex, ethnicity, age, education, income, health, lifestyle habits	PA	No association between characteristics of the built environment and the likelihood of walking among older adults.	
(38)	C	Adults, 452 participants El Paso, Texas	United States	Number of physical activity facilities, road distance to closest physical activity facility, slope, land-use, number of intersections, population density		Buffer (network/time)	0.5, 2.5 miles	Socioeconomic status, health, lifestyle habits, number of children	BMI	Significant association between land-use mix and higher BMI.	Aerial photos, census data and Yellow Pages

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
					Food consumption						
(57)	C	Youth, CLAN study (137 children aged 8-9 years and 243 aged 13-15 years) and their parents (322 fathers and 362 mothers) Melbourne	Australia	Availability of fast-food outlets		Buffer (straight line)	2 km	Marital status, sex, education, children's dates of birth, parents' physical activity	BMI	Association between level of geographical accessibility to fast-food outlets and increased risk of obesity or overweight and higher BMI levels among participants.	Telephone directory
(63)	C	Adults, 1 033 participants Minnesota	United States	Restaurant density (restaurants and fast-food outlets)		Buffer (straight line) (residence and place of work)	0.5, 1 and 2 miles	Sex, education, employment status, household size, number of children, number of hours of TV watched, lifestyle habits	BMI and D	Proximity of fast-food restaurants to home or work was not significantly associated with eating at fast-food restaurants or with BMI.	Business directories (SIC)
(64)	C	Adults, United States National	United States	Density of fast-food restaurants, number of fast-food restaurants	Average age of adults	State		Age, sex, ethnicity, lifestyle habits	BMI	Associations between increased density of fast-food restaurants and prevalence of obesity.	Yellow Pages, census data
(58)	C	Adults, 714 054 2002-2006 National	United States	Density of fast-food and full-service restaurants	Education, residential density, median household income	County		Age, age^2, sex, ethnicity, education, smoking status, income	BMI	A higher ratio of fast-food to full-service restaurants is significantly associated with higher BMI and risk of being obese.	Economic census

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
(65)	C, P	Adults, 2 384 residents National	United States	Density of supermarkets		Kernel estimation	1 mile	Age, ethnicity, sex, income	D	Participants who do not have supermarkets near their place of residence were 25% to 46% less likely to have a healthy diet.	Business lists (InfoUSA)
(66)	C	Adults, 10 763 participants in the Atherosclerosis Risk in Communities study Mississippi, North Carolina, Maryland and Minnesota	United States	Availability of grocery stores, availability of convenience stores, availability of full-service restaurants, availability of fast-food restaurants		Census tract		Education, income, age, sex, ethnicity, physical activity.	BMI	Prevalences of obesity and overweight decrease with the presence of supermarkets in neighbourhoods and increase with greater availability of grocery stores and convenience stores.	Business addresses of food stores and food service places from local departments of environmental health and state departments of agriculture (NAICS)
(59)	C	Adults, 12 529 adults aged 15 and over from the New Zealand Health Survey 2002/3, national	New Zealand	Travel distances to closest fast-food outlet (multinational and locally operated)	Deprivation	Meshblock		Education, social class, social programs, employment, income	BMI and D	Positive association between access to fast-food outlets and consumption of vegetables, positive association between access to fast-food restaurants and overweight.	Territorial authorities' directories (inspection, hygiene)

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
(67)	C	Youth, 73 079 youth in grades 8, 10 and 12 from the Monitoring the Future (MTF) Survey, national	United States	Density of supermarkets , density of grocery stores, density of fast-food restaurants, density of non-fast-food restaurants	Per capita income, food price index	Zip codes (school)		Sex, age, ethnicity, education, parents' education, rural/urban, income	BMI	Increased geographical availability of conventional restaurants and supermarkets or grocery stores is associated with lower adolescent BMI and lower prevalence of overweight	D&B business lists (SIC)
(68)	L	Youth, 6 918 children aged 4-5, followed over 3 years, Early Childhood Longitudinal Study, national	United States	Availability of grocery stores and fast-food restaurants, density of convenience stores, density of full-service restaurants		Zip codes		BMI, birth weight, income, sex, mother's education, ethnicity, lifestyle habits	BMI	No association between density of fast-food restaurants, conventional restaurants, convenience stores and grocery stores and changes in BMI among children followed over 3 years.	Census data
(60)	C	Youth, 340 children aged 5-6 and 461 children aged 10-12	Australia	Road distance to the closest food store, availability of food stores (greengrocers, supermarkets, convenience stores, fast-food outlets, restaurants, cafés, takeaways)		Buffer (straight line)	800 m	Language spoken, marital status, employment, mother's education	D	The shorter the distance between home and some food stores (fast-food outlets and convenience stores) the lower the likelihood of children consuming fruit.	Municipality, telephone directory and restaurant guide

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
(61)	C	Adults, 1 001 households Brisbane	Australia	Density of takeaway shops, road distance to the closest takeaway shop, road distance to takeaway shops	Deprivation	Buffer (straight line), census tracts	2.5 km	Not indicated	D	No association between accessibility of takeaway shops and participants purchasing takeaway food.	Municipality
(62)	C	Adults, 7 595 aged 25 to 74 years Rural regions, California	United States	Distance to closest fast-food restaurant and food stores, density of food stores	SES index	Buffer (straight line), census tracts	0.5 mile	Sex, age, ethnicity, SES, smoking, lifestyle habits	BMI	No association between accessibility to food stores and BMI of participants	Census data

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
Food consumption and physical activity											
(51)	C	Youth, 7 020 children aged 3 to 4 years Cincinnati, Ohio	United States	Proximity to playgrounds, proximity to fast-food restaurants	Safety of neighbourhood (crime)	Neighbourhood		Sex, ethnicity	BMI	No significant association between proximity to playgrounds and to fast food restaurants, and risks of overweight	Public health department directory of playgrounds and parks
(35)	C, P	Youth, 2 482 children aged 5-18 in the Child Development Supplement (CDS-II) of the Panel Study of Income Dynamics (PSID), national	United States	Population density, intersection density, crashes involving pedestrians and motor vehicles, urban design, restaurant density, grocery store density, convenience store density		Census tract		Age, sex, ethnicity, income, BMI (mother), education, mean age of parents	BMI	Significant associations between living in a neighbourhood with higher convenience store density, a neighbourhood built after 1969 and higher probability of being overweight.	Census data, Economic census data, TIGER
(25)	C	Adults, 15 358 participants Boston	United States	Retail density, establishment density, presence of a supermarket, density of fast-food outlets, intersection density, population density, employment density	Median household income, % of African-Americans, % of Hispanics, education	Zip codes		Age, education, income, smoking, sex, ethnicity	BMI	Significant associations between obesity risk and population density, employment density, establishment density and presence of a supermarket.	Economic census

Studies	Design	Survey sample and locations	Country	Measures of the built environment	Other contextual measures	Spatial scales	Area	Control variables	Participant measures	Main findings	DB and DB sources
(24)	C	Older adults, 1 221 participants aged 50 to 75 years Portland, OR	United States	Land use mix, density of fast-food outlets, density of intersections, density of public transit stations and stops, area of parks, playgrounds and green spaces	Median household income, % of African-Americans, % of Hispanics, residential density	Neighbourhood		Age, sex, education, ethnicity, employment status, income, home ownership, alcohol use, tobacco use, general health status, lifestyle habits	PA and BMI	Increased neighbourhood land-use mix is associated with a significant reduction in the prevalence of overweight and obesity.	Land-use data and InfoUSA (SIC)
(18)	C	Women, 2 692 women in the WISEWOMAN program of the Centers for Disease Control and Prevention National	United States	Land-use mix, density of fitness facilities, density of grocery stores, density of fast-food outlets, density of restaurants, density of convenience stores	Index of racial segregation, safety (crime), income inequality	Zip codes		Age, ethnicity, education	BMI	Women living in an environment of maximum mixed land use had significantly lower BMI (2.60 kg/m^2) than women living in less mixed environments.	U.S. Geologic Survey of land use (land use mixed index); census data

C: Cross-sectional.
L: Longitudinal.
P: Perceived data.
BMI: Body mass index.
PA: Physical activity.
D: Diet.

APPENDIX 2

CODES FOR RESTAURANTS, GROCERY STORES AND OTHER FOOD OUTLETS

722110 (5811): Full-service restaurants and establishments (without terrace): Establishments that serve seated patrons who pay after eating. These establishments have permits to serve alcoholic beverages and include pubs, cafés and brasseries.

722110 (5812): Full-service restaurants and establishments (with terrace): Establishments that serve seated patrons who pay after eating. These establishments have permits to serve alcoholic beverages and include pubs, cafés and brasseries.

722210 (5813): Limited-service eating places: Establishments that provide food services to patrons who order at a counter or by telephone and pay before eating (e.g. fast-food restaurants).

722210 (5814): Restaurants and establishments that provide food services to patrons who select items at a food bar or cafeteria. Establishments that provide services to clients who serve themselves and pay before eating.

The codes for grocery stores and other food outlets are as follows:

445110 (5411): Supermarkets and other grocery stores (with meat counter)

445110 (5412): Supermarkets and other grocery stores (without meat counter)

445120 (5413): Convenience store (without gasoline sales)

452910 (5320): Warehouse clubs and superstores

447110 (5533): Gasoline stations (with or without service), with convenience store but with no car repair service

445210 (5421): Meat, retail

445220 (5422): Fish and seafood, retail

445230 (5431): Fruit and vegetable, retail

445299 (5432): Public market

445292 (5440): Confectionery and nut, retail

445299 (5450): Milk and other dairy products, retail

445291 (5461): Baked goods (not manufactured), retail: Includes only establishments that produce part or all the merchandise sold on premises.

445291 (5462): Baked goods (not manufactured), retail: Includes only establishments that do not produce the merchandise sold on premises.

446191 (5470): Natural health products and dietary foods, retail

445299 (5491): Poultry and egg, retail

445299 (5492): Coffee, tea, spices and herb, retail

445299 (5493): Beverages and soft drinks, retail

445299 (5499): Other food stores

We could also include retail establishments, discount variety stores (5331, 45299) (e.g. Dollarama) and establishments retailing prescription drugs and other products (5911, 446110) (e.g. pharmacies).

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