The association of perceived and objective built environment features with physical activity, adiposity and blood glucose

by

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Abstract

Physical inactivity, obesity and diabetes are major public health problems and risk factors for cardiovascular disease, a number one cause of death globally. There is growing evidence to link built environment (BE) with physical inactivity, obesity and diabetes. However, published studies mostly focused on the macro-environment; perceived or objective BE measures; and self-reported rather than objectively assessed adiposity. There is also a lack of investigation of metabolic risk factors and lack of consideration for distinct demographic and socio-economic groups. Therefore, the objectives of this study were to explore the associations of both perceived and objective BE measures with distinct domains of physical activity (PA), objectively measured adiposity and fasting blood glucose (FBG); and to investigate the differences in environmental perceptions and the agreement between perceived and objective BE features based on gender, income level and ethnicity. Adults (n=356) between the ages of 35 and 70 years, from high- (median household income >$75,000) and low-income (<$55,000) areas in Vancouver were assessed for socio-demographics, PA (reported), adiposity (measured; body mass index, waist circumference, waist-to-hip ratio, and percentage of body fat), FBG, and environmental perceptions (Neighborhood Environment Walkability Scale). Neighbourhoods, a 500-meter buffer around a participant's home, were directly assessed using the Irvine Minnesota Inventory (122 BE features). The study results indicate that more objective than perceived BE features were associated with PA; and associations were strongest for transportation PA followed with overall walking. Greatest effects were observed for features related to safety from traffic and presence of sidewalks. Associations of BE features with adiposity and FBG were limited. Additionally, environmental perceptions and the agreement between perceived and objective BE measures differed across gender, ethnicity, and income. The results suggest that improving pedestrian infrastructure and increasing safety from traffic may help residents engage more in transport PA and overall walking. Observed differences in BE perceptions may be used to direct the development of public health interventions aimed at increasing awareness about facilities in the neighbourhood whereby special consideration should be given to ethnic minorities and residents from low-income neighbourhoods.

Keywords: built environment; physical activity; obesity; diabetes

To Dragan

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1. Introduction

Physical inactivity, obesity and type 2 diabetes are global public health problems. (1–3) They are also the risk factors for cardiovascular diseases that are the number one cause of death globally. (4) In the past few decades, there has been a rapid global decrease in physical activity (PA), (5) and increases in obesity (6) and diabetes. (7) It has been argued that these rapid changes in the health of populations are due to changes in the lived environments that promote sedentary behaviours and weight gain. (8,9) Lived environments may be both natural and built. While natural environments include landscapes, topography and vegetation, built environments (BE) refer to the human-made or modified environments. (10) The latter ones are the focus of this thesis.

Multiple models have been proposed to depict the complexity of factors influencing PA, (11,12) obesity, (13,14) and diabetes. (15) Common to all the models is the ecological paradigm that recognizes the interwoven relationship between the individual and their environments. (16) However, while ecological theorists believe that geographically defined places predict health and health-related behaviours, compositional theorists argue that social characteristics of people such as education, income or ethnicity have a greater effect on peoples' health than places themselves. (17,18) While acknowledging that the line between contextual and compositional factors is not always as clear, (19) the objective of this thesis was to explore whether the effects of the BE on PA, adiposity and blood glucose are independent of the effects of individual attributes. This thesis is set to explore the following questions: 1) Is the association between perceived and objectively measured BE features and PA independent of individual attributes including age, sex, income, education, and ethnicity? 2) Is the association between perceived and objectively measured BE features and adiposity independent of individual attributes? and 3) Is the association between perceived and objectively measured BE features and blood glucose independent of individual attributes? This thesis also addresses two additional questions: 4) Does the agreement between perceived and objective measures of the BE differ by gender, ethnicity and income? and 5) Are there gender, ethnic and income differences in the way neighbourhood residents perceive the BE?

1.1. Defining and measuring the built environment

The BE refers to the physical form and characteristics of communities. (20) As defined by urban planners, the BE is a multidimensional concept comprising of: 1) *transportation systems* – physical infrastructure of roads, sidewalks and paths that provide connection between activities; 2) *land development patterns* – density and location of various land uses such as residential, commercial, and industrial; and 3) *urban design* – design of the city reflected in the arrangement and appearance of its physical elements (21,22). Others broadened its definition to include: 1) *access to amenities*, such as sports facilities, health services and food shops; 2) *physical features of the environment*, including bike paths, sidewalks, degree of urbanization and green space; 3) *the reputation of the neighbourhood*, reflected in perceived or objectively measured safety (crime figures); 4) *aesthetics* or general attractiveness; and 5) *social support and social capital*, as a reflection of the social organization of the local community (23). In addition, some researchers identified two levels of BE, termed “macro” and “micro” (24). While the “macro” level of the BE encompasses larger-scale walkability features such as residential density, street connectivity and mixed land use, “micro” refers to BE features smaller in scale, including pedestrian/cycling facilities, street-crossing features, incivilities, traffic volume and speed, and crime (24). The “micro” level of the BE is the focus of this thesis.

To date, several BE assessment methods have been identified: *direct* measures, where characteristics of the environment are assessed through in-person audits by trained observers; *intermediate* measures, where BE variables of interest are identified through the assessment of individuals’ perceptions of local environments, or through the use of business telephone listings or aerial photography; and *indirect* measures, where BE features are assessed through data obtained from secondary sources such as censuses, geographic information systems (GIS) or street network maps (25). Similarly, Brownson et al. (26) broke BE measures down into the following three categories: 1) *perceived* (self-reported); 2) *observational* (community audits); and 3) *GIS-based*. This thesis focuses on perceived and observational BE measures.

1.1.1. Perceived built environment measures

Environmental perception has been defined as an "information processing system in which individuals actively explore their surroundings and extract and use information in constant interaction between themselves and their environment" (27). Perceived BE measures assess individuals' perceptions about the place they live. They are collected by self-administered questionnaires or interviews that mostly assess how easily the environment lends itself to PA and healthy diets (28).

Although multiple tools have been developed to measure the perceived BE (26), the most commonly utilized tool is the Neighbourhood Environment Walkability Scale (NEWS) or its abbreviated version (ANEWS), which was designed to explore the relationship between BE characteristics and walking and cycling (29–32). The NEWS assesses perceptions of several environmental characteristics, including: *residential density* – i.e., what types of housing exist in the neighbourhood, including detached single-family residences, multi-user dwellings or apartments; *proximity to nonresidential uses* (land-use mix diversity), such as grocery stores, parks, and restaurants; *ease of access to non-residential uses* (land-use mix access), such as stores, bus stops, and hilliness of the terrain; *street connectivity*, such as presence of cul-de-sacs, walkways, intersections and alternative routes for getting from place to place in the neighbourhood; *walking/cycling facilities*, such as sidewalks, and bicycle or pedestrian trails; *aesthetics*, including presence of trees, attractive sights and buildings, and absence of litter in the neighbourhood; *pedestrian safety from traffic* – i.e., evaluating the volume and speed of traffic, as well as the presence of crosswalks and pedestrian signals for safe roadway crossing; and *safety from crime*, including neighbourhood crime rate and street lighting perceptions (31).

1.1.1.1. Differences in perceiving the built environment

Not all groups perceive their BE in the same way. The evidence, though limited, indicates significant gender, ethnic and socio-economic differences in BE perceptions. It has been argued that the differences in the way men and women perceive their surroundings may stem from women generally having lower PA levels (33) and more barriers to PA compared to men (34). Women tend to be more concerned than men about the sense of personal safety in the area they live (35,36), and they are more likely to report their neighbourhoods as being unsafe for walking (37–40). Compared to men, women are more likely to perceive lower access to places for PA in their neighbourhood (38,41). However, women report greater access to shopping malls, higher neighbourhood aesthetics and lower traffic levels (41), and they are more likely to notice other people being active in the neighbourhood (38). In contrast, men are more likely to perceive greater access to transit, presence of sidewalks, availability of free or low-cost recreation facilities and presence of four-way intersections (39). Furthermore, men report greater access to indoor and outdoor places to exercise, greater park access and greater neighbourhood presence of sidewalks and hills (37). The evidence on gender differences in environmental perceptions is scarce, and available studies have only explored a limited number of perceived BE features. One focused exclusively on access to indoor and outdoor places to exercise (41) without consideration of other BE features such as food stores, bus stops, and retail, whose proximity may positively influence residents' PA levels. Another investigated only a single BE feature, the perceived neighbourhood safety from violence (36). Neither of the studies explored gender-based differences in residents' satisfaction with BE features which potentially may serve as a measure of BE quality in a neighbourhood. Therefore, before developing and implementing any gender-based population health strategies to increase residents' perceptions of available BE features and to increase PA levels, the analysis of a wider range of neighbourhood BE features is needed.

Evidence also indicates that there exist significant ethnic disparities in PA levels (42,43). This may be a contributor to the health inequalities that exist among different ethnic groups (44) and may influence the way individuals of diverse ethnic background perceive their BE. Several research groups have observed significant ethnic differences in environmental perceptions. For example, compared to White, African American and Hispanic residents, American Indian-Alaskan Native individuals were less likely to report the presence of sidewalks and streetlights and to see others exercising in their neighbourhood (45). Furthermore, compared to White individuals, African American residents were more likely to report high crime rates (45) and lower safety from crime in their neighbourhood (44), but were also more likely to report park presence within walking distance of their residence (46). In contrast, White adults were more likely to report light traffic volumes in their neighbourhood and to express trust in their neighbours as compared to African American residents (44). Given the limited evidence on ethnic differences in environmental perceptions, planning for ethnic-based strategies to increase people's perceptions of the availability of neighbourhood BE features may be premature. Available studies only examined a limited number of BE features and did not explore the ethnic differences in neighbourhood satisfaction or in access to various BE features.

Lower-income residents, compared to residents with higher incomes, are also less likely to meet PA recommendations (47). It has been argued that understanding differences in perceptions of neighbourhood features for PA may help address PA and obesity disparities between lower versus higher income groups (48). Evidence has indicated that compared to individuals from high income groups, residents from low income groups are more likely to report their neighbourhood as unattractive and unsafe from crime (41,48,49) and traffic (41,48). In addition, low-income residents are more likely to report the presence of a transit stop within walking distance from their home (48), presence of streetlights and unattended dogs, and less likely to report seeing many people exercising in their neighbourhood (41). At present, studies researching the differences in environmental perceptions between residents of various income levels focused on the limited number of environmental features such as neighbourhood aesthetics and safety (49). Others explored greater numbers of environmental features, but their exclusive focus on a single ethnic group significantly limits the generalizability of the findings (48). More evidence is needed to better understand the impact of income on the way people perceive their physical environment.

Individuals living in areas of lower socio-economic status are less likely to engage in vigorous activity (50) and to meet PA recommendations (51) compared to those living in high socio-economic status areas. Lower PA participation in disadvantaged communities may in part be due to a lower provision of PA services and features, as influenced by the area's socio-economic status. Compared to the least deprived areas, the most deprived areas tend to have a lower density of food retail establishments, public transport links, parks and public sports facilities, higher crime rate

(52), and lower provision of walking and bicycling trails (51). However, even in the objective presence of such features, their use may be affected by residents' perceptions of the presence of the features and other factors such as neighbourhood safety. In fact, it has been reported that, compared to individuals from high socio-economic status areas, people residing in socio-economically deprived areas are more likely to perceive their neighbourhood as being unattractive and unsafe (50,51), as having lower access to public recreation facilities (51) but greater presence of sidewalks (50,51) and more traffic and busy roads present (50). While some evidence indicates that differences in environmental perceptions exist between people living in high and low socio-economic status areas, a greater range of environmental features needs to be examined before estimating the impact of neighbourhood socio-economic status on residents' environmental perceptions.

Given the association between people's neighbourhood perceptions and their PA levels, it is important to research and understand the roles that gender, ethnicity and income play in shaping these perceptions so that interventions for decreasing socio-economic inequalities in PA engagement may be created. Thus far, only a handful of studies have explored demographic and socio-economic differences in environmental perceptions; and most have focused on a limited number of BE variables. This study will, therefore, explore the gender, ethnic and income differences in environmental perceptions more comprehensively to further elucidate relevant perceived environmental measures that may help to improve PA participation inequalities.

1.1.2. Objective built environment measures

Observational measures and GIS-based measures are frequent methods of carrying out objective environmental assessments. The use of either requires adequate training; however, due to the labour and resource intensiveness of BE auditing, the use of GIS technology in health research is more prevalent. The GIS technology refers to a collection of software, hardware and practices that allow for the ability to capture, store, edit, organize, analyze and display spatially-referenced data (53). Some of the advantages of GIS include the ability to handle and quickly manipulate large volumes of data, to complete quick comparisons of data from various sources and different geographical areas, and to quickly explore "what if" questions (54). Furthermore, data can be mapped and analyzed with GIS regardless of the way they were collected (via perceived and/or objective measures) (54). Additionally, the use of GIS-based BE data is currently considered the only feasible method of producing objective BE measures when individuals or geographic units of interest span across large areas (55).

Considering that GIS-based measures are derived from existing data sources, there are multiple challenges associated with the use of these data: the data of interest may not be available from existing sources or are not available for the entire geographic area of interest; the type of information available may be inconsistent across geographical regions; and the time of data collection may not match the timing of the research outcome measures (26,55,56). It is also possible that due to the dynamic nature of the BE, the data available may not be representative of the current availability of features in that environment. Comparing 80 census block groups, a study by Boone et al. (57) found a moderate agreement between the presence of PA facilities as identified through direct observation and those present in a commercial database. Hence, GIS can be a valuable tool for objective environmental assessments, but the most recent databases should ideally be utilized.

In addition to perceived and GIS-based measures, BE characteristics can be assessed through in-person audits of the environment. An audit tool is defined as a "tool used to inventory and assess physical environmental conditions associated with walking and bicycling" (58). A range of audit tools and corresponding protocols have been developed for direct assessment of BE features (58–72). The tools vary along a number of dimensions, such as by level of detail and complexity as well as the level of expertise required to perform the audits (73). The audit tool is commonly a paper document comprised of close-ended questions (e.g. yes/no, Likert scale) assessing multiple BE features such as walking and cycling facilities, features related to safety from traffic and crime, and features related to land use, such as presence and type of housing and retail (26). Trained auditors walk or drive through a geographic area of interest and collect environmental data using the audit tool. The common unit of assessment within the geographic area is a street segment (the distance between two intersections).

The training of auditors, the collection of data from multiple segments within an environment, and the entering and analyzing of data makes direct environmental assessments a laborious and a time-consuming approach. Yet despite this, neighbourhood audits allow for the comprehensive collection of micro-level BE data (e.g., sidewalk assessment, safety, incivilities) that are often not available in existing GIS databases (74). These data can, however, be used in combination with GIS databases to attain more comprehensive information on objectively measured environment features.

1.1.3. Correspondence between perceived and objective environmental measures

There is an ongoing debate in BE literature about which is superior, perceived or objective BE measures (75). While perceived environmental measures reflect residents' attitudes about the BE, objective measures capture a more complete, unbiased picture of the BE (76). It has been recognized that neither perceived nor objective measures are considered a gold standard for evaluating neighbourhood environments (77), and that both measures should be used when exploring the environmental influences on health-related behaviours (74,77–80). Indeed, both types of BE measures were found to be associated with health and health-related behaviours (81–87). Furthermore, it has been shown that the level of disagreement between perceived and objective measures itself can influence health. A recently-published prospective study followed over 1000 adults for four years and found that a greater mismatch between perceived and objective BE measures was significantly associated with decreases in transportation and leisure PA and increases in weight (88). Namely, decreases in PA levels and increases in weight were greater in individuals who misperceived highly walkable neighbourhood features to be less walkable compared to their counterparts whose environmental perceptions matched the objective measures (88). These negative changes in residents' PA and weight can most likely be attributed to poor utilization of misperceived but available BE features. The authors concluded that interventions that improve the agreement between perceived and objective BE measures may help reduce the decline in adult PA levels and assist with their weight maintenance (88).

Only a few studies have investigated the concordance between perceived and objective BE measures in which low to modest agreement was detected (74,75,77–80,88–98). Some researchers have postulated that the low level of agreement between BE measures suggests that perceived and objective features influence health-related behaviours through different mechanisms (95). Others have argued that perceived and objective environmental measures assessed in the studies captured different constructs/dimensions of the environment (77–80,89,96), and that levels of agreement are likely to be higher when both measures assess the same construct (32,80). However, while adequate perceived/objective matches are available for some features (e.g. presence or absence of grocery stores, parks, and bus stops), finding an equivalent objective measure for perceived measures such as aesthetics, and safety from crime and traffic still remains a challenge (90).

One explanation for this low agreement between perceived and objective BE measures is that people vary in their level of PA and their preferred modes of transportation (90). Consequently, residents who walk and/or use public transportation within their neighbourhood will be more aware of neighbourhood features compared to people who predominantly travel by car (99). Similarly, residents tend to be more aware of features that they have an interest in (97); people who exercise in fitness facilities, for example, are more likely to be aware of such facilities than people who do not use them (99). In light of this, some have argued that achieving a match between perceived and objective measures is important, given that people are less likely to use resources they are not aware of (75).

Another potential explanation for low agreement between perceived and objective BE measures is that there exists a difference between residents' notions of neighbourhood boundaries and the way boundaries are defined by researchers (93). It has been shown that residents with higher levels of formal education, family income, numbers of friends or relatives living in their neighbourhood, and those with more participation in different civic activities, were more likely to view their neighbourhood as being larger (100). Alternately, neighbourhoods are seen as smaller for recent immigrants (100), women, children, and long-term residents (101), as are neighbourhoods that are poorer and contain a larger proportion of minority language-speakers (100).

Quantifying the agreement between perceived and objective environmental measures will help to further define the relationship between the two (91). In most cases, agreements have been quantified for only a limited number of environmental features

(74,75,78–80,88,89,91,96,98), and sometimes for only a single type of feature, such as recreational facilities (92,93,99). Given that perceived measures are more likely to be influenced by gender, household income and culture (90,99), it is also important to explore whether the agreement between perceived and objective measures differs across these demographic and socio-economic categories. Given that the level of agreement between perceived and objective measures has been shown to influence health (88), discovering which groups of residents show more pronounced disagreement in measures would potentially lead to health promotion strategies that target such groups. Taking the above knowledge gaps into account, one of the aims of this research project was to explore the agreement between several matched perceived and objective environmental measures, as well to investigate whether the agreement between the measures differs across gender, neighbourhood and individual income, and ethnicity.

1.2. The neighbourhood concept

While there is no single definition of neighbourhood, many scholars have conceptualized neighbourhoods either from entirely ecological perspectives or by integrating ecological and social perspectives (102). Some defined a neighbourhood as an "area one can easily walk over" (103), or they looked at it as "a physical or geographical entity with specific (subjective) boundaries" (104). Others emphasized the importance of a social component, defining neighbourhoods as follows: a "limited territory within a larger urban area, where people inhabit dwellings and interact socially" (105); a "social organization of a population residing in a geographically proximate locale" (106); or a "small residential area primarily consisting of residences and the social interactions between individuals within these residences" (107). Some put forth that ethnic homogeneity, physical barriers and economic characteristics are all important in the process of establishing neighbourhood boundaries (108). In more recent years, residents and policy makers have commonly seen neighbourhoods as "meaningful congregations of people with common interests" (109). A large number of other definitions of neighbourhood exist in the literature and show that this is a complex structure that encompasses physical as well as social dimensions.

There has been an increased interest since the early 1980s in the relationship between neighbourhood and health, but conceptualization of “neighbourhood” emerged more than a half a century before that. In 1915, sociologist Robert Park recognized that neighbourhoods are the smallest but fundamental social and political units within a city (110). He emphasized the importance of investigating neighbourhoods, as they can reveal a lot about human behaviour and nature. A decade later, Robert Park, along with sociologist Ernest Burgess, proposed the *Concentric zone theory* that was among the first models to explain the spatial organization of cities (111). According to the *Concentric zone theory* model, cities are composed of five concentric ring zones surrounding a central area. Starting from the innermost circle, the zones go as follows: 1) central business district; 2) zone in transition; 3) working class zone; 4) residential zone; and 5) commuter zone. Within each zone, groups that share similar social status occupy certain communities that Park and Burgess defined as “natural areas” (112). “Natural areas” were established as a result of competition between different socio-economic groups for urban resources and land. With increasing prosperity, people would move from inner toward outer zones in a process Burgess and Park called *succession*.

Sociologist Gerald Suttles (113) expanded upon the work of Robert Park and Ernest Burgess by conceptualizing the neighbourhood as a unit containing multiple levels of organization. Within the proposed multilayered unit, Suttles identifies four unique scales: 1) face block, 2) defended neighbourhood, 3) community of limited liability, and 4) expanded community of limited liability. A *face-block*, a social unit for both children and adults, is the smallest area. Adults often have a clear representation of the boundaries that mark their face-block, and within those, they share local facilities and residential environments with their neighbours. By constantly crossing pathways, residents continuously strengthen and extend their social networks. For children, a face block is an artificially formed social unit that originates mainly from parents’ needs to keep an eye on and protect their children from the outside world. A *defended neighbourhood,* however, is the smallest geographical unit where people feel relatively secure as compared to adjacent areas. In some low-income areas where distrust is pronounced, a defended neighbourhood may be limited to the residents of a single building or a face-block. Normally, however, the defended neighborhood includes a range of establishments (such as grocery shop, coffee shop, church, liquor store, etc.), and it is a spatial unit where people's daily activities take place.

A c*ommunity of limited liability* is a geographical unit larger than a defended neighbourhood and whose boundaries are created and preserved by various large-scale organizations and community press. Boundaries created by one organization do not necessarily correspond to the community-of-limited-liability boundaries established by another organization. Oftentimes, a mosaic of overlapping boundaries exists, where residents tend to live in more than one community of limited liability. Participation in the community of limited liability is voluntary and is driven by residents' interests (politics, community organizations, housing standards, pollution, etc.). In addition, an *expanded community of limited liability* is the highest geographical scale of a neighbourhood that often includes entire sectors of a city. Boundaries of such large constituents may be established and claimed by government organizations, large commercial firms, and community groups.

Kearns and Parkinson (114) adapted Suttles's definition of neighbourhood, supporting the notion of the multilayered phenomenon and outlining three levels of neighbourhood: home area, locality, and urban district. *Home area* refers to an area of 5-10 minute-walk from one's home. Some of the main functions of the "home area" are to foster attachment and belonging and establish connections with others. The main benefits achieved at this level are psycho-social in nature. *Locality* is an area larger than the "home area" where everyday residential activities take place. Localities could be culturally- and regionally-specific and reflect one's social status and position. *Urban district or region* is the largest area viewed as a landscape of social and economic opportunities. Engagement of people within this level mostly depends on their employment connections, leisure interests and the extent of their social networks.

In addressing its complexity, Galster (102) conceptualizes the neighbourhood as a "bundle of spatially based attributes associated with clusters of residences, sometimes in conjunction with other land uses." He perceives neighbourhood as a multidimensional bundle comprising the following attributes/characteristics: 1) structural characteristics of residential and non-residential buildings such as type, design, state of repair, and density; 2) infrastructural qualities such as roads, sidewalks, and utility services; 3) resident demographics such as age, ethnicity, race, and family composition; 4) resident class status characteristics such as income, occupation and education; 5) tax/public service package characteristics (quality and safety of public schools, parks and recreation) in relation to the local taxes assessed; 6) environmental characteristics such as pollution and topography; 7) proximity characteristics such as access to retail, entertainment and employment, influenced by distance and transport infrastructure; 8) political sphere, influence of local political networks; 9) interactive opportunities such as social networking and volunteering; and 10) sentimental characteristics such as a person's sense of identification with and attachment to the neighbourhood, and their sense of the historical significance of its buildings (102). Although many of the above outlined attributes are present in every neighbourhood, the extent and composition of each attribute varies across neighbourhoods. Such diversity allows for neighbourhood categorization and cross-neighbourhood comparisons (102).

As in sociology, the meaning of neighbourhood in architectural and planning theory also transformed over time, having first been theorized by the humanistic approach, then by the instrumental approach, and subsequently by the phenomenological approach (115). According to the *humanistic* approach, a neighbourhood is defined by the characteristics of the people residing in it. The neighbourhood is considered a physical setting created to provide for the most fundamental human needs, such as the need for association, social bonds and a sense of community. The main goal of planners using the humanistic approach is to relate to these collective needs by creating suitable environments. The *instrumental* approach, on the other hand, conceptualizes the neighbourhood as a planning device where neighbourhoods are perceived as structural units and serve as building blocks for more complex urban systems such as a city. Finally, the *phenomenological* approach views the neighbourhood as a unique urban phenomenon and a cultural, rather than a social, construction originating from a deep and sustained relationship between people and the place they live in. According to this approach, planners, when designing neighbourhoods, should take into account residents' experiences, knowledge and awareness of the place they inhabit.

The geography of street patterns is another approach to defining neighbourhoods. Using this approach, neighbourhoods are defined as "tertiary communities” in which each residence can be reached from every other residence by “tertiary streets” (streets with two undivided traffic lanes) (116). Basically, a “tertiary community” is an aggregation of street blocks in which residents can walk without having to cross over a major road or a highway. In comparison to neighbourhoods defined by census tracts or block groups, living in “tertiary communities” enables greater social interactions among residents, thereby extending their social network (116). It was noted that small residential streets are the basic unit of “tertiary communities”, as communities rise from pedestrian streets (117). People use small residential streets to complete their daily routines such as buying newspapers, food, going to the bank or coffee shop.

There is an ongoing challenge in BE research on how to define the boundaries of neighbourhoods whose features will be studied (118). Commonly, administratively established units, such as census tracts and postal codes, are used to represent neighbourhoods (52,119–122), mostly because the data for these units (e.g., socio-demographics, crime data) are readily available and are convenient to use. However, it has been argued that these administratively established units may not be able to “capture a sociologically meaningful neighbourhood” (107), nor are they likely to correspond to what people perceive as boundaries of their neighbourhood (123). On the other hand, defining neighbourhoods based on residents’ input may pose a challenge given that even people living close to each other may define their neighbourhoods differently (124). Since it was demonstrated that residents tend to perceive their neighbourhoods as territorially smaller units (101), there has been a recent shift from administratively defined units to assessing smaller geographic areas in BE research studies. The common approach in such research consists of creating a radius around each participant’s residence, work place or school. There is still, however, a lack of agreement on which range of distances best represent a neighbourhood. Some researchers use radial distances of 300m and 500m, 400m, 1km, 0.5 miles, or 1500m (125–132), while others utilized street/road network distance from a person’s work place, household or their postal code when defining the neighbourhood (133–139). Given the above, it is evident that there are no consistent spatial definitions of neighbourhood, and it has been suggested that researchers should define them in the way that best fits their research hypothesis (107).

1.3. The built environment and physical activity

Note: BE studies cited in sections 1.3., 1.4., and 1.5. are cross-sectional if not stated otherwise.

Physical activity is any bodily movement produced by the skeletal muscles that results in an expenditure of energy (140). As summarized by many, a substantial amount of evidence has identified the benefits of PA. It has been reported that PA reduces incidence of, and mortality from, cardiovascular disease, type 2 diabetes and some forms of cancer such as colon and breast cancers; it reduces rates of fall incidences, helps in the treatment of patients with sleep disorders, and contributes positively to a general sense of well-being and a positive frame of mind (141–144). Despite known benefits of PA, 31% of adults globally are insufficiently active; the prevalence of inactivity increases with the level of country income, being much higher in upper middle income and high income countries (more than 40% of population) than in the lower income countries (33,145). Moreover, it has been estimated that physical inactivity is the cause of 6 to 10 percent of the major non-communicable diseases, such as type 2 diabetes mellitus, coronary heart disease, and breast and colon cancers, and of 9 percent of premature mortality (142). In Canada in 2011 (based on reported PA data), 54% of the Canadian population was considered moderately active or active, with men being more active than women (56% vs. 51%) (146). These data suggest that almost half of the Canadian population is insufficiently active. However, data based on objectively measured PA reveal that 85% of Canadian adults do not meet Canada's PA recommendations (147). Based on the accelerometer data, only 15% of Canadian adults accumulate 150 minutes of moderate-to-vigorous PA per week in 10-minute bouts; while only 5% accumulate the same amount in at least 30 minutes of MVPA on 5 or more days per week (147). Furthermore, based on pedometer data, only 35% of Canadian adults achieve a target of 10,000 steps per day (147). Moreover, Canadian men and women are sedentary for about 9.5 hours per day (147). In addition, the economic burden attributed to physical inactivity is large; it was estimated at $5.3 billion ($1.6 billion in direct and $3.7 billion in indirect costs), or 2.6% of the total Canadian health care costs (148).

The energy cost of PA is often quantified by metabolic equivalents (METs). One MET is defined as energy expenditure at rest (when sitting quietly) and approximates 3.5mL of oxygen uptake per kilogram of body weight per minute (1.2kcal/min for a 70-kg individual) (149). Physical activities can be performed at various intensities ranging from light or low intensity (less than 3 METs; stretching, light household activities such as food preparation, cooking and ironing), moderate (3-6 METs; brisk walking, cycling for leisure of less than 10 miles per hour) to vigorous (more than 6 METs; cycling, aerobic dancing) (150,151). According to the Canadian PA guidelines, adults (including older adults) should accumulate at least 150 minutes of moderate-to vigorous-intensity aerobic PA per week, in bouts of 10 minutes or more (152). Using METs as an indicator of activity of intensity, the guideline of at least 150 minutes of moderate-to vigorous-intensity aerobic PA per week is equivalent to accumulating a minimum of between 450 to 750 MET*minutes per week of combined moderate and vigorous PA (153). Individuals who do not accumulate recommended levels of moderate-to vigorous-intensity aerobic PA per week are considered physically inactive (154). In addition, individuals who engage in an activity that is characterized by an energy expenditure of less than or equal to 1.5 METs while in sitting or reclining posture are considered sedentary (154); however, sedentary behaviour is not a focus of this thesis.

One of the most common forms of PA is walking. It is an inexpensive, lifelong activity that is easily adopted by different age groups and can be performed both indoors and outdoors; and it requires no additional skills or equipment (155). It appears to be an acceptable and accessible activity for low-income individuals, unemployed and obese (156). Walking is a popular PA among Canadian adults, and it is more prevalent among women, older adults, those with lower BMI and among Canadians in higher-income groups (157). Although Canadian women, older adults, and those in lower income groups were found to have lower levels of leisure PA (158), the results of the study of Bryan et al. indicate that women, older adults, individuals with higher BMI and those in lower income groups often derive 100% of their leisure-time PA energy expenditure from walking (157). Cross-sectionally, greater walking intensity was found to be associated with a lower prevalence of hypertension, hypercholesterolemia and type 2 diabetes (159). Furthermore, the results of a recent longitudinal study indicate that a slower walking pace predicts greater all-cause mortality and the risk of death attributed to cardiovascular disease, diabetes, nervous system diseases and dementia (160).

Depending on the purpose, there are several different domains of PA: occupational (work-related), household-related, transportation and leisure (recreational) PA (161). Out of these four, this study focuses on transportation and leisure PA. Transportation PA refers to walking and cycling for utilitarian purposes, and some of the terms often used to describe transportation PA include: non-motorized transport, human powered transport, and active transport (162). An example of transportation PA would be walking from home to school or cycling from home to work. Leisure PA, such as walking in the park or playing badminton, refers to the activities “undertaken for discretionary reasons in someone’s leisure time” (20). Therefore, leisure PA refers to activities individuals engage in for pleasure.

Due to the high prevalence of insufficient PA worldwide (145), its negative impact on health and wellbeing, and its contribution to a worldwide epidemic of non-communicable diseases (33,142), physical inactivity has been regarded as a public health crisis (162) and increases in physical activity a global public health priority (163). It is, therefore, imperative that we continue promoting the benefits of PA and work on strategies that will increase population PA levels while making it an important part of people’s everyday living.

The main approach for a long time was to advise individuals to increase personal PA levels (164), but it has since been recognized that, rather than targeting individuals or small groups, PA interventions should be aimed at large groups of people or populations so as to bring about a ‘population wide-change’ (165). Moreover, involving multiple communities, as opposed to solely focusing on individual-based programs and interventions, may lead to a sustainable increase in PA (166). In addition, it has been argued that one of ways to increase PA at the population level is by restructuring the environments in which PA takes place (164,167).

Based on Brofenbrenner’s Ecological Systems Theory (Human Ecology Theory) that states that human development is influenced by the distinct types of environmental systems, ecological models have been proposed to allow for better understanding of multiple factors that influence PA participation. In the Ecological Model of PA proposed by Spence and Lee, PA participation is influenced by the complex interplay of intra-individual and extra-individual factors (11). Intra-individual factors include biologic and genetic factors (e.g., body composition, physical fitness, heritability) and psychological factors (e.g., attitudes, self-efficacy); while extra-individual factors depict environmental influences on PA participation. Starting from most proximal to most distal levels in the model, environmental levels include *microsystem* (social and physical characteristics of immediate setting within which people interact), *mesosystem* (contains the microsystem and focuses on connections and processes between microsystems), *exosystem* (encompasses micro- and mesosystems whereby PA participation of the individual is influenced indirectly i.e. without person's presence), and *macrosystem* (larger sociocultural context that encompasses all previous levels). Furthermore, according to the model, PA behaviour can be influenced by *pressure for macrosystem change* (e.g., urbanization, modernization) and *physical ecology* (e.g., climate, air pollution) constructs while exerting their influences through the macrosystem. In addition, the *physical ecology* construct may influence a person's PA behaviour through direct influence on biological and psychological factors (11).

When exploring the relationship between the environment and PA, it has been argued that it is important to explore the type of PA, and especially to contrast leisure and transportation PA (168). Trends of these PA domains differ over time (169–172) which justifies the need for exploring the environmental influences on separate PA domains (12). Sallis et al. proposed an ecological model that is built around four domains of active living (active recreation, active transport, household activities, and occupational activities) while emphasizing multiple levels of influences on each of the domains (12). According to the proposed model, and going from the most proximal to most distal level, PA is influenced by intrapersonal characteristics (e.g., demographics, biological and psychological factors), perceived environment, behaviour settings (e.g. neighbourhood, recreation, home, school and work environment (PA domain specific)), and policy environment; while the social and cultural environment cuts across all other levels. In addition, the natural environment (e.g., weather, topography, and air quality) and information environment (e.g., news, advertising, and counselling in health care settings) variables in the model cut across behaviour setting and policy environment levels (12).

The above mentioned ecological models of PA reflect the complex relationships and dynamic interplay between PA and multiple levels of factors influencing it. It has been argued, however, that complexity of and over-inclusiveness of variables in ecological models of PA may limit the model's utility as a basis for research (what variables to study?) and intervention (where, when and how policy makers should intervene?) (173). While using the model of Sallis et al. as a basis for researching environmental influences on PA domains, and acknowledging the importance of all the potential influences and levels of influences on PA outlined in ecological models of PA and their dynamic interplay, the first objective of this thesis focuses on exploring the association of perceived and objectively measured BE features and distinct types of PA, while taking into account the confounding effect of individual level variables and neighbourhood income (Figure 1).

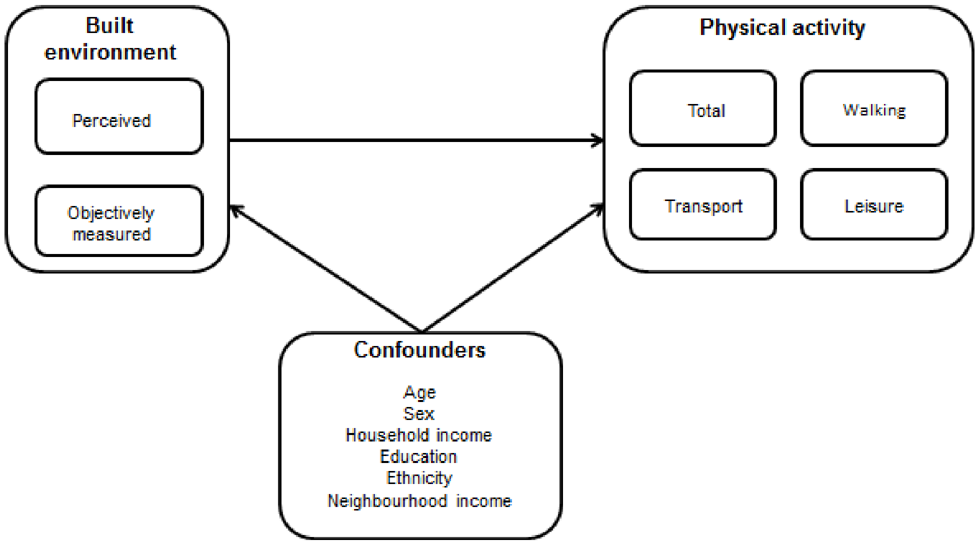

Figure 1. Conceptual diagram of the association between the BE and PA

1.3.1. The built environment and physical activity – review of the literature

1.3.1.1. The association between perceived built environment features and physical activity

Researchers reviewing the literature on the association between PA and BE in adults have reported consistent associations between perceived as well as objective BE characteristics and different PA domains (30,166,174–190). Citing primary studies, higher levels of overall PA were observed among adults who reported living in neighbourhoods with greater land use mix diversity (191), walkability (192), greater access and/or presence of shops, stores and services (193–197), number of places to go within walking distance (192,198–200), and with a greater presence of bus stops (195) and 4-way intersections (199). Higher levels of overall PA have also been noted among adults who reported working at a place that is in close proximity to their home (198), as was living in neighbourhoods that are aesthetically pleasing (41,193,196,200,201), hilly (41,198,202), contain lots of greenery (203,204), and have many interesting things to look at (199). Furthermore, reports of feeling safe from crime (46,196,205), the presence of street lights (125,202), and less litter (203) were also associated with higher levels of overall PA.

With regard to perceived access to places for PA, higher levels of PA have been observed among adults who reported a greater presence and/or access to places (206,207) such as free or low cost recreational facilities (195,197), leisure facilities (23,205), golf courses, public parks, skating rinks, swimming pools and tennis courts. (202) Similar results were observed for those who reported good active transportation infrastructure in their neighbourhoods, including sidewalks (41,195,197), walking, hiking or biking trails (194,198,201,202,207), and cycling facilities (195). In addition, reported use of certain BE features for PA such as recreation centres (125,200), schools and health clubs (200) were found to be associated with greater levels of overall PA in adults. However, a recent Canadian study found no association between perceived access to facilities for PA and individuals' PA (208).

Many research groups have focused on the association between perceived BE features and specific domains of PA such as walking, transportation PA or leisure PA. Isolating walking as an activity, more walking has been observed among people who reported greater land use mix diversity in their neighbourhood (120,209) and greater access to shops and services (37,39,120,194,197,210,211), recreational facilities (120,197,210) and public transportation (39,209,210). Furthermore, overall walking among neighbourhood residents was higher if they reported greater neighbourhood aesthetics (39,81,120,210–215), greater safety from crime (37,210,216) and traffic (212,216,217), and more sidewalks (125,197,201,209), walking/cycling facilities (81) and trails (192). In addition, the results of a recent qualitative study from Edmonton, Canada indicate that neighbourhood walking path connectivity and quality, and greater social interactions with neighbours, may positively influence residents' walking and PA, while traffic safety was perceived as a barrier to being active (218).

Three recent studies explored whether the association between perceived BE features and PA is consistent across countries. In the study that examined the inter-country differences in the association between perceived BE features (residential density, shops near home, transit stops, sidewalks, bicycle facilities, recreation facilities, safety from crime) and perceived PA (meeting PA recommendations), the associations were similar for having shops near home and presence of sidewalks BE features, while the associations for the rest of the tested BE features varied across countries. (219) However, two other studies found similar associations of perceived BE features (in both studies: residential density, land use mix-access, street connectivity, pedestrian infrastructure and safety, aesthetics, traffic and crime safety, few cul-de-sacs, no major barriers to walking; land use mix diversity only in Cerin et al; (220) proximity to parks only in Sugiyama et al. (221)) with reported recreation walking and accelerometer-measured PA across countries (220,221).

Moving towards the causal relationships between the BE and walking, Handy et al. (211) conducted a quasi-longitudinal study that examined the association between changes in the BE and changes in walking among neighbourhood residents who had moved to the neighbourhood within the last year and those who lived in the same neighbourhood in the past year. The results indicate that changes in perceived neighbourhood access to shops and services, PA options, safety and socializing had a positive impact on walking change (211). Moreover, a prospective study of Humpel et al. (215) assessed the associations between changes in adults' environmental perceptions and changes in their walking behaviour after a 10-week long PA intervention trial. Men who increased their perceptions of aesthetics and neighbourhood convenience for walking were about 2 times more likely to have increased walking more than 30 minutes per week compared with their counterparts who reported a decrease or no change in environmental perceptions. Similar to men, positive changes in perceived neighbourhood convenience to walking was associated with increased walking among women. However, changes in perceptions of traffic safety by perceiving it to be less of a problem when walking in the neighbourhood resulted in men being less and women being more likely to increase their walking in or around the neighbourhood (215).

With regard to other PA domains, positive associations of perceived BE features and transportation PA were found for perceived land use mix diversity (133,191,222,223) and access, the presence of many walkable destinations in the neighbourhood (78,127), access to shops, stores and services (120,193,224,225), and public transportation. (127,222,225) Perceiving more alternative routes to get to places (226), less cul-de-sacs (222), greater access to exercise facilities (120), more walking and cycling facilities (222,223), and more bike lanes (127) was also found to be associated with greater transportation PA. Higher levels of transportation PA have also been observed among neighbourhood residents who reported greater neighbourhood aesthetics (120,193,222,227), more street lighting (225,226), and greater neighbourhood safety

(228). Similarly, BE features related to neighbourhood land use mix and access and diversity (191,225,229), PA infrastructure (81,127,191,212,227,230), aesthetics (50,81,120,212,226,229,231,232), crime (225) and traffic safety (81,233) have shown positive associations with leisure PA. Moreover, supportive social neighbourhood environments were found to positively influence overall PA (44,125,193,199,201,202), overall walking (44,50,120,125,210,211), transport PA (120,226), and leisure PA (50,120,212,226,228,229). In addition, the results of a recent Canadian study indicate a significant positive association of perceived access to services, street connectivity, motor vehicle traffic safety and recreation destination mix with walking for transportation, while greater perceived neighbourhood aesthetics was found to be associated with higher participation in walking for leisure among Calgary residents (234).

In a longitudinal study that explored the association between perceptions of the local neighbourhood at baseline and changes in walking for leisure and transport after two years of follow-up, supportive social environment and greater satisfaction with the quality of sports venues in the neighbourhood were associated with increase in both types of walking among mothers who were participants of the Children Living in Active Neighbourhoods (CLAN) study (226). Furthermore, higher levels of leisure walking at the two-year follow-up were observed among mothers who reported greater neighbourhood aesthetics and street connectivity at baseline, while higher levels of walking for transportation were noted among mothers who reported streets in the neighbourhood being well lit at night, greater street connectivity and neighbourhood road safety (226).

1.3.1.2. The association between the objective built environment features and physical activity

As for objectively-measured BE features, the ways they relate to PA have been the recent focus of multiple research studies. Greater overall PA has been observed among adults living in highly walkable neighbourhoods, as measured by the walkability index (235–237) and among people from neighbourhoods with high land use mix (135), greater street connectivity (135,238,239), transit stop density (239), recreational resource density (240), more green and open spaces (239), and lower risk from traffic as measured by the number of traffic violation incidents per neighbourhood population. (208) Walking levels were also higher among adults living in neighbourhoods that are more walkable (134,241), with greater street connectivity (216,242), dwelling density

(216,242,243), and greater accessibility (242) and density of destinations (244). Higher levels of walking were also observed among adults living in neighbourhoods that are hilly, (132) that have greater access to green and open space (50) and those with a greater number of facilities for walking (245).

Higher objectively-measured neighbourhood walkability, aside from its positive association with overall PA and walking, was also shown to be associated with greater levels of both transport PA (122,235,236,246–248) and leisure PA (122). Similarly, greater land use mix in the neighbourhood was associated with greater levels of both transport PA (130,239,249) and leisure PA (239,242,250). Moreover, transport PA was also found to be higher among adults who lived in neighbourhoods with greater residential density (249,251), street connectivity (239,242,249,251,252), road density(133), and greater bus/transit stop presence (127,198,239,253,254). Aside from its association with neighbourhood walkability and land use mix, leisure PA was found to be positively associated with the presence of trees (230), parks (217,230), green and open spaces (239), access to beaches (50), density of gym facilities (82) and negatively with traffic speed and volume (78). In addition, as a measure of the social environment, the number of people engaging in active behaviours has been found to be positively associated with overall PA (255) and transport PA (127).

Several Canadian studies explored the association between the objectively measured BE features and PA. In Calgary, residents from highly walkable neighbourhoods engaged in more neighbourhood-based PA compared to their counterparts from less walkable neighbourhoods (256). In Edmonton, higher access to sports fields was associated with greater odds of being physically active as recommended (208). In Montreal, greater density of destinations was associated with greater odds of total walking; while no BE features (density of destinations, activity friendliness, and safety) were associated with walking for recreation (244). In Ottawa, only park area was positively associated with leisure PA among women, while the rest of the researched BE features (number of indoor, summer and winter recreation facilities, park area, green space area, number of grocery stores, convenience stores, fast food outlets, restaurants and specialty stores (all per 1000 people); and total length of bike and walking paths) were not associated with leisure PA among women. Furthermore, no association was found between BE features and leisure PA in men (257). In Vancouver, living in areas with lower recreational and park land, commercial and institutional land as well as lower land use mix was associated with greater odds of low levels of walking for errands (less than one hour per week) (250). Furthermore, while there was no association between land use and walking to work/school and moderate PA, living in areas with lower land use mix and institutional land was associated with lower levels of leisure walking (15 minutes or less per day) (250).

In the study of Lee et al. (258) the association between objectively measured sprawl and PA was assessed both cross-sectionally and longitudinally (5-year follow-up). While a negative association was noted between sprawl and PA in cross-sectional analyses, no significant change in PA was observed among men (mean age: 70 years) who moved to a more or to a less sprawling area. Moreover, the results of a recent Canadian study indicate that closer proximity to local services and amenities is associated with greater likelihood of frequent walking at all times throughout three years among Quebec seniors (259).

In summary, perceived BE measures and the way they relate to adult PA have been an exclusive focus of many research groups (23,37,39,41,44,46,81,120,125,191,192,194,195,197,199–202,204–207,209,210,212–215,222–224,226–231,260–271). Some exclusively looked at the association between objectively-measured BE features and adult PA (29,52,70,82,121,122,126,128,130,132,134,135,235–242,244,246–249,251,253,254,272–285), but of these studies, seven collected information on BE features through direct assessment (74,242,244,272,273,281,282) leaving limited research on "micro"- environmental impact on adult PA. What is more, out of studies that have investigated both perceived and objective BE influences on PA (50,74,78,127,133,193,198,208,211,216,217,225,232,233,243,245,255,286–289), many have focused on a limited number of BE features (74,78,208,217,233,255,287,289). Therefore, the objective of this study was to explore the association between BE and PA while looking at the range of both perceived and directly-assessed BE features. Additionally, while a majority of research groups explored associations of BE features with total PA (23,29,41,44,46,125,128,135,191–208,213,224,232,235,237–240,255,260,264–266,268,269,271,274,281,282) and walking (23,29,37,39,44,74,81,91,120,125,126,132,134,192,194,197,198,201,209–217,238,241–

245,263,277,279,281,282,288,290), research on the relationship of BE features with specific types of PA such as transportation PA (91,127,133,224,227,231,242,246,262) and leisure PA (52,82,91,127,191,211,212,217,227,228,230,231,233,242,257,261,275,283) is still limited. Given that BE features tend to be specific to distinct PA domains (181), this study will explore the association of BE with total PA, transportation PA, leisure PA as well as walking.

1.4. The built environment and obesity

Obesity is considered one of the biggest public health challenges facing both children and adults (291). Results of a recent literature review and meta-analysis of prospective cohort studies indicate a significant relationship between obesity and incidence of multiple comorbidities including type 2 diabetes, cardiovascular diseases (hypertension, stroke, coronary artery disease), cancer (breast, colorectal, endometrial, kidney and ovarian), asthma, pulmonary embolism, osteoarthritis, chronic back pain, and gallbladder disease (292). Body mass index (BMI), calculated as weight in kilograms divided by height in metres squared, is an established measure for classifying and defining weight categories that further evaluates health risk associated with each of weight categories: underweight, BMI <18.5 kg/m^2 (increased risk of developing health problems), 18.5-24.9 kg/m^2 normal weight (least risk); overweight, BMI = 25.0-29.9 kg/m^2 (increased risk); and obesity, BMI of 30 kg/m^2 and higher (high risk). (293) In Canada in 2012, based on self-reported height and weight, about 40% of men and 27% of women were overweight and 18.4% of adults were classified as obese (294). Though the percentage of Canadians in the ‘overweight’ category is the same compared to 2003 values, obesity numbers have increased since 2003 from 16% to 19% in men and from 14.5% to 18% in women (294). Taken together, about 60% of Canadian men (7.7 million) and 45% of Canadian women (5.8 million) are at increased health risk due to carrying excess weight (294); and in fact, rates are likely to be higher than these estimates, since self-reporting of height and weight measures is susceptible to bias (295). Indeed, according to the results of the Canadian Health Measures Survey, the prevalence of obesity among adults assessed in 2007 to 2009 was 24.1% (296) which is already significantly higher from obesity prevalence of 18.1% based on self-reported height and weight. With overweight and obesity come greater health risks as well as a greater economic burden to health care. From 2000 to 2008, there was an increase in both direct (from 1.55% to 1.98%) and indirect (from 2.33% to 2.63%) costs to the health care system that was attributable to obesity, whereby the annual economic burden of obesity increased from $3.9 to $4.6 billion (297). Decreasing the prevalence of obesity may help prevent and/or curb non-communicable diseases, decrease health care costs and improve overall health and well-being.

As stated above, BMI is an established tool for defining obesity in clinical practice. It is a simple, standardized, non-invasive and inexpensive tool; however, BMI is also an indirect and imperfect measure of body fat, as it cannot delineate between excessive weight due to bone, lean muscle, or fat mass (298). There is also an assumption that weight is evenly distributed throughout the body (299), thereby disregarding heterogeneity in body fat distribution that plays an important role in obesity-related health risk (300,301).

French physician Jean Vague was among the first to observe that the association between obesity-related health complications and regional distribution of body fat was stronger than that with overall obesity (302). He also noted the differences in the way men and women accumulate body fat, whereby men tend to accumulate adipose tissue in the trunk area (*android* obesity), while premenopausal women are more likely to accumulate adipose tissue in the thighs and hips (*gynoid* obesity). Anthropometric measures commonly used as indirect measures of body fat distribution include measurement of waist circumference (WC), waist-to-hip-ratio (WHR) and skinfold thickness. Waist circumference is an indirect measure of central obesity, and, after BMI, the second most commonly used anthropometric measurement in clinical and research practice. It has been shown that for a given BMI category, individuals with higher WC are at greater health risk compared to their counterparts with lower WC (303). Although WC is one of the key criteria for defining metabolic syndrome (304) and part of the Canadian clinical practice guidelines algorithm for the assessment of obesity (305), WC is not routinely measured in clinical practice. Indeed, only 6% of Canadian primary care physicians are reported to routinely measure WC in clinical practice (306). It has been argued that this low adoption of measuring WC among physicians may be due to lack of a standardized protocol for WC measurement, physicians’ belief that WC is a tool used mostly for research purposes, and lack of effort to continuously inform physicians about the clinical usefulness of routine WC measurement (307). Waist-to hip ratio and skinfold thickness, as indirect measures of body fat distribution, are measured mostly in epidemiologic studies.

The results of multiple longitudinal studies indicate a significant relationship between abdominal adipose tissue deposition (measured by anthropometry) and the development of coronary heart disease (308,309) and diabetes (310); increased risk of myocardial infarction, stroke and mortality (311); and the occurrence of ischemic heart disease and stroke (312). Although relatively simple to obtain and inexpensive, anthropometric measures are limited in the information they can provide, as these cannot distinguish adipose tissue from muscle, bone and other tissues in the abdominal cavity. Therefore, use of more advanced imaging techniques such as dual-energy X-ray absorptiometry, computed tomography and magnetic resonance imaging provides greater insight in the way body fat tissue is distributed (298). The latter two imaging techniques can additionally identify abdominal adipose tissue compartments, subcutaneous and visceral adipose tissue, that differ in anatomy and physiological characteristics (313). Compared to subcutaneous adipose tissue, visceral adipose tissue appears to be of greater clinical importance in regulating insulin resistance (314). This is important, as it may help in evaluation of health risk among different ethnic groups, given that it has been shown that certain ethnic groups, such as South Asians, are more prone to accumulating adipose tissue in the visceral adipose tissue depot (315).

Given the high prevalence of obesity and significant relationship between obesity and multiple comorbidities, the new guidelines for the management of overweight and obesity in adults released by the American College of Cardiology, American Heart Association and The Obesity Society suggest that doctors should consider obesity a disease and be more proactive in treating obese patients for weight loss (316). While this move may indeed push physicians to better prepare themselves to address obesity in their patients, it has been argued that calling obesity a disease implies that blame resides within an obese person instead of acknowledging the complexity of factors that contribute to obesity (317). Indeed, genetic, cultural, social and behavioural factors all contribute to the development of obesity (318). Environmental factors are also highly influential (319), predominantly by facilitating the consumption of energy-dense foods and discouraging PA (8). Consequently, it has been argued that in order “to combat the epidemic of obesity, we must first cure the environment” (8).

Obesity ultimately stems from an imbalance of energy intake and output; however factors that contribute to the energy imbalance are complex (14). Although psychosocial models have been dominant in guiding individual obesity prevention programs, these models alone are not sufficient enough to inform the development of population-based intervention strategies needed to reverse current obesity trends (173,320).

Multiple models have been proposed to depict the complexity of factors influencing energy intake and energy output (10,13,14,321–324). Common to all the models is the ecological paradigm that recognizes the interwoven relationship between the individual and their environments (16). Furthermore, these social-ecological models view human behaviours as being determined by factors that span across multiple layers, such as individual, social environment, physical environment, and policy, thus moving away from a victim-blaming approach to unhealthy behaviours (325,326) toward the targeting of the many social and physical factors that maintain and reinforce such unhealthy behaviours (327).

In one of the models that features a complexity of factors influencing energy balance (13), levels of influence are presented as interdependent elliptical layers. The innermost layer, *psychobiologic core*, includes genetically programmed metabolism and behaviour (e.g. instinctive behaviour, positive and negative reinforcement of pleasure) and current health status. Going toward the outer layers, the core layer is encompassed by the *cultural* (“inherited” values and beliefs, e.g. ethnic and cultural identity), *social* (roles and relationships, “acquired” values and beliefs), and *enablers of choice* (enhancers or barriers to change) layers. These are encircled by the environmental layers of the framework starting from *behavioural settings* (microenvironment e.g. neighbourhood, workplace, school), *proximal leverage points* (these control behavioural settings e.g. local government, employer, school board) to *distal leverage points* (e.g. government, labor-saving device industry, education system).

The International Obesity Task Force focused on the societal factors and processes that contribute to obesity, and presented them in a form of a “causal web”(14). Starting from those most proximal to the individual, several levels of influence have been identified: work/school/home, community/locality, national/regional, and international levels. Under each of the levels, there are multiple societal sectors, processes, and settings that influence energy balance. The “causal web” emphasizes the structural organization, and the interrelationships between societal sectors that converge on the individual’s closest environment (328). Another model, produced by Powell et al. at the University of Illinois, in a very simplistic way summarizes factors that influence energy balance (10). These factors include individual (genetics, socio-economic and other individual characteristics), social (family and peer influences, socio-economic characteristics), and environmental factors (BE, economic influences, neighbourhood safety, and transportation opportunities).

There is not a preferred framework of determinants of obesity, and it has been suggested that levels/layers of a chosen model could be labeled to fit the perspective in question (328). While acknowledging the complexity of obesity, the interrelationships of factors influencing it, and possible multiple mediation pathways that would most likely include physical activity and diet, it is important to note that this study does not focus on exploring complex mediation effects by which BE influences adiposity. It is rather set to explore the association between perceived and objective features of the BE and adiposity while accounting for individual level variables and neighbourhood income (Figure 2).

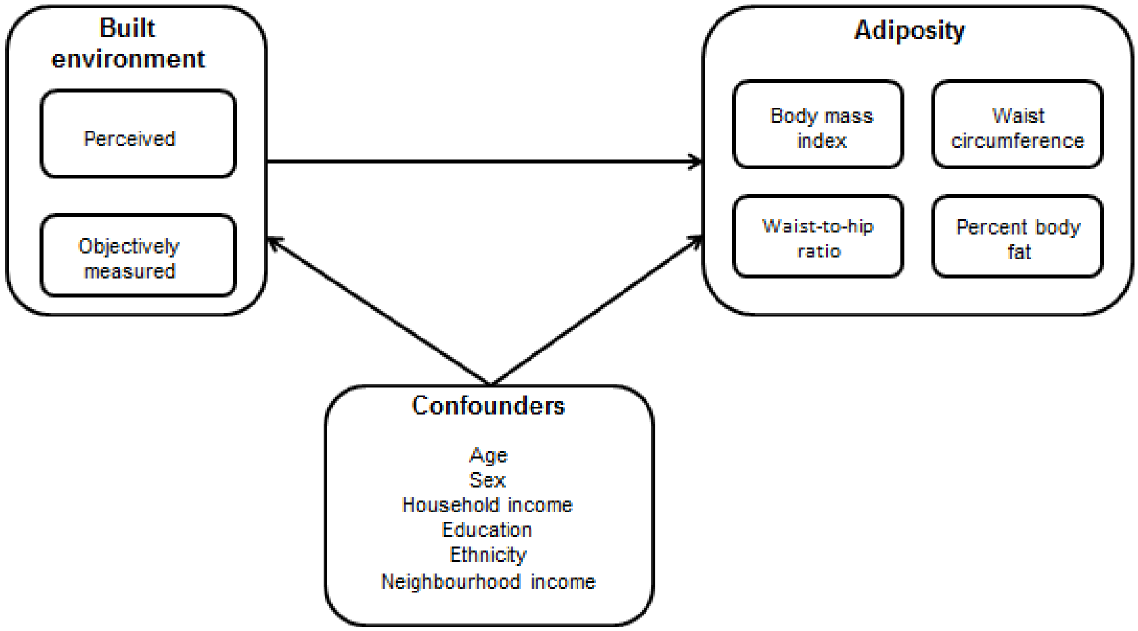

Figure 2. Conceptual diagram of the association between the BE and adiposity

1.4.1. The association between the built environment and obesity – review of the literature

Research on the association between environmental measures and overweight and/or obesity is less abundant compared to that on the association between PA and BE. Of the research on perceived environmental measures and overweight/obesity, overweight/obesity rates were lower among residents who perceived greater access to shops (329), commercial places (330), many destinations within walking distance (331), and many places to be physically active (331,332) within their neighbourhood. Similarly, lower levels of obesity were associated with a greater perceived presence of sidewalks (331,332), better neighbourhood aesthetics (330–332), and the presence of interesting things to look at while walking in the community (331,332). Moreover, levels of overweight/obesity were found to be lower among people who perceived their community as well maintained, generally free from garbage, litter or broken glass (331), and among those who perceived their neighbourhoods as safe from crime and traffic (209,330,331,333). In contrast, multiple perceived BE features positively associated with overweight/obesity include the presence of graffiti and vandalism (23,333), heavy traffic (334), absence of walking/cycling infrastructure (329,331), and/or absence of recreational facilities (331,335).

Certain objectively-measured BE features have also been associated with obesity. Lower levels of overweight/obesity were found in neighbourhoods that are more walkable (29,134,236,241,246,248,336), have greater land use mix (239,249,336–339), have greater access to public transportation (338) and have a greater number of grocery stores (83) and supermarkets (340–342). Similarly, obesity levels among residents were lower if they lived in neighbourhoods where streets were well connected (249,336), where there was more greenery (203,343), a greater number of parks (289) and more sidewalks (329,332), and in neighbourhoods with a higher density of recreation and public sports facilities (52,339,344). Conversely, obesity levels were higher among residents who lived in neighbourhoods with a greater presence of incivilities (345), including litter, graffiti and broken glass (203,332), higher crime rates (241), and greater access to fast-food establishments (346,347).

In Canada, several research groups have focused on the objectively-measured BE features and their association with obesity among adults. More specifically, when exploring the association between the BE and BMI for Vancouver and Toronto, Poulio and Elliot (336) reported lower BMI of Vancouver residents living in areas of greater walkability (determined by a composite walkability index), with greater land-use mix, residential density, and street connectivity. In Toronto, however, the negative relationship with BMI was observed only for residential density, while no association was found between the rest of BE features and BMI (336). In a study from Quebec, the odds of obesity were lower among families living in neighbourhoods with lower traffic, while no association with obesity was found for neighbourhood poverty, signs of physical disorder and deterioration, and pedestrian friendliness (348). In Ottawa, residents living in neighbourhoods with lower density of facilities for recreation had, on average, higher BMI compared to their counterparts residing in neighbourhoods with higher density of recreational facilities (349). Also in Ottawa, an increase in the number of specialty food stores (350), the amount of park area, density of convenience stores and summer outdoor facilities was associated with greater odds of overweight/obesity among women, while greater green space area was associated with increased odds of being overweight/obese in men; however, higher restaurant density (350) and increase in the crime rate was associated with lower odds of overweight/obesity among both men and women (257). In Edmonton, a lower ratio of fast-food restaurants and convenience stores to grocery stores and produce vendors around people's homes was found to be associated with lower odds of being obese (351).

While the majority of studies exploring the relationship between the BE and obesity use nonspatial methods such as regression, it has recently been argued that spatial clustering techniques, in conjunction with GIS, may be useful in identifying clusters of individuals with similar heath behaviours or health risk, which may be linked to the BE (352). Using spatial cluster analysis, Poulio and Elliot (353) observed significant differences in age-standardized rates of overweight and obesity by health region in Canada. The prevalence was increasing from Western to Eastern Canada; however, significant clusters of high values of obesity were detected, for both men and women, in the northern health regions of Alberta, Saskatchewan and Manitoba, and in the Eastern Regional Health Region of Prince Edward Island, Zones 1 and 2 in Nova Scotia and Regions 1 and 2 in New Brunswick (353). It has been suggested that the observed obesity 'hot spots' may be a reflection of potentially obesogenic environments in these health regions (353). Another group of Canadian researchers has also used spatial clustering techniques to explore clustering of obesity and moderate PA in eight neighbourhoods of varying residential density and median family income located in Greater Vancouver area in British Columbia; however, they went a step further and examined the association of neighbourhood BE with obesity and PA using geographically weighted regression (352). Schuurman et al. (352) found no global clustering of obesity and PA in researched neighbourhoods (obese/nonobese and physically active/not physically active individuals not found in close proximity but rather regularly distributed throughout the neighbourhoods) suggesting little or no direct effect of the BE on obesity and PA. However, the researchers did observe some local clustering of obesity and PA within some of the neighbourhoods and postulated that there could be specific neighbourhood features behind such clustering, and that further investigation of the relationship between the micro-environmental features and obesity and PA is warranted (352). Data on micro-environmental features were collected through a direct assessment of the BE, and this study will explore the association of micro-environmental features with PA, adiposity and blood glucose.

Recently, several longitudinal studies produced evidence on the relationship between the BE and obesity. The results of the study from Portland, US (one year follow-up) indicate that living in neighbourhoods with a high density of fast food restaurants and also frequently visiting these restaurants increases one's weight and WC over time (354). Moreover, living in highly walkable neighbourhoods and engaging in vigorous PA is associated with decrease in weight and WC over time (354). In a recent study from Australia (mean follow-up of 3.5 years), an increase in a Relative Food Environment Index (ratio of fast-food restaurants and unhealthful food stores to healthful food stores) was associated with higher risk of being abdominally obese (355). In Edmonton, Canada, a 6-year longitudinal study was undertaken to explore the relationship between perceived and objectively measured BE and obesity (356). While no relationship was found between objectively measured neighbourhood walkability and BMI, living in lower socio-economic status neighbourhoods and reporting that traffic makes it difficult to walk in the neighbourhood predicted increased BMI among study participants (356). In another study (357) participants were also followed for 6 years, and the study examined the relationship between the urban form of the neighbourhood ("urbancity" score derived from housing density, street connectivity, intersection density, access to public transit and percentage of streets with sidewalk coverage) and weight gain and incident obesity in African-American women from New York, Chicago and Los Angeles, US. The results of the study indicate that living in dense urban neighbourhoods, compared to living in suburban or rural neighbourhoods, is associated with lower weight gain and incident obesity (357).

Several longitudinal studies focused on older adult populations. A study from the UK (358), which followed men for about 12 years, observed a significant relationship between objectively measured BE features and changes in BMI. Higher densities of retail land use, churches, recreation and leisure facilities, more uneven topography, and greater overall city level accessibility to various attractive destinations (measured by route betweenness at a city radius of 3000 meters) were related to decreasing BMI levels, while higher land-use mix, greater pedestrian movement and street level crowding (measured by the route betweenness at a local scale of 1200 meters) predicted increased BMIs among elderly men (358). In contrast, in a prospective study (a 14-year follow-up) of non-sedentary older women, objectively measured BE (neighbourhood walkability) did not predict change in BMI (359). Similarly, a retrospective cohort study that examined a relationship between BE and BMI over 18 years in older women in Portland found no relationship between neighbourhood BE (objectively measured walkability and access to parks/green space), or change in BE, and change in BMI (360).

To date, studies looking at obesity and BE have used BMI as an indicator of obesity, and the majority of these studies were limited to values based on participants' self-reported height and weight (29,52,84,209,236,241,246,248,257,274,289,329,331–337,341–344,350,351,356,361–365), though a limited number of studies did measure height and weight directly (239,330,338,340,345,348,349,366–368). The use of BMI places doubts on the accuracy of the existing study results and their potential to be translated into policies for two reasons: 1) compared to WC, WHR and percent body fat (%BF), BMI is a less reliable indicator of obesity, and 2) self-reported measures underestimate rates of overweight and obesity (369,370). Furthermore, the majority of studies in this area have focused exclusively on objective BE features (29,52,83,134,203,236,239,241,246,248,249,274,336–345,361–364,366–368,371) and how they relate to obesity; less information is available on the association between perceived BE and obesity (23,84,209,330,331,335,365), while even fewer studies assess perceived and objective measures simultaneously (289,329,332–334,356). It has been argued that in order to explain the relationship between weight gain, obesity and the BE more accurately, it is important to use both perceived and objective environmental measures (372). Additionally, despite it having been argued that features of the "micro" environment can readily be changed with less financial investment compared to those of the "macro" environment, only a limited number of studies have directly assessed "micro" environmental features (329,332,345,367). This study addresses the above-mentioned limitations by using directly-measured indicators of adiposity and exploring how these relate to both perceived and objectively-assessed "micro" BE features.

1.5. The built environment and diabetes

Diabetes mellitus is a metabolic disorder characterized by elevated fasting plasma glucose levels due to defects in insulin secretion, insulin action or both (373). If left untreated, the resulting long-term hyperglycemia leads to debilitating complications such as cardiovascular disease, nephropathy and retinopathy (373). It was estimated that 366 million people were living with diabetes in 2011, and that this number will reach 552 million by 2030 (7). In Canada in 2008/09, 2.4 million Canadians (6.8%) were living with diabetes, and it was estimated that this number will increase to 3.7 million by 2018/19 (374).

Aside from its health implications, diabetes poses a significant burden to the economy. In 2011, world healthcare expenditures attributable to diabetes were estimated at 465 billion US dollars, or 11% of total adult healthcare spending (7). Canadian data from 2000 estimate that $2.5 billion in total costs were attributable to diabetes, and that excludes costs associated with diabetes complications (374). According to some projections, diabetes-related health care costs in Canada will increase by 75% between 2000 and 2016. (375)

There are four clinical classes of diabetes: 1) type 1 diabetes (the result of β-cell destruction that leads to insulin deficiency); 2) type 2 diabetes (due to insulin secretory defect); 3) gestational diabetes; and 4) specific type of diabetes caused by genetic defects in β-cell function and insulin action, diseases of exocrine pancreas (e.g. cystic fibrosis), or drugs and chemicals (after organ transplantation or in the treatment of acquired immunodeficiency syndrome) (376). A person is diagnosed with diabetes if their fasting plasma glucose levels are equal to or higher than 7 mmol/L; if their 2-h plasma glucose is equal or exceeds 11.1 mmol/L during an oral glucose tolerance test; or if a random plasma glucose of 11.1 mmol/L or higher is observed in individuals with symptoms of hyperglycemia or hyperglycemic crisis. Additionally, a person is diagnosed with diabetes if their hemoglobin A1C is 6.5% or higher (376).

Prediabetes, diagnosed by the presence of impaired fasting glucose (IFG) and impaired glucose tolerance (IGT), is an intermediate state in glucose metabolism between normal glucose tolerance and diabetes (377). A person is diagnosed with IFG if their fasting glucose concentration is between 5.6 mmol/L and 6.9 mmol/L; while they are diagnosed with IGT if their 2-h glucose concentrations in the oral glucose tolerance test are between 7.8 mmol/L and 11.0 mmol/L; in addition, a person is at increased risk for diabetes if their hemoglobin A1C levels are between 5.7% and 6.4% (376). Although both IFG and IGT are intermediate states between normal glucose tolerance and diabetes, they differ in the site of insulin resistance; namely, IFG is characterized by hepatic insulin resistance and normal muscle insulin sensitivity, while individuals with IGT have normal to slightly reduced hepatic insulin resistance and moderate to severe insulin resistance (378). The rate of developing diabetes is two times higher among individuals who have both IFG and IGT compared to those who have just one of the insulin resistance states (377). In addition, insulin resistance tends to cluster with dyslipidemia and hypertension which is especially prevalent among individuals with central obesity who have higher amounts of visceral adipose tissue (379).

Several clinical trials have demonstrated the value of a healthy lifestyle in preventing or delaying the onset of diabetes. In a large, randomized control trial conducted by the Diabetes Prevention Program Research Group, over 3000 people with elevated fasting and post-load glucose concentrations were randomized to placebo, metformin or a lifestyle-modification program (goal: at least 7% weight loss and at least 150 minutes of PA per week). The average follow-up was 2.8 years. Compared with placebo, the lifestyle intervention reduced the incidence of diabetes by 58% and metformin by 31% (380). Similar findings were reported in the study conducted by the Finnish Diabetes Prevention Study Group where 522 men and women with IGT were randomized to either the intervention or control group. The individuals in the intervention group received individualized counselling with a goal to reduce weight by at least 5%; to keep total intake of fat and saturated fat to less than 30% of energy consumed and less than 10% of energy consumed, respectively; to increase intake of fiber to at least 15g per 1000 kcal; and to be moderately active for at least 30 minutes per day. After mean follow-up of 3.2 years, compared to the control group, the risk of diabetes was reduced by 58% in the intervention group (381). In the follow-up of the Finnish Diabetes Prevention Study, the individuals free of diabetes were additionally followed-up for a median of 3 years after discontinuation of counselling. Among the followed individuals with impaired glucose tolerance, lifestyle intervention produced sustained lifestyle changes and reduction in diabetes incidence that remained after discontinuation of active counselling (382). Furthermore, in the DaQing IGT and Diabetes Study, over 110,000 Chinese men and women were randomized to control, diet only, exercise only, and diet plus exercise groups. After a mean follow-up of 6 years, the diet, exercise, and diet plus exercise interventions were associated with 31%, 46%, and 42% reduction in risk of developing diabetes (383). In addition, a recent systematic review and meta-analysis summarized evidence of the efficacy of multi-component lifestyle interventions that included diet, aerobic and resistance training in individuals with prediabetes (384). The results of the study indicate that these lifestyle interventions are modestly effective in inducing weight loss, and improving glucose tolerance among individuals with prediabetes (384).

Of the forms of diabetes, type 2 (T2D) is the most prevalent one, accounting for about 90% to 95% of all individuals living with the disorder. The risk of developing T2D increases with age, physical inactivity and overweight (373). While lifestyle intervention programs focusing on increasing individuals' PA and reducing weight have shown tremendous success in reducing the risk for the development of type 2 diabetes (380,381,383), these individual behaviour modification interventions are costly and labour-intensive, making them hard to implement for the overall population (385). Given that our current environment promotes high energy intake and discourages energy expenditure (8), environmental and policy interventions were identified as most promising and sustainable strategies to increase PA and improve diet at a population level (14,386,387).

The majority of research on diabetes risk reduction has focused on the individual. However, it has been argued that a socioecological approach to a problem offers better understanding of potential socio-ecological determinants of diabetes risk; and that it may be of greater help in identifying pragmatic diabetes prevention and management strategies (15,388). Whittemore et al. (388) recognize multiple levels of influence on diabetes risk, including intrapersonal factors, interpersonal processes, institutional and community factors and public policy. Furthermore, Hill et al.(15) have recently argued that the Institute of Medicine's socioecological model of childhood obesity may serve as a good framework for understanding the determinants of diabetes risk. The framework is represented by concentric circles whereby energy balance is influenced by individual factors (e.g., demographics, psychosocial factors, gene-environment interactions), behavioural settings (e.g. worksite, home, school, community), sectors (e.g., government, agriculture, education, media, industry) and by social norms and values (15). Based on the above mentioned socioecological frameworks, the environment plays a role in shaping diabetes risk, and these frameworks suggest that the association between the environment and diabetes is complex and most likely mediated by PA and diet. That being said, it is important to note that this thesis does not focus on the exploration of complex mediation effects by which the BE influences blood glucose; but it rather explores independent of individual attributes the association between perceived and objectively measured BE features and blood glucose in order to identify environmental features that could be potentially intervened on in order to help reduce diabetes risk. (Figure 3)

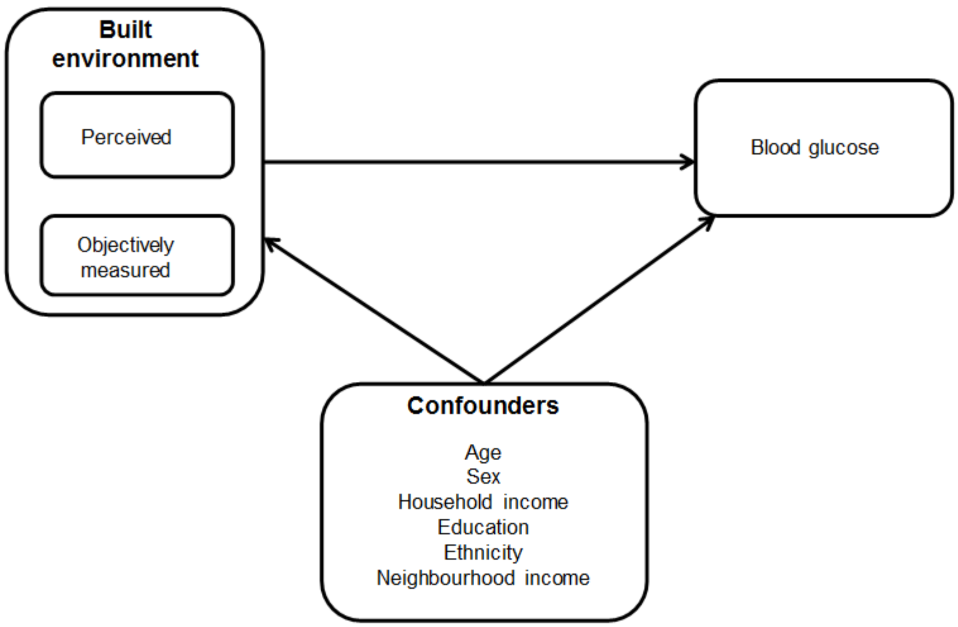

Figure 3. Conceptual diagram of the association between the built environment and blood glucose

1.5.1. The association between the built environment and diabetes – review of the literature

Only a handful of studies have investigated the association between the BE and diabetes. In a Canadian study that examined the association of neighbourhood environments and resources for healthy living with diabetes, lower diabetes rates were observed in areas with higher residential density, higher safety from crime, and areas with increased access to public transit, PA facilities, healthy food resources, and retail services (389). The results of a recent study conducted in Western Australia indicate that living in highly walkable neighbourhoods (objectively measured walkability) is associated with lower odds of diabetes; however, these associations were stronger for immediate

(800 meters) than extended (1600 meters) neighbourhoods and more pronounced in men than in women (390). In another Australian study, living in hillier neighbourhoods (higher objectively measured slope) was associated with lower odds of diabetes (391). Moreover, it has been suggested that the environment may play a role in whether people adhere or do not adhere to diabetes treatment whereby a positive association was found between self-reported neighbourhood safety and diabetes treatment nonadherence (392). This association persisted after adjustment for multiple barriers to accessing a pharmacy and paying for medications such as access to transportation, income, and insurance status. It has been argued that individuals who perceived their neighbourhood as unsafe also perceive neighborhood problems and being affected by them; whereby the burden of problems may diminish the importance of filling prescriptions and adherence to diabetes treatment (392). Moreover, researchers looking at the environmental determinants of insulin resistance observed positive associations between distance to wealthy areas and insulin resistance (393), while greater presence of neighbourhood facilities for PA and healthy food options were associated with lower insulin resistance (394). Additionally, it has been argued that deprivation inequality between areas and their neighbours may negatively affect the health of neighbourhood residents. Indeed, the results of a study from Scotland indicate that, although area deprivation was positively associated with T2D incidence, less deprived areas that neighboured more deprived areas had a higher incidence of T2D than what would be expected from the deprivation of the area alone (395).

Results of longitudinal studies are inconsistent. No relationship was found between neighbourhood condition (condition of houses, amount of noise, air quality, condition of the streets, and condition of the yards and sidewalks in front of participant's homes) and incident diabetes in a study that followed-up African-American adults for 3 years (396). In contrast, in a recent Australian study (mean follow-up of 3.5 years) the increase in objectively measured neighbourhood walkability and in size of public open space was associated with lower risk of developing pre-diabetes/diabetes among adults; however, the association between a Relative Food Environment Index (ratio of fast-food restaurants and unhealthful food stores to healthful food stores) and incident pre-diabetes/diabetes was not significant (355). Moreover, in the Multi-Ethnic Study of Atherosclerosis, in the US, with a median follow-up of 5 years, higher diabetes incidence was observed in neighbourhoods with lower levels of reported supports for PA and healthy diet (85). In a study from Toronto, Canada (5-year follow-up), objectively measured neighbourhood walkability was found to predict diabetes incidence among both immigrants and long-term residents (397). The effects were more pronounced in low-income neighbourhoods whereby the highest diabetes incidence rates were observed among immigrants living in less walkable and low-income neighbourhoods (397). In contrast, in a recently published Swedish study (4-year follow-up), neighbourhood walkability was not associated with the incidence of clinically diagnosed type 2 diabetes after adjustment for neighbourhood deprivation and individual socio-demographic factors (398).

Given the rise in T2D prevalence and the seriousness of its complications, there is a need for identifying environmental features that can potentially alleviate a T2D epidemic by influencing people's PA levels and diet. Studies conducted to date have mostly looked at perceived measures and their relationship with T2D (85,389,394), while the studies that objectively measured the BE only included a limited number of environmental features (393,396). Considering that perceived and objective environmental measures do not necessarily relate to the same constructs, and in order to comprehensively explore the association between the environment and diabetes risk factors, it is important to examine both types of environmental features. In response to this need, one of the research objectives of this study was to explore the association of both perceived and objective BE features with fasting blood glucose (FBG), the main biomarker used for the diagnosis of diabetes (373), among individuals drawn from a general population.

1.6. Canadian context

Canadian BE research on the association of the BE and PA, obesity and diabetes in adults has grown in the past 2 decades, and the majority of studies have been published in the past several years. Table 1 briefly summarizes Canadian studies on the association between the BE and PA, obesity and diabetes in adult population. The majority of the studies explored the association between the BE and PA, while less evidence is available for the association between the BE and obesity and diabetes. Five studies exclusively focused on perceived BE measures (38,39,218,399,400), two of which were qualitative (218,400). Only four studies researched both perceived and objective BE measures (208,234,259,356), and the rest of the studies focused on the objective BE measures. Out of these, the majority relied on the *indirect* measures of BE features such as GIS-based objective BE measures, while a limited number of studies assessed the BE directly leaving a limited evidence on the association between micro-BE and outcomes (244,348,401,402). None of the studies that assessed the BE directly were done in Vancouver, BC. Findings on the associations between micro-BE and PA from studies from other provinces may not necessarily generalize to Vancouver setting. Vancouver is a coastal city, and, therefore, its physical environment may significantly differ from that of other Canadian cities, such as those in the Canadian Prairies; and the associations between the BE and PA and obesity may not necessarily be consistent across Canadian cities. For example, researchers that conducted a recent study that explored the association between the BE and BMI in two Canadian cities, Vancouver, British Columbia and Toronto, Ontario observed negative associations between walkability, land-use mix and street connectivity with BMI in Vancouver only (336). The results of this study suggest that findings from one Canadian setting may not be readily translated to policies meant for another Canadian setting. In addition, the majority of the studies exploring the association between the BE and obesity, calculated BMI from self-reported height and weight, while only two studies derived BMI from objectively measured height and weight (348,349). Neither of the studies used measures of obesity other than BMI. Therefore, the present study will contribute to the pool of Canadian studies by providing insights on the association of both perceived and directly measured micro-BE features and PA domains, directly measured adiposity (BMI, WC, WHR, and %BF) and fasting blood glucose in Vancouver urban settings.

Table 1. The built environment and physical activity, obesity and diabetes in adults: findings from Canada, by province, from West to East

First author, year Canadian setting Population	Built environment measures	Outcomes	Findings
Physical activity			

First author, year Canadian setting Population	Built environment measures	Outcomes	Findings
Spence, 2006 Canada 3144 Canadians, visitors to the Canada on the Move website (39)	Perceived	Self-reported walking: sufficient (at least 600 MET-min/wk) vs. insufficient to achieve health benefits	In the overall sample, individuals who perceived interesting scenery and many places to go within walking distance were more likely to report walking at a sufficient level. When analyses are performed by sex, no associations were found between perceived environmental measures and walking among men. In women, those who reported interesting scenery and many places to go within walking distance were more likely to report walking at a sufficient level.
Schuurman, 2009 Vancouver, BC 1863 adults residing in 8 suburban neighbourhoods in Metro Vancouver (352)	Objective	Self-reported moderate PA: nonactive vs. active (a minimum of 3-3.75h/wk and more than 2h of sedentary leisure/day; or a minimum of 2-2.75h/wk with less than 2 h of sedentary leisure per day)	There was no significant clustering for the attributes of moderate PA.
Winters, 2010 Vancouver, BC 1902 adults from Metro Vancouver (136)	Objective	Self-reported non-recreational cycling (likelihood that a trip is made by bicycle instead of car)	Built environment features significantly associated with increased odds of cycling included less hilliness, higher intersection density, less highways and arterials, presence of bicycle signage, traffic calming, and cyclist-activated traffic lights, more neighbourhood commercial, educational and industrial land uses, greater land use mix, and higher population density. The characteristics of routes were more influential compared to those of trip origin and destination.

First author, year Canadian setting Population	Built environment measures	Outcomes	Findings
Oliver, 2011 Vancouver, BC 1602 adults from Metro Vancouver (250)	Objective	Self-reported walking to work or school, walking for errands (all: less than one hour/wk vs. hour or more/wk), and walking for leisure (15 min or less/day vs. more than 15min/day)	Living in areas with lower recreational and park land, commercial and institutional land as well as lower land use mix was associated with greater odds of low levels of walking for errands. Living in areas with lower land use mix and institutional land was associated with lower levels of leisure walking. There was no association between land use and walking to work or school and moderate PA.
Bengoechea, 2005 Alberta 1209 adults from Alberta (38)	Perceived	Self-reported leisure-time PA: inactive vs. active (38 METs/wk for men or 35 METs/wk for women)	Perceiving many interesting things to look at while walking in the neighbourhood, presence of shops and places to buy things within easy walking distance, and easy access to places for PA were associated with higher levels of leisure-time PA in men (after adjustment for socio-demographics and self-efficacy). In women, higher levels of leisure-time PA were observed among women who perceived availability of free or low-cost recreational facilities, easy access to places for PA and who reported seeing many people engaging in PA in their neighbourhood. However, neither of these associations in women remained statistically significant in the fully adjusted models.
Taylor, 2010 Alberta 771 adults with type 2 diabetes (399)	Perceived	Self-reported walking for transport and recreation: inactive walkers vs. active walkers (≥396MET*min/wk)	Perceiving shops or places to buy things close by was associated with higher levels of walking for transportation. No associations were found between perceived environmental measures and walking for recreation.
Montemuro, 2011 Edmonton, AB 63 adults from Edmonton (218)	Perceived factors influencing PA-Qualitative study		Factors influencing walking and PA included path connectivity and quality, seasonal conditions and traffic-related safety.

First author, year Canadian setting Population	Built environment measures	Outcomes	Findings
McCormack 2012 Calgary, AB 4034 adults from Calgary (403)	Objective	Self-reported neighbourhood-based transportation and recreation walking: non participation vs. participation (cut-off: 10 min/wk); duration of walking (min/wk); and insufficient vs. sufficient (cut-off: 150 min/wk	Residents from medium- and high-walkable neighbourhoods were more likely to engage in neighbourhood-based transportation walking compared to individuals living in low-walkable neighbourhoods. No significant neighbourhood differences were observed in the likelihood of participating in neighbourhood-based recreational walking.
Cutumisu, 2012 Edmonton, AB 2879 adults from Edmonton (208)	Perceived and objective	Self-reported PA: insufficient vs. sufficient (cut-off: 750 MET*min/wk)	Residents who had higher access to sports fields were 1.65 times more likely to report sufficient PA as recommended. No association was found between perceived BE measures and PA.
McCormack 2014 Calgary, AB 2006 adults from Calgary (256)	Objective	Self-reported neighbourhood-based PA	Residents from high-walkable neighbourhoods engaged in more neighbourhood-based PA compared to individuals living in medium- and low-walkable neighbourhoods.

First author, year Canadian setting Population	Built environment measures	Outcomes	Findings
Jack, 2014 Calgary, AB 1875 adults from Calgary (234)	Perceived and objective	Self-reported neighbourhood-based transportation and recreation walking: continuous and non-walkers vs. walkers (cut off: 10 min/wk)	Perceived access to services, street connectivity, and utilitarian destination mix were positively associated with participation in transportation walking. Perceived safety from crime and recreation destination mix were negatively associated with transportation walking minutes. Perceived neighbourhood aesthetics was positively associated with participation in recreation walking, while perceived access to services was negatively associated with minutes of recreational walking. Residents from high- and medium-walkable neighbourhoods were more likely to walk for transportation compared to counterparts from low-walkable neighbourhoods. No statistically significant differences in recreation walking were observed across neighbourhood types.
Schopflocher, 2014 Edmonton, Medicine Hat, AB 780 adults from North Central Edmonton and 1262 adults from Medicine Hat (401)	Objective	Self-reported total walking, walking for leisure and walking for travel	Medicine Hat: There was a positive association between traffic safety and attractiveness and walking for leisure. Edmonton: There was a negative association between crime safety and total walking and walking for travel. Furthermore, accessibility was positively associated with walking for travel.
Craig, 2002 AB, ON, QC Residents from 27 neighbourhoods in Alberta, Ontario and Quebec (402)	Objective	Self-reported walking to work	There was a positive association between the neighbourhood environment score (based on 18 neighbourhood characteristics) and walking to work.

First author, year Canadian setting Population	Built environment measures	Outcomes	Findings
Lockett, 2005 Ottawa, ON 22 seniors from Ottawa (400)	Perceived environmental barriers to and facilitators of walking – Qualitative study		Seniors identified risks related to traffic and falls hazards as the main barriers to walking. Furthermore, they identified the following environmental features as facilitators of walking: aesthetics, convenient routes, and accessible transit services and amenities, such as public washrooms and benches.
Prince, 2011 Ottawa, ON 113 adults from Ottawa (349)	Objective	Objectively measured PA: minutes of light, moderate, vigorous, moderate-to-vigorous PA and step count; meeting vs. not meeting PA guidelines by weekly minutes of moderate-to-vigorous PA or daily step count.	Individuals living in neighbourhoods of high socio-economic status and with lower density of facilities for recreation engaged in more light intensity PA compared to residents from low socio-economic status neighbourhoods that had lower density of facilities for recreation. Other PA variables did not significantly differ among neighbourhoods with contrasting socio-economic status and recreation environments.
Prince, 2011 Ottawa, ON 3883 adults from Ottawa (350)	Objective	Self-reported PA: insufficiently active vs. active	Greater green space area was associated with lower likelihood of being active among men. Higher density of convenience stores and restaurants was associated with greater likelihood of being active in men, and women, respectively.
Prince, 2012 Ottawa, ON 4727 adults from Ottawa (257)	Objective	Self-reported leisure-time PA: inactive vs. active (cut-off: 3 kcal/kg/day)	In women, greater park area was associated with increased odds of leisure-time PA. No association between BE features and PA was observed in men.

First author, year Canadian setting Population	Built environment measures	Outcomes	Findings
De Sa, 2014 York Region, ON 1158 adults from the York Region (404)	Objective	Self-reported walking or cycling for leisure and transportation (any vs. none)	Individuals who lived in areas with highest number of intersections were more likely to walk or cycle for leisure. No associations were found between residential density, area of building space, area of parks/green spaces and leisure PA. Residents from area with higher residential density and number of intersections were more likely to walk or cycle for transportation. No associations were found between the rest of the BE features and transportation PA.
Gauvin, 2008 Montreal, QC 2614 adults from Montreal (244)	Objective	Self-reported total walking and recreation walking for at least 5 times per week for an average of at least 30 minutes	Greater density of destinations in the neighbourhood was associated with greater likelihood of walking for any reason. No BE features were significantly associated with recreation walking.
Gauvin, 2012 Montreal, QC 521 seniors from Montreal (259)	Perceived and objective	Self-reported walking: walking often (5-7 days) vs. never/seldom (1-2 days)/sometimes (3-4 days)	Closer proximity to local services and amenities was associated with greater likelihood of frequent walking at all times throughout the 3-year period. Perceived access to neighbourhood amenities and services was not associated with walking.
Obesity			
Pouliou, 2009 Canada 111,947 Canadian adults (353)	Objective	BMI (kg/m²), self-reported height and weight	Age-standardized rates of overweight and obesity were increasing from Western to Eastern Canada. Significant clusters of high values of obesity (hot spots) were detected in northern health regions of Alberta, Saskatchewan and Manitoba, and in the Eastern Regional Health Region of Prince Edward Island, Zones 1 and 2 in Nova Scotia and Regions 1 and 2 in New Brunswick.

First author, year Canadian setting Population	Built environment measures	Outcomes	Findings
Schuurman, 2009 Vancouver, BC 1863 adults residing in 8 suburban neighbourhoods in Metro Vancouver (352)	Objective	BMI (kg/m²), self-reported height and weight	There was no significant clustering for the attributes of obesity at either the global or local level of analysis.
Spence, 2009 Edmonton, AB 2900 adults from Edmonton (351)	Objective	BMI (kg/m²), self-reported height and weight: obese (≥ 30kg/m²) vs. nonobese	The odds of a resident being obese were significantly lower if they lived in an area with the lowest Retail Food Environment Index (RFEI) (ratio of fast food restaurants and convenience stores to grocery stores and produce vendors) in comparison to the highest RFEI. While this association was found for RFEI calculated for 800m buffer around people's homes, no such association with obesity was found for RFEI calculated for 1600m buffer around people's homes.
Berry, 2010 Edmonton, AB 500 adults from Edmonton (356)	Perceived and objective	BMI (kg/m²), self-reported height and weight	Agreeing with the statement that 'traffic makes it difficult to walk' predicted increased BMI. No relationship was found between walkability and BMI.
Pouliou, 2010 Toronto, ON; Vancouver, BC 5,418,218 adults (weighted sample) from Toronto and Vancouver (336)	Objective	BMI (kg/m²), self-reported height and weight	Vancouver: Residential density, land-use mix, street connectivity and walkability were negatively associated with BMI. Toronto: Residential density was negatively associated with BMI.

First author, year Canadian setting Population	Built environment measures	Outcomes	Findings
Prince, 2011 Ottawa, ON 3883 adults from Ottawa (350)	Objective	BMI (kg/m²), self-reported height and weight: underweight/normal weight vs. overweight/obese (≥25 kg/m²)	Greater green space area was associated with increased odds of being overweight/obese in men, and decreased odds of being overweight/obese in women. Higher restaurant density was associated with lower odds of being overweight/obese in both men and women. Higher density of specialty food stores and summer outdoor facilities was associated with greater likelihood of overweight/obesity among women.
Prince, 2011 Ottawa, ON 113 adults from Ottawa (349)	Objective	BMI (kg/m²), measured height and weight	BMI did not significantly differ among neighbourhoods with contrasting socio-economic status and recreation environments.
Prince, 2012 Ottawa, ON 4727 adults from Ottawa (257)	Objective	BMI(kg/m²): under-/normal weight vs. overweight/obese, self-reported height and weight	Greater park area and greater neighbourhood density of convenience stores and fast food outlets were associated with increased odds of being overweight/obese among women, while there was no association between BE features and overweight/obesity among men.
Van Hulst, 2013 Montreal, QC 417 families from Montreal (348)	Objective	BMI (kg/m²), measured height and weight: obese (≥ 30kg/m² in adults and ≥ 95th percentile in children) vs. normal weight/overweight	Living in neighbourhoods with lower traffic (vs. higher traffic) was associated with a lower likelihood of being obese. Level of urbanicity, physical disorder and deterioration and pedestrian friendliness were not associated with obesity.
Diabetes			
Glazier, 2007 Toronto, ON Population residing in 140 Toronto neighbourhoods (389)	Objective	Diabetes rates	Lower diabetes rates were observed in areas with higher residential density, higher safety from crime, and areas with increased access to public transit, PA facilities, healthy food resources and retail services.

First author, year Canadian setting Population	Built environment measures	Outcomes	Findings
Booth, 2013 Toronto, ON 1,239,262 adults from Toronto (397)	Objective	The development of diabetes	Neighbourhood walkability was an independent predictor of diabetes incidence.
Other			
Winters, 2014 Vancouver, BC 184 older adults from Vancouver (405)	Explored older adults travel behaviour in highly walkable environment	Objectively measured step count (per day) and moderate-to-vigorous PA (MVPA) (min/day); bouted MVPA (min/day); meeting vs. not meeting PA guidelines	Top four destination types visited by older adults included: grocery stores, restaurants, malls/marketplaces, and other's homes. Trip rates were significantly associated with PA outcomes.
Smoyer-Tomic, 2006 Edmonton, AB 212 Edmonton's urban and residential neighbourhoods (406)	Objective	Accessibility to supermarkets	Inner-city and high-need neighbourhoods had better accessibility to supermarkets than did the remainder of the city. However, six neighbourhoods were identified as potential food deserts due to low accessibility to supermarkets, limited means to access stores and high rates of low-income and/or elderly households (high need).
Schopflocher, 2012 Bonnyville, AB (407)	Objective	n/a	Developed a method for reducing BE data that they can be effectively communicated to researchers and community stakeholders.

First author, year Canadian setting Population	Built environment measures	Outcomes	Findings
Joseph, 2012 Six Nations Reserve, ON 63 adults from the Six Nations Reserve (408)	Perceived	To describe contextual determinants of health behaviours	Study participants did not perceive favourably walkability to community facilities, street connectivity, walking/cycling facilities, aesthetics, pedestrian/traffic safety and crime safety. However, they reported high community satisfaction. Everyone purchased groceries off-reserve, however fresh fruits and vegetables were reported to be available and affordable both on and off-reserve. The associations between BE and food behaviours were not tested.
Apparicio, 2007 Montreal, QC Census tracts on the Island of Montreal (409)	Objective	Presence of food deserts; based on accessibility to supermarkets	Food deserts do not represent a major problem in Montreal.

BE- built environment; wk – week; h – hour(s); MET – metabolic equivalent; PA – physical activity; BMI – body mass index; BC – British Columbia; AB – Alberta; ON – Ontario; QC - Quebec

1.7. Challenges to addressing the relationship between the built environment and health

While evidence on the BE and health is growing, there are still multiple challenges researchers encounter that most likely contribute to low effect sizes reported for BE features in BE studies. One of the major challenges in BE research is *defining a geographic area of interest* (commonly referred to as a neighbourhood) (118). The way a neighbourhood is defined substantially varies across BE literature, and this makes cross-study comparisons challenging. Various administratively-established units are commonly used as neighbourhood proxies (122,222,232,233,242,262,277), as the data for these spatial units are readily available and convenient to use (92). Given that it has been shown that people tend to perceive their neighbourhoods as territorially smaller units (101), many researchers opted for an approach where they define neighbourhoods as smaller spatial units with boundaries that correspond to those of a small radius (e.g. 500

meters, 1 kilometer) surrounding residents' homes (279,280,288,289). However, even this approach has different application methods. In addition to the differences in the size of buffer used, some researchers use a circular buffer to define neighbourhood boundaries (249,251,278,279,288) while others opt for a road network buffer (82,132,134,135,253,290) radiating from a participant's home. Additionally, neither administrative unit-based nor small radius-based neighbourhoods reflect neighbourhood boundaries as they are perceived by residents. One of the solutions that has been proposed is to ask residents to draw the boundaries of their neighbourhoods on a map (124). Although this approach may be burdensome on the researcher since residents, even if living in proximity to one another, tend to define their neighbourhoods differently, it would certainly eliminate the discrepancies between researcher- and resident-defined neighbourhoods (124). If this method is to be adopted, proper techniques for analyzing residents' neighbourhood maps need to be developed, validated and standardized in order to enable cross-study comparisons.

Another challenge, which builds on the previously discussed one, and is specifically relevant to improving research on correspondence between perceived and objective BE measures, pertains to *specifying the locations of particular BE features* that *residents' perceptions are tested on*. Tools for assessing neighbourhood perceptions commonly ask about presence of various features in the neighbourhood (grocery store, park, pharmacy or transit stop) along with the time, in minutes, required to walk to the nearest of these features (31). However, the questionnaires used to collect this information do not require participants to specify locations of the particular neighbourhood features they are referring to. This information is important, as 10 minutes of walking for one respondent may not correspond to the same distance for a second respondent. For example, a frail elderly person or parents walking with younger children are likely to walk shorter distances in 10 minutes compared to a young athletic person.

This lack of specification likely contributes to the poor correspondence between perceived and objective BE measures. One way to address this would be to ask participants to draw on a map the locations of the neighbourhood features they are referring to. Ideally, researchers would follow up with an objective assessment of the physical environment within each resident's neighbourhood. This approach would allow for more accurate verification of which objectively-measured neighbourhood features correspond to the ones perceived by study participants, and, more importantly, it would identify the BE features that are present in the neighbourhood but are not perceived by residents. The latter is important, as it would allow for further exploration of the reasons for the environmental misperceptions. It would additionally help create health promotion strategies that would increase awareness among residents of the BE features that are present in the environment but are potentially underutilized - e.g., parks, community centres, or grocery stores and restaurants offering healthier food choices.

Inconsistencies in the way BE features are measured and reported also contributes to the inconclusiveness of the results in literature regarding the association between the BE and health and health-related behaviours. Even when researchers used the same approach for assessing the BE (e.g., objective assessment), the tools used often differed (74,242,244,273,282). As a result, the same BE features were reported in different ways across studies and ranged from counts of a specific variable (e.g., number of bus stops on the segment), to the variable being reported as a binary outcome (e.g., bus stops present vs. bus stops absent) to it being presented as multiple categories (e.g., some, none, or a lot of bus stops on the segment). Standardizing the approach to the measurement and reporting of BE features may enable easier cross-study comparisons and lead to more conclusive study results.

Evidence on the association between BE and PA is growing, however, *inconsistency in PA measurements* remains a challenge in BE research. While the majority of studies collected self-reported PA (81,208,212,222,223,225,230,233,250,273–275,277,286,290), some opted for measuring PA objectively (122,128,196,237,263) or used both self-reported and objectively-measured PA values (29,192,197,198,232,235,236,238,242,260,410). In the review paper that looked at the relationship between self-reported and objectively-measured PA, correlations between the two measures were low to moderate (411), making it challenging to compare studies with the same objectives (e.g., exploring the association between BE features and PA) but different methods of PA measurement. It has been argued that the optimal approach would be to include both reported and objectively-measured total PA while also including domain-specific PA (232). Inconsistencies in study results can further be attributed to differences in the way PA values are categorized. Namely, some researchers present PA as a continuous variable (122,130,199), while others make it categorical – e.g., meeting vs. not meeting PA recommendations (82,233,274).

Regardless of whether PA was reported by study participants or objectively measured, the relationship between the neighbourhood BE environment and PA cannot be accurately tested if *the PA behaviour being measured is not limited to the neighbourhood* of interest. Studies asking residents to report on PA done only within their neighbourhood are scarce (74,214,223,230,243,245,267,286), and they differ in the type of PA being measured as well as their definition of neighbourhood, in addition to the discrepancy that exists, as previously mentioned, between researchers' and residents' definition of neighbourhood. Future studies exploring the relationship between the neighbourhood BE environment and PA of residents should clearly identify whether the PA measures collected were neighbourhood-related, and acknowledge the limitation if not. Assessing PA behavior specific to the neighbourhood people live in and standardizing the way PA is measured and reported may additionally significantly improve cross-study comparisons and draw more concrete conclusions that would inform policy.

Individual decision-making, residents' preferences, routines and social interactions are the additional drivers of the dynamic relationship between the BE and PA, but they are not well-explored. Neighbourhood environment questionnaires often ask for the estimated time it would take a person to walk to a certain BE feature; however, people are not asked whether they actually go to/visit/use a particular feature, and, if they do use it, which mode of transportation they opt for to reach the destination of interest. Furthermore, it is challenging to extract information from the current published data about the routes people decide to take to reach desired destinations and the circumstances that drive their decisions. For example, little is known about whether residents tend to choose routes that are aesthetically pleasing or one that gets them to the destination faster. Similarly, does an individual always take the same route to a certain destination, and what may nudge them to explore alternative routes or modes of transportation? For example, feeling unsafe from crime and traffic is often found to be associated with lower levels of PA (197,199,213,224,225), but less is known about what impacts the level of tolerance toward exposure to traffic or crime rate, and at which point would residents change their route or alter their daily routine?

Given that social networks are implicated as important correlates of health and health-related behaviours (412–414), more needs to be known about the role social networks play in the relationship between the BE and PA and to what extent these networks impact people's decision to engage in PA or alter their modes of transportation. Some BE questionnaires capture information on whether friends and relatives encourage exercise in the respondent, but it would be helpful to know whether this encouragement results in actual positive changes in PA behaviors. Furthermore, one's social network may change over time, so it would additionally be beneficial to know to what extent (if at all) these changes in the social environment impact a person's engagement in health-related behaviours.

1.8. Rationale

Physical inactivity, obesity and diabetes are risk factors for cardiovascular diseases that are the number one cause of death globally. The rapid increase in the prevalence of physical inactivity and incidence of obesity and diabetes in genetically stable populations implies an etiological role for environmental factors. Due to the limited success of individual lifestyle and pharmacological interventions to increase PA and decrease the prevalence of obesity and diabetes, new strategies are needed to prevent physical inactivity, obesity and diabetes at the population level. One such proposed strategy is the restructuring of built environments in which people live and work. The majority of research projects exploring the relationship between the BE and PA, obesity and diabetes done to date, predominantly outside of Canada, have been limited to the use of self-reported measures of obesity; the use of either perceived or objective BE measures; the assessment of the macro-environment; lack of investigation of metabolic risk factors and lack of consideration of distinct demographic and socio-economic groups when testing for differences in BE perceptions and when exploring the agreement between perceived and objective BE measures.

This project, aimed at addressing the above-mentioned limitations, is a cross-sectional study undertaken to explore the associations of perceived and objective BE measures with PA, adiposity and FBG in two distinct urban neighbourhoods. Furthermore, it investigates the differences in environmental perceptions and the agreement between perceived and objective BE features based on gender, income level and ethnicity. In addition, given that foreign research findings cannot readily be extrapolated to reflect the Canadian setting, this study will additionally offer a look into the relationship between health and the micro-environmental attributes of two urban settings within a Canadian context.

2. Study design and methods

This thesis is a cross-sectional study set to investigate the following objectives: 1) to explore whether the association between perceived and objectively measured BE features and PA is independent of individual level attributes (age, sex, income, education and ethnicity); 2) to explore whether the perception of BE features and the agreement between perceived and objective BE measures differ by gender, neighbourhood and individual income, and ethnicity; and 3) to explore whether the association of perceived and objectively measured BE features with adiposity, and FBG is independent of individual level attributes. Given that study participants are recruited from two areas (settings) differing by area income, the analyses to address the objectives 1 and 3 are additionally controlled for setting income.

This investigation is part of a larger study called the Prospective Urban Rural Epidemiology (PURE) study. The PURE study is an international longitudinal cohort study established to track lifestyle changes, risk factors, and chronic disease prevalence in urban and rural areas of seventeen countries (415). The Vancouver site of the PURE study is set in the Community Health Research Team (CoHeaRT) laboratory situated at the Simon Fraser University Harbour Centre Campus, Vancouver, British Columbia, Canada.

2.1. Hypotheses

2.1.1. Primary Hypothesis

1. Perceived and objective BE features are independently associated with PA beyond individual and neighbourhood demographic factors (age, sex, education, household income, ethnicity, and setting income). The association between the BE and PA is investigated for total PA, transportation PA, leisure PA and walking:

a) Perceived and objective BE features are associated with total PA independent of age, sex, education, household income, ethnicity, and setting income.

b) Perceived and objective BE features are associated with walking independent of age, sex, education, household income, ethnicity, and setting income.

c) Perceived and objective BE features are associated with transportation PA independent of age, sex, education, household income, ethnicity, and setting income.

d) Perceived and objective BE features are associated with leisure PA independent of age, sex, education, household income, ethnicity, and setting income.

2.1.2. Secondary Hypotheses

2. Perception of BE features and agreement between perceived and objective BE features differ by gender, setting and individual income, and ethnicity.

3. Perceived and objective BE features are independently associated with anthropometric measures (BMI, WC, WHR), %BF and FBG beyond individual and neighbourhood demographic factors (age, sex, education, household income, ethnicity, and setting income).

2.2. Study population

PURE study participants were recruited from various urban and rural communities internationally. The population for this study consists of a sub-group of individuals participating in the PURE study who were recruited from the Metro Vancouver. Recruitment was based on residence within 20 selected census tracts that varied in income and were categorized as: high- (> $75,000), middle- ($55,000 to $75,000), and low-income (< $55,000). As census tract data overlap with Canada Post forward sortation areas (FSAs, defined by first three digits of the postal code), these were used to define the communities and identify eligible households. The communities were selected to represent a range of urban and rural areas, income levels, and to facilitate mail-based recruitment.

All residents from each FSA were mailed an invitation letter and a brochure that explained more about the PURE study and the health assessments offered. The first set of mail-outs was sent to a subset of households whose first three digits of the postal code were V5X, V5V and V6J. These areas were in close proximity to the recruitment centre and purposely selected based on income level and feasibility. Two to four weeks after the initial mail-out, residents were contacted via telephone to assess their eligibility and interest in participating in the study. Up to six telephone calls were attempted before a household was listed as a non-responder. Individuals were eligible for the study if they were adults between the ages 35 and 70 years, fluent in either English or French (or had access to an interpreter), lived in one of the targeted communities and had plans to remain at their residence for at least the next four years. In total, 26 441 households were contacted, and 2754 participants were recruited for the study (response rate of 10.4%). Recruited participants were mailed the consent form and a set of questionnaires that assessed their socio-demographics, health-related behaviours and perceptions on neighbourhood BE features. Once at the research site, participants completed questionnaires and underwent an hour-and-a-half-long assessment. Prior to the assessment, research assistants ensured that the consent form was signed.

Participants eligible for this thesis project included men and women between the ages of 35 and 70 years who lived in one of two Vancouver postal code areas: V5X1 and V6J2. The median household incomes of V5X1 and V6J2 were less than $55,000 (low-income area) and more than $75,000 (high-income area), respectively. This study is based on a sample of convenience, and includes men and women from V5X1 and V6J2 areas recruited within a period of one year. These two areas were chosen because they were the first the mailout was sent to, facilitating convenience of recruitment, and represented both high- and low- income areas. Additional areas were not included at a later date to enable feasibility of direct environmental assessment. The components of the participant assessment relevant to this thesis project were the blood test, anthropometric measurements, the DEXA scan, and questionnaires that assessed participants' socio-demographics, PA and perception of the BE (Table 2). Men and women with physical limitations that impaired their ability to walk and pregnant women who were not permitted to undergo DEXA scans were excluded from the study.

Table 2. Assessment of participant and built environment characteristics

Demographics	Clinical assessment	Assessment of PA and BE features
Age Sex Education Ethnicity Household Income Area-level median household income	Height Weight Waist circumference Hip Circumference Percentage of body fat Fasting blood glucose	PA (International Physical Activity Questionnaire) Perceived BE features (Neighbourhood Environment Walkability Scale) Objective BE features (Irvine – Minnesota Inventory)

2.3. Assessment methods

2.3.1. Participant characteristics

2.3.1.1. Socio-demographics

Participants' socio-demographics were self-reported and included age (years), sex (female and male), education (none, primary, secondary/high school/higher secondary, trade school, and college/university), ethnicity (European and non-European), and household income (< \$20,000, \$20,000-\$30,000, \$30,001-\$45,000, \$45,001-\$65,000, \$65,001-\$90,000, and > \$90,000).

2.3.1.2. Physical activity

Levels of PA were estimated using the long version of the International Physical Activity Questionnaire (IPAQ), which assesses PA over the past seven days across four domains: job-related PA, transportation-related PA, housework- and house-maintenance-related PA, and recreation, sport, and leisure time PA (416). The IPAQ is an instrument developed to monitor population levels of PA, and its reliability and validity were tested in the diverse settings of 12 different countries. Test-retest reliability data has shown most Spearman correlation coefficients clustering around 0.8, indicating very good repeatability of the questionnaire (416). Furthermore, criterion validity of the IPAQ was tested against accelerometers, and fair to moderate agreement between the two measures was found (416).

The IPAQ assesses job-related PA by asking participants to record the number of days in the previous week when they did a) heavy activities, b) moderate activities and c) walking as part of their work, excluding walking to or from work. Transportation-related PA was assessed by asking how many days the person spent a) biking at least 10 minutes and b) walking for at least 10 minutes at a time to go from place to place. Questions related to housework and house maintenance PA asked participants to record the time spent doing vigorous and moderate home-oriented activities in the last seven days. Recreation, sport, and leisure-time walking was assessed by asking: "Not counting any walking you have already mentioned, during the last 7 days, on how many days did you walk for at least 10 minutes during your leisure time?" Similar questions were used to assess participants' moderate and vigorous leisure time activities in the previous 7 days. These questions required participants to record the number of days, hours and minutes they engaged in each type of PA.

Following the IPAQ guidelines for data processing (417), values in minutes of each type of PA were calculated and reported as continuous variables. Minutes per week for activities were multiplied by their corresponding MET value (METs; e.g. walking = 3.3 METs, moderate intensity = 4.0 METs, and vigorous intensity = 8.0 METs) to calculate MET-minutes per week (MET*min/wk) and, therefore, obtain an estimate of weekly energy expenditure. All activities within each domain were then summed to create the following MET*min/wk PA variables:

- Transportation PA (MET*min/wk) = 3.3 * walking for transportation (min) * walking days for transportation + 6 * cycling for transportation (min) * cycle days for transportation
- Leisure PA (MET*min/wk) = 3.3 * leisure walking (min) * walking days in leisure + 4.0 * leisure moderate PA (min) * moderate intensity days in leisure + 6 * leisure vigorous PA (min) * vigorous intensity days in leisure
- Total PA (MET*min/wk) = work-related PA (MET*min/wk) + transportation PA (MET*min/wk) + domestic-garden related PA (MET*min/wk) + leisure PA (MET*min/wk)
    - Work PA (MET*min/wk) = 3.3 * work walking (min) * walking days at work + 4.0 * work moderate PA (min) * moderate-intensity days at work + 8.0 * work vigorous PA (min) * vigorous-intensity days at work
    - Domestic-garden PA (MET*min/wk) = 5.5 * vigorous-intensity yard chores (min) *vigorous-intensity days doing yard work + 4.0 *

moderate-intensity yard chores (min) * moderate-intensity days doing yard work + 3.0 * moderate-intensity doing inside chores (min) * moderate-intensity days doing inside chores

- Total walking (MET*min/wk) = walking for work (MET*min/wk) + walking for transportation (MET*min/wk) + walking for leisure (MET*min/wk)

2.3.1.3. Adiposity measures

2.3.1.3.1. Anthropometry

Weight was measured with the participant barefoot and in minimal clothing with pockets emptied, and values were reported to the nearest 0.1 kg using a DRS, S/N:A01 255 weight scale (AmCells Corp.). Height was measured using a stadiometer (IPO955, Invicta Plastics Ltd, Leicester, UK) to the nearest 0.1 cm. The participant was barefoot, with their shoulder blades, gluteus and heels in contact with the stadiometer. Body mass index was calculated from weight in kilograms divided by height in square metres.

Waist circumference was measured at the smallest diameter between the costal margin and the iliac crest over the unclothed abdomen; a non-stretchable standard tape measure attached to a spring balance (Ohaus, Canada) exerting a force of 750g was used. Waist circumference was recorded at the end of normal expiration, and two measures were taken to the nearest 0.1 cm. The final value was calculated as the average of the two measures.

Hip circumference was measured over minimal clothing at the maximal gluteal diameter, determined from the lateral view. Two measures were recorded to the nearest 0.1 cm using a non-stretchable standard tape measure attached to a spring balance (Ohaus, Canada) exerting a force of 750g; the average of the two measures was used as the final value.

2.3.1.3.2. Percentage of body fat

The DEXA scan is the gold standard in bone density measurements, but it is also a widely-used method for measuring body composition in humans (418). It was used to assess participants' body fat in this study. Before the scan, participants were asked to remove jewellery and all clothes containing metal accessories such as underwire, zippers or metal buttons. While lying supine on the DEXA scanning bed, participants were asked to breathe normally and to stay in the same position, without moving, during the entirety of the scanning period. All scans were performed with the Hologic Discovery DEXA machine (Bedford, MA) using QRD software for Windows XP. The X-rays were generated underneath the scanning bed and projected upward, where detectors, located in the “C-arm”, converted the X-rays into electronic data viewable on the computer as a scan image. The actual scanning time lasted six to seven minutes. Body fat percentages were automatically calculated from total body fat in kilograms divided by total body mass in kilograms.

2.3.1.4. Blood glucose

Blood glucose was obtained the morning of the assessment after a 12-hour fast. The blood tube was centrifuged at 18°C and 3000 rpm for 15 minutes at the assessment site (Simon Fraser University, Vancouver, British Columbia), then taken to St. Paul’s Hospital laboratory (Vancouver, British Columbia) for final testing using the ADVIA 1650 Chemistry system Glucose Hexokinase II method. The method accuracy, as well as sufficiently low coefficient of variation, meets the criteria required by the Canadian Reference Foundation Laboratory. Participants’ glucose level results were mailed from St. Paul’s Hospital’s laboratory to the main study site.

2.3.2. Built environment features

2.3.2.1. Perceived built environment features

Perceived environmental features were assessed using the Neighbourhood Environment Walkability Scale (NEWS). Originally developed by Saelens and colleagues, NEWS is an instrument that includes self-report measures of neighbourhood environmental constructs previously hypothesized to influence PA (29,31). The test-retest reliability of NEWS neighbourhood environmental constructs was moderate to high (29). The questionnaire version used in the PURE study assesses the following categories of neighbourhood environmental characteristics: a) proximity to non-residential uses (land use mix-diversity); b) access to services; c) street connectivity; d) sidewalks as places for walking and cycling; e) aesthetics; f) pedestrian safety from traffic; g) safety from crime; and h) neighbourhood satisfaction. For the purposes of collecting perceived environmental measures, the creators of the NEWS defined a neighbourhood as an area within 10- to 15-minutes walking distance of a participant's home.

Land use mix-diversity was reported in the form of walking proximity from an individual's home to various non-residential destinations such as grocery and retail stores, restaurants, banks, pharmacies, transit stops and parks. Responses were grouped, and categories ranged from 1 to 5 minutes (coded as 5) to 31 or more minutes of walking distance (coded as 1). Higher scores on land use mix-diversity indicated shorter distances from respondent's home to various types of stores and facilities. For the purposes of this study the responses for each land use mix-diversity variable were dichotomized into categories 1-10 min (1-5 min and 6-10 min) and 11+ min (11-20 min, 21-30 min, 31+ min).

Responses to questions on neighbourhood features assessed within categories of access to services, street connectivity, sidewalks as places for walking and cycling, aesthetics, pedestrian safety from traffic and safety from crime were scaled from 1 (strongly disagree) to 4 (strongly agree). Lower scores indicated a less favourable value for the environmental characteristic, with the exception of questions related to the amount of traffic and crime rate in the neighbourhood, where lower scores were more favourable. For the purposes of this study, the responses 'strongly disagree' and 'somewhat disagree' were collapsed into 'disagree' category, while responses 'strongly agree' and 'somewhat agree' were merged into 'agree category'. Finally, participants' ratings of satisfaction with their neighbourhood were scaled from 1 (strongly dissatisfied) to 5 (strongly satisfied), with higher scores giving the environmental characteristic a more favourable value. For the purposes of this study, the responses for each satisfaction variable were joined together to create two categories: 'satisfied' (strongly satisfied and somewhat satisfied) and 'not satisfied' (somewhat dissatisfied, strongly dissatisfied and neither satisfied or dissatisfied).

2.3.2.2. Objective built environment features

2.3.2.2.1. Audit tool

Objective BE features were assessed using a modified version of the Irvine-Minnesota Inventory (IMI). The IMI is an audit tool that includes 160 BE features that may affect PA, and walking in particular. These BE items cover four domains:

accessibility (62 items), pleasurability (56 items), safety from crime (15 items), and safety from traffic (31 items) (59). The IMI includes both a paper version and a version in Microsoft Access to allow BE data to be entered into a computer directly. The main unit of assessment is a neighbourhood segment defined as the distance between two intersections (one block). The tool shows high inter-rater reliability for most objective BE items (419), and it was chosen for this project because of its ability to cover the greatest number and variety of BE features compared to other tools available at the time (420).

Prior to assessing neighbourhood BE features, a general environmental assessment was conducted by driving through the selected neighbourhoods. Considering that the IMI consists of over 160 items, the goal of the general assessment was to exclude the items that were not present in any of the neighbourhoods of interest. This resulted in the exclusion of the following items from the tool: ocean, river, canal, forest, mountains, desert, drainage ditches, harbor/marina, agricultural land, undeveloped land and impassable land.

Given that only one person was conducting the assessments (individual contributions to the project presented in the end of the methods section), all questions susceptible to rater subjectivity were also excluded from the audit tool. This is based on the fact that subjective ratings are influenced by previous walking experience and familiarity with the neighbourhood, and result in poor inter-rater reliability (60). Some examples of these questions include: “How safe do you feel walking in this area?”, “Rate the attractiveness of the area” and “What is the condition or maintenance of the sidewalk?”.

After the general assessment, preliminary assessments of several neighbourhood segments were performed using the modified IMI audit tool. The initial goal of the second assessment was to estimate the amount of time that would be required, per segment and for the entirety of both neighbourhoods, to complete audits in residential as well as commercial areas. In addition to this, this second step helped to further refine the audit tool. Namely, as many houses had high fences that hindered the ability to assess features such as front porches, garage doors, and the presence of bars on windows, these types of items were further excluded from the audit tool. The selection of responses to certain questions was also modified to make them more specific. For instance, the original responses to the question “Indicate how many bus stops are on the segment” were “some/a lot”, “few” and “none”. However, I was interested only in presence/absence of bus stops, so the answer choices were therefore simplified to “bus stop present” and “no bus stops present on the segment”. After all modifications, the final audit tool consisted of 122 items (Appendix A).

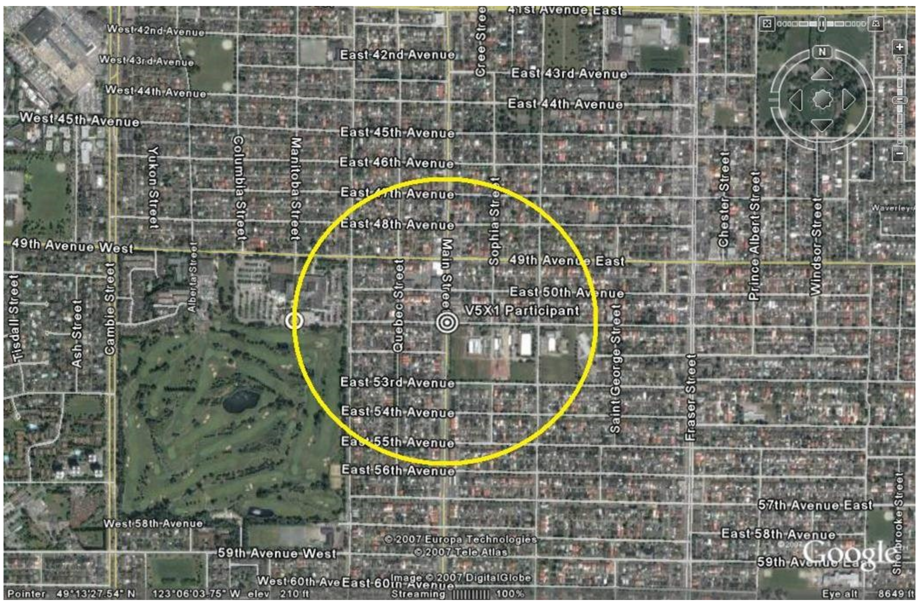

Figure 4. ***Participant’s neighbourhood defined as a 500m buffer around the participant’s residence***

2.3.2.2.2. Direct assessment of neighbourhood built environment features

Before carrying out the assessments, a participant neighbourhood needed to be defined. At present, there are no consistent spatial definitions of neighbourhoods; and the optimal buffer size has yet to be established (421). I considered a smaller buffer to better depict participants’ immediate surroundings because the purpose of this study was to explore the association between the immediate neighbourhood surrounding one’s home (micro-environment) and residents’ PA, adiposity and FBG. A 500-metre buffer was chosen, as it was estimated that this buffer size corresponds to a 5-minute walking distance from a person’s residence; suggesting that walking to and from the periphery would add to 10 minutes of walking, which is a small bout of the recommended daily level of PA participation (404). The choice of a 500-metre buffer also enabled a relatively good match between objective BE features and perceived measures. This match was important to test the correspondence between perceived and objective BE measures. Given that many of the participants lived in the same dwellings or very close to each other, a neighbourhood was defined as a 500-metre radius around each participant (Figure 4) or a cluster of participants living at a distance of no more than 50 metres from what was taken as the centre of the neighbourhood. After clustering participants in this way 117 unique neighbourhoods remained (52 in high- and 65 in low-income settings, as defined below). The total number of segments within each neighbourhood ranged from 60 to 130. Participants were geocoded using Yahoo! Geocoding API software (http://www.batchgeocode.com/), and neighbourhood boundaries (buffers) were made manually around participants using a Steadler compass.

The majority of participants lived close to each other, and their neighbourhoods largely overlapped. Therefore, to avoid assessing segments more than once, two large areas of assessment (settings) were outlined, one each for the high- and low-income census tracts that study participants were recruited from. Each area was roughly defined as a 500-meter buffer around the conglomerate of participants. To avoid incomplete neighbourhood buffers (332), settings were determined after one-year of participant recruitment (Figure 5). These high- and low-income settings would contain all high- and low-income individual (participant) neighbourhoods.

Before starting assessments, I trained myself on the proper use of the audit tool using existing IMI training materials (422). Detailed maps of each setting were obtained using Google Maps (http://maps.google.com), and each study segment was assigned a unique chronological identifier. A total of 749 segments in low-income and 881 segments in high-income settings were identified for auditing.

Direct assessment of BE features consisted of walking through each of the 1630 segments and coding the observations based on the modified IMI checklist. The audits were performed during daylight hours, while walking on the right side of the segment. If there were no sidewalks on the segment, the environmental assessment was conducted from the left side of the road to watch for oncoming traffic. The segment assessment time ranged from 5 minutes (for a purely residential segment) to 30 minutes (highly commercial segment).

To calculate intra-rater reliability, five percent of segments from each setting required re-auditing. A registered dietitian who was not part of the PURE research team and who did not live in the selected areas was given maps and asked to randomly draw routes containing 38 segments (5% of 749 segments) in the low income setting and 44 segments (5% of 881 segments) in the high income setting. Though the final routes consisted of 42 segments in the low income setting and 48 segments in the high income setting, slightly exceeding the required 5%, I reassessed all 90 segments.

Figure 5. High-income (green) and low-income (blue) settings (500-meter buffer around a conglomerate of recruited participants)

2.3.2.2.3. Handling objective built environment data

Data collected during the direct BE assessments were entered into an Access database. Although the IMI research group provides an Access database intended for their audit tool, I developed a new Access database to accommodate the modifications made to the tool. Data from this database were then exported to an Excel spreadsheet and coded according to the guidelines provided by the IMI research team (423). This main Excel spreadsheet contains environmental data from each segment collected from both high- and low-income settings.

In order to create neighbourhood-specific data for each of the 117 neighbourhoods, a separate Excel spreadsheet (117 spreadsheets in total) was created containing neighbourhood-specific segment numbers. Next, coded segment data from the main Excel spreadsheet were manually transferred to the corresponding neighbourhood-specific Excel spreadsheets. This allowed for the creation of summary statistics for audit BE features within each neighbourhood (Appendix B). Summary statistics were presented as frequencies (continuous variables), i.e., the percentage of segments in a participant's neighbourhood that have access to a feature of interest, such as recreational facilities. Each of the objective neighbourhood BE summary variables was connected to study participants in an outputted SPSS database. In addition, environmental data collected to explore for intra-rater reliability were entered into an Access database, transferred to an excel spreadsheet, coded and linked to the original data for each segment. Intra-rater reliability was explored using kappa statistics in SPSS. Considering the extensive manual labour required to transform and link the data, each of above-mentioned steps was rechecked at least twice for accuracy.

2.4. Statistical analyses

Participant characteristic data are presented as means and standard deviations (or median and interquartile ranges if data are not normally distributed) for continuous variables, and counts and percentages for categorical variables. The distribution of continuous variables was tested for normality using Kolmogorov-Smirnov and Shapiro-Walk tests and plotted in order to further explore the extent of data normality. Non-normally distributed variables (PA variables and FBG) were log transformed using the natural logarithm. Between-group comparisons of continuous variables were performed using independent t-tests, while Pearson Chi-square tests were used for comparison of categorical variables. The statistical significance level was set at a *p*-value of less than 0.05. All statistical tests were performed using the Statistical Package for Social Sciences (SPSS) version 19.

2.4.1. Primary hypothesis (Hypothesis 1)

The associations of perceived and objective environmental features with PA were initially tested using Spearman correlation analyses. Environmental measures shown to be significantly associated with PA were further tested for their independent relationship with distinct types of PA in multiple linear regression models adjusted for confounders known to be associated with PA, such as age (424,425), sex (426), household income (47), education (427), ethnicity (43,428), and setting income (429,430). Associations of confounders with PA outcomes are presented in Appendix C.

Before carrying out the regression analyses, perceived environment measures were converted into dichotomous variables (120,195). Objective environmental data were also entered into the regression models as dichotomous variables (access vs. no neighbourhood access to the BE feature) or as tertiles of access to the environmental feature. This is because the objective variables were highly skewed, and application of data transformations such as log, square root or reciprocal transformations did not correct the skew. Separate regression models were carried out for each perceived (120,195,199) and objective built environment feature (71). All regression models were also tested for multicollinearity. Variance inflation factors were well below 10 (431), while tolerance statistics were above 0.1 (432), indicating no multicollinearity in the data.

Post-hoc power analysis was performed using G*Power software (433). It was found that the effect size of 0.04 could be detected with a power of 80% for the given sample size (n = 356) at a significance level of 0.05. Therefore, these analyses were able to detect BE features that share 4% or more variance with PA. This is consistent with the literature, which has shown that environmental features can explain 4% or more of the variance in PA (191,209,213,247,434).

2.4.2. Secondary hypotheses

2.4.2.1. Hypothesis 2

Gender, neighbourhood and individual income, and ethnic differences in BE perceptions were explored using Chi-square tests. In cases where expected frequencies in any of the table cells were less than 5, Fisher’s exact test was used instead. Kappa statistics were used to assess the agreement between perceived and objective environmental measures. This agreement was further assessed across gender, ethnicity and individual and setting income. Kappa statistics of < 0.00, 0.00-0.20, 0.21-0.40, 0.41-0.60, 0.61-0.80, and 0.81-100 correspond to “poor”,” slight”, “fair”, “moderate”, “substantial”, and “almost perfect” strength of agreement, respectively (435).

Study participants reported their ethnicity by choosing from one of 18 pre-determined ethno-racial categories. The majority (58.9%) of individuals reported being of European origin, and 33.7% were of South Asian or East Asian origin, while the remaining 7.4% were individuals of Aboriginal, Latin American, African, or Hemitic origin. It has recently been reported that ethnic minorities, with the exception of Aboriginals, are more likely to report engaging in no PA and are less likely to engage in PA compared to individuals of European origin (42,43,436). However, compared to Europeans, Aboriginals are less likely to engage in endurance, recreational, and sports activities (43). Due to above-mentioned differences in PA engagement, and given the significant association between environmental perception and PA (195,215), all study participants were divided into Europeans and non-Europeans to explore the ethnic differences in perceptions. This approach also enabled greater power to detect the differences in environmental perceptions between the non-European and European groups.

2.4.2.2. Hypothesis 3

The association of perceived and objective environmental features with adiposity measures and FBG was tested using multiple linear regression models adjusted for age, sex, household income, education, ethnicity, and setting income. These confounders were chosen given their known associations with the study outcomes, adiposity measures (315,437–440) and blood glucose (441–443). Associations of confounders with adiposity measures and FBG are presented in Appendix D.

Before carrying out the regression analyses, Spearman correlation analyses between environmental features and adiposity measures and FBG were performed. The environmental measures that were significantly ($p<0.05$) correlated with adiposity measures and FBG were further used in linear regression analyses. Similar to steps for Hypothesis 1, perceived BE features were dichotomized and the objective ones were either dichotomized or presented in tertiles before performing linear regression analyses.

All regression models were also tested for multicollinearity; and variance inflation factors and tolerance statistics indicated no multicollinearity in the data.

2.4.2.3. Intra-rater reliability

Intra-rater reliability was assessed using both the percent agreement and kappa statistics.

2.4.2.4. Individual contributions to the study

Considering that a portion of this project relies on data collected as part of the PURE study, it is important to specify my contributions to the project.

1. Designed the study. It is important to note that direct assessment of the environment was not initially part of the PURE study, and has not been done in any of the sites within the 17 countries. I presented the design of my study, detailed methodology of direct assessment of the environment and some preliminary data at the PURE meeting in Florida, US (2008). It is then when, based on my proposal, it was decided that it would be valuable to add direct assessment of the environment as part of the PURE study.

2. Using the modified version of IMI, I directly assessed over 1700 street segments in the high- and low-income areas study participants were recruited from. Each segment I assessed for 122 built environment features which resulted in over 207,000 data points collected. I built an Access database and entered all collected BE data.

3. Using the Yahoo! Geocoding API software, I geocoded study participants and made neighbourhood boundaries (500-meter buffer around the participant's home) using a Steadler compass. To identify neighbourhood specific data (117 neighbourhoods), I created 117 separate Excel spreadsheets, one for each neighbourhood and created summary statistics for audit BE features. I, thereafter, linked objective BE summary variables to study participants in the SPSS database. Given the extensive

manual labour around the handling of the objective BE data, I rechecked each step at least twice for accuracy.

4. I performed all statistical analyses and interpretation specific to defined thesis hypotheses.

5. I performed clinical assessments of study participants and participated in the PURE clinical assessments until I personally assessed 356 people which corresponds to the number of participants included in this study. Clinical assessments I performed include the following:

    a. Blood drawing and laboratory work (centrifuging and pipetting the specimens and preparing them for transport to and further analyses in St. Paul's Hospital, Vancouver)

    b. Anthropometric measurements

    c. DEXA scan operation and scan analysis

    d. Administrative work related to clinical assessments such as confirming the participant appointments, preparing and later re-checking the questionnaires for their completeness.

6. I also assisted in PURE participant recruitment, data entry and re-checking of participants data.

3. Results

After one year recruitment, a total of 356 individuals were included in the study. Table 3 outlines baseline characteristics of study participants. Men and women from the low-income setting were on average younger, more likely to be of non-European origin, and with secondary-school-or-lower level of formal education, and had household incomes of $65,000 or less. Although no setting-based differences were observed for total PA levels and walking, participants from the high-income setting were more likely to engage in transportation and leisure PA compared to their counterparts from the low-income setting. In addition, the WHR average of participants from the low-income setting was higher than that of participants from the high-income setting, while no differences were noted in BMI, WC, %BF and blood glucose levels.

Table 3. Characteristics of study participants

Characteristic	Low-income setting n = 147	High-income setting n = 209	Significance (p)
Females	72 (49.0)	123 (58.9)	0.065
Age (years)	50.6 ± 9.2	53.0 ± 10.1	0.024
Education			< 0.001
Secondary and less	51 (34.7)	24 (11.5)	
Higher than secondary	96 (65.3)	185 (88.5)	
Household income*			0.016
≤ $ 65,000	66 (48.5)	70 (35.4)	
> $ 65,000	70 (51.5)	128 (64.6)	
Ethnicity**			< 0.001
European	38 (27.7)	163 (79.9)	
Non-European	99 (72.3)	41 (20.1)	
Total PA	2867 (1195, 7899)	3206 (1634, 5575)	0.581
Transportation PA	297 (66, 693)	445 (198, 1152)	0.002

Leisure PA	454 (66, 1431)	1188 (297, 2160)	< 0.001
Walking	792 (297, 1757)	1039 (446, 2277)	0.327
Body mass index (kg/m²)	26.1 ± 4.8	25.8 ± 4.5	0.559
Waist circumference cm)	83.9 ± 13.7	82.0 ± 12.8	0.189
Waist-to-hip ratio	0.85 ± 0.09	0.82 ± 0.09	0.003
Percent body fat	29.9 ± 8.5	29.1 ± 8.9	0.370
Blood glucose (mmol/L)	5.4 (5.1, 5.8)	5.3 (5.0, 5.6)	0.110

Categorical variables presented as n (%). Continuous variables presented as mean ± SD if normally distributed or median (25%, 75%) if non-normally distributed. PA – physical activity. Unit for PA variables is MET*min/week. *Household income was not reported by 11 participants in each of the settings. ** Ethnicity was not reported by 10 and 5 participants from low- and high-income settings, respectively.

The environmental perceptions of study participants are presented in Appendix E. About half of the participants reported having grocery stores, restaurants, pharmacies, and banks within a 5 to 10 minute walk from their residence. About 70% of participants reported having a park within a 5 to 10 minute walking distance, while about 90% reported having a transit stop within a 10 minutes or less walk. The majority reported short distances between intersections in their neighbourhoods (85.9%), many places to go within walking distance (85.6%) and getting to these places via alternative routes (90.6%). Almost all study participants agreed that sidewalks are present on most streets in their neighbourhoods (98.2%) and that these are well maintained (91.5%). The majority also reported living in neighbourhoods free from litter (85.9%), where trees give shade for sidewalks (94.1%), and with many interesting things to look at while walking (85.0%). While 53.8% of study participants reported not being satisfied with the amount and speed of traffic in their neighbourhood, about three quarters of participants did not find traffic along the street they live on or nearby streets as an obstacle to walking in their neighbourhoods. The majority also reported that their neighbourhood streets were well lit at night (88.9%), and they disagreed that crime rates in their neighbourhoods make it unsafe to go on walks during the day (94.4%) or the night (77.4%). Additionally, while 93.3% reported their neighbourhoods as good places to live, 43.1% were not satisfied with the number of people they know in the neighbourhood; and 34.1% did not perceive their neighbourhood as a good place to raise children.

While the high- and low-income settings did not differ in access to community centres, presence of lighting and block watch signs, significant differences were observed in a number of other objectively measured BE features (Table 4). Compared to the low-income setting, the high-income setting had higher residential density and vertical mix use, greater access to offices, services, and multiple amenities such as fitness centres, supermarkets, grocery stores, restaurants, banks, pharmacies, hotels, liquor stores, night clubs, bakeries, coffee shops, book shops, galleries, dining areas, and public washrooms. The high-income setting also had greater access to high schools, colleges/universities, parks, gardens, bike routes and bike racks; more street segments were marked for safe pedestrian crossing, and had sidewalks present on both sides of the street. However, compared to the low-income setting, there was a greater presence of litter and graffiti in the high-income setting.

Compared to the high-income setting, the low-income setting had lower residential density, greater access to elementary schools, playgrounds, playing fields, religious institutions, drive-through service, convenience stores, golf course and bus stops. It also had more stop and speed limit signs, and speed bumps. Segments were steeper compared to those in the high-income setting and had a greater presence of trees.

Table 4. Objective built environment features in high- and low- income settings

Objective built environment feature	**Low-income setting n = 147**	**High-income setting n = 209**	**p value**
Monuments and markers (%)	0.0 (0.0, 1.0)	0.0 (0.0, 0.0)	< 0.001
Places marked for pedestrian crossing (%)	14.2 (12.2, 15.0)	39.5 (31.5, 43.1)	< 0.001
White lines (%)	11.5 (10.1, 13.5)	30.5 (20.9, 37.1)	< 0.001
Zebra (%)	1.9 (0.7, 3.0)	3.8 (3.4, 4.8)	< 0.001
Different road (%)	0.0 (0.0, 0.0)	0.0 (0.0, 2.3)	< 0.001
Curbcuts (%)	73.6 (70.8, 79.6)	82.3 (74.8, 89.7)	< 0.001

Traffic light (%)	9.6 (7.4, 11.9)	28.1 (17.1, 33.8)	< 0.001
Stop sign (%)	92.9 (89.9, 94.4)	74.8 (71.6, 79.0)	< 0.001
Yield sign (%)	0 (0.0)	0.9 (0.5, 1.0)	< 0.001
Activated signal (%)	6.0 (4.8, 8.6)	16.3 (9.7, 19.6)	< 0.001
Crossing sign (%)	2.9 (2.0, 4.3)	4.5 (3.8, 5.5)	< 0.001
Overpass/underpass (%)	0 (0.0)	0 (0.0)*	< 0.001
Streetway (one, two way) (%)	100.0 (99.0, 100.0)**	100.0 (99.0, 100.0)	0.001
Lanes two and up (%)	24.3 (20.2, 27.8)	35.2 (28.6, 44.6)	< 0.001
Single family home – detached (%)	98.6 (97.3, 98.8)	53.5 (37.5, 70.6)	< 0.001
Single family home – duplex (%)	7.4 (4.8, 9.5)	18.8 (11.5, 21.5)	< 0.001
Condo (%)	9.5 (6.1, 12.7)	70.2 (48.2, 80.0)	< 0.001
Elementary school (%)	4.9 (3.1, 5.7)	2.8 (1.0, 2.9)	< 0.001
High school (%)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)*	< 0.001
University/college (%)	0.0 (0.0, 0.0)	2.7 (0.9, 3.0)	< 0.001
Park (%)	2.7 (2.2, 4.8)	3.9 (3.6, 4.8)	< 0.001
Playground (%)	6.7 (4.9, 8.1)	3.6 (2.8, 3.8)	< 0.001
Playing fields (%)	3.6 (2.4, 5.8)	1.9 (1.1, 2.9)	< 0.001
Garden (%)	0.0 (0.0, 0.0)	0.0 (0.0, 0.9)	< 0.001
Landscaped open space n (%)	0.0 (0.0, 0.0)	1.9 (0.0, 4.7)	< 0.001
Gym, fitness centre n (%)	0.0 (0.0, 0.0)	3.6 (1.8, 4.8)	< 0.001
Community centre	1.6 (0.0, 2.7)	1.8 (1.0, 2.1)	0.671
Post office	0.0 (0.0, 0.0)	3.0 (1.2, 3.9)	< 0.001
Religious institution	7.9 (5.8, 14.1)	7.7 (5.8, 9.3)	0.003
Hospital	3.7 (2.4, 6.2)	9.1 (4.6, 11.5)	< 0.001

Supermarket	0.0 (0.0, 0.0)	0.0 (0.0, 0.9)	< 0.001
Grocery store	1.6 (1.2, 3.2)	1.0 (0.0, 1.9)	< 0.001
Convenience store	2.7 (1.4, 4.1)	1.9 (0.9, 3.6)	< 0.001
Retail stores	2.9 (1.2, 7.8)	15.2 (7.1, 19.0)	< 0.001
Bank	0.0 (0.0, 2.0)	4.8 (1.9, 9.1)	< 0.001
Hotel	0.0 (0.0, 0.0)	0.9 (0.8, 1.0)	< 0.001
Car dealership	0.0 (0.0, 0.0)	0.0 (0.0, 2.8)	< 0.001
Gas station	0.0 (0.0, 0.0)	1.9 (0.9, 2.8)	< 0.001
Offices	1.4 (1.2, 2.5)	9.5 (3.7, 15.9)	< 0.001
Services	5.1 (2.5, 7.5)	17.1 (10.1, 25.0)	< 0.001
Industrial	0.0 (0.0, 2.4)	2.8 (0.0, 4.5)	< 0.001
Vertical mix use	4.1 (2.5, 6.3)	9.5 (6.1, 16.3)	< 0.001
Big box shop	0.0 (0.0, 0.0)	1.8 (0.9, 1.9)	< 0.001
Drive through	0.0 (0.0, 0.0)**	0.0 (0.0, 0.0)	0.007
Night club	0.0 (0.0, 0.0)	0.9 (0.0, 1.9)	< 0.001
Adult uses	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)*	< 0.001
Liquor store	0.0 (0.0, 0.0)	0.9 (0.0, 1.0)	< 0.001
Restaurant	2.9 (1.4, 5.3)	9.7 (5.4, 14.2)	< 0.001
Bakery	0.0 (0.0, 1.0)	2.8 (1.8, 3.7)	< 0.001
Coffee shop	0.0 (0.0, 2.1)	4.5 (1.8, 6.8)	< 0.001
Meat shop	1.2 (0.0, 1.4)	0.0 (0.0, 1.0)	< 0.001
Library/book store	0.0 (0.0, 0.0)	1.2 (0.0, 4.7)	< 0.001
Art/craft gallery	0.0 (0.0, 1.0)	2.0 (0.9, 4.0)	< 0.001
Movie theatre	0.0 (0.0, 0.0)	0.9 (0.9, 1.0)	< 0.001
Pharmacy	0.0 (0.0, 2.5)	1.8 (0.4, 2.9)	< 0.001
Video store	2.4 (0.0, 4.1)	1.0 (0.9, 1.9)	0.145

Golf course	0.0 (0.0, 0.0)**	0.0 (0.0, 0.0)	0.017
Sidewalks on both sides of the street	68.5 (63.0, 75.0)	97.0 (93.9, 98.6)	< 0.001
Buffer between street and sidewalk	91.0 (88.7, 92.7)	97.1 (95.6, 98.1)	< 0.001
Awnings	1.6 (0.0, 3.7)	2.9 (0.0, 5.7)	0.024
Dining area	0.0 (0.0, 0.0)	0.0 (0.0, 1.0)	< 0.001
Benches	0.0 (0.0, 2.5)	3.4 (1.0, 4.1)	< 0.001
Bike racks	0.0 (0.0, 0.0)	3.4 (1.8, 4.7)	< 0.001
Public washroom	0.0 (0.0, 0.0)	1.0 (0.9, 1.0)	< 0.001
Bus stop present	11.9 (8.9, 14.5)	7.8 (6.7, 9.5)	< 0.001
Bike route	2.6 (0.0, 8.4)	15.1 (9.3, 21.2)	< 0.001
Steepness	20.3 (11.5, 31.4)	11.0 (9.6, 16.2)	< 0.001
Trees	74.0 (67.9, 79.2)	68.2 (60.6, 75.5)	< 0.001
Midblock crosswalk	0.0 (0.0, 1.2)	0.0 (0.0, 0.9)	< 0.001
Speed limit	9.6 (7.5, 12.8)	6.3 (4.0, 6.8)	< 0.001
Speed bumps	5.1 (7.5, 12.8)	1.0 (0.9, 1.0)	< 0.001
Traffic circle	2.5 (0.0, 10.0)	17.5 (9.4, 23.4)	< 0.001
Median	0.0 (0.0, 0.0)	1.9 (0.0, 2.9)	< 0.001
Street parking	95.8 (93.3, 97.5)	91.1 (89.5, 92.4)	< 0.001
Cul-de-sac	0.0 (0.0, 0.0)	0.0 (0.0, 0.9)	< 0.001
Curbs	86.9 (83.3, 91.0)	100 (100, 100)	< 0.001
Lighting	100 (100, 100)	100 (100, 100)	0.091
Graffiti	2.08, 0.0, 3.7	2.9 (1.0, 4.7)	< 0.001
Litter	47.6 (39.1, 56.8)	76.9 (67.1, 83.2)	< 0.001
Block watch	3.8 (2.5, 6.7)	3.7 (2.1, 5.3)	0.058

Variables, given as median (25%, 75%), present a percent of setting street segments with access to a BE feature of interest. Differences explored by Mann-Whitney U test. *higher in high-income setting; **higher in low-income setting.

3.1. Association between built environment features and physical activity

3.1.1. Perceived built environment features and physical activity

Table 5 presents the correlations between perceived BE features and PA. A limited number of perceived environmental features were correlated with total PA. Perceived presence of grass/dirt strip between streets and sidewalks, safety from threat of crime, traffic volume and perception of neighbourhood streets being well lit at night were positively correlated with total PA. The latter perceived BE feature as well as perceiving greater traffic volume on nearby streets, short distance between intersections and stores within walking distance were also positively correlated with transportation PA and walking. Perceived shorter distances to grocery and retail stores, restaurants and pharmacies, and perceiving interesting things to look at while walking, were associated with higher levels of both transportation and leisure PA. Leisure PA was also positively correlated with greater access to fruit and vegetable stores and banks, and with perceiving neighbourhood being generally free from litter. Furthermore, shorter distances to parks were negatively, while perceiving that most of shopping can be done at local stores and many alternative routes for getting from place to place were positively associated with transportation PA. In addition, perceiving many places to go within walking distance, and neighbourhood satisfaction with access to entertainment and the safety from threat of crime were positively associated with transportation PA, leisure PA and walking. However, these PA domains were negatively correlated with perceived neighbourhood crime rate that made walking unsafe at night.

All perceived BE features that were found to be correlated with PA (total, transport, leisure and walking) were further carried into multiple linear regression models adjusted for age, sex, formal level of education, household income, ethnicity and setting income. A model with age, sex, formal level of education, household income, ethnicity and setting income explained the 3.5%, 10.7%, 11.1% and 2.5% variability in total PA, transportation PA, leisure PA and walking, respectively. Perceived environmental measures additionally explained from 1.6% to 2.0% of variability in PA (Appendix F).

Table 5. Correlations between perceived built environmental features and physical activity

Perceived BE feature	Total PA ρ	Transport PA ρ	Leisure PA ρ	Walking ρ
Land use mix				
Time to walk from home to:				
Buy groceries	0.022	0.123*	0.132*	0.033
Buy clothes	0.044	0.124*	0.193***	0.076
Buy fruits and vegetables	0.023	0.097	0.136*	0.002
Restaurant	0.018	0.156**	0.143**	0.066
Bank	0.011	0.074	0.121*	0.024
Video store	0.084	0.150**	0.100	0.075
Buy medicine	0.024	0.114*	0.119*	0.050
Bus stop	0.063	0.029	0.052	0.007
Park	-0.040	-0.109*	0.081	-0.086
Access to services				
I can do most of shopping at local stores.	0.014	0.146**	0.096	0.103
Stores are within walking distance.	0.052	0.191***	0.107	0.159**
There are many places to go within walking distance.	0.044	0.192***	0.118*	0.137*
It is easy to walk to a bus stop.	0.010	0.126*	-0.010	-0.034
Streets in my neighbourhood				
The distance between intersections is short.	-0.010	0.140*	0.062	0.109*
There are many 4-way intersections in the neighbourhood.	-0.096	0.046	-0.012	-0.021
There are many alternative routes for getting from place to place.	0.007	0.115*	0.096	0.054
Places for walking and cycling				
There are sidewalks on most of the streets.	0.031	0.053	0.063	-0.002
The sidewalks are well maintained.	-0.023	-0.022	0.033	0.027
There is a grass/dirt strip between streets and sidewalks.	0.110*	0.023	0.071	0.039
Neighbourhood surroundings				
Trees give shade for the sidewalks.	0.033	-0.005	0.032	0.002
There are many interesting things to look at while	0.057	0.137*	0.192***	0.095

walking.				
My neighbourhood is generally free from litter.	0.020	0.072	0.167**	0.064
Safety from traffic				
There is so much traffic along the street I live on.	0.109*	0.099	-0.022	0.101
There is so much traffic along nearby streets.	0.135*	0.124*	-0.008	0.134*
The crosswalks help walkers feel safe.	0.021	0.024	0.047	0.067
Safety from crime				
My streets are well lit at night.	0.166**	0.143**	0.091	0.159**
Crime rate makes it unsafe to walk during the day.	-0.002	-0.031	-0.086	-0.039
Crime rate makes it unsafe to walk at night.	-0.080	-0.144**	-0.125*	-0.135*
Neighbourhood satisfaction				
The access to public transportation	-0.033	0.095	0.006	0.067
Commuting time to work/school	0.009	-0.007	0.024	0.004
Access to shopping	-0.004	0.103	0.065	0.039
The number of people you know	0.040	-0.063	-0.048	-0.029
How easy and pleasant is to walk in the neighbourhood	0.003	0.048	0.074	0.065
Access to entertainment	0.001	0.140*	0.185**	0.135*
The safety from threat of crime	0.127*	0.142**	0.174**	0.206***
The amount and speed of traffic	-0.029	-0.068	0.001	0.052
Your neighbourhood as a good place to raise children	0.041	-0.039	-0.064	0.049
Your neighbourhood as a good place to live	-0.040	0.041	0.079	0.039

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; PA – physical activity, BE – built environment, ρ – Spearman correlation coefficient

Perceived BE features significantly associated with different types of PA after adjustment for age, sex, formal level of education, household income, ethnicity and setting income are presented in Table 6. Of significance, study participants who perceived high traffic volumes in their neighbourhood as an obstacle to walking were found to engage in less transportation PA ($p = 0.009$), walking ($p = 0.011$) and total PA ($p = 0.011$) compared to their counterparts who reported that traffic on nearby streets did not hinder their walking. Participants who reported the presence of a grass/dirt strip between roads and sidewalks in their neighbourhood had lower total PA levels than those who disagreed with the statement ($p = 0.032$). Transportation PA was higher for individuals who reported having a restaurant within a 10-minute walk from home versus those who reported longer walking times to restaurants (p = 0.027). The mean leisure PA of people who perceived having many interesting things to look at while walking in the neighbourhood was found to be significantly lower compared to those who did not perceive it (p = 0.022). On the other hand, being satisfied with access to entertainment in the neighbourhood was associated with higher leisure PA (p = 0.017). Finally, walking rates were lower among people who reported having stores within walking distance compared to their counterparts who disagreed that there were stores within walking distance of their home (p = 0.011).

Table 6. Perceived built environment features associated with physical activity

Total PA B (95%CI) (p value)	**Transportation PA B (95%CI) (p value)**	**Leisure PA B (95%CI) (p value)**	**Walking B (95%CI) (p value)**
Grass/dirt strip between streets and sidewalk	Time to walk to a restaurant:	Many interesting things to look at while walking	Stores are within walking distance
Agree vs. Disagree	≤10min vs. 11+min	Agree vs. Disagree	Agree vs. Disagree
-0.385 (-0.606, -0.042)*	0.912 (0.079, 2.387)*	-0.637 (-0.847, -0.134)*	-0.482 (-0.717, -0.049)*
So much traffic along nearby streets	So much traffic along nearby streets	Access to entertainment	So much traffic along nearby streets
Agree vs. Disagree	Agree vs. Disagree	Satisfied vs. Not satisfied	Agree vs. Disagree
-0.374 (-0.564, -0.101)*	-0.544 (-0.747, -0.179)**	1.408 (0.169, 3.963)*	-0.470 (-0.674, -0.137)*

* $p < 0.05$, ** $p < 0.01$; PA – physical activity; BE – built environment. Dependent variable: ln PA; Independent variable of interest: perceived environmental measure; All models adjusted for age, sex, household income, formal level of education, ethnicity and setting income. B (95%CI): Unstandardized regression coefficient (95 percent confidence interval) presented as $e^b - 1$ to enable the interpretation of PA in its original units (MET*min/week). Interpretation of B: $100*(e^b - 1)$ = % change in PA for 1 unit difference in BE feature (e.g. % difference in PA between Agree and Disagree categories).

3.1.2. Objective built environment features and physical activity

Table 7 presents the correlations between objective BE features and PA (total, transport, leisure and walking). None of the objective BE features were correlated with total PA. All three domains of PA were positively correlated with access to places marked for pedestrian crossing, white lines, traffic lights, duplex houses and condos, sidewalks and buffers between streets and sidewalks, gym/fitness centres, supermarkets, offices, liquor stores and bakeries; while they were negatively correlated with presence of single family homes, stop signs and playing fields. Several BE features were positively correlated with transportation PA and walking but not with leisure PA. These include: presence of zebra crossings, curbcuts, pedestrian activated signals, hospitals, retail stores, services, vertical mix use, night clubs, restaurants, and litter. Features positively correlated with transportation PA and leisure PA but not with walking include presence of yield signs, traffic circles, curbs, bike routes, hotels, movie theatres, gas stations, and industrial features; these PA domains were negatively associated with presence of speed bumps. Some BE features were associated with transportation PA but not with other domains. These include: presence of crossing signs, streets with two lanes or more, universities/colleges, gardens, landscaped open spaces, post offices, banks, car dealerships, big box shops, art/craft galleries, awnings, dining areas, benches, bike racks, and graffiti that were positively correlated with transportation PA, while presence of trees was negatively correlated with transportation PA. Similarly, features correlated only with leisure PA include presence of elementary schools, playing fields, grocery stores, meat shops, bus stops, midblock crosswalks, posted speed limit, and street parking. These were negatively correlated with leisure PA; while presence of cul-de sacs was positively correlated with leisure PA.

All objective BE features found to be correlated with PA domains were further carried into multiple linear regression models adjusted for age, sex, formal level of education, household income, ethnicity and setting income. A model with age, sex, formal level of education, household income, ethnicity and neighbourhood income explained 3.5%, 10.7%, 11.1% and 2.5% of the variability in total PA, transportation PA, leisure PA and walking, respectively. Objective environmental measures additionally explained from 0.7% to 3.8% of variability in PA (Appendix G).

Table 7. Correlations between objective built environment features and physical activity

Objective BE feature	**Total PA** ρ	**Transport PA** ρ	**Leisure PA** ρ	**Walking** ρ
Monuments and markers	-0.093	-0.086	-0.035	-0.078
Places marked for	-0.011	0.259***	0.119*	0.142**

pedestrian crossing				
White lines	-0.028	0.261***	0.140*	0.131*
Zebra	0.014	0.203***	0.047	0.124*
Different road	-0.010	0.078	0.155**	0.071
Curbcuts	-0.007	0.181**	0.050	0.116*
Traffic light	-0.014	0.258***	0.132*	0.126*
Stop sign	0.046	-0.227***	-0.131*	-0.127*
Yield sign	-0.022	0.161**	0.192***	0.094
Activated signal	0.031	0.243***	0.049	0.127*
Crossing sign	-0.030	0.152**	0.023	0.101
Overpass/underpass	-0.020	0.070	0.035	0.018
Streetway (one, two way)	0.066	0.031	-0.030	0.044
Lanes two and up	-0.018	0.241***	0.101	0.100
Single family home - detached	0.037	-0.253***	-0.152**	-0.126*
Single family home - duplex	-0.014	0.230***	0.195***	0.133*
Condo	-0.002	0.248***	0.119*	0.139*
Elementary school	0.074	-0.031	-0.154**	-0.024
High school	0.077	0.014	0.050	0.035
University/college	-0.058	0.173**	0.092	0.069
Park	-0.002	0.089	0.010	0.080
Playground	0.028	-0.089	-0.204***	-0.034
Playing fields	-0.002	-0.139*	-0.196***	-0.115*
Garden	0.078	0.115*	0.055	0.046
Landscaped open space	-0.009	0.205***	0.064	0.097
Gym, fitness centre	0.006	0.223***	0.156**	0.125*
Community centre	-0.037	0.084	0.004	0.030

Post office	-0.001	0.201***	0.102	0.106
Religious institution	0.050	0.094	-0.081	0.062
Hospital	0.014	0.233***	0.073	0.127*
Supermarket	0.059	0.159**	0.144**	0.122*
Grocery store	-0.068	-0.041	-0.120*	-0.059
Convenience store	-0.059	0.025	-0.071	-0.042
Retail stores	-0.005	0.225***	0.106	0.120*
Bank	-0.001	0.176**	0.068	0.085
Hotel	-0.044	0.131*	0.134*	0.061
Car dealership	0.037	0.181**	0.042	0.102
Gas station	-0.001	0.147**	0.122*	0.066
Offices	0.013	0.240***	0.107*	0.133*
Services	0.012	0.250***	0.095	0.133*
Industrial	0.019	0.150**	0.134*	0.086
Vertical mix use	0.003	0.246***	0.032	0.126*
Big box shop	-0.036	0.199***	0.067	0.090
Drive through	-0.076	-0.033	-0.041	-0.042
Night club	0.003	0.277***	0.098	0.131*
Adult uses	-0.082	0.055	-0.017	-0.018
Liquor store	0.030	0.240***	0.145**	0.172**
Restaurant	-0.011	0.243***	0.083	0.119*
Bakery	0.011	0.242***	0.131*	0.132*
Coffee shop	0.007	0.202***	0.041	0.100
Meat shop	-0.023	-0.044	-0.142**	-0.037
Library/book store	-0.035	0.190***	0.079	0.095
Art/craft gallery	-0.020	0.178***	0.058	0.066

Movie theatre	-0.017	0.139*	0.160**	0.079
Pharmacy	-0.010	0.092	-0.078	0.032
Video store	0.031	0.088	-0.047	0.043
Golf course	-0.061	-0.064	-0.013	-0.085
Sidewalks on both sides of the street	0.008	0.231***	0.209***	0.126*
Buffer between street and sidewalk	0.032	0.217***	0.229***	0.129*
Awnings	-0.014	0.166**	-0.027	0.067
Dining area	-0.019	0.136*	0.054	0.062
Benches	-0.027	0.182**	0.075	0.087
Bike racks	-0.019	0.237***	0.105	0.103
Public washroom	-0.061	0.014	0.026	0.019
Bus stop present	-0.014	-0.031	-0.154**	-0.052
Bike route	-0.052	0.167**	0.141**	0.077
Steepness	0.002	-0.030	-0.103	-0.032
Trees	0.018	-0.132*	0.038	-0.058
Midblock crosswalk	0.027	-0.082	-0.144**	-0.043
Speed limit	-0.007	-0.013	-0.166**	-0.010
Speed bumps	-0.029	-0.150**	-0.223***	-0.078
Traffic circle	-0.020	0.123*	0.153**	0.085
Median	0.021	0.060	0.076	-0.002
Street parking	0.033	-0.047	-0.182**	0.036
Cul-de-sac	-0.017	0.091	0.118*	0.031
Curbs	-0.010	0.149**	0.208***	0.060
Lighting	0.051	-0.068	0.001	-0.050
Graffiti	-0.086	0.150**	0.049	0.039

Litter	0.029	0.251***	0.092	0.156**
Block watch	-0.021	0.044	0.005	0.069

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; PA – physical activity, BE – built environment, ρ – Spearman correlation coefficient

Objective BE features found to be significantly associated with transportation PA, leisure PA and walking after adjustment for confounders are presented in Tables 8, 9, and 10, respectively. Of the features that were significantly associated with PA, the majority were related to transportation PA (24 features), followed by walking (10 features), and only 4 objective BE features were associated with leisure PA. No objective BE features were significantly associated with total PA.

Transportation PA was found to be higher among people living in neighbourhoods with higher residential density compared to their counterparts from neighbourhoods with lower residential density (neighbourhoods with more duplex homes, $p = 0.010$; neighbourhoods with more condominiums, $p = 0.015$). Furthermore, greater safety from traffic, reflected in more segments marked for pedestrian crossing ($p < 0.001$), the presence of traffic lights ($p = 0.003$) and pedestrian-activated crossing signals ($p = 0.013$), was associated with higher levels of transportation PA. Moreover, transportation PA of residents living in neighbourhoods where the majority of street segments had sidewalks was higher than that of people from neighbourhoods with low prevalence of segments with sidewalks ($p = 0.007$). Additionally, transportation PA levels were higher among participants living in neighbourhoods with higher vertical mix use ($p = 0.009$) and in ones that contained a variety of features such as service-oriented businesses (0.001), retail stores ($p = 0.015$), car dealerships (0.021), big box shops ($p = 0.013$), hospitals ($p = 0.021$), restaurants (0.001), liquor stores (0.012), and landscaped open spaces ($p = 0.007$). The presence of bike racks ($p = 0.004$) and litter ($p = 0.026$) were also positively associated with transportation PA, but living in neighbourhoods with a bike route ($p = 0.029$), trees ($p = 0.022$), and stop signs ($p = 0.001$) was associated with lower transport PA.

Table 8. Objective built environment features associated with transportation physical activity

Transportation PA **B (95%CI)**			
Places marked for pedestrian crossing T3 vs. T1 4.409 (1.197, 12.316)***	Car dealership Present vs. not present 1.241 (0.131, 3.442)*	White lines at the street crossing T3 vs. T1 2.959 (0.553, 9.105)**	Pedestrian crossing activated signal T3 vs. T1 1.784 (0.237, 5.259)*
Vertical mix use T3 vs. T1 1.563 (0.261, 4.207)**	Stop sign T2 vs. T1 -0.678 (-0.839, -0.357)**	Big box shops Present vs. not present 1.537 (0.215, 4.296)*	Services T3 vs. T1 2.463 (0.614, 6.426)**
Night club Present vs. not present 1.425 (0.213, 3.855)*	Liquor store Present vs. not present 1.705 (0.241, 4.900)*	Hospital T3 vs. T1 1.368 (0.142, 3.914)*	Restaurant T3 vs. T1 2.751 (0.674, 7.398)**
Single-family home detached T2 vs. T1 -0.600 (-0.800, -0.201)*	Single-family home duplex T2 vs. T1 1.445 (0.236, 3.836)*	Condo T3 vs. T1 2.589 (0.284, 9.034)*	Retail stores T3 vs. T1 1.593 (0.202, 4.601)*
Bike route Present vs. not present -0.569 (-0.797, -0.084)*	Bike racks Present vs. not present 2.228 (0.468, 6.099)**	Trees T2 vs.T1 -0.538 (-0.761, -0.108)*	Litter T3 vs.T1 1.959 (0.143, 6.660)*
Traffic light T2 vs. T1 1.102 (0.013, 3.358)*	Streets with 2 or more lanes T2 vs. T1 1.036 (0.070, 2.869)*	Sidewalks on both sides T2 vs. T1 1.635 (0.516, 5.417)*	Landscaped open space Present vs. not present 1.606 (0.294, 4.249)**
T3 vs. T1 3.116 (0.645, 9.299)**	T3 vs. T1 1.764 (0.241, 5.160)*	T3 vs. T1 3.433 (0.516, 611.164)**	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; BE – built environment, PA – physical activity. Associations explored by multiple linear regression analysis. Dependent variable: ln transportation PA; Independent variable: objective environmental measure; All models adjusted for age, sex, household income, formal level of education, ethnicity and setting income. B (95%CI): Unstandardized regression coefficient (95 percent confidence interval) presented as $e^b - 1$ to enable the interpretation of PA in its original units (MET*min/week). Interpretation of B: $100*(e^b - 1)$ = % change in transport PA for 1 unit difference in BE feature (e.g. % difference in transport PA between Present and Not present categories). T1-T3: tertiles of access to a BE feature (T1=lowest tertile, T3=highest tertile).

Similar to transportation, leisure PA of individuals living in neighbourhoods with a higher residential density was higher compared to their counterparts from lower-density neighbourhoods (p = 0.017). Furthermore, higher levels of leisure PA were observed among those living in neighbourhoods with more stop signs (p = 0.048), less midblock crosswalks (p = 0.042), and with a greater number of segments containing buffers that divide sidewalks from roads (p = 0.015).

Table 9. Objective built environment features associated with leisure physical activity

Leisure PA B (95%CI)			
Stop sign T3 vs. T1 2.086 (0.011-9.422)*	Single family home duplex T2 vs. T1 1.507 (0.182, 4.312)*	Buffer between street and sidewalk T2 vs. T1 2.007 (0.240, 6.294)* T3 vs. T1 2.770 (0.290, 10.012)*	Midblock crosswalk Present vs. not present -0.452 (-0.694, -0.021)*

* p < 0.05; BE – built environment, PA – physical activity. Associations explored by multiple linear regression analysis. Dependent variable: ln leisure PA; Independent variable: objective environmental measure; All models adjusted for age, sex, household income, formal level of education, ethnicity and setting income. B (95%CI): Unstandardized regression coefficient (95%CI) presented as $e^b - 1$ to enable the interpretation of PA in its original units (MET*min/week). Interpretation of B: 100*($e^b - 1$) = % change in leisure PA for 1 unit difference in BE feature (e.g. % difference in leisure PA between Present and Not present categories). T1-T3: tertiles of access to a BE feature (T1=lowest tertile, T3=highest tertile).

Living in neighbourhoods with more marked pedestrian crosswalks (p = 0.007), pedestrian-activated crossing signals (p = 0.005) and sidewalks on both sides of the street (p = 0.044) was found to be associated with higher levels of walking. Furthermore, greater access to restaurants (p = 0.033), services (p = 0.030), liquor stores (p = 0.002), and more litter (p = 0.030) in the neighbourhood was also associated with greater levels of walking. On the other hand, walking was found to be lower among people living in neighbourhoods with greater access to playing fields (highest vs. lowest tertile of access, p = 0.041) and stop signs (p = 0.017).

Table 10. Objective built environment features associated with walking

Walking B (95%CI)			
Places marked for pedestrian crossing T2 vs. T1 1.259 (0.255, 3.071)** T3 vs. T1 2.777 (0.790, 6.980)**	White lines at the street crossing T2 vs. T1 1.104 (0.135, 2.900)* T3 vs. T1 1.354 (2.111, 39.402)*	Playing fields T2 vs. T1 -0.431 (-0.661, -0.046)* T3 vs. T1 -0.455 (-0.696, -0.024)*	Sidewalks on both sides T3 vs. T1 1.507 (0.025, 5.123)*
Stop sign T2 vs. T1 -0.505 (-0.722, -0.121)*	Pedestrian crossing activated signal T3 vs. T1 1.641 (0.349, 4.171)**	Services T3 vs. T1 1.026 (0.070, 2.834)*	Liquor store Present vs. not present 1.809 (0.478, 4.333)**
Restaurant T3 vs. T1 1.083 (0.062, 3.092)*	Litter T3 vs. T1 1.389 (0.087, 4.254)*		

* p < 0.05, p < 0.01; BE – built environment; Associations explored by multiple linear regression analysis. Dependent variable: ln walking; Independent variable: objective environmental measure; All models adjusted for age, sex, household income, formal level of education, ethnicity and setting income. B (95%CI): Unstandardized regression coefficient (95%CI) presented as $e^b - 1$ to enable the interpretation of PA in its original units (MET*min/week). Interpretation of B: 100*($e^b - 1$) = % change in walking for 1 unit difference in BE feature (e.g. % difference in walking between Present and Not present categories). T1-T3: tertiles of access to a BE feature (T1=lowest tertile, T3=highest tertile)

3.2. Gender, ethnic and income differences in the perception of built environment features

3.2.1. Gender differences in built environment perceptions

Compared to men, women were more likely to report having stores for buying clothes (p=0.041) and restaurants (p=0.040) within a 10 minute walk from their residence (Table 11). Similarly, compared to men, women were more likely to agree that there are many interesting things to look at while walking in the neighbourhood (0.044), and they were also more likely to report being satisfied with access to entertainment in their neighbourhood (p=0.034). No other significant gender differences were observed for the remaining perceived environmental features (Appendix H).

Table 11. Gender differences in built environment perceptions

Perceived BE feature*	Males	Females	Significance (*p*)
Perceived distance to buy clothes			0.041
1-10 min	30 (19.2%)	53 (28.8%)	
11+ min	126 (80.8%)	131 (71.2%)	
Perceived distance to eat at a restaurant			0.040
1-10 min	72 (46.2%)	106 (57.3%)	
11+ min	84 (53.8%)	79 (42.7%)	
There are many interesting things to look at while walking in my neighbourhood			0.044
Agree	126 (80.8%)	163 (88.6%)	
Disagree	30 (19.2%)	21 (11.4%)	
Satisfaction with access to entertainment (restaurants, movies, clubs, etc.)			0.034
Satisfied	98 (62.8%)	136 (73.5%)	
Not satisfied	58 (37.2%)	49 (26.5%)	

BE – built environment; *Tables featuring all perceived BE features with participants' responses across all categories available in Appendix H.

3.2.2. Ethnic differences in built environment perceptions

Compared to individuals of non-European origin, Europeans reported shorter distances from their home to the nearest grocery and retail stores, places to buy fruits and vegetables, restaurant, bank, video store, pharmacy, and transit stop (Table 12). However, no ethnic differences were noted in the perceived walking time from home to a park (Appendix I).

Additional ethnic differences in neighbourhood BE features are presented in Table 13. Study participants of European origin, compared to their non-European counterparts were more likely to agree that there are many places to go within easy walking distance ($p=0.015$), many interesting things to look at while walking in the neighbourhood ($p=0.001$), and that there is grass/dirt strip that separates the streets from sidewalks in the neighbourhoods ($p=0.020$).

Table 12. Ethnic differences in perception of distance to built environment features

Perceived BE feature*	Non-European	European	Significance (*p*)
Land Use Mix			
Time to walk from home to:			
Buy groceries			0.005
1-10 min	57 (40.7%)	111 (56.1%)	
11+ min	83 (59.3%)	87 (43.9%)	
Buy clothes			0.004
1-10 min	23 (16.4%)	60 (30.3%)	
11+ min	117 (83.6%)	138 (69.7%)	
Buy fruits and vegetables			0.035
1-10 min	59 (42.1%)	107 (53.8%)	
11+ min	81 (57.9%)	92 (46.2%)	
Eat at a restaurant			< 0.001
1-10 min	55 (39.3%)	122 (61.3%)	
11+ min	85 (60.7%)	77 (38.7%)	
Go to the bank			< 0.001
1-10 min	54 (38.6%)	115 (57.8%)	
11+ min	86 (61.4%)	84 (42.2%)	
Rent a video			0.010
1-10 min	48 (34.3%)	96 (48.2%)	
11+ min	92 (65.7%)	103 (51.8%)	
Buy medicines			< 0.001
1-10 min	53 (37.9%)	123 (61.8%)	
11+ min	87 (62.1%)	76 (38.2%)	
Go to the bus or trolley stop			0.029
1-10 min	119 (85.0%)	183 (92.4%)	
11+ min	21 (15.0%)	15 (7.6%)	

BE – built environment; The association between ethnicity and perceived distance to BE features was explored by Chi-square test. *Tables featuring all perceived BE features are available in Appendix I.

In contrast, non-Europeans, compared to Europeans, were more likely to agree that the crosswalks in their neighbourhoods help walkers feel safe crossing busy streets (p=0.002). They were also more likely to agree that the crime rates in their neighbourhoods make it unsafe to go on walks during the night (p=0.005). No ethnic differences were observed for the perception of access to stores, local shopping and transit stops, streets in the neighbourhood, presence of sidewalks and sidewalk maintenance, and presence of trees, and litter. Similarly, Europeans and non-Europeans did not significantly differ in their perceptions of traffic volume, street lighting, and both groups disagreed that the crime rate in their neighbourhoods make it unsafe to go on walks during the day (Appendix I).

Table 13. Ethnic differences in built environment perceptions

Perceived BE feature*	Non-European	European	Significance (*p*)
There are many places to go within easy walking distance			0.015
Agree	112 (80.0%)	178 (89.4%)	
Disagree	28 (20.0%)	21 (10.6%)	
There is grass/dirt strip that separates the streets from sidewalks in my neighbourhood			0.020
Agree	110 (78.6%)	175 (87.9%)	
Disagree	30 (21.4%)	24 (12.1%)	
There are many interesting things to look at while walking in my neighbourhood			0.001
Agree	108 (77.1%)	179 (90.4%)	
Disagree	32 (22.9%)	19 (9.6%)	
The crosswalks in my neighbourhood help walkers feel safe crossing busy streets			0.002
Agree	119 (85.0%)	139 (70.2%)	
Disagree	21 (15.0%)	59 (29.8%)	
The crime rate in my neighbourhood makes it unsafe to go on walks during the night			0.005
Agree	42 (30.0%)	34 (17.1%)	
Disagree	98 (70.0%)	165 (82.9%)	

The association between ethnicity and perceived access to services and neighbourhood surroundings was tested by Chi-square test. BE – built environment, *Tables featuring all perceived BE features are available in Appendix I.

Significant ethnic differences were also observed in neighbourhood satisfaction (Table 14). More Europeans than non-Europeans reported being satisfied with neighbourhood access to entertainment (p=0.020), and safety from threat of crime (0.014). Non-Europeans, compared to their European counterparts, were more likely to report being satisfied with the amount and speed of traffic in their neighbourhood (p=0.008).They were also more likely to report being satisfied with the number of people they know in the neighbourhood (p=0.017), and to perceive their neighbourhood as a good place to raise children (p<0.001). The majority of both Europeans and non-Europeans reported being satisfied with access to public transportation, commuting time to work or school, neighbourhood shopping, and aesthetics; and the majority also reported that their neighbourhood is a good place to live (Appendix I).

Table 14. Ethnic differences in neighbourhood satisfaction

Perceived BE feature*	**Non-European**	**European**	**Significance (*p*)**
The number of people you know			0.017
Satisfied	90 (64.3%)	102 (51.3%)	
Not satisfied	50 (35.7%)	97 (48.7%)	
Access to entertainment (restaurants, movies, clubs, etc.)			0.020
Satisfied	86 (61.4%)	146 (73.4%)	
Not satisfied	54 (38.6%)	53 (26.6%)	
The safety from threat of crime			0.014
Satisfied	97 (69.3%)	161 (80.9%)	
Not satisfied	43 (30.7%)	38 (19.1%)	
The amount and speed of traffic			0.008
Satisfied	87 (62.1%)	94 (47.5%)	
Not satisfied	53 (37.9%)	104 (52.5%)	
Your neighbourhood as a good place to raise children			< 0.001
Satisfied	111 (79.9%)	111 (55.8%)	
Not satisfied	28 (20.1%)	88 (44.2%)	

The association between ethnicity and perceived neighbourhood satisfaction was explored by Chi-square test. BE – built environment, *Tables featuring all perceived BE features are available in Appendix I.

3.2.3. Differences in perception of built environment features by household income

Participants were arbitrarily divided into two income groups: those having household incomes above $65,000 (high) and those with $65,000 or less (low). Individuals in the high-income group were more likely than those in the lower-income group to report having grocery stores (p=0.030), fruit and vegetable stores (p=0.005), and parks (p<0.001) within a 10 minute walk from their home (Table 15). However, no differences by household income were noted in the perceived time to walk from home to buy clothes, eat at a restaurant, go to the bank, rent a video, buy medicine and walk to a transit stop (Appendix J).

Table 15. Differences in perception of distance to environmental features by household income

Perceived BE feature*	≤ $65,000	> $65,000	Significance (*p*)
Land Use Mix			
Time to walk from home to:			
Buy groceries			0.030
1-10 min	58 (43.0%)	108 (55.1%)	
11+ min	77 (57.0%)	88 (44.9%)	
Buy fruits and vegetables			0.005
1-10 min	54 (40.0%)	110 (55.8%)	
11+ min	81 (60.0%)	87 (44.2%)	
Go to the park			< 0.001
1-10 min	75 (56.0%)	150 (76.1%)	
11+ min	59 (44.0%)	47 (23.9%)	

BE – built environment; The association between household income and perceived distance to BE features was explored by Chi-square test. *Tables featuring all perceived BE features are available in Appendix J.

Compared to lower-income group, those from higher-income households were more likely to report being satisfied with access to shopping in their neighbourhood (p=0.044) (Table 16). No significant differences by household income were observed for BE features related to access to services, streets, places for walking and cycling in the neighbourhood and neighbourhood surroundings (Appendix J). Similarly, the two groups did not significantly differ in their perceptions related to neighbourhood safety from crime and traffic or in satisfaction with the rest of the neighbourhood features (Appendix J).

Table 16. Perceived environmental features by household income

Perceived BE feature*	≤ $65,000	> $65,000	Significance (*p*)
Neighbourhood satisfaction with access to shopping			0.044
Satisfied	111 (82.2%)	177 (89.8%)	
Not satisfied	24 (17.8%)	20 (10.2%)	

BE – built environment; The association between household income and perceived BE features was explored by Chi-square test. *Tables featuring all perceived BE features are available in Appendix J.

3.2.4. Differences in perception of built environment features by setting income

Compared to participants from the low-income setting, individuals from the high-income setting were more likely to perceive shorter distances from their home to the nearest grocery, fruit and vegetable and retail stores, restaurant, bank, video store, pharmacy, transit stop or park (p<0.001 for all, Table 17).

Table 17. Distance to environmental features as perceived by residents from low- and high-income settings

Perceived BE feature	Low-income setting	High-income setting	Significance (*p*)
Land Use Mix			
Time to walk from home to:			
Buy groceries			< 0.001
1-10 min	34 (24.6%)	135 (66.8%)	
11+ min	104 (75.4%)	67 (33.2%)	
Buy clothes			< 0.001
1-10 min	12 (8.7%)	71 (35.1%)	
11+ min	126 (91.3%)	131 (64.9%)	
Buy fruits and vegetables			< 0.001
1-10 min	43 (31.2%)	124 (61.1%)	
11+ min	95 (68.8%)	79 (38.9%)	
Eat at a restaurant			< 0.001
1-10 min	38 (27.5%)	140 (69.0%)	

Perceived BE feature	Low-income setting	High-income setting	Significance (*p*)
11+ min	100 (72.5%)	63 (31.0%)	
Go to the bank			< 0.001
1-10 min	98 (71.0%)	130 (64.0%)	
11+ min	40 (29.0%)	73 (36.0%)	
Rent a video			< 0.001
1-10 min	43 (31.2%)	102 (50.2%)	
11+ min	95 (68.8%)	101 (49.8%)	
Buy medicines			< 0.001
1-10 min	32 (23.2%)	145 (71.4%)	
11+ min	106 (76.8%)	58 (28.6%)	
Go to the bus or trolley stop			0.020
1-10 min	116 (84.7%)	188 (92.6%)	
11+ min	21 (15.3%)	15 (7.4%)	
Go to the park			0.034
1-10 min	85 (62.0%)	148 (72.9%)	
11+ min	52 (38.0%)	55 (27.1%)	

BE – built environment; The association between setting income and perceived distance to BE features was explored by Chi-square test. *Tables featuring all perceived BE features are available in Appendix K.

There were significant differences in perception of access to services and neighbourhood surroundings between study participants living in low- and high-income settings (Table 18). Compared to individuals from the low-income setting, people living in the high-income setting were more likely to agree that they can do most of their shopping locally (p=0.001), that they have stores within walking distance of their home (p=0.001) and that they have many places to go within easy walking distance (p<0.001). Similarly, compared to people coming from the low-income setting, individuals from the high-income setting were more likely to agree with the statements that trees give shade for sidewalks in their neighbourhoods (p=0.006), that there are many interesting things to look at while walking in the neighbourhood (p<0.001) and that their neighbourhoods are generally free from litter (p<0.001).

Table 18. Perception of access to services and neighbourhood surroundings by setting income

Perceived BE feature	Low-income setting	High-income setting	Significance (*p*)
I can do most of shopping at local stores			0.001
Agree	95 (68.8%)	170 (83.7%)	
Disagree	43 (31.2%)	33 (16.3%)	
Stores are within easy walking distance of my home			0.001
Agree	106 (76.8%)	183 (90.1%)	
Disagree	32 (23.2%)	20 (9.9%)	
There are many places to go within easy walking distance			< 0.001
Agree	101 (73.2%)	191 (94.1%)	
Disagree	37 (26.8%)	12 (5.9%)	
Trees give shade for the sidewalks in my neighbourhood			0.006
Agree	124 (89.9%)	197 (97.0%)	
Disagree	14 (10.1%)	6 (3.0%)	
There are many interesting things to look at while walking in my neighbourhood			< 0.001
Agree	94 (68.1%)	195 (96.5%)	
Disagree	44 (31.9%)	7 (3.5%)	
My neighbourhood is generally free from litter			< 0.001
Agree	102 (73.9%)	191 (94.1%)	
Disagree	36 (26.1%)	12 (5.9%)	

BE – built environment; The association between perceived built environment features and setting income was explored by Chi-square test. *Tables featuring all perceived BE features are available in Appendix K.

Participants from low- and high-income settings also differed in the way they perceived neighbourhood streets and crime safety (Table 19). Compared to residents from the low-income setting, people living in the high-income setting were more likely to perceive their neighbourhood as having short distances between intersections (p=0.006), many four-way intersections (p=0.006) and many alternative routes for getting from place to place (p=0.001). Furthermore, they were also more likely to disagree with the statement that the crime rate in the neighbourhood makes it unsafe to go on walks during the night (p<0.001). The majority of study participants from both low and high-income settings agreed that there are sidewalks on most streets in their neighbourhoods and that the sidewalks are well maintained. Similarly, no significant differences in perceptions of features related to neighbourhood safety from traffic were observed between individuals residing in the low-income setting versus those from the high-income setting (Appendix K).

Table 19. Perception of neighbourhood streets and crime safety by setting income

Perceived BE feature*	Low-income setting	High-income setting	Significance (*p*)
The distance between intersections in my neighbourhood is usually short			0.006
Agree	109 (79.6%)	183 (90.1%)	
Disagree	28 (20.4%)	20 (9.9%)	
There are many four-way intersections in my neighbourhood			0.006
Agree	101 (73.2%)	173 (85.2%)	
Disagree	37 (26.8%)	30 (14.8%)	
There are many alternative routes for getting from place to place in my neighbourhood			0.001
Agree	116 (84.1%)	193 (95.1%)	
Disagree	22 (15.9%)	10 (4.9%)	
My neighbourhood is generally free from litter			< 0.001
Agree	102 (73.9%)	191 (94.1%)	
Disagree	36 (26.1%)	12 (5.9%)	
The crime rate in my neighbourhood makes it unsafe to go on walks during the night			< 0.001
Agree	47 (34.1%)	30 (14.8%)	
Disagree	91 (65.9%)	173 (85.2%)	

BE – built environment; The association between perceived built environment features and setting income was explored by Chi-square test. *Tables featuring all perceived BE features are available in Appendix K.

There were significant differences in neighbourhood satisfaction between individuals from low- and high-income settings (Table 20). Residents from the high-income setting, compared to their counterparts from the low-income setting, were more likely to report being satisfied with neighbourhood access to shopping, entertainment and the safety from threat of crime (p<0.001 for all). They were also more likely to report being satisfied with how easy and pleasant it is to walk in their neighbourhood (p<0.001), and with their neighbourhood as a good place to live (p<0.001). In contrast, individuals from the low-income setting, compared to study participants coming from the high-income setting, were more likely to perceive their neighbourhood as a good place to raise children (p=0.001). Participant responses on satisfaction with the commuting

Table 20. Differences in neighbourhood satisfaction between individuals from low- and high- income settings

Perceived BE feature*	Low-income setting	High-income setting	Significance (*p*)
The access to public transport			0.022
Satisfied	118 (85.5%)	189 (93.1%)	
Not satisfied	20 (14.5%)	14 (6.9%)	
Access to shopping			< 0.001
Satisfied	108 (78.3%)	187 (92.1%)	
Not satisfied	30 (21.7%)	16 (7.9%)	
How easy and pleasant is to walk in your neighbourhood?			< 0.001
Satisfied	121 (87.7%)	201 (99.0%)	
Not satisfied	17 (12.3%)	2 (1.0%)	
Access to entertainment (restaurants, movies, clubs, etc.)			< 0.001
Satisfied	55 (39.9%)	179 (88.2%)	
Not satisfied	83 (60.1%)	24 (11.8%)	
The safety from threat of crime			< 0.001
Satisfied	79 (57.2%)	180 (88.7%)	
Not satisfied	59 (42.8%)	23 (11.3%)	
Your neighbourhood as a good place to raise children			0.001
Satisfied	105 (76.1%)	119 (58.9%)	
Not satisfied	33 (23.9%)	83 (41.1%)	
Your neighbourhood as a good place to live			< 0.001
Satisfied	117 (84.8%)	201 (99.0%)	

Perceived BE feature*	Low-income setting	High-income setting	Significance (*p*)
Not satisfied	21 (15.2%)	2 (1.0%)	

BE – built environment; The association between perceived built environment features and setting income was explored by Chi-square test. *Tables featuring all perceived BE features are available in Appendix K.

time to work/school, the number of people known and the amount and speed of traffic in the neighbourhood did not significantly differ between the participants from low- and high-income settings (Appendix K).

3.3. Correspondence between perceived and objective built environment features by gender, ethnicity, household- and neighbourhood income

Despite the fact that multiple perceived and objective BE features were assessed, correspondence between perceived and objective BE features was tested only for the BE features representing the same construct (Table 21).

Table 21. Perceived-objective built environment feature pairs matched to test their agreement

Perceived built environment feature present within 10 min-walk from home	Objective built environment feature present within 500-metre buffer from home
Grocery store	Grocery store
Clothing store	Retail store
Fruit and vegetable store	Supermarket and/or grocery store
Restaurant	Restaurant
Bank	Bank
Video store	Video store
Pharmacy	Pharmacy
Bust stop	Bust stop
Park	Park

The results of the tested agreement between nine pairs of carefully matched perceived and objective BE variables are presented in Table 22. The agreement between the measures ranged from poor to moderate. Some differences in the level of agreement were noted across gender, ethnicity and individual and neighbourhood income. Specifically, compared to men, higher agreement between perceived vs. objective measures was observed among women for presence of a grocery store, a fruit and vegetable store, a clothing store, and a restaurant. A very pronounced gender difference in agreement was noted for the presence of bus stops in the neighbourhood, where moderate agreement was observed among women (k=0.552) compared to fair agreement (k=0.306) for men. On the other hand, compared to women, higher perceived/objective agreement for the presence of a bank, video store, and pharmacy was noted among men. For both men and women, correspondence between the perceived and objectively-measured presence of parks within the neghbourhood was poor.

Ethnic differences in the agreement between perceived and objective measures were also observed. Compared to individuals of European origin, measures among non-European residents showed higher agreement for presence of a grocery store, fruit and vegetable store, and bank. However, higher agreement for the presence of a clothing store, restaurant, video store, and pharmacy was noted among Europeans. For both Europeans and Non-Europeans, poor agreement was seen between objective and perceived measures of bus stop and park presence in the neighbourhood.

When comparing agreement among residents of differing household incomes, lower agreement for presence of a clothing store, fruit and vegetable store, restaurant and video store was noted among lower-income (≤ $65,000) residents compared to higher-income ones (> $65,000). However, for the group of people with lower household incomes, higher agreement was observed for the presence of a grocery store, bank, and pharmacy. Agreement was poor among individuals in both household income brackets for presence of a bus stop and park within the neighbourhood.

Table 22. Correspondence between perceived and objective built environment features

Table 22. Correspondence between perceived and objective built environment features

Perceived/objective environmental feature pair for:	Women	Men	European	Non-European	Individual income of ≤ $65,000	Individual income of > $65,000	Low-income neighbourhood	High-income neighbourhood
Grocery store	0.136	0.115	0.104	0.139	0.117	0.108	0.093	0.144
Clothing store	0.068	0.042	0.069	0.027	0.027	0.066	0.019	0.044
Fruit and vegetable store	0.165	0.117	0.103	0.178	0.121	0.136	0.167	0.106
Restaurant	0.047	-0.013	0.053	-0.014	-0.015	0.029	-0.015	0.066
Bank	0.307	0.333	0.223	0.335	0.385	0.277	0.170	0.149
Video store	0.283	0.380	0.327	0.291	0.235	0.358	0.306	0.299
Pharmacy	0.277	0.370	0.303	0.261	0.343	0.312	0.236	0.153
Bust stop	0.552	0.306	-0.010	-0.014	-0.014	-0.010	0.446	0.425
Park	-0.034	-0.037	-0.039	-0.031	-0.026	-0.048	-0.048	-0.029

In comparing high- vs. low-income settings, there was lower agreement in low-income setting between perceived and objective measures for presence of a grocery store, clothing store and restaurant, and higher agreement for presence of a fruit and vegetable store, bank, and pharmacy. Agreement for the presence of bus stops was moderate and similar between the two groups (k=0.446 for residents from low-income and k=0.425 for high-income settings), as was the agreement for presence of a video store. In addition, poor perceived/objective agreement was found for park presence in both low-income and high-income settings.

3.4. Association of built environment features with adiposity and blood glucose

3.4.1. Perceived built environment features, adiposity and blood glucose

Correlations between perceived BE features and adiposity measures and FBG are presented in Table 23. Perceiving retail stores close to home was negatively correlated with all of the outcomes, while perceiving grocery stores nearby was negatively correlated with WHR, %BF and FBG. Perceived BE features including perceived access to shopping, short distance between intersections, and neighbourhood satisfaction with access to entertainment were negatively correlated with WC, WHR and FBG. Furthermore, perceiving restaurants, banks, pharmacies and many places to go to within walking distance, as well as many interesting things to look at while walking were negatively correlated with WHR and FBG. Perceiving greater access to fruit and vegetable stores was negatively correlated with WHR and %BF, while perceiving the neighbourhood as a good place to raise children was positively associated with %BF and FBG. Perceiving crime rates that make it unsafe to walk in the neighbourhood at night was negatively correlated with BMI and WC. Also, perceiving video stores and parks were negatively, while satisfaction with the number of people known in the neighbourhood was positively associated with %BF. In addition, neighbourhood satisfaction with access to shopping was negatively correlated with WHR.

Perceived BE features correlated with adiposity measures and FBG were further carried into multiple linear regression models adjusted for age, sex, level of formal education, household income, ethnicity and setting income. A regression model with only age, sex, level of formal education, household income, ethnicity and setting income explained 9.3% of the variability in BMI, 30.0% in WC, 51.5% in WHR, 48.5% in percentage of body fat (%BF) and 13.6% in FBG. Perceived BE features additionally explained 0.6% to 1.3% of the variability in the outcomes (Appendix L).

Table 23. Correlations between perceived built environment features and adiposity and blood glucose

Perceived BE feature	BMI	WC	WHR	%BF	FBG
	ρ	ρ	ρ	ρ	ρ
Land use mix					
Time to walk from home to:					
Buy groceries	-0.068	-0.075	-0.135*	-0.154**	-0.122*
Buy clothes	-0.182**	-0.198***	-0.244***	-0.154**	-0.191***
Buy fruits and vegetables	-0.068	-0.059	-0.136*	-0.134*	-0.044
Restaurant	-0.075	-0.088	-0.179**	-0.086	-0.139*
Bank	-0.054	-0.056	-0.115*	-0.098	-0.160**
Video store	0.006	-0.001	-0.029	-0.121*	-0.107
Buy medicine	-0.024	-0.050	-0.146**	-0.103	-0.191***
Bus stop	0.029	0.005	-0.024	-0.046	0.045
Park	-0.081	-0.076	-0.085	-0.192***	0.002
Access to services					
I can do most of shopping at local stores.	-0.087	-0.117*	-0.168**	-0.071	-0.121*
Stores are within walking distance.	-0.081	-0.121*	-0.181**	-0.009	-0.108*
There are many places to go within walking distance.	-0.005	-0.034	-0.144**	0.048	-0.133*
It is easy to walk to a bus stop.	-0.002	-0.037	-0.085	-0.030	-0.050
Streets in my neighbourhood					
The distance between intersections is short.	-0.069	-0.112*	-0.151**	-0.071	-0.168**
There are many 4-way intersections in the neighbourhood.	0.055	0.030	-0.014	-0.016	-0.038
There are many alternative routes for getting from place to place.	0.058	0.026	-0.001	-0.005	-0.074
Places for walking and cycling					
There are sidewalks on most of the streets.	0.044	0.047	-0.019	-0.025	-0.021

The sidewalks are well maintained.	-0.018	-0.017	-0.013	-0.037	-0.104
There is a grass/dirt strip between streets and sidewalks.	0.034	0.018	-0.033	0.030	0.040
Neighbourhood surroundings					
Trees give shade for the sidewalks.	-0.023	-0.018	-0.068	0.027	0.001
There are many interesting things to look at while walking.	-0.010	-0.052	-0.145**	0.047	-0.131*
My neighbourhood is generally free from litter.	0.005	-0.007	-0.083	0.036	-0.041
Safety from traffic					
There is so much traffic along the street I live on.	-0.068	-0.060	-0.016	-0.028	-0.054
There is so much traffic along nearby streets.	0.011	-0.002	-0.011	0.024	-0.011
The crosswalks help walkers feel safe.	0.032	0.020	0.004	0.042	-0.055
Safety from crime					
My streets are well lit at night.	0.035	0.047	0.037	-0.045	-0.016
Crime rate makes it unsafe to walk during the day.	-0.015	-0.019	0.012	0.061	0.001
Crime rate makes it unsafe to walk at night.	-0.119*	-0.127*	-0.074	0.048	-0.038
Neighbourhood satisfaction					
The access to public transportation	0.051	0.046	-0.009	0.061	0.033
Commuting time to work/school	0.069	0.050	-0.002	0.022	-0.013
Access to shopping	-0.043	-0.092	-0.174**	0.032	-0.112
The number of people you know	0.010	0.036	0.022	0.130*	0.055
How easy and pleasant is to walk in the neighbourhood	0.059	0.040	-0.039	0.093	-0.033
Access to entertainment	-0.077	-0.131*	-0.217***	0.027	-0.132*
The safety from threat of crime	0.053	0.052	-0.011	0.043	0.013
The amount and speed of traffic	0.044	0.034	-0.001	0.026	-0.025
Your neighbourhood as a good place to raise children	0.089	0.069	0.043	0.138*	0.116*
Your neighbourhood as a good place to live	0.026	-0.014	-0.095	0.075	-0.040

*p< 0.05, ** p < 0.01, *** p < 0.001; BE – built environment, BMI – body mass index, WC – waist circumference, WHR – waist-to-hip ratio, % BF – percent body fat, FBG – fasting blood glucose, ρ – Spearman correlation coefficient

Associations of perceived BE features with WC, WHR, %BF and FBG are presented in Table 24. In the adjusted models, no significant associations were observed between BMI and perceived BE features, while only one objective BE feature was associated with WC. Waist circumference (p = 0.040) and WHR (p = 0.019) were found to be higher in people who agreed they can do most of their shopping at local stores compared to their counterparts who reported the opposite. Similarly, having stores within walking distance was positively associated with WHR (p = 0.049). However, WHR was found to be lower among residents who reported being satisfied with access to shopping (p = 0.019) and whose time to walk to buy groceries was 10 minutes or less (p = 0.022). Further, %BF was found to be lower among study participants who reported that it takes them 10 minutes or less to walk to buy clothes (p = 0.014), fruits and vegetables (p = 0.049) or go to a park (p = 0.046), compared to people who reported that longer times were needed to reach the same destinations.

Table 24. Perceived built environment features associated with adiposity measures and fasting blood glucose

WC B (95%CI)	WHR B (95%CI)	% body fat B (95%CI)	FBG B (95%CI)
I can do most of shopping at local stores Agree vs. Disagree 3.193 (0.144, 6.241)*	Time to walk to buy groceries ≤ 10min vs. 11+ min -0.018 (-0.034,-0.003)*	Time to walk to buy clothes ≤ 10min vs. 11+ min -2.127 (-3.828, -0.426)*	Time to walk to a bank ≤ 10min vs. 11+ min -0.039 (-0.071, -0.004)*
	I can do most of shopping at local stores Agree vs. Disagree 0.021 (0.003, 0.038)*	Time to walk to buy fruits and vegetables ≤ 10min vs. 11+ min -1.469 (-2.934, -0.004)*	The distance between intersection is short Agree vs. Disagree 0.061 (0.009, 0.115)*
	Stores are within walking distance Agree vs. Disagree 0.020 (0.001, 0.040)*	Time to walk to a park ≤ 10min vs. 11+ min -1.567 (-3.106, -0.029)*	
	Satisfaction with access to shopping Satisfied vs. Dissatisfied -0.025 (-0.046, -0.004)*		

BE – built environment, WC – waist circumference, WHR – waist-to-hip ratio, %BF – percentage of body fat, FBG – fasting blood glucose; * p < 0.05; Associations explored by multiple linear regression analysis. Dependent variable: WC, WHR, %BF or lnFBG. Independent variable: perceived environmental feature; All models adjusted for age, sex, household income, formal level of education, ethnicity and setting income. For FGB models, B (95%CI) i.e. Unstandardized regression coefficient (95%CI) is presented as $e^b – 1$ to enable the interpretation of FBG in its original units (mmol/L). Interpretation of B: $100*(e^b – 1)$ = % change in FBG for 1 unit difference in BE feature (e.g. % difference in FBG between Agree and Disagree categories).

With regard to FBG, mean FBG levels of people who reported having a bank within a 10-minute walking distance were lower compared to individuals who reported an 11-or-more minute walk to the bank (p = 0.027). Furthermore, individuals who perceived short distances between street intersections had higher FBG levels compared to their counterparts who disagreed with the statement that intersection distances were short (p = 0.020).

3.4.2. Objective built environment measures, adiposity and blood glucose

Correlations between objective BE features and adiposity measures and FBG are presented in Table 25. The presence of playing fields was positively correlated with WC, WHR, %BF and FBG. Some features were correlated with WHR and FBG but not with other outcomes. Negative correlations with WHR and FBG were observed for the following features: presence of places marked for pedestrian crossing, white lines, traffic lights, yield signs, streets with two lanes or more, condos, universities/colleges, gym/fitness centres, and curbs. In contrast, WHR and FBG were positively correlated with presence of stop signs, detached single family homes, elementary schools, steep segments, and street parking. Waist to hip ratio was also positively correlated with presence of playgrounds, while it was negatively correlated with presence of zebra crossings, duplex homes, big box shops, bakeries, coffee shops, sidewalks and buffers between streets and sidewalks. Negative correlations were also observed between FBG and presence of activated signals at crossing points, curbcuts, post offices, retail stores, movie theatres, and benches. In addition, presence of gardens was positively associated with BMI.

Objective BE features correlated with obesity measures and FBG were entered into linear regression models and adjusted for age, sex, level of formal education, household income, ethnicity and setting income. A model with age, sex, level of formal education, household income, ethnicity and neighbourhood income explained 9.3%, 30.0%, 51.5%, 48.5%, 13.6% of variability in BMI, WC, WHR, %BF and FBG, respectively. Objective BE features additionally explained 1.1% to 2.0% of variability in the outcomes (Appendix M).

Table 25. Correlations between objective built environment features and adiposity and blood glucose

Objective BE feature	BMI ρ	WC ρ	WHR ρ	%BF ρ	FBG ρ
Monuments and markers	-0.066	-0.067	-0.032	-0.037	0.004
Places marked for pedestrian crossing	-0.018	-0.064	-0.137*	-0.022	-0.148**
White lines	-0.035	-0.061	-0.134*	-0.035	-0.145**
Zebra	-0.042	-0.067	-0.105*	-0.034	-0.097
Different road	-0.032	-0.084	-0.099	-0.063	-0.024
Curbcuts	0.033	-0.022	-0.099	0.049	-0.182**
Traffic light	-0.027	-0.059	-0.139**	-0.027	-0.163**
Stop sign	0.009	0.057	0.146**	-0.005	0.165**
Yield sign	-0.079	-0.080	-0.136*	-0.092	-0.123*
Activated signal	0.035	0.001	-0.083	0.034	-0.141**
Crossing sign	-0.041	-0.051	-0.041	-0.051	-0.022
Overpass/underpass	-0.011	-0.011	-0.039	0.021	-0.072
Streetway (one, two way)	0.058	0.044	0.038	0.047	0.052
Lanes two and up	-0.063	-0.057	-0.114*	-0.044	-0.153**
Single family home - detached	0.034	0.077	0.151**	0.039	0.141**
Single family home - duplex	-0.060	-0.083	-0.123*	-0.087	-0.054
Condo	-0.021	-0.065	-0.133*	-0.015	-0.143**
Elementary school	0.077	0.094	0.119*	0.091	0.138**
High school	0.065	0.034	-0.003	0.033	0.003
University/college	-0.016	-0.046	-0.113*	0.022	-0.130*
Park	0.015	0.012	0.024	-0.022	-0.016
Playground	0.089	0.101	0.154**	0.085	0.081

Playing fields	0.075	0.104*	0.118*	0.109*	0.117*
Garden	0.113*	0.060	0.005	0.056	0.023
Landscaped open space	0.044	0.017	-0.069	0.033	-0.101
Gym, fitness centre	0.006	-0.037	-0.118*	-0.010	-0.126*
Community centre	-0.046	-0.013	-0.046	-0.046	-0.085
Post office	0.012	-0.036	-0.103	-0.013	-0.148**
Religious institution	0.053	0.072	0.099	0.030	0.009
Hospital	0.016	-0.035	-0.059	0.006	-0.058
Supermarket	-0.003	-0.019	-0.017	-0.006	0.034
Grocery store	-0.035	-0.034	-0.009	-0.003	-0.036
Convenience store	0.033	-0.010	-0.044	0.051	-0.067
Retail stores	0.034	-0.014	-0.099	0.018	-0.117*
Bank	0.038	-0.004	-0.087	0.030	-0.097
Hotel	-0.060	-0.055	-0.075	-0.072	-0.089
Car dealership	0.094	0.054	-0.001	0.065	-0.033
Gas station	0.052	-0.007	-0.083	0.031	-0.072
Offices	0.053	-0.001	-0.071	0.027	-0.101
Services	0.043	-0.009	-0.092	0.034	-0.101
Industrial	-0.005	-0.008	-0.025	-0.044	-0.038
Vertical mix use	0.043	-0.005	-0.066	0.044	-0.079
Big box shop	0.001	-0.057	-0.114*	-0.036	-0.064
Drive through	0.001	-0.025	-0.020	-0.013	0.025
Night club	0.048	-0.009	-0.099	0.038	-0.077
Adult uses	0.023	-0.005	-0.089	0.074	-0.071
Liquor store	0.039	0.004	-0.062	-0.010	-0.090
Restaurant	0.027	-0.018	-0.102	0.026	-0.096

Bakery	0.017	-0.022	-0.104*	0.001	-0.081
Coffee shop	0.033	-0.016	-0.106*	0.052	-0.072
Meat shop	0.015	0.001	0.021	-0.001	-0.020
Library/book store	0.062	0.011	-0.087	0.050	-0.082
Art/craft gallery	0.058	0.018	-0.069	0.058	-0.071
Movie theatre	0.014	-0.008	-0.098	-0.015	-0.121*
Pharmacy	-0.037	-0.024	-0.010	0.007	-0.002
Video store	-0.039	-0.049	-0.025	-0.004	-0.048
Golf course	-0.054	-0.027	0.054	-0.043	-0.012
Sidewalks on both sides of the street	-0.025	-0.071	-0.155**	-0.030	-0.093
Buffer between street and sidewalk	-0.064	-0.077	-0.117*	-0.083	0.001
Awnings	0.058	0.011	-0.057	0.057	-0.090
Dining area	0.092	0.040	-0.075	0.077	-0.068
Benches	0.065	-0.015	-0.101	0.027	-0.126*
Bike racks	0.058	0.016	-0.069	0.029	-0.069
Public washroom	0.086	0.069	0.026	0.024	-0.022
Bus stop present	0.024	0.014	0.022	0.068	-0.020
Bike route	0.062	-0.011	-0.090	0.020	-0.105*
Steepness	-0.012	0.042	0.106*	0.040	0.144**
Trees	-0.005	-0.033	0.001	-0.038	0.022
Midblock crosswalk	0.067	0.059	0.039	0.096	0.044
Speed limit	0.005	0.029	0.094	0.047	0.073
Speed bumps	0.030	0.039	0.087	0.057	0.051
Traffic circle	0.027	-0.024	-0.073	-0.041	-0.075
Median	0.061	0.013	-0.078	0.057	-0.018

Street parking	0.018	0.056	0.108*	0.001	0.111*
Cul-de-sac	-0.018	-0.049	-0.050	0.008	0.005
Curbs	-0.032	-0.095	-0.171**	-0.059	-0.125*
Lighting	-0.074	-0.066	-0.029	-0.034	-0.034
Graffiti	0.027	0.002	-0.037	0.009	-0.036
Litter	0.033	0.003	-0.071	0.012	-0.048
Block watch	-0.019	-0.050	-0.050	0.060	-0.055

*p< 0.05, ** p < 0.01, *** p < 0.001; BMI – body mass index, WC – waist circumference, WHR – waist-to-hip ratio, % BF – percent body fat, FBG – fasting blood glucose, ρ – Spearman correlation coefficient

Objective BE features associated with adiposity measures and FBG are presented in Table 26. After adjusting for potential confounders, objective BE features were not found to be associated with WC and %BF. However, presence of gardens and zebra crossings within the neighbourhood were positively associated with BMI (p = 0.015) and WHR (p = 0.005), respectively. While only two objective BE features showed association with adiposity measures, four features showed association with FBG. Specifically, greater presence of curb cuts (p = 0.049) and access to a movie theatre (p = 0.006) were negatively associated with FBG. Similarly, glucose levels were lower among individuals from neighbourhoods where a gym was available compared to people from neighbourhoods with no access to a gym (p = 0.027). On the other hand, living in neighbourhoods with high a presence of steep segments was associated with higher glucose levels (p = 0.044).

Table 26. Objective built environment features associated with adiposity measures and fasting blood glucose

BMI **B (95%CI)**	**WHR** **B (95%CI)**	**FBG** **B (95%CI)**
Garden Present vs. not present 1.687 (0.334, 3.040)*	Zebra crossing T2 vs. T1 0.026 (0.008, 0.044)**	Curbcuts T3 vs. T1 -0.044 (-0.085, -0.001)*
		Gym Present vs. not present -0.062 (-0.114, -0.007)*

Movie theatre
Present vs. not present
-0.072 (-0.121, -0.021)**
Steepness
T3 vs. T1
0.049 (0.001, 0.099)*

BE – built environment, BMI – body mass index, WHR – waist-to-hip ratio, FBG – fasting blood glucose; * $p < 0.05$, ** $p < 0.01$; Associations explored by multiple linear regression analysis. Dependent variable: BMI, WHR or lnFBG. Independent variable: perceived environmental feature; All models adjusted for age, sex, household income, formal level of education, ethnicity and setting income. For FGB models, B (95%CI) i.e. Unstandardized regression coefficient (95 percent confidence interval) is presented as $e^b - 1$ to enable the interpretation of FBG in its original units (mmol/L). Interpretation of B: $100*(e^b - 1)$ = % change in FBG for 1 unit difference in BE feature (e.g. % difference in FBG between Present and Not present categories). T1-T3=tertiles of access to a built environment feature (T1-lowest access, T3-highest access)

3.4.2.1. Sensitivity analyses

Additional sensitivity analyses were performed to explore whether the associations between perceived and objective BE features and adiposity and FBG would change once total PA is added to regression models (Appendix N). The addition of total PA did not make a significant contribution to any of the models (p>0.05). Total PA additionally explained 0.1% or less variability in the outcomes (R square change 0.001 or less) with the exception of the model on the association between presence of gardens in the neighbourhood and BMI where R square change was 0.005. The addition of PA to the model resulted in attenuation of regression coefficients in the analyses on the association between perceived BE features and %BF; however, the rest of the regression coefficients remained unchanged or the change was negligible. After additional adjustment for PA, the following three models were no longer statistically significant: the association between perceived access to stores within walking distance and WHR (p=0.063), access to fruit and vegetable stores and %BF (p=0.119), and access to a park and %BF (p=0.074). The rest of the analyses remained statistically significant (Appendix N).

3.5. Intra-rater reliability

Table 27 features environmental variables from the IMI audit tool (41 of the 122 used) for which intra-rater agreement was less than 100% and kappa was less than one (k<1). Eighteen variables showed substantial to almost perfect agreement (k=0.81-1.00), 14 variables substantial (k=0.61-0.80), seven moderate (k=0.41-0.60), one slight agreement (k=0.00-0.20), and one variable showed poor agreement (k<0).

Table 27. Intra-rater agreement

Environmental feature	Percent agreement (%)	Kappa statistic
Town/condo/apartment	98.9	0.966
Offices	98.9	0.917
Crossing sign[2]	98.9	0.903
Playground	97.8	0.897
Playing fields	98.9	0.883
Vehicle lanes	96.7	0.883
Retail store	98.9	0.883
Single family home-detached	97.8	0.882
Traffic signal[2]	97.8	0.877
Traffic signal[1]	97.8	0.863
Stop sign[1]	97.8	0.863
Places marked for crossing[1]	96.7	0.861
Places marked for crossing[2]	95.6	0.848
Religious institution	97.8	0.845
Single family home-duplex	96.7	0.824
Trees	96.7	0.824
Activated signal[2]	97.8	0.822
Vertical mix	97.8	0.822
Crossing sign[1]	98.9	0.795
Bank	98.9	0.795
Curb cuts on alleys[2]	87.8	0.790
Activated signal[1]	97.8	0.789
Curbs	97.8	0.788
Stop sign[2]	94.4	0.769
White lines[2]	94.4	0.768
White lines[1]	94.4	0.731
Curb cuts[2]	88.9	0.717

Steepness	93.3	0.712
Curb cuts[1]	86.7	0.695
Yield sign[1]	98.9	0.662
Dining areas	98.9	0.662
Buffer between sidewalk and street	97.8	0.658
On street parking	96.7	0.554
Benches	97.8	0.492
Bike racks	97.8	0.492
Community centre	97.8	0.489
Block watch signs	97.8	0.489
Graffiti	95.6	0.483
Measures to slow traffic	95.6	0.483
Litter	57.8	0.195

[1] at the beginning of the segment, [2] at the end of the segment

4. Discussion

4.1. Summary

This project is a cross-sectional study undertaken to explore the associations of perceived and objective BE measures with PA, adiposity and FBG among residents from two Vancouver urban neighbourhoods. In addition, it tested the agreement between perceived and objectively measured BE features and whether this agreement differed based on gender, income level and ethnicity.

The results of this study indicate that more objective than perceived BE measures were associated with PA. Furthermore, objective BE measures showed the strongest association with transportation PA; and the greatest effects were observed for BE features related to safety from traffic and presence of sidewalks. Variability in transportation PA explained by these features ranged from 2.1% to 3.8%. Therefore, modifying the micro-BE to provide pedestrian infrastructure and increase safety of pedestrians from traffic may help residents engage in more utilitarian PA in their neighbourhood.

Associations of BE features with adiposity measures and FBG were limited, and effect sizes of BE features associated with adiposity and FBG were small, whereby BE features explained 0.6% to 2.0% variability in the outcomes. Seven perceived BE features that pertain to access to shopping, grocery stores, retail and parks, and two objectively measured BE features (presence of gardens and zebra crossings) were associated with one or more adiposity measures after adjustment for confounders. Two perceived (access to a bank, short distance between intersections) and four objectively measured BE features (presence of curbcuts, gyms, movie theatres, and segment steepness) were associated with FBG after adjustment for confounders. The study results may imply that building neighbourhoods where people have greater access to shops, grocery stores (and potentially healthier food choices) and gyms may improve the metabolic health of neighborhood residents. However, longitudinal studies are needed to confirm whether the observed associations between the micro-environment and PA, adiposity and FBG persist or change over time.

Another important study finding pertains to differences in the way people perceive their neighbourhood environment. Namely, significant differences were observed in BE perceptions of neighbourhood residents belonging to distinct demographic and socio-economic groups. This novel finding may direct the development of public health interventions aimed at increasing awareness about facilities in the neighbourhood; the results suggest that special consideration should be given to ethnic minorities and residents from low-income neighbourhoods.

Finally, the study results indicate moderate to poor agreement between perceived and objective BE measures. This finding suggests that either each measure captures a different construct, and, therefore, perceived and objective BE measures should not be used interchangeably; or that objective BE measures are not representative of perceived measures, in which case, the way in which environmental measures are defined should be revisited. Study findings are discussed in detail in the sections to follow.

4.2. Physical activity and the built environment

This study focused on the association between perceived and objectively measured BE features and PA. It was hypothesized that perceived and objective BE features would be associated with total PA, transportation PA, leisure PA and walking independently of potential confounders including age, sex, formal level of education, household income, ethnicity, and setting income. Out of 38 perceived BE features tested, the hypothesis was supported for six features that were found to be associated with one or more PA domains after adjusting for confounders (results summarized in Appendix O). Out of multiple objective BE features tested, the hypothesis was supported for the relationship between objective BE features and transportation PA (24 features), leisure PA (4 features) and walking (10 features) (results summarized in Appendix O).

Although 23 perceived BE features were correlated with one or more PA domains of interest, after adjusting the analyses for the above mentioned confounders, the associations of perceived BE features and PA domains remained significant for six features only. These include perceived presence of high traffic volume, access to restaurants, stores, and entertainment, presence of grass/dirt strip between streets and sidewalks, and many interesting things to look at while walking. Some of the features were associated with multiple domains of PA. An example of one such feature is the perceived presence of high traffic volume in the neighbourhood that was associated with total PA, transportation PA, as well as walking. Total PA, transportation PA and walking were about 37%, 54% and 47% lower, respectively, among individuals who agreed to the statement “there is so much traffic along nearby streets” compared to their counterparts who disagreed with the statement. The reported associations are consistent with those previously published (44,199). Interestingly, contrasting results were observed in the study of Wilbur et al. (271) where residents were more active if they lived in neighbourhoods with higher traffic volume. Given that the study participants were Latina women, the authors believed that it is possible that women feel safer exercising in neighbourhoods where there are a large number of cars and people present on busy streets (271).

Other BE features were only related to one specific PA domain; for example, the perceived prevalence of interesting things to look at and access to entertainment in the neighbourhood were positively associated with leisure PA but not other domains. Positive associations between neighbourhood aesthetics and leisure PA have also been reported by others (81,120,193,211,212,229), and this is important, as it has been argued that unfavourable safety and neighbourhood aesthetics may discourage businesses in the neighbourhood and reduce access to destinations such as PA facilities or local healthy food stores (24). Additionally, consistent with the evidence from recently published studies (81,120,133,208,212,231,232,260), this study showed no relationship between perceived safety from crime and PA.

Three of the perceived BE features were positively correlated with PA; however, these relationships became negative after adjustment for confounders. Namely, after adjustment for confounders, individuals who agreed, versus those who disagreed, to the statement that there is grass/dirt strip between streets and sidewalks engaged in less total PA. Similarly, residents who agreed, versus those who disagreed, that there are many interesting things to look at while walking and many stores within walking distance engaged in less leisure PA and walking, respectively. These counterintuitive findings were most likely due to the *reversal paradox* (the direction of the relationship between two variables might be reversed after a third variable is introduced) (444). It is possible that some of the confounders used are more likely moderators of the relationship between the above mentioned perceived BE features and PA; and further analyses are currently being performed on the larger PURE study sample to help explain these findings.

It is important to note that the association between perceived BE measures and PA may travel in both directions. While the majority of research reports on perceived BE features shaping PA, the results of recent PA interventions indicate that increases in PA are associated with favourable changes in the way residents perceive their neighbourhoods (445,446). These improvements are most likely the result of increases in residents' awareness of their neighborhood due to increased exposure to the environment during the intervention (445,446). Consequently, future research on the association between perceived environmental measures and PA should account for individual levels of neighbourhood exposure (446).

More objective than perceived BE measures were associated with PA. More than 20 objectively measured BE features were associated with transportation PA; 10 were associated with walking and only four features were associated with leisure PA. Interestingly, there was no association between objectively-measured BE features and total PA in this study. However, there are several studies where such a relationship was observed. Namely, there was a significant positive association between total PA and neighbourhood walkability (235–237), access to sports fields (208) and public open spaces (239), distance to post office (128), number of intersections (135), transit stop density (239), and block size (238). The discrepancy between this study's findings and others' may be due to differences in the way the neighbourhood was defined or due to differences in the way BE features and/or PA behaviour were measured. Neither of the above-mentioned studies assessed BE features through direct assessment of the neighbourhood environment. Also, many studies focused on macro-environmental features such as neighbourhood walkability calculated using GIS and derived from residential density, intersection density and land use mix (235–237) versus micro-environmental neighbourhood features examined in this study. Neighbourhoods were also characterized differently with some defined based on administrative boundaries (208,236,239) and others as road network buffers around participant residences, at a distance of 1kilometer (237) or 1.5 kilometers (128). These neighbourhood definitions differed significantly from the 500-meter circular buffer around participant residences used in this study. Additionally, PA was also assessed differently across studies: while PA was self-reported by participants in this study, the majority of the above studies measured PA objectively using accelerometers (135,236,237) or pedometers (128), with some collecting PA data both objectively and through self-report (235,238).

As for the domains of PA, higher levels of transportation PA were noted among individuals who lived in neighbourhoods with higher residential density, higher land-use mix, greater safety from traffic, and more sidewalks present on both sides of the street. This corresponds to findings of other research groups that show a positive association of land-use mix (130,239,249), and residential density (249,251) with transportation PA. Several other objectively measured BE features showed positive associations with transportation PA including presence of big box shops, hospitals, liquor stores, night clubs, car dealerships, and landscaped open spaces. However, variability of these features was small, so it is possible that these associations occurred by chance. Also, a cautionary note should be added regarding the interpretation of the negative association between the presence of bike routes and transportation PA. This feature was positively correlated with transportation PA; however, after adjustment for confounders this relationship became negative. This is most likely due to the *reversal paradox* mentioned earlier in this section, and further analyses are needed to explore potential moderating effect of the variables used as confounders.

In examining leisure PA, levels were higher among individuals living in neighbourhoods with lower residential density compared to counterparts living in places with higher residential density. These results are consistent with those reported in the Twin Cities Walking study, whereby leisure PA of residents living in areas with lower residential density was significantly higher compared to the levels of leisure PA among residents living in areas where residential density was higher (447). In several other studies residential density was not associated with leisure PA, however, all these studies researched walking for leisure in isolation rather than overall leisure PA (81,120,230,232,280). In addition, two more BE features showed associations with leisure PA, however lack of variance of these features (buffer between street and sidewalk was almost always present, while midblock crosswalk feature almost never occurred) suggests that these associations may have been a chance occurrence.

Overall walking was another PA domain that was examined in this study, and it was found to be associated with greater presence of objectively measured features for safe pedestrian street crossing, such as places marked for pedestrian crossing and pedestrian activated signals; access to neighbourhood amenities such as restaurants, playing fields, and services, and presence of sidewalks. Other studies have reported different results: for example, sidewalk features, such as objectively-measured sidewalk density (288), percentage of sidewalk coverage (279), sidewalk length (198,243), and sidewalk obstruction (74) were not associated with walking rates when examined by others. This discrepancy is most likely due to a significant difference in the way sidewalk variables were defined and measured in this and the above-mentioned studies. Also, in some studies, neighbourhood boundaries, defined by 1-mile- (288), 0.8 kilometer- (279), and 1 kilometer-buffers (243) around participant homes, were larger than those established for the present study. Furthermore, the majority of the above studies did not assess BE features directly, therefore limiting the comparability of their results with the results of this thesis project. Only one study measured BE features directly (in this case, only five BE features were assessed), and it found that a greater presence of malls was associated with higher levels of walking. On the other hand, no association was found between walking and the objectively-measured presence of graffiti, parks, trails and sidewalk obstruction (74). In the same study, however, researchers did not assess all street segments within the neighbourhood but, rather, randomly selected only 10% of street segments to represent the general characteristics of the neighbourhood (74). While this approach indeed decreased neighbourhood assessment time, it still left 90% of neighbourhood segments unassessed, therefore challenging the representativeness of the collected data.

In this study, many of the objectively assessed BE features were not associated with any of PA domains. Such features included presence of overpass/underpass, whether streets are one or two ways, presence of high schools, parks, community centres, convenience stores, drive-throughs, pharmacies, video stores, golf courses, public washrooms, street medians, lighting and block watch signs. This may be a reflection of the overall low levels of variability in these BE features across study areas. In addition, the results should be interpreted with caution due to the wide confidence intervals observed. Analyses are to be repeated on a larger sample size before any final conclusions are made. In addition, longitudinal studies are needed to confirm whether any of the observed associations persist or change over time.

By comparing results of this study to others, it can be noted that the evidence on the association between BE characteristics and PA is inconclusive; as some characteristics have shown positive and negative as well as no associations with PA. For example, this study and others (81,120,211,212,229) found a positive association between perceived neighbourhood aesthetics and PA, but others found no such association (125,127,191,202,213,227,232,260–262). Results from this study and others also indicate a negative association between perceived traffic volume in the neighbourhood and residents' levels of total PA (199) and walking (44); however, some studies found no such associations (46,78,125,194,202,255,264,288), while others found a positive association between perceived neighbourhood traffic volume and total PA (41,271). One explanation for the latter finding could be that people, and especially some population groups such as women, feel safer being physically active on busy streets where more cars and people are present (271). Similar to the perceived BE results, inconsistency is also seen in associations between objective BE measures and PA. For example, while this study and others reported positive associations between land-use mix and transport PA (130,239,249), others found no such associations (133,232,242,287).

Reasons for inconsistent results could be multiple. One may be that evidence on the association between BE and PA is produced by two distinct research groups, PA (public health) and transportation researchers, who use different conceptual models and theoretical approaches as well as different measures of PA (166). While public health researchers explore the determinants of PA by relying on a social ecological model, transportation researchers use a demand theory to examine influences on transportation activity while looking at the costs, feasibility and benefits of various transportation choices (166).

Another difference may stem from the population types under study. Some studies focused exclusively on certain ethnic or racial groups (46,199,270,271,273,410), older adult populations (132,202,245,263,273), individuals living in socio-economically disadvantaged areas (228,410), or else the studies were gender-specific (226,262,264). Since this study and others reported on significant differences in the way different demographic and socio-economic groups perceive their neighbourhood environment (35–41,44,45,48,49), this may further contribute to the differences in the association between perceived BE features and PA observed in the literature. Finally, inconsistent definitions of neighbourhood across studies as well as inconsistent methodology for measuring BE features and PA all may have contributed to the reported inconsistencies in the results of studies examining the relationship between BE and PA.

4.3. Differences in perceptions of the built environment

Environmental perceptions have been shown to influence people's PA levels (23,39,197,210,212,222), and because there exist socio-economic inequalities in PA engagement, it is important to understand the way different socio-economic groups perceive their BE. This may shed more light on which key environmental features should be included in interventions aimed at decreasing socio-economic PA inequalities.

This study aimed to explore whether there are differences in BE perceptions based on socio-demographic categories. It was hypothesized that perceptions of BE features differ by gender, setting and individual income, and ethnicity (results summarized in Appendix P). The hypothesis was supported for four perceived environmental features in the analyses that tested gender-based differences in environmental perceptions. Women, compared to men, perceived greater access to retail stores and restaurants; and they were more likely to report many interesting things to look at while walking and being satisfied with access to entertainment in their neighbourhood. No other significant gender differences were observed for the remaining perceived BE features. Similar observations were seen in a study researching an elderly population, where there was no difference between men and women when it came to perceived access to a transit stop, street connectivity, walking/cycling infrastructure, and traffic safety (40). While this study and others (448) have noted that men and women appear to have similar perceptions of their surroundings, there is evidence reporting several differences in the way men and women perceive their neighbourhood environment. Several investigators were consistent in finding that women are more concerned about personal or neighbourhood safety as compared to men (35–40). Others observed that men were more likely to report greater access to indoor and outdoor places for PA (37) and a greater availability of free or low-cost recreation facilities (39). Men also perceived a greater presence of sidewalks (37,39), access to transit, and greater presence of four-way intersections (39) compared to women. In contrast, women were more likely to report seeing other people being active in the neighbourhood (38) and to perceive greater access to shopping, higher neighbourhood and lower traffic levels (41). Given the gender differences in environmental perceptions and in the relationship between the perceived neighbourhood environment and PA, it has been argued that the moderating effect of gender and sex should be examined more closely in future studies (449).

Gender inequalities in environmental perceptions may be somewhat remedied by the implementation of promotional strategies that would increase awareness of the presence (and state of) BE features in residents' neighbourhoods. However, well-designed health promotion programs are needed given that perceptions are further influenced by factors such as ethnic origin and socio-economic status. Indeed, women of African-American origin were more likely to report the presence of parks within walking distance of their residence compared to White American women (46). Furthermore, African American women of low income, compared to their high-income counterparts, were more likely to report their neighbourhoods as being unsafe from crime and traffic but as having a transit stop within walking distance from their home (48).

When testing the ethnic differences in the perception of BE features, the hypothesis was supported for 18 environmental features. Compared to non-Europeans, Europeans reported greater access to stores, services and transit stops; greater aesthetics; greater satisfaction with neighbourhood access to entertainment and safety from threat of crime. However, they were less likely to be satisfied with the amount and speed of traffic in the neighbourhood (summarized in Appendix P). There is a limited number of studies that have examined the role that ethnicity plays in shaping people's environmental perceptions (44–46). From those available, the results of this study are congruent with findings which show that traffic and crime safety were more often reported as issues by non-European than by European ethnic groups (44,45). The observed ethnic differences in environmental perceptions have implications in the design of community health promotion interventions that will, in order to be successful, need to take into account diverse ethnicity-related social norms and cultural expectations.

Household income was another factor found in this study to have an influence on people's environmental perceptions, and the hypothesis was supported for four perceived environmental features. Individuals with incomes of greater than $65,000, compared to their counterparts with lower incomes, reported greater access to grocery and fruit and vegetable stores and parks. They were also more satisfied with neighbourhood access to shopping. While in this study residents of higher and lower household income did not significantly differ in their perceptions about safety from threat of crime, other studies reported that residents of lower household incomes were more likely to express concerns about the safety from threat of crime in their neighbourhoods compared to their counterparts with higher household incomes (41,48,49). Similarly, while the present study reported no statistically significant household income-based differences in perceived access to a transit stop, another study reported that low-income residents are more likely to perceive greater access to a transit stop compared to higher income residents (48). These differences are likely due to differences in the population and levels of low income defined by the study.

Unfavourable BE perceptions observed among lower-income residents may be improved through health promotion strategies aimed at increasing awareness of existing BE features or through environmental change strategies. The latter may include, for example, increasing access to parks and stores with healthier food choices. However, it has been argued that a combination of environmental strategies and community strategies that encourage social cohesion among residents may result in the most successful improvements in residents' perceptions of the BE (49).

According to the results of this study, area-level income appears to have greater impact on residents' BE perceptions than household incomes do. When testing the area-based differences in environmental perceptions, the hypothesis was supported for 25 perceived BE features (summarized in Appendix P). Individuals living in the high-income setting reported greater access to shops, grocery and fruit and vegetable stores, services, transit stops and parks; greater aesthetics; street connectivity; and greater safety from crime. They were also more likely to report being satisfied with access to shopping and entertainment in their neighbourhood and with their neighbourhood as a good place to live (Appendix P). The study findings are in congruence with a recently published study in which, regardless of neighbourhood walkability, residents from high-income neighbourhoods were more likely to perceive higher neighbourhood aesthetics and safety from crime (24).

The observed differences in BE perceptions between individuals from high- and low-income areas may stem from the differences in the presence of BE features in the neighbourhoods. Indeed, in this study, there were significant differences in the provision of services and amenities in favour of the high-income area. On the other hand, where features are present in both low- and high-income neighbourhoods, differences in environmental perceptions may stem from the differences in interactions that people have with their environments. In this study, individuals living in low-income setting engaged in significantly less transportation and leisure PA compared to their counterparts from the high-income setting. Lower engagement in PA means less time interacting with neighbourhood BE features.

There is also the possibility that the differences in environmental perceptions are based in the socio-economic and cultural profile of a neighbourhood, since low-income neighbourhoods tend to have higher proportions of low-income and non-European residents. Indeed, in this study, there was a greater percentage of residents with lower household incomes (48.5% vs. 35.4%) and those of non-European origin (72.3% vs. 20.1%) in low- than in high-income settings. Therefore, it may be a significant challenge to unravel whether the differences in environmental perceptions are due to differences in neighbourhood affluence, the socio-economic and cultural profile of the neighbourhoods or due to differences in the way neighbourhood affluence interacts with the socio-cultural milieu of the neighbourhoods.

In order to improve awareness, targeted health promotion and educational strategies may improve residents' awareness of already-present BE features while simultaneously educating residents from low-income areas about the potential benefits of using such BE features. However, if differences in environmental perceptions are a reflection of disadvantages of low-income neighbourhoods compared to high-income ones, some of these disadvantages may be improved in the short term through the implementation of specific policies (24). Based on the results of this study, some policies that may improve PA among individuals residing in low-income areas could include enhancing neighbourhood aesthetics, building new and improving the condition of existing sidewalks, and increasing access to public transportation. Some longer-term policies could include strategies to decrease crime rates and increase safety from crime through initiatives such as policing strategies.

Differences in perceptions of environmental supports among distinct population groups indicate that increased efforts are needed to promote the availability of neighbourhood supports among groups unaware of their existence. Building new as well as enhancing and promoting existing neighbourhood BE features may largely improve residents' perceptions of environmental supports, especially when targeted to specific demographic and socio-economic groups. Furthermore, the social environment and people's psychosocial characteristics should also be taken into consideration when developing interventions to reduce socio-economic inequalities in people's environmental perceptions (49). Some researchers have found that social capital is associated with a person's sense of insecurity in the neighbourhood (450), and still others have shown that perceptions of neighbourhood disorder are shaped partially by observed disorder but even more so by the racial and economic composition of the neighbourhood (451). Further to this, trust in one's neighbours and a person's length of residence was found to influence people's perceptions of neighbourhood safety (452). Given the impact psychosocial factors have on residents' environmental perceptions, successful strategies to improve residents' BE perceptions should also include a community aspect that will increase people's involvement in their neighbourhood's social processes (49). These interventions also need to take into consideration the socio-cultural and economic diversity of the neighbourhood's residents. In addition, future research on the relationship between perceived BE, health and health-related behaviours should account for psychosocial factors and socio-economic differences in environmental perceptions.

4.4. Correspondence between perceived and objective built environment features

One of the objectives of this study included investigating whether there are differences in the agreement between perceived and objectively measured BE features based on socio-demographic categories. It was hypothesized that the agreement between perceived and objectively measured BE features would differ by gender, neighbourhood and individual income, and ethnicity. The results of this study indicate "poor" to "moderate" agreement between perceived and objective BE features across socio-demographic categories. The findings are consistent with past publications where agreement between perceived and objective features was also found to be "poor" to "moderate" (74,75,77–80,88–98). Although agreement was generally poor, some differences, as hypothesized, were observed across socio-demographic categories.

Among women, compared to men, a slightly higher agreement was observed for the presence of grocery, fruit and vegetable and clothing stores, restaurants, and bus stops, while agreement for the presence of banks, video stores and pharmacies was higher in men. The gender differences in the agreement between perceived and objective BE measures may be the result of gender divisions in the roles and responsibilities within the household. For example, feeding the family has traditionally been the responsibility of women (453), and it has indeed recently been shown that women are more likely than men to report being in charge of meal planning/preparation and food shopping (454). More frequent trips to shop for food may have familiarized women more than men with the local environment.

This study also found ethnic differences in the agreement between perceived and objective environmental features. Among non-Europeans, compared to Europeans, agreement was higher for presence of grocery and fruit and vegetable stores and banks, while it was lower for the presence of clothing stores, restaurants, video stores, and pharmacies. Given that it has been reported that individuals belonging to ethnic minority groups commit a greater share of their earnings to total food expenditures (455), it is possible that they, compared to Europeans, shop at local food stores more frequently and therefore have greater awareness of the food stores in their neighbourhood. Also, given that ethnic minority groups are on average poorer compared to individuals of

European origin (456,457), it is possible that limited budgets do not leave much space for frequenting other places such as restaurants, clothing stores, video stores and pharmacies for which agreement was lower than that in the European group. Additionally, non-Europeans may drive further to visit ethnic restaurants and clothing stores that are not available in the neighbourhood, leading to a lower perception of the availability of such BE features. Finally, it has been reported that individuals belonging to ethnic minority groups engage in less PA compared to individuals of European origin (43), potentially resulting in lower interaction with BE features and lower awareness of their existence.

Differences in the agreement between perceived and objective BE features were also found between residents of lower and higher household income. Compared to individuals with higher neighbourhood income, individuals with lower household incomes had lower agreement for the presence of a clothing store, fruit and vegetable store, restaurant and video store in their neighbourhood. However, for those with lower household incomes, higher agreement was observed for the presence of a grocery store, bank, and pharmacy. Given limited household budgets, it is possible that BE features such as clothing stores and restaurants were frequented less often by individuals with lower household incomes compared to those with higher incomes. Less frequent use of the features may lower residents' awareness of these features in their neighbourhood.

It has also been reported that lower-income residents, compared to their higher-income counterparts, generally engage less in PA (47) and may therefore interact less with neighbourhood BE features. Less interaction with the BE may result in a lower awareness of features present and the lower agreement between perceived and objective BE features that was observed. Interestingly, the results of this study indicate that the agreement between the perceived and objective presence of fruit and vegetable stores was lower, while that of grocery stores was higher, among individuals with lower household incomes compared to their more affluent counterparts. This discrepancy may be due to differences in funds that individuals in low- and high-income households allocate to fruits and vegetables. Namely, it has been reported that low-income households spend significantly less on fruits and vegetables compared to more affluent households (458,459), while allocating more funds to other food items deemed more essential to the household (459). Therefore, it is possible that fruit and vegetable stores may have been less frequented by lower-income individuals who also had greater awareness of the existence of neighbourhood grocery stores they frequented more often for buying food and other household supplies.

Differences in the agreement between perceived and objective BE features were also found between individuals living in high- vs. low-income settings. Compared to the high-income setting, lower agreement was found for presence of grocery stores, clothing stores and restaurants in the low-income setting. This difference may stem from the setting differences in the objective presence of these BE features. Indeed, the results of this study indicate that the low-income setting had lower provision of retail and grocery stores and restaurants compared to the high-income setting. These differences in provision of resources may have been reflected in the differences in awareness of such resources that would have driven the setting differences in the agreement between perceived and objective BE features. Also, individuals living in the low-income setting engage in less PA compared to their counterparts from the high-income setting (50,51), which may have led to lower engagement with, and influence on their awareness of neighbourhood features.

Interestingly, the agreement between perceived and objective features for presence of fruit and vegetable stores, banks and pharmacies was higher for the low- than for the high-income settings, despite other results in this study that indicate a greater presence of each of these features in the high- versus low-income settings. Higher neighbourhood deprivation is associated with poorer health (460), so it is possible that people residing in the low-income setting frequented pharmacies more often compared to their counterparts from the high-income setting; hence the higher awareness of their presence.

Higher agreement for fruit and vegetable store presence may seem counterintuitive given that lower-income individuals allocate less funds to fruits and vegetables (458,459) and possibly frequent such stores less often than more affluent individuals. However, given that the analyses looked at the potential effects of area-level income on the agreement between perceived and objective BE features, higher agreement between perceived and objectively measured presence of fruit and vegetable stores in the low-income setting may be a reflection of a heterogeneous population within the setting. Indeed, about 50% of individuals living in the low-income setting had a household income of $65,000 or greater, and more than 60% of residents had a formal level of education higher than secondary. These individuals may have been more health conscious and frequented fruit and vegetable stores more often, and would have translated to a higher awareness of the presence of fruit and vegetable stores in the setting. Also, it is possible that individuals from the low-income setting tend to purchase fruits and vegetables in local neighbourhood stores, compared to individuals from the high-income setting who might have purchased fruits and vegetables at farmers markets and stores outside of setting boundaries.

There are other reasons that could have potentially influenced the level of the agreement between perceived and objective BE features in this study. One such factor could have been the result of differences in the way participants perceived their neighbourhood boundaries. Perceived neighbourhood boundaries have been found to be influenced by multiple factors such as educational attainment, family income, immigration status, affluence of the neighbourhood people live in (100), gender, and the length of time people lived in a certain neighbourhood (101). Interestingly, in one study that researched resident-defined neighbourhood boundaries, there was a substantial difference in boundaries outlined by residents who lived within a single block of each other and who were quite homogeneous in race, age and gender - characteristics that are known to impact residents' perceptions of neighbourhood boundaries (124). This finding is important, as it suggests that the differences in perceived neighbourhood boundaries may result in measured differences on the health behaviours and social conditions occurring within the perceived boundaries of neighbourhoods residents live in (124). These measured differences may be even more pronounced in a research population that is more heterogeneous and is from places that are far apart or have different levels of urbanization.

The above-described potential differences in resident-defined neighbourhood boundaries suggest that the geographical units used to define the neighbourhoods in this study may not have necessarily matched the boundaries of neighbourhoods as perceived by their residents. Indeed, in a study that explored whether residents perceived the boundaries of their neighbourhoods according to census geography, a mismatch was found between the census-defined boundaries and those of the neighbourhoods as perceived by residents (124). While the average land area of perceived neighbourhoods was close in size to that of a census tract, the boundaries of perceived neighbourhoods included multiple census tracts (124). It was concluded that similarity between resident- and census-defined neighbourhoods should not be assumed (124).

Poor agreement between BE features may also be the result of perceived and objective BE measurements not being perfectly matched (89). Although only the closest-matched perceived and objective features were used to explore the agreement between the BE measures in this thesis project, the questions for assessing features in NEWS did not perfectly match those from the audit tool used for objective measures. For future assessments, questionnaires and audit tools need to be modified to ask the same question in order to establish a perfect match between perceived and objective features. However, while this may be an easy task for some features, such as finding the presence or absence of certain BE features, matching other questions may be more challenging. For example, finding the perfect objective BE match for perceived safety from crime and traffic or perceived neighbourhood aesthetics remains a challenge (90).

Another contributor to disagreement between perceived and objective BE features may be the residents' inability to perceive distances accurately (90). The geographical scale outlined by NEWS for the self-reported environmental measures was a 10-15-minute-walk from the study participants' homes, which may have been too long of a distance for some of the residents to recall environmental supports correctly. Although there is no agreement on what is an ideal distance for the recall of neighbourhood BE features, it has been argued that shorter distances to environmental supports may enhance residents' perceptions of the presence of such supports in their neighbourhoods (90).

The level of interaction of people with their neighbourhood environment may also influence the agreement between perceived and objective BE measures. It has been argued that environmental perceptions can be improved with higher exposure to, and interaction with the neighbourhood environment (95), whereby people's lifestyles play a significant role in shaping their environmental perceptions (99). Residents who spend time walking in their neighbourhood are more likely to recall a greater level of detail of neighbourhood environmental supports than those who predominantly drive a car and travel larger distances, usually outside of their neighbourhoods (99). Similarly, residents who exercise in a gym or use a local ice rink or pool are more likely to recall the presence of these neighbourhood exercise facilities compared to residents who do not use them. Conversely, the presence of certain environmental features in the neighbourhood does not guarantee that these will be used; it may appear that the existent environmental supports do not match the residents' standards (95). People tend to pay more attention to things that are of interest to them (79), and it is therefore likely that residents will not be able to recall the presence of features that are not of interest to them. It has also been reasoned that perceptions of features present in one's environment are impacted by an individual's personality, past experiences, aspiration levels and adaptation processes, all suggesting that two individuals living in the same neighbourhood may perceive its BE characteristics differently (77). Future qualitative studies may shed further light on people's judgments about the location of resources and the role that social and personal characteristics play in people's environmental perceptions (96).

It is interesting that the level of agreement itself between perceived and objective BE measures, as reported in the study of Gebel et al. (88) was shown to influence individuals' health and health-related behaviours, whereby greater mismatches were associated with lower PA levels and higher weight. Consequently, an increase in the level of agreement between perceived and objectively-measured features may help improve people's PA levels and weight. Interventions aimed at improving residents' perceptions of their neighbourhood, while taking into consideration the differences in perceptions among distinct demographic and socio-economic groups, are needed in order to increase the strength of the agreement between perceived and objective environmental measures and consequently positively influence people's health.

4.5. Adiposity, blood glucose and the built environment

This study aimed to explore the association between perceived and objectively measured BE features and adiposity and FBG. It was hypothesized that perceived and objective BE features would be associated with measures of adiposity and FBG independently of potential confounders including age, sex, formal level of education, household income, ethnicity, and setting income. The hypothesis was supported for a limited number of both perceived and objective environmental features (results summarized in Appendix Q).

After adjustment for confounders, this study showed no association between perceived BE measures and BMI, much like another study that found no association between BMI and multiple perceived environmental features, including land-use mix, aesthetics, walking infrastructure, street connectivity, the presence of food outlets and PA destinations; however, unlike the present study, they did find that lower perceived traffic safety and a higher presence of graffiti and vandalism were associated with higher BMI (333). The difference in results may be due to the way outcomes were determined (Christian et al. (333) calculated BMI from self-reported height and weight) or simply because the number of study participants in their study was substantially higher than in this one, allowing for more power to detect the associations between perceived BE features and BMI. A negative relationship between traffic safety and BMI was also observed in a recent longitudinal study, which reported that individuals were more likely to have increased BMI if they felt that traffic made walking in their neighbourhood unpleasant (356). However, consistent with findings of this thesis project, the longitudinal study found no associations between BMI and perceived presence of shops within walking distance, access to a transit stop, presence of sidewalks, cycling trails and recreational facilities, safety from crime, presence of many interesting things to look at while walking and of seeing others in the neighbourhood being active. This thesis also builds on the above-mentioned studies by reporting no association between perceived neighbourhood satisfaction and BMI. No associations were found between BMI and residents' satisfaction with access to public transportation, shopping, entertainment, safety from crime and traffic, the ease and pleasantness of walking in the neighbourhood, the number of acquaintances in the neighbourhood, and whether their neighbourhood is a good place to raise children and to live in.

Another study also explored the association between perceived environmental measures and BMI and indicated that residing in better physical environments was associated with lower BMI (84). However, it is challenging to compare these findings with the results of this study, as environmental features were represented by a 'physical environment' variable that combined composite scores for the neighbourhood walking environment and availability of healthy foods (84). A composite score was also used in a study by Catlin et al. (335) which explored the association between perceived BE and being overweight (BMI>25kg/m²). A 'community perceptions' score was derived from residents' perceptions of safety from crime and traffic, as well as of neighbourhood aesthetics, and it was found that a larger number of negative environmental perceptions was associated with greater odds of being overweight. While these results are indeed informative and point to the modest but significant effects perceived neighbourhood environment has on residents' BMI, because the studies worked with composite scores, it is challenging to separate which of the perceived environmental variables showed the largest effect on BMI and to therefore translate these study results in a way that can inform policy.

Similar to the latter study that used BMI to create a categorical outcome (overweight vs. normal weight), several other studies have also researched perceived environmental measures and their association with overweight (BMI>25kg/m²) (330) and obesity (BMI>30kg/m²) (23,332,365). These studies indicate that the odds of being obese are higher among residents who perceive larger distances to green areas (365), and higher presence of vandalism and graffiti in their neighbourhood (23). Meanwhile, greater access to commercial places, better aesthetics, greater safety from traffic and crime, and absence of garbage were associated with lower odds of being overweight (330). Although two of the above-mentioned studies derived BMI from objectively-measured height and weight (23,330), comparability of the results between those studies and this project is challenging for several reasons: all studies used overweight or obesity as a study outcome, while this study used BMI (continuous variable); some explored one or a very limited number of perceived environmental variables (23,365) and none of them researched the effect residents' satisfaction with neighbourhood features has on their BMI.

Similar to the results of perceived BE measures, this study showed no association between objectively-measured BE features and BMI. The exception was the directly assessed presence of gardens in the neighbourhood, which had a positive association with residents' BMI. It is possible that beautiful gardens stimulate sedentary activity among the residents rather than being motivators for PA, as people are more likely to sit, relax and enjoy the scenery. However, given the low variance of this feature across the study areas, it is possible that the observed association is chance occurrence. A study by Christian et al. also found no relationship between objectively measured BE features and BMI (333), However, it is important to note that comparability between that study and this one is limited because of the way neighbourhoods were defined (a 500-meter-circular buffer in this study versus a 1.6 kilometer road network around residential addresses in the other), and because of the way BE features were assessed. While this study assessed BE features directly and focused on micro-environment, Christian et al. (333) used composite indices of residential density, street connectivity, and land use mix derived from GIS. Also, this study derived BMI from measured height and weight, while the other study calculated BMI from height and weight values reported by study participants.

There are several other studies that also focused on objective BE features and used BMI as a study outcome (24,246,339,361,362,364,366). However, comparing their results with the findings of this study would be a challenge given that none of them assessed BE features through direct environmental assessment. According to the results of these studies, features not found to be associated with BMI include population density (361,364,366), number of PA facilities (361), slope, sidewalk availability, number of intersections (361), and number of grocery stores, fast-food establishments and restaurants (339). Furthermore, contrary to the authors' expectations, the study that explored the effect of BE on change in BMI over 6 years among adults living in Edmonton, Canada, showed no association between walkability and BMI (356). The authors believe that this may be due to self-selection to neighbourhoods; namely, people who are more active and health conscious choose to live in walkable neighbourhoods. They also suggested that no relationship between walkability and BMI may be due to no changes in BMI over time, as people who are not inclined to walk will not be affected by neighbourhood features even when living in highly walkable neighbourhoods (356).

In contrast to the results of this study, others reported significant associations between several objectively-measured BE features and BMI including the number of fitness facilities (339), walkability (241,246), and land-use mix (339), whereby more fitness facilities, higher land-use mix and higher walkability were associated with lower

BMI. Interestingly, one study found a positive association between land-use mix and BMI indicating that individuals living in areas with greater mix of land use - including the presence of more commercial and industrial buildings - had higher BMIs (361). The authors believe that the disparity in findings may be attributable to measures of land use and their choice of confounding variables (other studies did not account for individual socio-economic status) (361).

Associations between BE and BMI were additionally explored in a recent Canadian study that included two settings: Vancouver and Toronto (336). Findings in the Vancouver setting indicate negative associations of land-use mix, street connectivity, and walkability with BMI, while no such associations were found in the Toronto setting. The authors concluded that results should be interpreted with caution; however, they gave no suggestions as to what effect their results may have on urban design and policy.

Despite being challenged for its accuracy in defining obesity (461), BMI is a commonly-used obesity measure in both clinical and research practice. The results of this study revealed no association of perceived and objective BE measures with BMI. In contrast, BE features did show some associations with other measures of obesity such as WC, WHR and %BF. Waist -to-hip ratio of individuals who reported that it takes them 10 minutes or less to get to a grocery store was lower compared to that of their counterparts who reported longer times to reach the store. Similarly, being satisfied with neighbourhood access to shopping was associated with lower WHR. Furthermore, individuals who reported shorter times to walk to retail, fruit and vegetable stores and a park had lower %BF compared to people who reported that it takes them 11 minutes or more to reach these features. Several features were negatively correlated with adiposity; however, once analyses were adjusted for confounders the direction of the relationship changed. For example, the correlation between access to local stores and WC and WHR was negative, while the sign of the relationship changed to positive after adjusting for confounders. Further studies are needed to look at whether confounding factors used in this study moderate the relationship between perceived BE features and adiposity.

A study that also used alternative adiposity measures explored neighbourhood BE and individual eating-out and PA behaviours in relation to a one-year change in body weight among adults aged 50 and 75 (354). According to the study results, living in high-walkability neighbourhoods was associated with decreases of 1.2 kg in weight and 1.6 cm in WC among residents who increased their PA during the one-year assessment period (354). Another study by McAlexander et al. (2009) looked at the association between objectively-measured BE features and %BF; they assessed %BF using a bioelectrical impedance scale, which is a less accurate method than the DEXA scan used in this study (367). Interestingly, McAlexander et al. (367) found a positive association between sidewalk connectivity and %BF, but given that they only measured a limited number of BE variables, it is possible that other unmeasured features were affecting residents' health attitudes and behaviours that would translate into higher levels of obesity. Nevertheless, including measures of adiposity that reflect an individual's adiposity status better than BMI does, such as WC, WHR or %BF, may uncover some new relationships between BE and adiposity that may have been missed by using BMI alone.

There are only a handful of studies that have examined the association between BE and obesity through direct assessment of BE features (203,329,332,345,367). Consistent with this study, some found no association between street connectivity (345), access to PA resources (332,345,367) and obesity. However, some of these same studies reported a negative association between sidewalk availability and obesity (329,332) and a positive association between incivilities and obesity (332,345).

The inconsistency in the results across studies on the BE and adiposity is most likely due to differences in study design and methodology. There was a significant difference in the way neighbourhood was defined, with some researchers using administrative units as neighbourhood proxies (239,274,343,356), and some identifying neighbourhood boundaries using a road network (83,248,337) or a circular buffer (249,332,338,345,367,371). Furthermore, while this study and several others assessed obesity measures objectively (239,330,338,340,345,366–368), the majority of other studies calculated BMI from height and weight values that were self-reported by study participants (52,209,236,248,274,289,333,336,337,343,344,356,361,362,364). The obesity variable was also presented in different ways; this study and several others used BMI as a continuous variable (209,289,333,336,338,361,362,364,366), while the others presented it as a categorical variable (23,52,83,134,236,239,248,249,274,330,343,344,356).

Another factor that may have contributed to the inconsistency in results across studies is the way BE features were assessed and presented. As mentioned above, only a limited number of studies, including this one, assessed neighbourhood BE features directly. However, these studies did not all use the same audit tool, which resulted in different features being assessed. Even when tools contained similar features, they differed in the way those features were defined, which may have also contributed to the differences in results. The majority of other studies used GIS data to objectively quantify BE features of interest (52,83,134,236,239,241,246,249,274,336,338,342,361,368,371). According to the results of these studies, lower obesity levels were found in neighbourhoods with higher residential density, street connectivity (248,336), land-use mix, and walkability (134,236,241,246,248,336). Standardizing methodology wherever possible may increase the comparability of results across studies.

Only a limited number of BE features was associated with FBG after adjustment for confounders. Blood glucose was 3.9% lower among individuals who reported that it takes them 10 minutes or less to get to a bank compared to residents who reported longer times to reach it. Furthermore, after adjusting for confounders, FBG of individuals living in neighbourhoods where gyms are present, compared to those living in neighbourhoods where no gyms are present, was 6.2% lower. This is consistent with the observations from Toronto where lower diabetes rates were noted in areas with higher access to PA facilities (389). In this study, lower FBG was also observed among residents living in neighbourhoods with greater presence of curbcuts, while living in neighbourhoods with steeper segments was associated with higher FBG levels. This is in contrast to the findings of a recent Australian study where it was noted that living in hillier neighbourhoods was associated with lower odds of diabetes (391). In addition, there was a negative association between presence of movie theatres and FBG; however, it is possible that the observed association is chance occurrence given the low variance of this BE feature across the study areas.

Diabetes can be prevented through PA and healthy diet (380,382,462), factors that have been argued to be intermediaries in the association between neighbourhood features and diabetes (85). Living in environments that hinder PA and healthy eating may present a barrier for people to maintain healthy blood glucose levels. Indeed, the results of this study indicate that living in neighbourhoods with no access to a gym, and where street segments are steep and have no curb cuts at intersections for increased sidewalk accessibility, is associated with higher levels of FBG. Some of these unfavourable BE features are modifiable and some could be more readily remedied than others in order to reduce barriers to PA. For example, building curb cuts at street segment ends may increase walking among neighbourhood residents, especially among the elderly, individuals with disabilities and women with young children. Building resources for PA and healthy diets in neighbourhoods may appear challenging given the significant amount of funds needed; however, provision of such resources is important given that these support healthier lifestyles crucial for achieving and maintaining healthy FBG levels. Indeed, the evidence from longitudinal studies shows that living in neighbourhoods with more resources to support PA and healthy diet is associated with lower incidence of diabetes among residents (85). Therefore, it has been argued that modifying the environment to make it supportive of PA and healthy nutrition is key to decreasing population rates of type 2 diabetes (463).

Despite the evidence that shows significant associations between neighbourhood BE features and diabetes, and due to the multifactorial nature of the disease, environmental strategies in which the physical environment alone is addressed may be less likely to result in a substantial decrease in population diabetes prevalence. Also, social disadvantage tends to have a significant impact on people's health: it has been shown that the odds of having diabetes were 2 to 3 times higher among residents living in neighbourhoods with the highest unemployment rate and lowest income compared to those from neighbourhoods with the lowest unemployment rate and highest income index (464). Furthermore, moving from a neighbourhood with a high level of poverty to a less-poor neighbourhood was associated with a reduction in diabetes prevalence (465). Therefore, population health strategies to decrease population levels of diabetes may be more successful when both physical and social environments are addressed. In addition, in order to address complex issues associated with prevention of obesity and diabetes, collaboration of people across diverse sectors such as government, academia, private sector, non-governmental non-for-profit organization, and various community groups is needed.

4.6. Canadian context

The present study contributes to the Canadian pool of studies through its exploration of the association of the BE with PA domains, adiposity and blood glucose in adults from two Vancouver urban areas. The uniqueness of this study lies in the direct assessment of a large number of micro-BE features (using the IMI) and how they relate to the abovementioned outcomes. This study is also among rare Canadian studies to assess adiposity objectively and maybe the only one to use adiposity measures other than BMI. It is also among rare ones to explore differences in environmental perceptions based on gender, ethnicity and income.

Another group of Canadian researchers recently also used the IMI to objectively assess the BE of two urban communities in Alberta (North Central Edmonton and Medicine Hat), and they summarized their BE data based on domains determined by Werner et al. (466). While they found no associations between the BE domains and total walking (an exception was a negative association between crime safety and total walking in North Central Edmonton community), the present study found significant positive associations between objective BE features related to safety from traffic, presence of sidewalks, restaurants and services with total walking. The differences in findings may be due to a different approach to dealing with the BE data (Albertan study used summary scores) and differences in context where the studies took place.

There are a few other studies that also directly assessed the BE. One researched walking to work that was not assessed in the present study (402), and the other, from Montreal, used an approach to assess the BE that significantly differed from the one employed in the present study (244). In the Montreal study each observation was recorded on a 10-point rating scale, and the limited number of features was assessed. Furthermore, while in the present study all segments were assessed in each of the participants' neighbourhoods, in the Montreal study trained observers collected data while walking down the predetermined walking route that connected ten previously randomly selected neighbourhood segments. The differences in methodology may have led to the differences in the study findings between the Montreal (only neighbourhood density of destinations was positively associated with walking) and a present study (features related to safety from traffic, presence of sidewalks, restaurants and services were positively associated with total walking).

A research group from Ottawa has also looked at the neighbourhood micro-environmental features; however, their approach to assessing features substantially differed from the one in the present study. As part of the qualitative exploratory study, they asked seniors to take photographs of facilitators of and barriers to walking in their neighbourhood, and photographs were used in focus-group sessions as touchstones for discussion (400). Despite the differences in the design of the present study and that of the qualitative study, they both suggest that better safety from traffic may lead to more walking.

Despite the differences in methodologies, the findings of this study are in congruence with the findings from the York Region-based study where a positive association was observed between residential density and transportation PA, although the York study researched specific walking domains rather than domains of PA like it was done in the present study (404); and findings from Montreal where greater access to services was positively associated with more walking (259). Additional studies also explored the association between the BE, PA, obesity and diabetes, however, it was challenging to compare their results with the present study because they investigated gender differences in the association of the BE with PA and obesity (257); differences in obesity and PA across neighbourhoods with contrasting socio-economic and recreation environments (349), investigated destinations and mobility of older adults in highly walkable neighbourhoods (405), looked exclusively at bicycling (136), at families rather than at adults (348), were qualitative (218), used spatial methods of analysis (352,353); or focused on outcomes that significantly differed from those in the present study, such as diabetes prevalence and incidence (389,397), specific walking domains (234,403) or engaging in sufficient versus insufficient activity (208).

An additional challenge to comparing the results of this and other Canadian studies lies in the way neighbourhoods were operationalized. A study of de Sa and

Ardern (404) also defined neighbourhood as 500-meter buffer; however others defined neighbourhoods as buffers of larger sizes ranging from 1kilometer to 1.6 kilometers (208,234,250,256,351,403), or neighbourhoods were based on administrative units (244,356,402,405), or defined while considering several factors including natural boundaries, similarity in socio-economic status and demographics, feedback from community members and experts city listing service maps (257,349). Also, in a few studies, such as those from Calgary (234,256,403) and Vancouver (405), researchers focused on neighbourhood-specific PA, while in this and many others the use of questionnaires that assessed PA (such as IPAQ) precluded researchers from capturing neighbourhood-based PA.

As stated earlier, the present study included both perceived and objective BE measures and explored how they relate to PA, adiposity and blood glucose of residents living in two urban areas in Vancouver. There is a temptation to conclude that the findings may generalize to similar Canadian urban settings that are with higher residential density, walkable, with good street connectivity and good access to public transportation. However, this conclusion should be viewed with caution, as other factors may significantly impact the relationship between the BE and PA even if settings are similar to the ones assessed in the present study. For example, one of the major barriers to PA identified by Edmonton residents is “drastic Edmonton winters” (218). Furthermore, a recent study from Poulio and Elliott (336), found significant differences in the association between the BE and BMI (using the same BE features) between Vancouver and Toronto, the two largest Canadian metropolitan areas. Also, it has been shown that proximity to the coast is independently associated with higher levels of PA (467). Vancouver is a coastal city, and, therefore, its physical environment may significantly differ from that of other non-coastal Canadian cities. Therefore, until more research is done, it is still unclear whether the results of this study are specific to urban areas of Canadian cities, exclusively to the city of Vancouver, or even just to the two settings assessed in this study. As part of the PURE study, we performed direct assessment of 20 communities that differ in level of urbanization and are positioned across Metro Vancouver. Data are being analyzed for the association between the BE and PA and obesity. The results will give us a better insight in how similar or different the associations are across these communities.

4.7. Direct assessment of the built environment: challenges and recommendations

The IMI tool used in this study for direct assessment of the BE provided important information on the micro-scale features present in the environment. Assessing micro-scale features is important, as some built environments, especially in more disadvantaged areas, may simultaneously have neighbourhood-level (macro-scale) features that support PA and healthy diets and less-supportive street-level (micro-scale) features (236,468). One study from Austin, Texas demonstrates this discrepancy: compared to least-poor areas, areas of higher poverty exhibited higher neighbourhood-level walkability, as represented by greater residential density, sidewalk completeness and land-use mix; however, street-level walkability was lower, as represented by poorer sidewalk and building maintenance, aesthetics, higher crime and traffic collision rates and lower overall reported neighbourhood safety levels (469). In some cases, unfavourable microscale features are influential enough to override any positive effects of macroscale characteristics, thereby hindering residents' tendencies to be physically active within their neighbourhood (236). Therefore, assessing and acting upon "macro" BE attributes only may not be sufficient to bring about a positive change in resident PA levels.

Microscale features can also play an important role in BE interventions independent of "macro" ones. Making changes to macroscale features can often be costly and slow, while changes to "micro" BE features can happen promptly and with less costs involved (236). For example, removing graffiti and litter, improving street lighting and pedestrian safety may help increase the PA of neighbourhood residents and decrease environmental disparities (236). While the collection of "micro" BE data from all street segments in a neighbourhood gives a complete picture on the state of microscale features within the neighbourhood, this approach may be very time- and resource-consuming. However, a recent finding suggests that sampling 25% of the neighbourhood street segments located within 400 m of residents' homes sufficiently represents the pedestrian BE and may translate into a more cost-effective method of "micro" BE data collection (470).

Audit tools are essential for recording the state of microscale BE features. It has been argued that it is important that researchers, both creators and users of environmental audit tools, share their experiences and exchange ideas regarding the usability of tools for direct environmental assessments (471,472) that would lead to further refinement of existing environmental measures and audit tools (123). Therefore, this section presents the challenges faced during the assessment, and recommendations for overcoming these challenges in future BE studies. In addition, this section also outlines the potential reasons for the differences in the initial assessment and reassessment of the BE features, given that for about 30% of BE features, the intra-rater agreement ranged from poor to almost perfect (k<1).

Due to a lag in time (about one year) between this study's initial BE assessment and its reassessment, and the dynamic nature of the BE, multiple changes in environmental features were to be expected. For example, there were observed changes in the BE features responsible for enhancing traffic safety: crosswalk lines were repositioned, stop signs and traffic signals were removed due to sidewalk and road remodeling, or sewer operations. Some improvements in neighbourhood walkability also occurred, such as newly-built curb cuts to improve the safety of people crossing the street. In the low-income setting, an old community centre was demolished and a new one was rebuilt nearby. Certain retail stores and offices closed while new ones opened in their place. The above-mentioned changes in the BE undoubtedly contributed to lower agreement between the initial audits of some BE features and in their re-audits.

Several challenges were encountered during the comprehensive audits of the two urban settings in this study. A set of solutions and recommendations for overcoming such challenges helped modify the audit tool used for these assessments can be used to inform future research while in its developmental phase. This will decrease ambiguity for the users of the audit tool, make BE assessments easier to conduct, enable easier training of the auditors and increase intra-rater consistency (473). The challenges encountered and the corresponding proposed solutions are as follows:

Segment slope – Steep hills are implicated as a barrier to engagement in PA; however, there is no one standard measure for assessing street slope (26). The IMI offers a choice of predefined categories of steepness such as 'steep slope', 'moderate slope’ and ‘flat or gentle slope’, and photos of each choice are available to make assessments easier (419). However, in practice, differentiating among the categories is not always simple. An auditor may assess the same segment differently at two different points in time, influencing rater consistency. For example, segments may appear steeper when a rater has a lower level of physical fitness, is fatigued, or is wearing a heavy backpack (474). Ratings can additionally be influenced by whether one is going uphill or downhill, as hills with a slant of more than 25 degrees appear steeper when viewed from the top than the bottom (475). In order to increase intra-rater reliability, and when relying on a rater’s perceptions of street steepness, dichotomizing the ‘steepness’ BE feature is recommended. When this is done, only two choices are given: segments are flat vs. segments are sloped. In contrast to the perceived steepness method, other researchers have measured slope objectively while still dichotomizing the steepness variable into steep vs. flat according to a predetermined slope cut-off (89,91). However, given that some researchers found no associations between segment slope and PA using this approach (91), analyzing steepness as a continuous variable when measuring it objectively is recommended.

Curb cuts – The presence of this BE feature is especially important for improving sidewalk accessibility and mobility of persons walking with strollers, using wheelchairs, or those with limited mobility. As part of the IMI instrument, curb cuts are to be assessed at street intersections. However, curb cuts are also commonly needed between street intersections, where alleys and streets intersect. For some people, high curbs present a barrier to crossing an alley and continuing a trip safely, therefore, recording the presence/absence of curb cuts at street-alley intersections as well as at street intersections is recommended.

Trees – These provide shelter and protection from sun and precipitation, and contribute to neighbourhood aesthetics. The choices offered in the IMI audit tool for categorizing the amount of trees in the environment are ‘some trees/trees along most or the entire segment’ vs. ‘none/few trees’; however, these choices leave categorization open to interpretation. For example, two large trees on a short segment may give adequate shade to the sidewalks underneath, making walking pleasant during warm days and protecting walkers from rain or other precipitates. They also significantly increase the aesthetics of the streets they are planted on. The question is whether these trees should be rated as ‘some trees’ or ‘none/few trees’ given there are only two of them. On the other hand, 5 to 6 small trees along the segment (for example, recently-planted ones, as were encountered during neighbourhood audits) are less likely to give shade, protect from precipitation or significantly contribute to neighbourhood aesthetics. The problem is that these can be rated differently by multiple raters, as some may focus on the number of trees alone, while others may take into consideration their size, type and deciduousness. Given that attempts to measure the number and height of trees have also demonstrated poor intra-rater reliability (60), offering two categories – trees present vs. trees not present – may significantly ease the assessment of this feature and increase reliability. In addition, trees assessed are commonly the ones present between the road and sidewalk; however, if trees in parks or front yards are large enough to give shade to sidewalks and protect walkers from precipitation, it is recommended that these be counted as well.

Street parking – This provides a buffer between pedestrians and traffic and is therefore a contributor to pedestrian safety. However, the presence of parking can vary depending on the time of day. For example, parking is forbidden for most of the day on busy multi-lane streets, while parking in residential areas is allowed most of time. Similarly, some parking is free and some is metered. If parking is a feature of interest, several categories should be created in order to capture its diversity in the environment: free on-street parking and paid on-street parking, and whether or not these are restricted to certain times of the day; no street parking available should also be included.

Graffiti and litter – Poor to fair intra-rater agreement for graffiti and litter was expected given the dynamic nature of these two environmental features. For example, some large pieces of graffiti were repainted and new ones emerged elsewhere in the meantime. The assessment of these BE features is important, as it has been shown that living in less attractive areas with graffiti and litter has been linked to obesity and lower PA levels (203). Some researchers chose to look at these two features as parts of incivilities (203) or the cleanliness of the environment (65). According to the IMI inventory, graffiti and litter are assessed as separate features, quantified by predefined categories such as “some/a lot”, little” or “none” (419). Some researchers found litter hard to quantify reliably, and therefore excluded it from environmental assessments (476). However, instead of excluding the variable due to potentially low inter-rater reliability, it has been argued that the inter-rater reliability of some features can be enhanced with more intensive auditor training (419). To increase the reliability of litter measures, one suggestion may be to, in the training manuals, clearly outline the criteria for classifying the amount and type of litter. Furthermore, auditors should avoid conducting assessments on days associated with unusually increased waste production, such as holidays and street festivals. As for graffiti, training manuals should include guidelines outlining the most probable graffiti locations (for example, backs of traffic signs, bus stop benches, electricity pillars, and post office mail boxes) so that these are not overlooked.

Street lighting – Research findings related to the association between street lighting and PA are inconsistent (178), possibly due to the different ways in which street lighting is assessed. Researchers using the IMI tool assess for presence or absence of outdoor lighting (419), while others take more interest in the quality of lighting available, rating it by values such as ‘good/fair’ and ‘poor’ (125). During this study’s assessment of two urban settings using the IMI instrument, it was noted that the number of streetlights per segment changed even as segment length stayed the same, meaning that segments differed in how well they were lit. Thus, capturing the density of streetlights (number of streetlights per given segment) may be a better indicator of lighting than would be the number of or presence/absence of streetlights alone. Where possible, street light density could also be complemented with objective measures such as light meter readings to determine just how well streets, and sidewalks in particular, are lit at night. In the areas where there may be concerns about safety, auditors should travel in pairs.

Golf course – The presence of this BE feature in the neighbourhood was found to be associated with higher levels of PA (128). The problem with assessing golf courses, however, is that they commonly span a large area, but accessibility is usually limited to one or two entry points. Therefore, while a section of the golf course may be within a person’s neighbourhood boundaries, residents may have to travel far to get to a point of access. Consequently, only the entranceways of a golf course should be noted during audits, given that they fall within the boundaries of the neighbourhood being assessed.

There are several general recommendations that may improve the intra- and inter-rater reliability of audited BE features: take photos during environmental audits to serve as a visual reference and enable consultations with other researchers post-assessment to classify features that are ambiguous; dichotomize (present/absent) the categories for certain BE features in order to avoid the use of nonspecific identifiers such as many/some/few; and incorporate breaks into audits to avoid fatigue, which would otherwise influence raters' attention to detail as well as their rating of certain BE features such as segment steepness (473). If resources are available, having two or more raters completing environmental audits as a team may minimize subjectivity and allow raters to feel safer in unfamiliar environments. Working together also allows raters to drive instead of walk in areas with longer, less feature-dense segments such as those in rural areas.

4.7.1. Challenges to summarizing large amounts of Irvine-Minnesota Inventory data

Summarizing large amounts of IMI data still remains a challenge. At the time of data analysis for this thesis, no scoring system was available to summarize IMI-based data. Therefore, a large number of analyses were performed, which often leads to a multiple comparisons problem. Several research groups developed approaches to summarize IMI data. A group of Canadian researchers used a three-phase approach to reduce large amounts of IMI data collected from 296 segments in a semi-rural community in Alberta. In phases one and two a set of groupings of geographically contiguous segments were created by six experts, and these experts' groupings were analyzed by cluster analysis to form a single consensus grouping or a neighbourhood. In the third phase, meaningful scales of BE features that separated the neighbourhoods were constructed using discriminant function analysis. As a result of this three-phase approach, the 296 segments were reduced to a consensus of 10 neighbourhoods, which could be distinguished from each other by 9 functions that were constructed from 24 IMI items (407). While this approach was proven very useful in catalyzing discussion among community stakeholders toward the development of health-promoting BE interventions, it is yet to be determined whether the derived discriminant functions are specific to semi-rural communities in Alberta or could also reflect BE characteristics of urban and rural areas in Alberta and other Canadian regions.

Another approach to reducing a large amount of IMI data comes from the developers of IMI who proposed two shortened versions of this audit tool that included features most strongly associated with PA or walking for travel (71). While this approach reduced the number of items in the audit tool, the approach to data analysis (one BE variable per one regression analysis) did not change, as no scoring protocol was provided to summarize the data. Additionally, the developers excluded all items that had no or almost no variability across assessed segments. This may limit the use of these reduced versions of IMI, as it is possible that the excluded items may actually show variability across segments in different contexts. The authors indeed stated that users of the audit tool may wish to include the excluded IMI items in case they are specifically interested in such variables or want to test hypotheses in different contexts or populations (71).

An alternative approach to summarizing IMI data comes from Werner et al. (466) who explored whether people were more likely to walk to a transit stop if they lived on a "walkable" segment in Salt Lake City, Utah. After excluding 84 IMI items due to a lack of variance across segments, the rest of the IMI items were summarized into 6 subscales: density, diverse destinations, pedestrian access, attractiveness, crime safety, and traffic safety. While this approach significantly reduced large amount of information obtained by IMI and eased the analyses, a recent work from Schopflocher and colleagues indicates that constructing reliable and valid scales from IMI variables still remains a challenge (401). While using IMI data collected in two urban settings in Alberta (The North Central Edmonton community and Medicine Hat), Schopflocher and colleagues repeated the scale construction procedures described by both Boarnet et al. (71) and Werner et al. (466) to explore whether the proposed scales have general value for establishing the association between the BE and health behaviours. The results of their investigation failed to support the viability of scales in the Albertan settings created using the methods of Boarnet et al. and Werner et al. indicating that a viable scoring scheme for IMI is yet to be developed (401).

4.8. Study limitations and strengths

Several study limitations should be acknowledged. This is a cross-sectional study, so longitudinal ones are needed to explore whether the observed associations between BE features, PA, adiposity measures and blood glucose persist or change over time. Furthermore, the study sample was one of convenience and included individuals willing to participate to the study. Therefore, the representativeness of the study population cannot be presumed. Indeed, due to PURE study eligibility criteria to include only individuals between ages 35 and 70 years, study participants were on average older than individuals from the census tracts they were recruited from where the median age was about 37 years (Canada 2006 Census) (477,478). Furthermore, individuals with higher than secondary level of education were slightly overrepresented among study participants in both low-income (65.3% vs. 59.2%) and high-income (88.5% vs. 79.9%) settings. Also, the visible minority population from the low-income setting was underrepresented (72.3% vs. 80.7%), while that from the high-income setting was overrepresented (20.1% vs. 18.4%) compared to the populations in census tracts the study recruitment was derived from (477,478).

Another limitation is that, because study participants were not asked to outline the boundaries of their neighbourhood as they perceived it, it is possible that residents' environmental perceptions lay outside the boundaries of the 500-meter buffer used by the study to define neighbourhoods. This may have been one of the possible reasons for the poor agreement observed among perceived and objectively-measured BE features. Furthermore, a cut-off of $65,000 to distinguish high- from low-income households was picked arbitrarily; however, household income of less than $65,000 is not a true low-income category. In this study sample, only 4.5% of study participants (n=16) reported an income of less than $20,000. Studies with a larger sample size of individuals in the lowest income brackets and with more robust low-income measures (e.g. low income cutoffs, low income measures or market basket measure (479)) are needed in order to explore the true differences in environmental perceptions between individuals of high- and low-income status.

Participants were also not asked about their reasons for choosing the neighbourhood they live in, and the analyses did not take into account self-selection (“the tendency of people to choose locations based on their travel abilities, needs and preferences” (480)). Therefore, it is hard to conclude whether the associations between the BE and PA in this study are attributed to the neighbourhood BE itself or rather to residential self-selection (481). Similarly, not taking neighbourhood self-selection into account may have led to overestimation of the magnitude of the association between the BE and PA (482). However, McCormack and Shiell (482) recently reviewed studies on the relationship between the objective measures of the BE and PA, including both cross-sectional studies that controlled for neighbourhood self-selection and quasi-experimental studies. They reported that “the association between the BE and PA likely exists independent of residential location choices”. Similarly, Cao et al. (483) reported that the association between the BE and travel behaviour (walking, cycling and driving) was independent of neighbourhood self-selection in all of the 38 transportation studies reviewed. However, to date, a limited number of cross-sectional studies have controlled for neighbourhood self-selection; therefore, to get more robust estimates of the magnitude of the association between the BE and PA, it is important to adjust analyses for neighbourhood self-selection (482). In this study, data on self-selection were not available. However, given that people’s neighbourhood choices are likely influenced by their socio-economic standing and ethnicity, an attempt was made to minimize the potential effect of self-selection with statistical adjustment for personal-level characteristics.

A further limitation of the study is that PA was self-reported rather than objectively measured, but the former may be a more feasible method for obtaining PA data in a large epidemiological study such as this one. Also, given that objective measurement of domain-specific PA is a challenge, research needs to rely on self-reported PA measures (221). However, the IPAQ used may not be an optimal tool for collecting PA data. The reliability and validity of the instrument used for collecting PA data have been tested in diverse settings, and the instrument has additionally been tested against accelerometers. While test-retest reliability of the questionnaire was generally good, the criterion validity of IPAQ data against accelerometers was poor; the criterion validity Spearman’s coefficients ranged from 0.02 to 0.06 for the long form of the questionnaire, and from 0.02 to 0.57 for the IPAQ short form (416) whereby the majority of the coefficients did not reach 0.50, the number recently recommended as the minimal acceptable standard for a satisfactory self-reported PA questionnaire (484). Another challenge is overreporting of PA in population samples. A recent systematic review of IPAQ short form validation studies also points to poor validity of the questionnaire and reports that the IPAQ short form overestimated PA level by an average of 84% (ranged from 28 to 173 percent) (485). In addition, the IPAQ may not be a suitable questionnaire for collecting PA data to be used for research on the impact of neighbourhood BE on PA given that the PA reported does not necessarily reflect neighbourhood-based PA.

The regression analyses performed focus on individual-level attributes therefore ignoring the multilevel structure (in this case individuals nested within neighbourhoods). When working with multiple hierarchical contexts, multilevel modelling should be a preferred choice of analysis (486). However, given that participants in this study were recruited from only 2 areas, this study was not powered enough for a multilevel study. Namely, while there is still no consensus on the issue of appropriate sample size for the multilevel study, it has been argued that a sample of 30 groups (neighbourhoods) with a minimum of 30 individuals per group (neighbourhood) may be needed for the design of the multilevel study with adequate power (487).

Another limitation pertains to the possibility of multiple comparisons leading to spurious findings. The developers of IMI assumed that the users of the tool might choose only BE items that are based on research needs or hypotheses (71); and at the time of data analysis for this thesis, there was no scoring system available to summarize IMI-based BE data. Therefore, statistical analyses in this thesis were conducted one BE variable at a time rather than including many BE variables simultaneously in the regression analyses. This resulted in a large number of analyses, known as a multiple comparisons problem, which may have led to finding associations between BE and the outcomes when, in reality, such associations did not exist (Type 1 error). By setting a significance level at 0.05, it is recognized that “for every 100 statistically significant relationships observed, five are produced by chance” (488). Based on the findings in this thesis, for example, among 46 observed statistically significant relationships between the perceived and objective BE features and PA domains, two to three are produced by chance. As discussed earlier, variability of multiple BE features was small across study settings, so it is possible that the observed associations such as those for big box shops, hospitals, night clubs, and car dealerships with transportation PA occurred by chance.

While there is no universally accepted approach for addressing the problem of multiple comparisons, a Bonferroni correction is considered a simple, albeit conservative (489), approach to this problem; in which case a significance level (alpha) value for an individual test is determined by dividing the established significance level value (usually 0.05) by the number of tests (490). In this thesis I investigated the association of 39 perceived and 122 objective BE features with various PA domains and measures of adiposity and FBG; therefore, a significance value for an individual test (based on Bonferroni correction) would have resulted in a value that is considerably lower than 0.001. It is most likely that after applying Bonferroni correction none of the associations would have been significant given that Bonferroni correction reduces power and increases a Type II error to unacceptable levels (491).

The IMI is a tool that focuses mainly on characteristics potentially linked to walking in settings that are of a “walkable” size (59). Although the modified version of IMI used for this study included some features related to the food environment (presence of supermarkets, grocery stores, convenience stores, restaurants, coffee shops, bakeries, and meat shops) the majority of other features were the ones related to PA and walking in particular. Therefore, IMI may not be a suitable tool to assess the BE features when exploring the associations between the BE and adiposity and glucose. This may be one of the reasons for the limited associations found between the BE and adiposity and blood glucose in this study, as the tool measures predominantly BE features related to PA. The limited associations may also be due to low variance of BE features across study areas. The neighbourhood in this study was defined as a 500-meter circular buffer around a participant’s home to assess BE features of participants’ local neighbourhoods. However, the study participants were mostly clustered within the setting. There was a lack of variability across settings for many of BE features pointing to homogeneity of study areas that consisted predominantly of urban blocks with gridded street pattern. Given that PURE participant recruitment is carried out in diverse environments, the PURE study is well positioned to address this limitation and maximize potential variability between neighbourhoods. This analysis is underway.

Another limitation pertains to the confounding variables used in this study analyses. The relationships between the BE and PA as well as between the BE and adiposity and blood glucose are complex (14,15); and there are multiple other factors besides those used in this study analyses that can potentially confound or moderate the above mentioned relationships. Also, there may be multiple mediators, and there is evidence on the factors mediating the relationship between the BE and PA such as perceived behavioural control (492), intrinsic motivation, self-efficacy (493), and attitudes toward PA (494), none of which were measured in the PURE study. Furthermore, it has been suggested that the most probable mediators of the association between the BE and obesity and diabetes are PA and diet (10,15). While PURE dietary data were not available at the time of data collection and analyses for this project, additional sensitivity analyses were performed to explore whether the associations between perceived and objective BE features and adiposity and FBG would change once total PA is added to regression models (Appendix N). The results of the analyses indicate that the addition of total PA did not make a significant contribution to any of the models. In addition, it is important to note that this study did not attempt, nor was it well positioned, to address the complex picture of the relationship between the BE and PA, adiposity and glucose. It rather addressed one piece from the puzzle of this complex picture, which was to explore whether perceived and objective environmental measures were associated with PA, adiposity and blood glucose independent of individual socio-demographics and neighbourhood income. More complex analyses that address some of the above mentioned limitations are being performed on the larger sample of PURE participants and larger sample of neighbourhoods.

Despite its limitations, the strength of the study is a direct assessment of the micro-environmental BE features. This is important, given that microenvironments are the aspects of the BE that people interact with on a daily basis. Furthermore, effecting change at a microenvironment level is often easier and less costly compared to macroenvironments, meaning that quicker improvements to the walkability of neighbourhoods can be made.

This study was also unique in that it measured anthropometrics directly and examined socio-demographic influences on BE perceptions. Given that self-reports lead to an underestimation of obesity prevalence due to people’s tendencies to overestimate height and underestimate weight (370,495) calculating BMI scores from objectively-assessed height and weight values allowed for a more robust exploration of the association between BE and BMI. Furthermore, this study includes objectively measured WC, WHR and %BF, measures that reflect people's adiposity status better than BMI does, therefore revealing novel relationships between BE and adiposity. In addition, given scarce evidence on the association between BE markers, this study adds to existing evidence by reporting novel findings on the association between perceived and objectively measured BE features and FBG.

The study also investigated whether BE perceptions were influenced by gender, neighbourhood/individual income and ethnicity, which is important given the socio-economic inequalities present in PA participation. Given that environmental perceptions can impact people's PA levels, uncovering socio-demographic differences in perceptions may reveal which BE features can be acted upon to help decrease the inequalities in PA participation. In addition, while several studies explored the agreement between perceived and objective BE measures, this study reported novel findings on the differences in such agreement based on demographic and socio-economic categories.

4.9. Recommendations for future research, policy and practice

Building healthy environments is important, as it sets the stage for community members to be less sedentary, to have greater access to healthier food choices, and to build and/or strengthen community social ties. Based on the results of this study and other existing evidence, there is strong support for building healthy environments or retrofitting existing communities into ones that will help increase residents' PA and promote healthy body weight (496). In order to make environments healthier, strong support from policy and other decision makers is needed. Therefore, it is very encouraging that support for urban design and zoning policies has been expressed by many Canadian decision makers. This is highlighted in a 2011 survey conducted by the Alberta Policy Coalition for Chronic Disease Prevention (497), the majority of over 200 decision makers (representatives of municipal and provincial government, school districts and boards, workplaces and media) from Alberta and Manitoba largely supported policy interventions related to urban design and zoning that promote active living (497).

Existing evidence, including findings from this study, shows that the way people perceive their neighbourhood environment can shape their PA levels. This study adds to the evidence by finding significant differences in environmental perceptions among individuals of differing gender, ethnic background, household income and neighbourhood-level income. It is therefore important, when engaging with the community members, to include individuals that are representative of these various demographic and socio-economic groups in order to create healthy communities that are also equitable and sustainable. This can be done by recruiting community champions to help raise awareness and promote the benefits of potentially underutilized neighbourhood features, such as new or existing community centres, bowling alleys, walking trails, grocery stores, sidewalks and cycling lanes. For new developments, it would also be beneficial to include community members in the planning process, as the interests of residents may not necessarily correspond with city planners' proposals. For example, a bowling alley and a gym may be planned for a neighbourhood in which residents would rather see a park with fitness equipment installed, playgrounds for their kids to play at, and improvements in sidewalks and street lighting.

A number of other findings have come out of this study that may be used to inform future recommendations. One such finding was that PA levels were lower among residents who reported higher traffic volumes in their neighbourhood versus those who did not; and among residents who lived in neighbourhoods with lower presence of places marked for safe pedestrian crossing. Therefore, taking measures to control traffic may help reduce vehicle speeds and volumes in the neighbourhood, leaving residents feeling safer. Enhancing safety to result in fewer traffic accidents involving pedestrians and cyclists may especially be important for parents, given their concerns for their children's safety (498). Some changes in BE design to enhance safety may include building narrower and pedestrian- and cyclist-only streets in the neighbourhood, or incorporating more traffic-calming measures such as curb-extensions, raised crosswalks, speed humps, traffic circles and signage. Such neighbourhood improvements may have a compounding effect, in that drivers are likely to drive more cautiously (499), and other community members may become more motivated to use active modes of transportation themselves when they see more people walking and cycling in the streets. Indeed, several studies observed higher levels of PA among residents who frequently reported seeing other people active in their neighbourhood (199,202,212).

This study also showed that a greater presence of sidewalks in the neighbourhood is associated with higher levels of transportation PA and overall walking; while leisure PA levels were higher among residents who lived in neighbourhoods where there was a buffer between street and sidewalks. Given that pedestrian crashes are more than twice as likely to happen on roadways without sidewalks as when sidewalks are present on both sides (500), adding sidewalks to neighbourhood streets may significantly improve pedestrian safety and feelings of safety. Moreover, sidewalk maintenance and presence of curb cuts may be equally as important given that they enable safe neighbourhood movements and minimize resident injuries and falls; this may be especially important for older adults using a cane or walker, parents walking with young children, individuals with strollers or shopping carts, and people with physical disabilities. The presence of sidewalks may increase access to and motivate residents to walk to neighbourhood features such as grocery stores, shops, and services, thereby potentially setting the stage for increased PA levels and access to healthier food choices.

It has been argued that enhancing sidewalks and other aspects of pedestrian and cycling infrastructure through the BE *complete street* policy initiatives may provide safer and convenient travel for all road users including pedestrians of all ages and abilities, cyclists, public transportation users (501). Some of the *complete street* policy solutions include traffic calming measures such as widening sidewalks and narrowing roadways; positioning transit stops in a convenient and safe environment; and improving the infrastructure to better meet the needs of travelers with disabilities (501).

While evidence shows there to be positive associations between residential density, land-use mix and PA, the majority of existing studies have approached these features from a macro-environment perspective. This study adds to the current body of evidence by reporting on associations between objectively-measured micro-environment features and PA. Residents who lived in neighbourhoods with a greater presence of condos and a lower presence of single-family homes engaged in more transportation PA compared to those who lived in neighbourhoods with lower residential density. Transportation PA levels were also higher among individuals who lived in neighbourhoods with greater access to different land uses such as restaurants, services, retail stores, hospitals, night clubs, liquor stores and bike routes. It is important to note that objective BE features showed stronger association with transportation PA than with other types of PA such as leisure PA or overall walking. Therefore, this study may suggest that building neighbourhoods to achieve higher residential density along with a variety of residential, commercial and institutional uses may increase peoples' transportation PA. The above suggested recommendations are in line with those recently proposed by Raine and colleagues (498) who recommended that local planning authorities need to be empowered to introduce zoning bylaws that increase high density and mixed land use.

It is important to note that making the above changes that may increase resident engagement in active modes of transportation such as walking and bicycling is not only beneficial at an individual level, but it may also reduce vehicle-related air pollution and lead to improvements in neighbourhood air quality (502). This is important, as it has recently been estimated that the number of premature annual deaths in Canada attributable to air pollution is 21,000,(503) which is 9 times higher than those related to motor vehicle collisions (504). Moreover, higher land-use mix and residential density, and the supportive pedestrian environment, are examples of *Smart growth* principles used for building *Smart growth* communities (505,506). Building such communities can make a significant positive impact on the health of residents living in them, as they tend to walk and bicycle more and drive less compared to counterparts living in isolated, automobile-dependent locations (507). Taken together, living in communities that promote active modes of transportation has implications for obesity, respiratory and mental health, for decreasing numbers and severity of traffic accidents and for neighbourhood social capital (508).

While there is evidence that points to an association between BE and BMI, studies using other adiposity measures are scarce. This study provides novel findings on the associations of perceived and objective BE features with WC, WHR, and %BF. Levels of adiposity were lower among residents who perceived greater access to grocery stores, fruit and vegetable stores, and retail stores. These findings may suggest that the use of policies to improve access to healthy food options may have a positive impact on residents' diet and activity levels and, thus, potentially lead to a decrease in adiposity. In a recent commentary by Raine and colleagues, it has been recommended that incentives and zoning bylaws should be utilized to influence the location and distribution of food stores, including fast food stores and suppliers of fruit and vegetables in order to create supportive BEs that encourage access to healthy foods (498). Others also recommended the use of policy to expand access to retail establishments that provide healthy food options; and argued that it is important to eliminate restrictions that may prohibit and/or limit sidewalk produce displays or use of specific sites for healthy food retail (501).

The results of the study also indicate that levels of adiposity were lower among residents who perceived greater access to parks. It has been suggested that access to parks may be increased through offering structured programming in parks which may also help increase park use and its safety; this structured programming may be offered by local parks and recreation departments and/or community-based organizations (501).

This study also provides findings on the association between perceived and objective BE features and FBG. Individuals living in neighbourhoods with no access to a gym, with steep street segments and with lower sidewalk accessibility due to absence of curb cuts at intersections had higher levels of FBG. These findings may suggest that retrofitting existing neighbourhoods to increase access to PA facilities, and sidewalks may reduce barriers to PA engagement and consequently improve the metabolic profile of neighbourhood residents.

Consistent with the literature, this study reported a low to moderate agreement between perceived and objectively-measured BE features. However, this study builds on existing evidence by reporting that correspondence between perceived and objectively-measured neighbourhood features differs across demographic and socio-economic categories. These differences may be attributed to the demographic and socio-economic differences in environmental perceptions that were also reported in this study. The results of this study may suggest that existing neighbourhood supports need to be better promoted to residents unaware of their existence, whereby interventions need to take into consideration the socio-cultural and economic diversity of neighbourhood residents.

However, it is also important to note that the results of this study and of others point to a need for better standardization of the way BE features are defined and assessed. Environmental tools are essential for conducting such assessments, and the development of high-quality tools is necessary for further exploration of the association of BE with PA and obesity. These tools should encompass the creation of new measures, the establishment of the reliability and validity of existent ones, and the field-testing of both (509). Presently, there is considerable variation in the types of environmental features that are being assessed, which is in part due to a lack of well-established conceptual models that present suggestions for which characteristics should be evaluated (510). The development and testing of such conceptual models – ones that show the association between the BE and obesogenic behaviours – has therefore been identified as a priority (123).

While on its own, a single cross-sectional study, such as this one, may not be sufficient to alter policy and urban design; however, the totality of evidence encourages shifts in built environment shaping policies toward those that will help create environments supportive of PA and healthy body weight (496). In addition, more longitudinal analyses are needed to explore whether these associations persist or change over time. These, and natural experiments, will offer more robust data to be translated into policies for creating BE that will support PA and healthy diet. Natural experiments will also offer insight about what BE interventions will work under which conditions (498).

Aside from the above mentioned needs for better standardization of the way BE features are defined and assessed; and a need for stronger study designs, additional methodological implications are worth noting. A change in the direction of association before and after the adjustment for individual-level variables, observed when exploring the relationship between the BE and PA and adiposity, suggests that these variables may serve as moderators rather than confounders (or simultaneously as moderators and confounders). Therefore, longitudinal studies that will explore the relationship between the changes in BE features and the development of individual-level characteristics over time will help elucidate the moderator vs. confounder question (511). Also, it is important to identify, and adjust for, all relevant individual-level variables to avoid biasing estimates of contextual effects (512). Furthermore, it has been observed that adjustment for residential self-selection attenuates the association between the BE and PA (236,513,514). Therefore, in order to get more robust estimates of the magnitude of the association between the BE and PA, better study designs are needed to account for residential self-selection (482).

At present, the definition of neighbourhoods differs across the BE literature, challenging comparability across studies. It has been argued that more accurate definitions of neighbourhoods are needed, and that externally imposed definitions of neighbourhoods, such as the use of administratively defined units (e.g., census tracts), may not capture well the population of interest and their socio-cultural milieu, which will preclude researchers from fully understanding the population of interest (515). Furthermore, a neighbourhood defined for obtaining data on environmental perceptions (e.g. definition provided by the NEWS developers) may not necessarily match the definition of the neighbourhood set for assessing the objective BE features, as it was the case in this study. Aligning neighbourhood definitions within the study may help to better compare the effects of perceived versus objective BE features on the outcomes of interest. This will also enable more accurate exploration of the correspondence between perceived and objective BE features. Additionally, obtaining qualitative data on individual decision-making, people's preferences and routines, and linking it with the quantitative BE and PA data may give additional insight into the dynamic relationship between the BE and PA.

4.9.1. Embracing new ways of thinking

Regression-based statistical analyses, such as multilevel modeling, are the most commonly used analytical approaches to exploring BE's relationships with health and health-related behaviours (216,516). However, it has been argued that this approach is limited in capturing the complex interactions between neighbourhood features and people's health (517). There is an assumption that effects of the "independent" variables can be isolated from each other and do not allow for feedback loops between health outcomes and predictors therefore simplifying the complex relationship between BE and health (518). Moreover, to extract independent contextual effects on health and health-related behaviours, regression analyses are commonly adjusted for individual-level characteristics such as the socio-economic status of an individual. Yet, adjusting for potential confounders could pose further challenges considering that these factors could simultaneously play both the roles of confounder and mediator of neighbourhood effects (511). Also, regardless of the number of variables the regression model is adjusted for, it still only explores the way neighbourhood features affect individuals, without accounting for the potential feedback mechanisms through which individuals affect neighbourhood features (518). Therefore, regression analyses may not be sufficient to address the complex relationship between the BE and health.

Several academics (517,519–521) have proposed embracing new ways of thinking, known as systems thinking, and the use of models with systems approaches to health to better understand the complex relationship between the BE and health. One such proposed methodological approach is agent-based modelling (ABM) (517). Agent-based modelling is the computational approach often used for studying complex systems, and its framework considers each entity (in this case, an individual) as an independent agent capable of carrying complex reasoning and of interacting with the environment as well as with other agents (522). It is the approach of choice when researching complex human systems in which the population is heterogeneous, interactions between individuals are complex, individuals' positions are not fixed but, rather, they move in the environment, and in which individuals' behaviours are complex, including the processes of learning and adaptation (523). Agent-based modelling helps guide data collection (524), and because ABM is a virtual system, experiments can be repeated multiple times under various conditions without the fear of ethical issues being raised (522). Furthermore, results can be expedited in time-sensitive test cases and costs are lower than those of real world experiments (525). Additionally, ABM can help identify data gaps (526) that, once addressed, would allow for the establishment of a more robust conceptual model of health behaviours in the BE.

The use of systems-modelling approaches to investigate the complex relationship between the BE and health may give further insights into and stimulate broader thinking of the way neighbourhood residents interact with each other and their neighbourhood environment (517). Therefore, systems-modelling approaches should complement existing approaches used to explore the relationship between the BE and health; as better understanding of the complex BE-health processes may allow for the development of more sophisticated theoretical models to represent them (517).

4.10. Conclusions

In conclusion, the results of this study indicate that living in neighbourhoods with greater residential density, land-use mix, pedestrian connectivity and safety from traffic is associated with higher resident PA levels. Furthermore, living in neighbourhoods with greater access to stores, shops and parks is associated with lower body fat. Additionally, greater access to PA facilities and sidewalk accessibility are associated with lower FBG. From a public policy perspective, the results of this study may suggest that enhancing the quality of neighbourhood BEs through increases in land-use mix, residential density, and supportive and safe pedestrian environments may increase PA levels and foster healthy weight among neighbourhood residents. In order to build new or retrofit existing communities to include these health-supportive BE features, a multidisciplinary approach is needed. This includes collaborations between experts from both across and within sectors/disciplines such as urban planning and property development, academia, community, public health agencies, and local government and non-governmental not-for-profit organizations. Significant differences in the way distinct demographic and socio-economic groups perceive their neighbourhood environment were also observed in this study, meaning that in certain cases, public health interventions need to be tailored to individual groups to raise awareness and promote the use of existing but underutilized BE features.

The results of this study also indicate poor to moderate agreement between perceived and objectively-measured BE features. This may be a reflection of the measures capturing different constructs or due to perceived and objective features being not a perfect match. The improvement in and standardization of the way BE features are defined and assessed may bring more insight into the relationship between these measures.

Finally, the majority of evidence on the relationship between BE and health is cross-sectional, so more longitudinal studies are needed to produce more robust results and confirm causality. However, given the severity of the obesity epidemic and the seriousness of its complications, the best strategy may be to take action now, evaluate any policy changes that take place and continue to produce more robust evidence through ‘natural experiments’ and longitudinal studies (496).

4.11. Knowledge translation

The results of this study have been presented to diverse stakeholders, including the attendees of national and international scientific meetings, public health officials of Public Health Agency of Canada, physicians, graduate and undergraduate university students trained in public health, and to Vancouver community members through counselling in ways to reduce risk factors for chronic non-communicable diseases. Also, after presenting the methodology for the direct assessment of the BE used in this study at the PURE international meeting in Florida, it was decided that direct environmental assessments were to be included as part of the PURE study and performed in the cities where Canadian PURE centers are positioned (Hamilton, Ottawa and Vancouver). Experiences I gained in this project helped in the development of the Physical Activity and Nutrition Features audit tool that was used for direct assessment of the PURE Canada BEs. Furthermore, challenges encountered and solutions to deal with such challenges during the direct assessment of the environments in this thesis project served as a guide to facilitate smoother environmental assessments in three PURE Canadian settings (473). Additionally, some writings based on this thesis's methodology and results have already been published and are listed below.

Journal articles:

Gasevic D, Vukmirovich I, Yusuf S, Teo K, Chow C, Dagenais G, Lear SA. A direct assessment of 'obesogenic' built environments - challenges and recommendations. Journal of Environmental and Public Health 2011; 2011:161574.

Conference abstracts:

Gasevic D, Yew A, Teo K, Yusuf S, Lear SA. Built environment, physical activity and adiposity in the Prospective Urban Rural Epidemiology (PURE) study Vancouver cohort. Canadian Journal of Diabetes 2013;37(suppl.2):S275.

Gasevic D, Chow CK, Teo K, Yusuf S, Lear SA. Environmental determinants of physical activity and being overweight. Obesity Reviews 2010;11(Suppl. 1):61.

Gasevic D, Matteson CL, Vajihollahi M, Acheson MA, Lear SA, Finegood DT. Data gaps in the development of agent-based models of physical activity in the built environment. Obesity Reviews 2010;11(Suppl. 1):459.

Gasevic D, Teo K, Yusuf S, Lear SA. Perceived and objective determinants of the built environment in relation to physical activity, measured anthropometry and glucose. Applied Psychology, Nutrition and Metabolism 2009; 32(2):242.

Gasevic D, Chow CK, Teo K, Yusuf S, Lear SA. Environmental determinants of obesity measures and blood glucose. Canadian Journal of Cardiology 2009; 25(suppl. B):255B.

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Appendices:

Audit tool and additional statistical analyses

Appendix A. Audit tool

Postal code area:

Segment #

Intersection (beginning of the segment):

Intersection (end of segment):

Date:

Other comments:

	Answer questions 1-4 based on this end of the segment intersection	
	Neighbourhood identification	
1.	Are there monuments or markers including neighbourhood entry signs that indicate that one is entering a special district area?	Yes=1 No=0
	Street crossing	
2.	Consider the places on the segment that are **intended** for pedestrians to cross the street. Are these places marked for pedestrian crossing?	All=3; Some=2 None=0; NA=8
3.	What type of marking do the crosswalks have? Mark all that apply.	
	White painted lines	Yes=1; No=0
	Colored painted lines	Yes=1; No=0
	Zebra striping	Yes=1; No=0
	Different road surface or paving (e.g. tiles, colored concrete, marble, etc.)	Yes=1; No=0
	Other	Yes=1; No=0
4.	Are there curb cuts at all places where crossing is expected to occur?	All=3; Some=2; No=0; NA=8
5.	What type of traffic/pedestrian signal(s)/system(s) is/are provided? Mark all that apply.	
6.	Traffic signal	Yes=1; No=0
7.	Stop sign	Yes=1; No=0
8.	Yield sign	Yes=1; No=0
9.	Pedestrian activated signal	Yes=1; No=0

10.	Pedestrian crossing sign	Yes=1; No=0
11.	Pedestrian overpass/underpass/bridge	Yes=1; No=0
	Answer questions 12-16 while standing at the beginning of the segment	
	Neighbourhood identification	
12.	Does the segment have banners that identify the neighbourhood?	Yes=1; No=0
	Street characteristics	
13.	Is this a pedestrianized street?	Yes=1; No=0
14.	Is the street a…	One way=1; Two way=2
15.	How many vehicle lanes are there for cars? (Include turning lanes)	Six or more=6; Five=5; Four=4; Three=3; Two=2; One=1; NA (no lanes for car travel)=8
	Begin walking along segment to answer questions 16-111	
	What types of land uses are present on this area? Mark all that apply.	
	Residential	
16.	Single family home-detached	Yes=1; No=0
17.	Single family home/duplex – attached (2 units or fewer)	Yes=1; No=0
18.	Town home/condo/apartment housing (3 units or more)	Yes=1; No=0
19.	Mobile homes (includes manufactured homes)	Yes=1; No=0
20.	Residential, others	Yes=1; No=0
	School	
21.	Elementary, middle or junior high school	Yes=1; No=0
22.	High school	Yes=1; No=0
23.	University or college (includes all types of building forms)	Yes=1; No=0
24.	School, other	Yes=1; No=0
	Public space	

25.	Plaza/square/courtyard	Yes=1; No=0
26.	Park	Yes=1; No=0
27.	Playground	Yes=1; No=0
28.	Playing fields	Yes=1; No=0
29.	Garden	Yes=1; No=0
30.	Landscaped open space	Yes=1; No=0
31.	Public space, other	Yes=1; No=0
	Recreational/fitness	
32.	Gym/fitness centre (also includes yoga/pilates studios etc.)	Yes=1; No=0
33.	Recreational, other	Yes=1; No=0
	Public/civic building	
34.	Community centre or library	Yes=1; No=0
35.	Museum, auditorium, concert hall, theatre	Yes=1; No=0
36.	Post office, police station, courthouse, department of motor vehicles	Yes=1; No=0
37.	Public building, other	Yes=1; No=0
	Institutional	
38.	Religious institution (church, temple, mosque, etc.)	Yes=1; No=0
39.	Hospital, medical facility, health clinic	Yes=1; No=0
40.	Institutional, other	Yes=1; No=0
	Commercial	
41.	Retail stores/restaurants	Yes=1; No=0
42.	Bank/financial service	Yes=1; No=0
43.	Hotel/hospitality	Yes=1; No=0
44.	Car dealership	Yes=1; No=0
45.	Gas/service station	Yes=1; No=0
46.	Commercial, other	Yes=1; No=0

	Office/service	
47.	Offices	Yes=1; No=0
48.	Service facilities (includes insurance offices, funeral homes, dry cleaning, Laundromats, etc.)	Yes=1; No=0
49.	Office/service, other	Yes=1; No=0
	Industrial/manufacturing	
50.	Light industrial (e.g. auto paint and auto body repair shops; i.e. clean industries)	Yes=1; No=0
51.	Medium or heavy industrial (e.g. chemical plants, oil wells, etc.)	Yes=1; No=0
52.	Industrial, other	Yes=1; No=0
53.	How many of the buildings in this segment contain vertical-mixed use, that is, the building has different land uses on different floors of the building?	Some/a lot=3; Few=2; None=0; NA (no buildings>1 story)=8
	Determine whether any of these distinctive retail types are present (focusing on the form of the building)	
54.	Big box shops (includes super stores or warehouse stores)	Yes=1; No=0
55.	Shopping mall	Yes=1; No=0
56.	Strip mall/row of shops	Yes=1; No=0
57.	Drive through	Yes=1; No=0
	Other land uses	
	Are these land uses are present on this segment?	
58.	Bars/night clubs	Yes=1; No=0
59.	Adult uses	Yes=1; No=0
60.	Check cashing stores/pawn shops/bail bond stores	Yes=1; No=0
61.	Liquor stores	Yes=1; No=0
	Are the following gathering places present on this segment?	
62.	Restaurants	Yes=1; No=0
63.	Coffee shops	Yes=1; No=0
64.	Libraries/book stores	Yes=1; No=0

65.	Art or craft galleries	Yes=1; No=0
66.	Movie theatre	Yes=1; No=0
67.	Farmers market	Yes=1; No=0
68.	Pharmacy	Yes=1; No=0
69.	Video store	Yes=1; No=0
	Are these nature features present on this segment?	
70.	Open field/golf course	Yes=1; No=0
71.	Fountain/reflecting pool	
	Are these features present on this segment?	
72.	Supermarket	Yes=1; No=0
73.	Grocery store	Yes=1; No=0
74.	Convenience store	Yes=1; No=0
75.	Bakery	Yes=1; No=0
76.	Meat shop	Yes=1; No=0
	Sidewalks	
77.	How many sides of the street have sidewalks?	Count 1 or 2
78.	Is the sidewalk complete on one or both sides	Yes=1; No=0; NA=8
79.	What is the condition or maintenance of the sidewalk?	Under repair=2; moderate or good=1; poor=0
80.	Is there a buffer (for example, parked cars, landscaped “buffer”, strip, etc.) between sidewalk and street?	Yes=1; no=0; NA=8
	Determine how much of the sidewalk is covered by these features that provide protection from sun, rain, and/or snow.	
81.	Arcades	Some/much of s’walk covered=1; no/little covered=0
82.	Awnings	Some/much=1; no/little=0
83.	Other	Some/much=1;

		no/little=0
	Sidewalk amenities	
84.	Are there outdoor dining areas (e.g. cafes, outdoor tables at coffee shops or plazas, etc.) located on the segment?	Some/a lot=3; few=2; none=0
	Indicate how many of each of the following street furniture/sidewalk amenities is/are present on the segment	
85.	Benches (not a bus stop), chairs and/or ledges for sitting	Some/a lot=3; few=2; none=0
87.	Heat lamps	Some/a lot=3; few=2; none=0
88.	Bike racks	Some/a lot=3; few=2; none=0
89.	Are there obvious public restrooms on this segment that are clearly open to the public?	Yes=1; No=0
86.	How many bus stops is on the segment?	3 or more=3; two=2; one=1; none=0
	Bicycle lanes	
90.	Is this block a designated bike route?	Yes=1; No=0
91.	Are there bicycle lanes on the segment?	Yes=1; No=0
92.	How are bicycle lanes demarcated?	On road, painted line/reflectors=3; on road physical separation=2; off road=1
	Steepness	
93.	How steep or hilly is the segment? Mark all that apply.	Steep slope=2; moderate slope=1; flat or gentle slope=0
	Street trees	
94.	How many trees are on this segment? (Do not include trees that are not on the public right of way; street trees are typically between the sidewalk and the street or if there is no sidewalk, trees usually line the street)	Some trees/trees along most or entire segment=1; None/few trees=0
	Safety from traffic	

95.	Is there a marked mid-block crosswalk for pedestrians?	Yes=1; No=0
96.	What is the posted speed limit on this segment?	Use number_____; Not posted=8
97.	Are there measures on this segment that could **slow down traffic**? Mark all that apply	Yes=1; No=0
98.	Speed bump/speed hump/raised crosswalk; or dips (that are intended to slow down traffic)	Yes=1 No=0
99.	Rumble strips or bumps (includes dots, reflectors, raised concrete strips, etc)	Yes=1 No=0
100.	Curb bulb out/curb extension	Yes=1; No=0
101.	Traffic circle/roundabout	Yes=1; No=0
102.	Median	Yes=1; No=0
103.	Angled/On street parking (that runs along most or the entire segment-does not have to be on both sides of segment)	Yes=1; No=0
104.	Is there a **cul-de-sac or permanent street closing** on this segment?	Yes=1; No=0
105.	Are cyclists able to mount the curb to move away from traffic?	Mountable curbs=2 Nonmountable curbs=1 No curbs=0 (SPACES)
	Safety from crime	
106.	Is there **outdoor lighting** on the segment? (Include lighting that is intended to light public paths and public spaces)	Yes=1; No=0
107.	Are there abandoned buildings or lots on this segment?	Some/a lot=3; Few=2; None=0; NA=8
108.	How much graffiti is apparent on this segment?	Some/a lot=3; Little=2; None=0
109.	How much **litter** is apparent on this segment?	Some/a lot=3; Little=2; None=0
110.	Block-watch signs present	Yes=1; No=0
	Other end of segment	

	Neighbourhood identification	
111.	Are there monuments or markers including neighbourhood entry signs that indicate that one is entering a special district area?	Yes=1 No=0
	Street crossing	
112.	Consider the places on the segment that are **intended** for pedestrians to cross the street. Are these places marked for pedestrian crossing?	All=3; Some=2 None=0; NA=8
113.	What type of marking do the crosswalks have? Mark all that apply.	
	White painted lines	Yes=1; No=0
	Colored painted lines	Yes=1; No=0
	Zebra striping	Yes=1; No=0
	Different road surface or paving (e.g. tiles, colored concrete, marble, etc.)	Yes=1; No=0
	Other	Yes=1; No=0
114.	Are there curb cuts at all places where crossing is expected to occur?	All=3; Some=2; No=0; NA=8
115.	What type of traffic/pedestrian signal(s)/system(s) is/are provided? Mark all that apply.	
116.	Traffic signal	Yes=1; No=0
117.	Stop sign	Yes=1; No=0
118.	Yield sign	Yes=1; No=0
119.	Pedestrian activated signal	Yes=1; No=0
120.	Pedestrian crossing sign	Yes=1; No=0
121.	Pedestrian overpass/underpass/bridge	Yes=1; No=0
122.	Consider the places on the segment that are **intended** for pedestrians to cross an alley. Does the sidewalk have curb cuts on each place designated to cross an alley?	All=3; Some=2; None=0 NA=8

Appendix B. Objective built environment features – summary statistics

Objective BE feature	
Monuments and markers[1]	percentage (%) of segments in the neighbourhood where there are monuments or markers indicating that one is entering a special district area at the beginning of the segment
Places marked for pedestrian crossing[1]	% of segments in the neighbourhood marked for pedestrian crossing at the beginning of the segment
White lines[1]	% of neighbourhood segments marked with white lines for pedestrian crossing at the beginning of the segment
Zebra[1]	% of neighbourhood segments marked with zebra for pedestrian crossing at the beginning of the segment
Different road[1]	% of neighbourhood segments where different type of usual road is placed for pedestrian crossing at the beginning of the segment
All curb cuts present[1]	% of neighbourhood segments with all curb cuts present where crossing is expected to occur at the beginning of the segment
Traffic signal[1]	% of neighbourhood segments where traffic signal regulates the traffic at the beginning of the segment
Stop sign[1]	% of neighbourhood segments with a stop sign present at the beginning of the segment
Yield sign[1]	% of neighbourhood segments with a yield sign at the beginning of the segment
Activated signal[1]	% of neighbourhood segments with a pedestrian activated signal at the beginning of the segment.
Crossing sign[1]	% of neighbourhood segments with a pedestrian crossing sign at the beginning of the segment
Overpass/underpass[1]	% of neighbourhood segments with a pedestrian overpass or underpass or bridge at the beginning of the segment
Two-way street	% of neighbourhood segments that are two-way
Two or more traffic lanes	% of neighbourhood segments with two or more traffic lanes
Single family home-detached	% of neighbourhood segments with single family homes-detached

Single family home-duplex	% of neighbourhood segments with single family homes-duplex
Condo	% of neighbourhood segments with town homes and/or condos and/or apartment housing
Elementary school	% of neighbourhood segments with access to elementary, middle or junior high schools
High school	% of neighbourhood segments with access to a high school
University	% of neighbourhood segments with access to a college or a university
Park	% of neighbourhood segments with access to a park
Playground	% of neighbourhood segments with access to a playground
Playing fields	% of neighbourhood segments with access to a playing field
Garden	% of neighbourhood segments with access to a garden
Landscaped opened space	% of neighbourhood segments with access to a landscaped open space
Gym-fitness	% of neighbourhood segments with access to a gym/fitness centre (also includes yoga and pilates studios)
Community centre	% of neighbourhood segments with access to a community centre
Post office	% of neighbourhood segments with access to a post office
Religious institution	% of neighbourhood segments with access to a religious institution (church, temple, mosque etc.)
Medical facility	% of neighbourhood segments with access to a hospital, medical facility or a health clinic
Supermarket	% of neighbourhood segments with access to a supermarket
Grocery store	% of neighbourhood segments with access to a grocery store
Convenience store	% of neighbourhood segments with access to a convenience store
Retail stores	% of neighbourhood segments with access to retail stores
Bank	% of neighbourhood segments with access to a bank
Hotel	% of neighbourhood segments with access to a hotel
Car dealership	% of neighbourhood segments with access to a car dealership
Gas station	% of neighbourhood segments with access to a gas station

Offices	% of neighbourhood segments with access to offices (e.g. administrative facilities)
Services	% of neighbourhood segments with access to services (e.g. insurance offices, dry cleaning, laundromats etc.)
Industrial	% of neighbourhood segments with access to industrial/manufacturing facilities
Vertical-mix	% of neighbourhood segments with buildings that contain vertical mixed use
Big box shops	% of neighbourhood segments with access to a big box shop
Drive-through	% of neighbourhood segments with access to drive-through
Night club	% of neighbourhood segments with access to a night club
Adult uses	% of neighbourhood segments with access to adult uses (e.g. adult book stores, adult video parlours etc.)
Liquor stores	% of neighbourhood segments with access to a liquor store
Restaurant	% of neighbourhood segments with access to a restaurant
Bakery	% of neighbourhood segments with access to a bakery
Coffee shop	% of neighbourhood segments with access to a coffee shop
Meat shop	% of neighbourhood segments with access to a meat shop/butcher store
Library, book store	% of neighbourhood segments with access to a library and/or a book store
Art/craft gallery	% of neighbourhood segments with access to art and/or craft galleries
Movie theatre	% of neighbourhood segments with access to a movie theatre
Pharmacy	% of neighbourhood segments with access to a pharmacy
Video store	% of neighbourhood segments with access to a video store
Golf course	% of neighbourhood segments with access to a golf course
Sidewalks on both sides	% of neighbourhood segments having sidewalks present on both sides of the segment
Buffer between a sidewalk and a street	% of neighbourhood segments with a buffer between a sidewalk and a street

Awnings	% of neighbourhood segments with awnings (protect walkers from rain, snow, sun)
Dining areas	% of neighbourhood segments with outdoor dining areas
Benches	% of neighbourhood segments with benches as sidewalk amenities
Bike racks	% of neighbourhood segments with bike racks available
Public washrooms	% of neighbourhood segments with obvious public restrooms that are clearly open to the public
Bus stops_present	% of neighbourhood segments with access to a bus stop
Bike route	% of neighbourhood segments that are a designated bike route
Steepness	% of neighbourhood segments with moderate or steep slope
Trees	% of neighbourhood segments with some trees or with trees along most or entire segment
Midblock crosswalk	% of neighbourhood segments with midblock crosswalk present
Posted speed limit	% of neighbourhood segments with speed limit posted
Speed bumps	% of neighbourhood segments with speed bumps/speed humps/raised crosswalk/dips intended to slow down traffic
Traffic circle	% of neighbourhood segments with a traffic circle/roundabout
Median	% of neighbourhood segments with a median
Street parking	% of neighbourhood segments with on street parking
Cul-de-sac	% of neighbourhood segments with a cul-de-sac
Curbs	% of neighbourhood segments with curbs
Lighting	% of neighbourhood segments with street lighting
Graffiti	% of neighbourhood segments with graffiti present
Litter	% of neighbourhood segments with apparent litter
Block-watch	% of neighbourhood segments with a block-watch sign
Monuments and markers[2]	percentage (%) of segments in the neighbourhood where there are monuments or markers indicating that one is entering a special district area at the end of the segment
Places marked for	% of segments in the neighbourhood marked for pedestrian

pedestrian crossing[2]	crossing at the end of the segment
White lines[2]	% of neighbourhood segments marked with white lines for pedestrian crossing at the end of the segment
Zebra[2]	% of neighbourhood segments marked with zebra for pedestrian crossing at the end of the segment
Different road[2]	% of neighbourhood segments where different type of usual road is placed for pedestrian crossing at the end of the segment
All curb cuts present[2]	% of neighbourhood segments with all curb cuts present where crossing is expected to occur at the end of the segment
Traffic signal[2]	% of neighbourhood segments where traffic signal regulates the traffic at the end of the segment
Stop sign[2]	% of neighbourhood segments with a stop sign present at the end of the segment
Yield sign[2]	% of neighbourhood segments with a yield sign at the end of the segment
Activated signal[2]	% of neighbourhood segments with a pedestrian activated signal at the end of the segment
Crossing sign[2]	% of neighbourhood segments with a pedestrian crossing sign at the end of the segment
Overpass/underpass[2]	% of neighbourhood segments with a pedestrian overpass or underpass or bridge at the end of the segment

Appendix C. Associations of confounders with physical activity

The associations between confounders and PA domains were explored by bivariate correlations. Pearson's product moment correlation was used to explore the association between age and study outcomes (PA domains). Spearman correlation was used to test the relationship of education and household income with study outcomes. In addition, point biserial correlation was used to explore the association between binary covariates (sex, ethnicity and neighbourhood income) and study outcomes.

	Total PA	**Transport PA**	**Leisure PA**	**Walking**
	r	**r**	**r**	**r**
Age	0.012	-0.005	-0.024	0.074
Sex	0.116*	-0.035	0.010	0.023
Education	-0.054	0.079	0.131*	0.002
Household income	0.063	-0.068	0.197***	-0.045
Ethnicity	0.031	0.267***	0.195***	0.064
Neighbourhood income	-0.030	0.174**	0.213***	0.053

Covariates: age (continuous), sex (male, female), formal level of education (none, primary, secondary/high school/higher secondary, trade school, and college/university), household income (< $20,000, $20,000-$30,000, $30,001-$45,000, $45,001-$65,000, $65,001-$90,000, and > $90,000), ethnicity (European, non-European), neighbourhood income (high- and low income). * p < 0.05, ** p< 0.01, *** p < 0.001. PA – physical activity.

Appendix D. Associations of confounders with adiposity and fasting blood glucose

The associations between confounders and adiposity and FBG were explored by bivariate correlations. Pearson's product moment correlation was used to explore the association between age and study outcomes (adiposity and FBG). Spearman correlation was used to test the relationship of education and household income with study outcomes. In addition, point biserial correlation was used to explore the association between binary covariates (sex, ethnicity and neighbourhood income) and study outcomes.

	BMI r (p)*	**WC** r (p)*	**WHR** r (p)*	**%BF** r (p)*	**FBG** r (p)*
Age	0.137*	0.192***	0.208***	0.205***	0.168**
Sex	0.122*	0.443***	0.641***	-0.614***	0.119*
Education	-0.148**	-0.115*	-0.103	-0.207***	-0.123*
Household income	0.056	0.031	-0.013	-0.160**	-0.034
Ethnicity	-0.002	0.001	-0.068	-0.134*	-0.041
Neighbourhood income	-0.031	-0.070	-0.156**	-0.048	-0.085

Covariates: age (continuous), sex (male, female), formal level of education (none, primary, secondary/high school/higher secondary, trade school, and college/university), household income (< \$20,000, \$20,000-\$30,000, \$30,001-\$45,000, \$45,001-\$65,000, \$65,001-\$90,000, and > \$90,000), ethnicity (European, non-European), neighbourhood income (high- and low income). * p < 0.05, ** p< 0.01, *** p < 0.001. BMI – body mass index, WC – waist circumference, WHR – waist-to-hip ratio, %BF – percentage of body fat, FBG – fasting blood glucose

Appendix E. Environmental perceptions of study participants

Table E-1. Perceptions of the distance to environmental features

Perceived BE feature	n = 356
Land Use Mix	
Time to walk from home to:	
Buy groceries	
1-10 min	169 (49.7%)
11+ min	171 (50.3%)
Buy clothes	
1-10 min	83 (24.4%)
11+ min	257 (75.6%)
Buy fruits and vegetables	
1-10 min	167 (49.0%)
11+ min	174 (51.0%)
Eat at a restaurant	
1-10 min	178 (52.2%)
11+ min	163 (47.8%)
Go to the bank	
1-10 min	170 (49.9%)
11+ min	171 (50.1%)
Rent a video	
1-10 min	145 (42.5%)
11+ min	196 (57.5%)
Buy medicines	
1-10 min	177 (51.9%)
11+ min	164 (48.1%)
Go to the bus or trolley stop	
1-10 min	304 (89.4%)
11+ min	36 (10.6%)
Go to the park	

Perceived BE feature	n = 356
1-10 min	233 (68.5%)
11+ min	107 (31.5%)

Table E-2. Perceptions of access to services in the neighbourhood

Perceived BE feature	n = 356
I can do most of shopping at local stores	
Agree	265 (77.7%)
Disagree	76 (22.3%)
Stores are within easy walking distance of my home	
Agree	289 (84.8%)
Disagree	52 (15.2%)
There are many places to go within easy walking distance	
Agree	292 (85.6%)
Disagree	49 (14.4%)
It is easy to walk to a transit stop (bus train) from my home	
Agree	333 (97.7%)
Disagree	8 (2.3%)

Table E-3. Perceptions of streets in the neighbourhood

Perceived BE feature	n = 356
The distance between intersections in my neighbourhood is usually short	
Agree	292 (85.9%)
Disagree	48 (14.1%)
There are many four-way intersections in my neighbourhood	
Agree	274 (80.4%)
Disagree	67 (19.6%)
There are many alternative routes for getting from place to place in my neighbourhood	

Perceived BE feature	n = 356
Agree	309 (90.6%)
Disagree	32 (9.4%)

Table E-4. Perceptions of places for walking and cycling in the neighbourhood

Perceived BE feature	n = 356
There are sidewalks on most of the streets in my neighbourhood	
Agree	335 (98.2%)
Disagree	6 (1.8%)
The sidewalks in my neighbourhood are well maintained	
Agree	312 (91.5%)
Disagree	29 (8.5%)
There is grass/dirt strip that separates the streets from sidewalks in my neighbourhood	
Agree	287 (84.2%)
Disagree	54 (15.8%)

Table E-5. Perceptions of neighbourhood surroundings

Perceived BE feature	n = 356
Trees give shade for the sidewalks in my neighbourhood	
Agree	321 (94.1%)
Disagree	20 (5.9%)
There are many interesting things to look at while walking in my neighbourhood	
Agree	289 (85.0%)
Disagree	51 (15.0%)
My neighbourhood is generally free from litter	
Agree	293 (85.9%)
Disagree	48 (14.1%)

Table E-6. Perceptions of safety from traffic

Perceived BE feature	n = 356
There is so much traffic along the street I live on that makes it difficult or unpleasant to walk in my neighbourhood	
Agree	71 (20.8%)
Disagree	270 (79.2%)
There is so much traffic along nearby streets that it makes it difficult or unpleasant to walk in my neighbourhood	
Agree	87 (25.5%)
Disagree	254 (74.5%)
The crosswalks in my neighbourhood help walkers feel safe crossing busy streets	
Agree	260 (76.5%)
Disagree	80 (23.5%)

Table E-7. Perceptions of safety from crime

Perceived BE feature	n = 356
My neighbourhood streets are well lit at night	
Agree	303 (88.9%)
Disagree	38 (11.1%)
The crime rate in my neighbourhood makes it unsafe to go on walks during the day	
Agree	19 (5.6%)
Disagree	322 (94.4%)
The crime rate in my neighbourhood makes it unsafe to go on walks during the night	
Agree	77 (22.6%)
Disagree	264 (77.4%)

Table E-8. Neighbourhood satisfaction

Perceived BE feature	n = 356

Perceived BE feature	n = 356
The access to public transport	
Satisfied	307 (90.0%)
Not satisfied	34 (10.0%)
Commuting time to work/school	
Satisfied	236 (76.4%)
Not satisfied	73 (23.6%)
Access to shopping	
Satisfied	295 (86.5%)
Not satisfied	46 (13.5%)
The number of people you know	
Satisfied	194 (56.9%)
Not satisfied	147 (43.1%)
How easy and pleasant is to walk in your neighbourhood?	
Satisfied	322 (94.4%)
Not satisfied	19 (5.6%)
Access to entertainment (restaurants, movies, clubs, etc.)	
Satisfied	234 (68.6%)
Not satisfied	107 (31.4%)
The safety from threat of crime	
Satisfied	259 (76.0%)
Not satisfied	82 (24.0%)
The amount and speed of traffic	
Satisfied	183 (53.8%)
Not satisfied	157 (46.2%)
Your neighbourhood as a good place to raise children	
Satisfied	224 (65.9%)
Not satisfied	116 (34.1%)
Your neighbourhood as a good place to live	
Satisfied	318 (93.3%)
Not satisfied	23 (6.7%)

Answers to questions are missing for 15-16 study participants. Answer to a question “Commuting time to work/school” is missing for 47 participants.

Appendix F. Percent variability in physical activity explained by perceived built environment measures

Total PA	Transportation PA	Leisure PA	Walking
Grass/dirt strip between streets and sidewalk	Time to walk to a restaurant	Many interesting things to look at while walking	Stores are within walking distance
1.4%	1.4%	1.5%	1.4%
So much traffic along nearby streets	So much traffic along nearby streets	Satisfaction with access to entertainment	So much traffic along nearby streets
2.0%	1.9%	1.6%	2.0%

Appendix G. Percent variability in physical activity explained by objective built environment features

Transportation PA			
Places marked for pedestrian crossing 3.8%	Car dealership 1.5%	White lines at the street crossing 2.3%	Pedestrian crossing activated signal 2.5%
Vertical mix use 3.7%	Stop sign 3.0%	Big box shops 1.7%	Services 3.7%
Night club 1.8%	Liquor store 1.8%	Hospital 2.1%	Restaurant 3.1%
Single-family home detached 1.9%	Single-family home duplex 1.9%	Condo 2.3%	Retail stores 1.7%
Bike route 0.7%	Bike racks 2.6%	Trees 1.5%	Litter 1.5%
Traffic light 2.6%	Streets with 2 or more lanes 2.0%	Sidewalks on both sides 2.1%	Landscaped open space 2.0%
Leisure PA			
Stop sign 1.4%	Single family home duplex 1.7%	Buffer between street and sidewalk 1.9%	Midblock crosswalk 1.2%
Walking B (95%CI)			
Places marked for pedestrian crossing 3.8%	White lines at the street crossing 1.9%	Playing fields 1.9%	Sidewalks on both sides 1.3%
Stop sign 2.6%	Pedestrian crossing activated signal 2.5%	Services 2.1%	Liquor store 3.0%
Restaurant 1.5%	Litter 1.5%		

Appendix H. Gender differences in perception of built environment features

Table H-1. Gender differences in perceiving the distance to environmental features

Perceived BE feature	Males	Females	Significance (p) (effect size, φ)
Land Use Mix			
Time to walk from home to:			
Buy groceries			0.920
1-10 min	78 (50.0%)	91 (49.5%)	
11+ min	78 (50.0%)	93 (50.5%)	
Buy clothes			0.041 (-0.111)
1-10 min	30 (19.2%)	53 (28.8%)	
11+ min	126 (80.8%)	131 (71.2%)	
Buy fruits and vegetables			0.602
1-10 min	74 (47.4%)	93 (50.3%)	
11+ min	82 (52.6%)	92 (49.7%)	
Eat at a restaurant			0.040 (-0.111)
1-10 min	72 (46.2%)	106 (57.3%)	
11+ min	84 (53.8%)	79 (42.7%)	
Go to the bank			0.412
1-10 min	74 (47.4%)	96 (51.9%)	
11+ min	82 (52.6%)	89 (48.1%)	
Rent a video			0.558
1-10 min	69 (44.2%)	76 (41.1%)	
11+ min	87 (55.8%)	109 (58.9%)	
Buy medicines			0.668
1-10 min	79 (50.6%)	98 (53.0%)	
11+ min	77 (49.4%)	87 (47.0%)	
Go to the bus or trolley stop			0.218
1-10 min	136 (87.2%)	168 (91.3%)	

Perceived BE feature	Males	Females	Significance (*p*) (effect size, φ)
11+ min	20 (12.8%)	16 (8.7%)	
Go to the park			0.058
1-10 min	115 (73.7%)	118 (64.1%)	
11+ min	41 (26.3%)	66 (35.9%)	

Table H-2. Gender differences in perceiving access to services in the neighbourhood

Perceived BE feature	Males	Females	Significance (*p*)
I can do most of shopping at local stores			0.172
Agree	116 (74.4%)	149 (80.5%)	
Disagree	40 (25.6%)	36 (19.5%)	
Stores are within easy walking distance of my home			0.203
Agree	128 (82.1%)	161 (87.0%)	
Disagree	28 (17.9%)	24 (13.0%)	
There are many places to go within easy walking distance			0.267
Agree	130 (83.3%)	162 (87.6%)	
Disagree	26 (16.7%)	23 (12.4%)	
It is easy to walk to a transit stop (bus train) from my home			1.000
Agree	152 (97.4%)	181 (97.8%)	
Disagree	4 (2.6%)	4 (2.2%)	

Table H-3. Gender differences in perceiving streets in the neighbourhood

Perceived BE feature	Males	Females	Significance (*p*)
The distance between intersections in my neighbourhood is usually short			0.110
Agree	128 (82.6%)	164 (88.6%)	
Disagree	27 (17.4%)	21 (11.4%)	
There are many four-way intersections in my neighbourhood			0.239

Perceived BE feature	Males	Females	Significance (*p*)
Agree	121 (77.6%)	153 (82.7%)	
Disagree	35 (22.4%)	32 (17.3%)	
There are many alternative routes for getting from place to place in my neighbourhood			0.612
Agree	140 (89.7%)	169 (91.4%)	
Disagree	16 (10.3%)	16 (8.6%)	

Table H-4. Gender differences in perceiving places for walking and cycling in the neighbourhood

Perceived BE feature	Males	Females	Significance (*p*)
There are sidewalks on most of the streets in my neighbourhood			0.692
Agree	154 (98.7%)	181 (97.8%)	
Disagree	2 (1.3%)	4 (2.2%)	
The sidewalks in my neighbourhood are well maintained			0.203
Agree	146 (93.6%)	166 (89.7%)	
Disagree	10 (6.4%)	19 (10.3%)	
There is grass/dirt strip that separates the streets from sidewalks in my neighbourhood			0.326
Agree	128 (82.1%)	159 (85.9%)	
Disagree	28 (17.9%)	26 (14.1%)	

Table H-5. Gender differences in perceiving neighbourhood surroundings

Perceived BE feature	Males	Females	Significance (*p*) (effect size, φ)
Trees give shade for the sidewalks in my neighbourhood			0.595
Agree	148 (94.9%)	173 (93.5%)	
Disagree	8 (5.1%)	12 (6.5%)	
There are many interesting things to look at while walking in my neighbourhood			0.044 (0.109)
Agree	126 (80.8%)	163 (88.6%)	

Perceived BE feature	Males	Females	Significance (*p*) (effect size, φ)
Disagree	30 (19.2%)	21 (11.4%)	
My neighbourhood is generally free from litter			0.207
Agree	130 (83.3%)	163 (88.1%)	
Disagree	26 (16.7%)	22 (11.9%)	

Table H-6. Gender differences in perceiving safety from traffic

Perceived BE feature	Males	Females	Significance (*p*)
There is so much traffic along the street I live on that makes it difficult or unpleasant to walk in my neighbourhood			0.351
Agree	29 (18.6%)	42 (22.7%)	
Disagree	127 (81.4%)	143 (77.3%)	
There is so much traffic along nearby streets that it makes it difficult or unpleasant to walk in my neighbourhood			0.090
Agree	33 (21.2%)	54 (29.2%)	
Disagree	123 (78.8%)	131 (70.8%)	
The crosswalks in my neighbourhood help walkers feel safe crossing busy streets			0.526
Agree	121 (78.1%)	139 (75.1%)	
Disagree	34 (21.9%)	46 (24.9%)	

Table H-7. Gender differences in perceiving safety from crime

Perceived BE feature	Males	Females	Significance (*p*)
My neighbourhood streets are well lit at night			0.242
Agree	142 (91.0%)	161 (87.0%)	
Disagree	14 (9.0%)	24 (13.0%)	
The crime rate in my neighbourhood makes it unsafe to go on walks during the day			0.743
Agree	8 (5.1%)	11 (5.9%)	
Disagree	148 (94.9%)	174 (94.1%)	

Perceived BE feature	Males	Females	Significance (*p*)
The crime rate in my neighbourhood makes it unsafe to go on walks during the night			0.174
Agree	30 (19.2%)	47 (25.4%)	
Disagree	126 (80.8%)	138 (74.6%)	

Table H-8. Gender differences in neighbourhood satisfaction

Perceived BE feature	Males	Females	Significance (*p*) (effect size, φ)
The access to public transport			0.872
Satisfied	140 (89.7%)	167 (90.3%)	
Not satisfied	16 (10.3%)	18 (9.7%)	
Commuting time to work/school			0.945
Satisfied	111 (76.6%)	125 (76.2%)	
Not satisfied	34 (23.4%)	39 (23.8%)	
Access to shopping			0.115
Satisfied	130 (83.3%)	165 (89.2%)	
Not satisfied	26 (16.7%)	20 (10.8%)	
The number of people you know			0.207
Satisfied	83 (53.2%)	111 (60.0%)	
Not satisfied	73 (46.8%)	74 (40.0%)	
How easy and pleasant is to walk in your neighbourhood?			0.884
Satisfied	147 (94.2%)	175 (94.9%)	
Not satisfied	9 (5.8%)	10 (5.4%)	
Access to entertainment (restaurants, movies, clubs, etc.)			0.034 (-0.115)
Satisfied	98 (62.8%)	136 (73.5%)	
Not satisfied	58 (37.2%)	49 (26.5%)	
The safety from threat of crime			0.527
Satisfied	116 (74.4%)	143 (77.3%)	
Not satisfied	40 (25.6%)	42 (22.7%)	
The amount and speed of traffic			0.668

Perceived BE feature	**Males**	**Females**	**Significance (*p*) (effect size, φ)**
Satisfied	82 (52.6%)	101 (54.9%)	
Not satisfied	74 (47.4%)	83 (45.1%)	
Your neighbourhood as a good place to raise children			0.779
Satisfied	104 (66.7%)	120 (65.2%)	
Not satisfied	52 (33.3%)	64 (34.8%)	
Your neighbourhood as a good place to live			0.836
Satisfied	145 (92.9%)	173 (93.5%)	
Not satisfied	11 (7.1%)	12 (6.5%)	

Appendix I. Ethnic differences in perception of built environment features

Table I-1. Ethnic differences in perceiving the distance to environmental features

Perceived BE feature	Non-European	European	Significance (*p*) (effect size, φ)
Land Use Mix			
Time to walk from home to:			
Buy groceries			0.005 (0.151)
1-10 min	57 (40.7%)	111 (56.1%)	
11+ min	83 (59.3%)	87 (43.9%)	
Buy clothes			0.004 (0.159)
1-10 min	23 (16.4%)	60 (30.3%)	
11+ min	117 (83.6%)	138 (69.7%)	
Buy fruits and vegetables			0.035 (0.115)
1-10 min	59 (42.1%)	107 (53.8%)	
11+ min	81 (57.9%)	92 (46.2%)	
Eat at a restaurant			< 0.001 (0.217)
1-10 min	55 (39.3%)	122 (61.3%)	
11+ min	85 (60.7%)	77 (38.7%)	
Go to the bank			< 0.001 (0.189)
1-10 min	54 (38.6%)	115 (57.8%)	
11+ min	86 (61.4%)	84 (42.2%)	
Rent a video			0.010 (0.139)
1-10 min	48 (34.3%)	96 (48.2%)	
11+ min	92 (65.7%)	103 (51.8%)	
Buy medicines			< 0.001 (0.236)
1-10 min	53 (37.9%)	123 (61.8%)	
11+ min	87 (62.1%)	76 (38.2%)	
Go to the bus or trolley stop			0.029 (0.112)
1-10 min	119 (85.0%)	183 (92.4%)	

Perceived BE feature	Non-European	European	Significance (*p*) (effect size, φ)
11+ min	21 (15.0%)	15 (7.6%)	
Go to the park			0.113
1-10 min	51 (36.4%)	142 (71.7%)	
11+ min	89 (63.6%)	56 (28.3%)	

Table I-2. Ethnic differences in perceiving access to services in the neighbourhood

Perceived BE feature	Non-European	European	Significance (*p*) (effect size, φ)
I can do most of shopping at local stores			0.871
Agree	108 (77.1%)	155 (77.9%)	
Disagree	32 (22.9%)	44 (22.1%)	
Stores are within easy walking distance of my home			0.440
Agree	116 (82.9%)	171 (85.9%)	
Disagree	24 (17.1%)	28 (14.1%)	
There are many places to go within easy walking distance			0.015 (-0.132)
Agree	112 (80.0%)	178 (89.4%)	
Disagree	28 (20.0%)	21 (10.6%)	
It is easy to walk to a transit stop (bus train) from my home			1.000
Agree	137 (97.9%)	194 (97.5%)	
Disagree	3 (2.1%)	5 (2.5%)	

Table I-3. Ethnic differences in perceiving streets in the neighbourhood

Perceived BE feature	Non-European	European	Significance (*p*)
The distance between intersections in my neighbourhood is usually short			0.260
Agree	117 (83.6%)	174 (87.9%)	
Disagree	23 (16.4%)	24 (12.1%)	

Perceived BE feature	Non-European	European	Significance (*p*)
There are many four-way intersections in my neighbourhood			0.927
Agree	112 (80.0%)	160 (80.4%)	
Disagree	28 (20.0%)	39 (19.6%)	
There are many alternative routes for getting from place to place in my neighbourhood			0.400
Agree	125 (89.3%)	183 (92.0%)	
Disagree	15 (10.7%)	16 (8.0%)	

Table I-4. Ethnic differences in perceiving places for walking and cycling in the neighbourhood

Perceived BE feature	Non-European	European	Significance (*p*) (effect size, φ)
There are sidewalks on most of the streets in my neighbourhood			0.407
Agree	139 (99.3%)	194 (97.5%)	
Disagree	1 (0.7%)	5 (2.5%)	
The sidewalks in my neighbourhood are well maintained			0.700
Agree	129 (92.1%)	181 (91.0%)	
Disagree	11 (7.9%)	18 (9.0%)	
There is grass/dirt strip that separates the streets from sidewalks in my neighbourhood			0.020 (-0.126)
Agree	110 (78.6%)	175 (87.9%)	
Disagree	30 (21.4%)	24 (12.1%)	

Table I-5. Ethnic differences in perceiving neighbourhood surroundings

Perceived BE feature	Non-European	European	Significance (*p*) (effect size, φ)
Trees give shade for the sidewalks in my neighbourhood			0.555
Agree	133 (95.0%)	186 (93.5%)	
Disagree	7 (5.0%)	13 (6.5%)	

Perceived BE feature	Non-European	European	Significance (*p*) (effect size, φ)
There are many interesting things to look at while walking in my neighbourhood			0.001 (-0.182)
Agree	108 (77.1%)	179 (90.4%)	
Disagree	32 (22.9%)	19 (9.6%)	
My neighbourhood is generally free from litter			0.710
Agree	119 (85.0%)	172 (86.4%)	
Disagree	21 (15.0%)	27 (13.6%)	

Table I-6. Ethnic differences in perceiving safety from traffic

Perceived BE feature	Non-European	European	Significance (*p*) (effect size, φ)
There is so much traffic along the street I live on that makes it difficult or unpleasant to walk in my neighbourhood			0.649
Agree	31 (22.1%)	40 (20.1%)	
Disagree	109 (77.9%)	159 (79.9%)	
There is so much traffic along nearby streets that it makes it difficult or unpleasant to walk in my neighbourhood			0.438
Agree	39 (27.9%)	48 (24.1%)	
Disagree	101 (72.1%)	151 (75.9%)	
The crosswalks in my neighbourhood help walkers feel safe crossing busy streets			0.002 (0.171)
Agree	119 (85.0%)	139 (70.2%)	
Disagree	21 (15.0%)	59 (29.8%)	

Table I-7. Ethnic differences in perceiving safety from crime

Perceived BE feature	Non-European	European	Significance (*p*) (effect size, φ)
My neighbourhood streets are well lit at night			0.915
Agree	124 (88.6%)	177 (88.9%)	
Disagree	16 (11.4%)	22 (11.1%)	

Perceived BE feature	Non-European	European	Significance (*p*) (effect size, φ)
The crime rate in my neighbourhood makes it unsafe to go on walks during the day			0.207
Agree	10 (7.1%)	8 (4.0%)	
Disagree	130 (92.9%)	191 (96.0%)	
The crime rate in my neighbourhood makes it unsafe to go on walks during the night			0.005 (0.152)
Agree	42 (30.0%)	34 (17.1%)	
Disagree	98 (70.0%)	165 (82.9%)	

Table I-8. Ethnic differences in neighbourhood satisfaction

Perceived BE feature	Non-European	European	Significance (*p*) (effect size, φ)
The access to public transport			0.725
Satisfied	125 (89.3%)	180 (90.5%)	
Not satisfied	15 (10.7%)	19 (9.5%)	
Commuting time to work/school			0.981
Satisfied	99 (76.2%)	135 (76.3%)	
Not satisfied	31 (23.8%)	42 (23.7%)	
Access to shopping			0.750
Satisfied	120 (85.7%)	173 (86.9%)	
Not satisfied	20 (14.3%)	26 (13.1%)	
The number of people you know			0.017 (-0.129)
Satisfied	90 (64.3%)	102 (51.3%)	
Not satisfied	50 (35.7%)	97 (48.7%)	
How easy and pleasant is to walk in your neighbourhood?			0.685
Satisfied	133 (95.0%)	187 (94.0%)	
Not satisfied	7 (5.0%)	12 (6.0%)	
Access to entertainment (restaurants, movies, clubs, etc.)			0.020 (0.126)
Satisfied	86 (61.4%)	146 (73.4%)	

Perceived BE feature	**Non-European**	**European**	**Significance (*p*) (effect size, φ)**
Not satisfied	54 (38.6%)	53 (26.6%)	
The safety from threat of crime			0.014 (0.134)
Satisfied	97 (69.3%)	161 (80.9%)	
Not satisfied	43 (30.7%)	38 (19.1%)	
The amount and speed of traffic			0.008 (-0.145)
Satisfied	87 (62.1%)	94 (47.5%)	
Not satisfied	53 (37.9%)	104 (52.5%)	
Your neighbourhood as a good place to raise children			< 0.001 (-0.250)
Satisfied	111 (79.9%)	111 (55.8%)	
Not satisfied	28 (20.1%)	88 (44.2%)	
Your neighbourhood as a good place to live			0.510
Satisfied	129 (92.1%)	187 (94.0%)	
Not satisfied	11 (7.9%)	12 (6.0%)	

Appendix J. Differences in perception of built environment features by household income

Table J-1. Household income differences in perceiving the distance to environmental features

Perceived BE feature	≤ $65,000	> $65,000	Significance (*p*) (effect size, φ)
Land Use Mix			
Time to walk from home to:			
Buy groceries			0.030 (0.119)
1-10 min	58 (43.0%)	108 (55.1%)	
11+ min	77 (57.0%)	88 (44.9%)	
Buy clothes			0.294
1-10 min	29 (21.5%)	52 (26.5%)	
11+ min	106 (78.5%)	144 (73.5%)	
Buy fruits and vegetables			0.005 (0.156)
1-10 min	54 (40.0%)	110 (55.8%)	
11+ min	81 (60.0%)	87 (44.2%)	
Eat at a restaurant			0.359
1-10 min	67 (49.6%)	108 (54.8%)	
11+ min	68 (50.4%)	89 (45.2%)	
Go to the bank			0.516
1-10 min	65 (48.1%)	102 (51.8%)	
11+ min	70 (51.9%)	95 (48.2%)	
Rent a video			0.179
1-10 min	53 (39.3%)	92 (46.7%)	
11+ min	82 (60.7%)	105 (53.3%)	
Buy medicines			0.956
1-10 min	71 (52.6%)	103 (52.3%)	
11+ min	64 (47.4%)	94 (47.7%)	
Go to the bus or trolley stop			0.118
1-10 min	116 (86.6%)	181 (91.9%)	

Perceived BE feature	≤ $65,000	> $65,000	Significance (*p*) (effect size, φ)
11+ min	18 (13.4%)	16 (8.1%)	
Go to the park			< 0.001 (0.212)
1-10 min	75 (56.0%)	150 (76.1%)	
11+ min	59 (44.0%)	47 (23.9%)	

Table J-2. Household income differences in perceiving access to services in the neighbourhood

Perceived BE feature	≤ $65,000	> $65,000	Significance (*p*)
I can do most of shopping at local stores			0.932
Agree	105 (77.8%)	154 (78.2%)	
Disagree	30 (22.2%)	43 (21.8%)	
Stores are within easy walking distance of my home			0.544
Agree	117 (86.7%)	166 (84.3%)	
Disagree	18 (13.3%)	31 (15.7%)	
There are many places to go within easy walking distance			0.430
Agree	113 (83.7%)	171 (86.8%)	
Disagree	22 (16.3%)	26 (13.2%)	
It is easy to walk to a transit stop (bus train) from my home			0.278
Agree	130 (96.3%)	194 (98.5%)	
Disagree	5 (3.7%)	3 (1.5%)	

Table J-3. Household income differences in perceiving streets in the neighbourhood

Perceived BE feature	≤ $65,000	> $65,000	Significance (*p*)
The distance between intersections in my neighbourhood is usually short			0.293
Agree	113 (84.3%)	174 (88.3%)	
Disagree	21 (15.7%)	23 (11.7%)	

Perceived BE feature	≤ $65,000	> $65,000	Significance (*p*)
There are many four-way intersections in my neighbourhood			0.084
Agree	102 (75.6%)	164 (83.2%)	
Disagree	33 (24.4%)	33 (16.8%)	
There are many alternative routes for getting from place to place in my neighbourhood			0.258
Agree	119 (88.1%)	181 (91.9%)	
Disagree	16 (11.9%)	16 (8.1%)	

Table J-4. Household income differences in perceiving places for walking and cycling in the neighbourhood

Perceived BE feature	≤ $65,000	> $65,000	Significance (*p*)
There are sidewalks on most of the streets in my neighbourhood			0.690
Agree	132 (97.8%)	194 (98.5%)	
Disagree	3 (2.2%)	3 (1.5%)	
The sidewalks in my neighbourhood are well maintained			0.859
Agree	124 (91.9%)	182 (92.4%)	
Disagree	11 (8.1%)	15 (7.6%)	
There is grass/dirt strip that separates the streets from sidewalks in my neighbourhood			0.103
Agree	109 (80.7%)	172 (87.3%)	
Disagree	26 (19.3%)	25 (12.7%)	

Table J-5. Household income differences in perceiving neighbourhood surroundings

Perceived BE feature	≤ $65,000	> $65,000	Significance (*p*)
Trees give shade for the sidewalks in my neighbourhood			0.582
Agree	127 (94.1%)	188 (95.4%)	
Disagree	8 (5.9%)	9 (4.6%)	

Perceived BE feature	≤ $65,000	> $65,000	Significance (*p*)
There are many interesting things to look at while walking in my neighbourhood			0.146
Agree	110 (82.1%)	173 (87.8%)	
Disagree	24 (17.9%)	24 (12.2%)	
My neighbourhood is generally free from litter			0.165
Agree	112 (83.0%)	174 (88.3%)	
Disagree	23 (17.0%)	23 (11.7%)	

Table J-6. Household income differences in perceiving safety from traffic

Perceived BE feature	≤ $65,000	> $65,000	Significance (*p*)
There is so much traffic along the street I live on that makes it difficult or unpleasant to walk in my neighbourhood			0.354
Agree	31 (23.0%)	37 (18.8%)	
Disagree	104 (77.0%)	160 (81.2%)	
There is so much traffic along nearby streets that it makes it difficult or unpleasant to walk in my neighbourhood			0.304
Agree	39 (28.9%)	47 (23.9%)	
Disagree	96 (71.1%)	150 (76.1%)	
The crosswalks in my neighbourhood help walkers feel safe crossing busy streets			0.243
Agree	98 (73.1%)	155 (78.7%)	
Disagree	36 (26.9%)	42 (21.3%)	

Table J-7. Household income differences in perceiving safety from crime

Perceived BE feature	≤ $65,000	> $65,000	Significance (*p*)
My neighbourhood streets are well lit at night			0.170
Agree	117 (86.7%)	180 (91.4%)	
Disagree	18 (13.3%)	17 (8.6%)	
The crime rate in my neighbourhood makes it unsafe to go on walks during the day			0.274
Agree	10 (7.4%)	9 (4.6%)	

Perceived BE feature	≤ \$65,000	> \$65,000	Significance (*p*)
Disagree	125 (42.6%)	188 (95.4%)	
The crime rate in my neighbourhood makes it unsafe to go on walks during the night			0.932
Agree	30 (22.2%)	43 (21.8%)	
Disagree	105 (77.8%)	154 (78.2%)	

Table J-8. Household income differences in neighbourhood satisfaction

Perceived BE feature	≤ \$65,000	> \$65,000	Significance (*p*) (effect size, φ)
The access to public transport			0.880
Satisfied	122 (90.4%)	179 (90.9%)	
Not satisfied	13 (9.6%)	18 (9.1%)	
Commuting time to work/school			0.967
Satisfied	92 (76.0%)	138 (75.8%)	
Not satisfied	29 (24.0%)	44 (24.2%)	
Access to shopping			0.044 (0.110)
Satisfied	111 (82.2%)	177 (89.8%)	
Not satisfied	24 (17.8%)	20 (10.2%)	
The number of people you know			0.676
Satisfied	75 (55.6%)	114 (57.9%)	
Not satisfied	60 (44.4%)	83 (42.1%)	
How easy and pleasant is to walk in your neighbourhood?			0.274
Satisfied	125 (92.6%)	188 (95.4%)	
Not satisfied	10 (7.4%)	9 (4.6%)	
Access to entertainment (restaurants, movies, clubs, etc.)			0.086
Satisfied	86 (63.7%)	143 (72.6%)	
Not satisfied	49 (36.3%)	54 (27.4%)	
The safety from threat of crime			0.214
Satisfied	99 (73.3%)	156 (79.2%)	
Not satisfied	36 (26.7%)	41 (20.8%)	

Perceived BE feature	≤ $65,000	> $65,000	Significance (*p*) (effect size, φ)
The amount and speed of traffic			0.989
Satisfied	72 (53.7%)	106 (53.8%)	
Not satisfied	62 (46.3%)	91 (46.2%)	
Your neighbourhood as a good place to raise children			0.433
Satisfied	86 (63.7%)	133 (67.9%)	
Not satisfied	49 (36.3%)	63 (32.1%)	
Your neighbourhood as a good place to live			0.244
Satisfied	123 (91.1%)	186 (94.4%)	
Not satisfied	12 (8.9%)	11 (5.6%)	

Appendix K. Differences in perception of built environment features between individuals from low- and high-income settings

Table K-1. Distance to environmental features perceived by residents from low- and high-income settings

Perceived BE feature	Low-income setting	High-income setting	Significance (*p*) (effect size, φ)
Land Use Mix			
Time to walk from home to:			
Buy groceries			< 0.001 (0.414)
1-10 min	34 (24.6%)	135 (66.8%)	
11+ min	104 (75.4%)	67 (33.2%)	
Buy clothes			< 0.001 (0.302)
1-10 min	12 (8.7%)	71 (35.1%)	
11+ min	126 (91.3%)	131 (64.9%)	
Buy fruits and vegetables			< 0.001 (0.294)
1-10 min	43 (31.2%)	124 (61.1%)	
11+ min	95 (68.8%)	79 (38.9%)	
Eat at a restaurant			< 0.001 (0.407)
1-10 min	38 (27.5%)	140 (69.0%)	
11+ min	100 (72.5%)	63 (31.0%)	
Go to the bank			< 0.001 (0.344)
1-10 min	98 (71.0%)	130 (64.0%)	
11+ min	40 (29.0%)	73 (36.0%)	
Rent a video			< 0.001 (0.190)
1-10 min	43 (31.2%)	102 (50.2%)	
11+ min	95 (68.8%)	101 (49.8%)	
Buy medicines			< 0.001 (0.474)
1-10 min	32 (23.2%)	145 (71.4%)	
11+ min	106 (76.8%)	58 (28.6%)	
Go to the bus or trolley stop			0.020 (0.127)

Perceived BE feature	Low-income setting	High-income setting	Significance (*p*) (effect size, φ)
1-10 min	116 (84.7%)	188 (92.6%)	
11+ min	21 (15.3%)	15 (7.4%)	
Go to the park			0.034 (0.115)
1-10 min	85 (62.0%)	148 (72.9%)	
11+ min	52 (38.0%)	55 (27.1%)	

Table K-2. Access to services in the neighbourhood perceived by residents from low- and high-income settings

Perceived BE feature	Low-income setting	High-income setting	Significance (*p*) (effect size, φ)
I can do most of shopping at local stores			0.001 (-0.176)
Agree	95 (68.8%)	170 (83.7%)	
Disagree	43 (31.2%)	33 (16.3%)	
Stores are within easy walking distance of my home			0.001 (-0.182)
Agree	106 (76.8%)	183 (90.1%)	
Disagree	32 (23.2%)	20 (9.9%)	
There are many places to go within easy walking distance			< 0.001 (-0.292)
Agree	101 (73.2%)	191 (94.1%)	
Disagree	37 (26.8%)	12 (5.9%)	
It is easy to walk to a transit stop (bus train) from my home			1.000
Agree	135 (97.8%)	198 (97.5%)	
Disagree	3 (2.2%)	5 (2.5%)	

Table K-3. Streets in the neighbourhood perceived by residents from low- and high-income settings

Perceived BE feature	Low-income setting	High-income setting	Significance (*p*) (effect size, φ)

Perceived BE feature	Low-income setting	High-income setting	Significance (*p*) (effect size, φ)
The distance between intersections in my neighbourhood is usually short			0.006 (-0.149)
Agree	109 (79.6%)	183 (90.1%)	
Disagree	28 (20.4%)	20 (9.9%)	
There are many four-way intersections in my neighbourhood			0.006 (-0.149)
Agree	101 (73.2%)	173 (85.2%)	
Disagree	37 (26.8%)	30 (14.8%)	
There are many alternative routes for getting from place to place in my neighbourhood			0.001 (-0.185)
Agree	116 (84.1%)	193 (95.1%)	
Disagree	22 (15.9%)	10 (4.9%)	

Table K-4. Places for walking and cycling in the neighbourhood perceived by residents from low- and high- income settings

Perceived BE feature	Low-income setting	High-income setting	Significance (*p*)
There are sidewalks on most of the streets in my neighbourhood			0.227
Agree	134 (97.1%)	201 (99.0%)	
Disagree	4 (2.9%)	2 (1.0%)	
The sidewalks in my neighbourhood are well maintained			0.371
Agree	124 (89.9%)	188 (92.6%)	
Disagree	14 (10.1%)	15 (7.4%)	
There is grass/dirt strip that separates the streets from sidewalks in my neighbourhood			0.210
Agree	112 (81.2%)	175 (86.2%)	
Disagree	26 (18.8%)	28 (13.8%)	

Table K-5. Neighbourhood surroundings perceived by residents from low- and high-income settings

Perceived BE feature	**Low-income setting**	**High-income setting**	**Significance (*p*) (effect size, φ)**
Trees give shade for the sidewalks in my neighbourhood			0.006 (-0.150)
Agree	124 (89.9%)	197 (97.0%)	
Disagree	14 (10.1%)	6 (3.0%)	
There are many interesting things to look at while walking in my neighbourhood			< 0.001 (-0.391)
Agree	94 (68.1%)	195 (96.5%)	
Disagree	44 (31.9%)	7 (3.5%)	
My neighbourhood is generally free from litter			< 0.001 (-0.285)
Agree	102 (73.9%)	191 (94.1%)	
Disagree	36 (26.1%)	12 (5.9%)	

Table K-6. Safety from traffic perceived by residents from low- and high-income settings

Perceived BE feature	**Low-income setting**	**High-income setting**	**Significance (*p*)**
There is so much traffic along the street I live on that makes it difficult or unpleasant to walk in my neighbourhood			0.375
Agree	32 (23.2%)	39 (19.2%)	
Disagree	106 (76.8%)	164 (80.8%)	
There is so much traffic along nearby streets that it makes it difficult or unpleasant to walk in my neighbourhood			0.337
Agree	39 (28.3%)	48 (23.6%)	
Disagree	99 (71.7%)	155 (76.4%)	
The crosswalks in my neighbourhood help walkers feel safe crossing busy streets			0.244
Agree	110 (79.7%)	150 (74.3%)	
Disagree	28 (20.3%)	52 (25.7%)	

Table K-7. Safety from crime perceived by residents from low- and high-income settings

Perceived BE feature	Low-income setting	High-income setting	Significance (*p*) (effect size, φ)
My neighbourhood streets are well lit at night			0.827
Agree	122 (88.4%)	181 (89.2%)	
Disagree	16 (11.6%)	22 (10.8%)	
The crime rate in my neighbourhood makes it unsafe to go on walks during the day			0.881
Agree	8 (5.8%)	11 (5.4%)	
Disagree	130 (94.2%)	192 (94.6%)	
The crime rate in my neighbourhood makes it unsafe to go on walks during the night			< 0.001 (0.226)
Agree	47 (34.1%)	30 (14.8%)	
Disagree	91 (65.9%)	173 (85.2%)	

Table K-8. Neighbourhood satisfaction of residents from high- and low income settings

Perceived BE feature	Low-income setting	High-income setting	Significance (*p*) (effect size, φ)
The access to public transport			0.022 (0.124)
Satisfied	118 (85.5%)	189 (93.1%)	
Not satisfied	20 (14.5%)	14 (6.9%)	
Commuting time to work/school			0.875
Satisfied	101 (75.9%)	135 (76.7%)	
Not satisfied	32 (24.1%)	41 (23.3%)	
Access to shopping			< 0.001 (0.199)
Satisfied	108 (78.3%)	187 (92.1%)	
Not satisfied	30 (21.7%)	16 (7.9%)	
The number of people you know			0.095
Satisfied	52 (37.7%)	108 (53.2%)	

Perceived BE feature	**Low-income setting**	**High-income setting**	**Significance (*p*) (effect size, φ)**
Not satisfied	86 (62.3%)	95 (46.8%)	
How easy and pleasant is to walk in your neighbourhood?			< 0.001 (0.243)
Satisfied	121 (87.7%)	201 (99.0%)	
Not satisfied	17 (12.3%)	2 (1.0%)	
Access to entertainment (restaurants, movies, clubs, etc.)			< 0.001 (0.511)
Satisfied	55 (39.9%)	179 (88.2%)	
Not satisfied	83 (60.1%)	24 (11.8%)	
The safety from threat of crime			< 0.001 (0.361)
Satisfied	79 (57.2%)	180 (88.7%)	
Not satisfied	59 (42.8%)	23 (11.3%)	
The amount and speed of traffic			0.951
Satisfied	74 (53.6%)	109 (54.0%)	
Not satisfied	64 (46.4%)	93 (46.0%)	
Your neighbourhood as a good place to raise children			0.001 (-0.178)
Satisfied	105 (76.1%)	119 (58.9%)	
Not satisfied	33 (23.9%)	83 (41.1%)	
Your neighbourhood as a good place to live			< 0.001 (0.279)
Satisfied	117 (84.8%)	201 (99.0%)	
Not satisfied	21 (15.2%)	2 (1.0%)	

Appendix L. Percent variability in adiposity and blood glucose explained by perceived built environment features

WC	WHR	% body fat	FBG
I can do most of shopping at local stores 0.9%	Time to walk to buy groceries 0.8%	Time to walk to buy clothes 1.0%	Time to walk to a bank 1.3%
	I can do most of shopping at local stores 0.8%	Time to walk to buy fruits and vegetables 0.6%	The distance between intersection is short 1.5%
	Stores are within walking distance 0.6%	Time to walk to a park 0.7%	
	Satisfaction with access to shopping 0.8%		

Appendix M. Percent variability in adiposity and blood glucose explained by objective built environment features

BMI	WHR	FBG
Garden 1.7%	Zebra crossing 1.3%	Curbcuts 1.1%
		Gym 1.3%
		Movie theatre 2.0%
		Steepness 1.6%

Appendix N. The association between the built environment and adiposity and fasting blood glucose: results after the additional adjustment for physical activity

Table N-1. Perceived built environment features associated with adiposity measures and fasting blood glucose

WC B (95%CI)	WHR B (95%CI)	% body fat B (95%CI)	FBG B (95%CI)
I can do most of shopping at local stores Agree vs. Disagree 3.269 (0.176, 6.363)*	Time to walk to buy groceries ≤ 10min vs. 11+ min -0.018 (-0.034,-0.002)*	Time to walk to buy clothes ≤ 10min vs. 11+ min -1.836 (-3.558, -0.113)*	Time to walk to a bank ≤ 10min vs. 11+ min -0.037 (-0.070, -0.002)*
	I can do most of shopping at local stores Agree vs. Disagree 0.022 (0.004, 0.039)*	Time to walk to buy fruits and vegetables ≤ 10min vs. 11+ min -1.175 (-2.652, -0.303)	The distance between intersection is short Agree vs. Disagree 0.065 (0.013, 0.120)*
	Stores are within walking distance Agree vs. Disagree 0.019 (-0.001, 0.039)	Time to walk to a park ≤ 10min vs. 11+ min -1.414 (-2.967, 0.139)	
	Satisfaction with access to shopping Satisfied vs. Dissatisfied -0.025 (-0.046, -0.004)*		

* $p < 0.05$; Associations explored by multiple linear regression analysis. Dependent variable: WC, WHR, %BF or lnFBG. Independent variable: perceived environmental feature; All models adjusted for age, sex, household income, formal level of education, ethnicity, neighbourhood income and total physical activity. For FGB models, B (95%CI) i.e. Unstandardized regression coefficient (95 percent confidence interval) is presented as $e^b - 1$ to enable the interpretation of FBG in its original units (mmol/L).

Table N-2. Objective built environment features associated with adiposity measures and fasting blood glucose

BMI B (95%CI)	WHR B (95%CI)	FBG B (95%CI)
Garden Present vs. not present	Zebra crossing T2 vs. T1	Curbcuts T3 vs. T1

1.639 (0.288, 2.990)*	0.028 (0.019, 0.046)**	-0.046 (-0.088, -0.003)*
		Gym
		Present vs. not present
		-0.062 (-0.114, -0.007)*
		Movie theatre
		Present vs. not present
		-0.072 (-0.121, -0.021)**
		Steepness
		T3 vs. T1
		0.047 (0.001, 0.097)*

* $p < 0.05$, ** $p < 0.01$; Associations explored by multiple linear regression analysis. Dependent variable: BMI, WHR or lnFBG. Independent variable: perceived environmental feature; All models adjusted for age, sex, household income, formal level of education, ethnicity, neighbourhood income and total physical activity. For FGB models, B (95%CI) i.e. Unstandardized regression coefficient (95 percent confidence interval) is presented as $e^b - 1$ to enable the interpretation of FBG in its original units (mmol/L). T1-T3=tertiles of access to a built environment feature (T1-lowest access, T3-highest access)

Appendix O. Summary of findings on the association between the built environment and physical activity

	Total PA	Transport PA	Leisure PA	Walking
Perceived	So much traffic along nearby streets (-) Grass/dirt strip between streets and sidewalk (-)	So much traffic along nearby streets (-) Time to walk to a restaurant (-)	Satisfaction with access to entertainment (+) Many interesting things to look at while walking (-)	So much traffic along nearby streets (-) Stores are within walking distance (-)
Objective	/	Places marked for pedestrian crossing (+) White lines at the street crossing (+) Pedestrian crossing activated signal (+) Traffic light (+) Streets with 2 or more lanes (+) Sidewalks on both sides (+) Single-family home duplex (+) Condo (+) Vertical mix use (+) Services (+) Restaurant (+) Night club (+) Liquor store (+) Hospital (+) Retail stores (+) Car dealership (+) Big box shops (+) Bike racks (+) Litter (+) Landscaped open	Buffer between street and sidewalk (+) Single family home duplex (+) Stop sign (+) Midblock crosswalk (-)	Places marked for pedestrian crossing (+) White lines at the street crossing (+) Pedestrian crossing activated signal (+) Sidewalks on both sides (+) Services (+) Liquor store (+) Restaurant (+) Litter (+) Stop sign (-) Playing fields (-)

	space (+)	
	Single-family home detached (-)	
	Stop sign (-)	
	Bike route (-)	
	Trees (-)	

(+), positive association; (-), negative association; /, no association. All models adjusted for age, sex, household income, education, ethnicity, and setting income.

Appendix P. Summary of the results on gender, ethnic, individual and setting income differences in environmental perceptions

Women vs. Men	High income vs. Low income
• More likely to report greater access to retail stores and restaurants • More to report many interesting things to look at while walking • More satisfied with access to entertainment	• More likely to report greater access to grocery and fruit and vegetable stores; and parks • More satisfied with access to shopping
European vs. non-European	**High-income setting vs. Low-income setting**
• More likely to report greater access to grocery, fruit and vegetable, retail and video stores, restaurants, banks, pharmacies and transit stops • More to report many places to go to within walking distance; many interesting things to look at while walking; and grass/dirt strip between streets and sidewalks • More satisfied with access to entertainment, and safety from threat of crime • Less likely to agree that crime rates make it unsafe to go on walks during the night • Less likely to agree that crosswalks help walkers cross street safely • Less likely to be satisfied with the amount and speed of traffic	• More likely to report greater access to grocery, fruit and vegetable, retail and video stores, restaurants, banks, pharmacies, transit stops and parks • More to report shopping locally; and stores and many places to go to within walking distance • More to report trees giving shade for sidewalks, many interesting things to look at while walking, and neighbourhoods free from litter • More to perceive many 4-way intersections, short distances between intersections, and many alternative routes to get to places • More to disagree that crime rates makes it unsafe to walk at night • More satisfied with access to shopping, entertainment, safety from threat of crime, how easy and pleasant is to walk in the neighbourhood, and neighbourhood as a good place to live • Less satisfied with neighbourhood as a good place to raise children

Appendix Q. Summary of findings on the association between the built environment and adiposity and blood glucose

	BMI	WC	WHR	% body fat	FBG
Perceived	/	I can do most of shopping at local stores (+)	Time to walk to buy groceries (-)	Time to walk to buy clothes (-)	Time to walk to a bank (-)
			I can do most of shopping at local stores (+)	Time to walk to buy fruits and vegetables (-)	The distance between intersection is short
			Stores are within walking distance (+)	Time to walk to a park (-)	
			Satisfaction with access to shopping (-)		
Objective	Garden (+)	/	Zebra crossing (+)	/	Curbcuts (-) Gym (-) Movie theatre (-) Steepness (+)

(+), positive association; (-), negative association; /, no association. All models adjusted for age, sex, household income, education, ethnicity, and setting income.