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Movement-Attractors and Generic Neighbourhood Environment Traits

(MAGNET):

The Association between Urban Form and Physical Activity

by

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Abstract

Background: Urban form is a contributor to physical inactivity, which is a problem around the world. The association between urban form and physical activity is not fully understood, in part because improved methodologies of assessing urban form are necessary. This thesis consists of four studies that examined the association between urban form and physical activity in Edmonton, Alberta, using Geographic Information Systems. The research goals of this thesis were: (1) to compare two objective methods of assessing urban form walkability; (2) to examine the association between objective and subjective urban form measures and physical activity; and (3) to compare self-reported physical activity of individuals living in high and low walkability neighborhoods.

Methods: Study 1 addressed Goal 1 and focused on objectively measuring urban form walkability based on public health and architectural (space syntax) measures. Study 2 addressed Goal 2 and focused on urban form association with self-reported physical activity. Study 3 addressed Goals 2 and 3 and focused on urban form association with self-reported walking. Study 4 addressed Goal 3 and involved an observational study of the pedestrian, cyclist, and vehicular movement in four neighbourhoods stratified by walkability and socio-economic status (SES).

Results: Study 1 revealed agreement between public health and space syntax measures of assessing urban form. Study 2 revealed that only the objective environment was associated with physical activity. Study 3 revealed that only the perceived environment was associated with walking. Study 3 also revealed that walking as recommended was not different for individuals living in environments objectively assessed as higher versus lower in walkability. Study 4 revealed that observed pedestrian movement was higher in volume in neighbourhoods objectively assessed as higher in walkability. Cyclist movement was lower in volume in the neighbourhood classified as lower in walkability and in SES than in the other three neighbourhoods. Vehicular movement was no different in volume in the four neighbourhoods.

Conclusion: Both objective and subjective urban form influence physical activity. A common Social Ecological Models - Space Syntax framework would enable a better understanding of urban form influences on physical activity.

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CHAPTER 1. INTRODUCTION

Background

The prevalence of obesity observed among populations around the world (World Health Organization, 2002) has been blamed on an imbalance in energy intake and energy expenditure (Hill, Wyatt, Reed, & Peters, 2003). According to Lakdawalla and Philipson (2002), 60% of the growth in obesity rates is due to declining physical activity. This translates to a decrease in walking behaviour of approximately 15 to 30 minutes per day (Hill, Wyatt, Reed, & Peters, 2003; Slentz et al., 2004). However, this decline in the physical activity of the population is not due to changes in leisure-time activity (Brownson, Boehmer, & Luke, 2005; Craig et al., 2003), but rather to declines in work-related activity, transportation activity, and activity in the home (Brownson, Boehmer, & Luke, 2005). Half of Canadians reported being at least moderately active during their leisure-time, the equivalent of walking about a half an hour per day, with 71% of Canadians indicating walking as their primary form of physical activity (Cameron, Craig, & Paolin, 2005).

Physical activity, including walking, is an important health behaviour for the prevention of chronic diseases such as coronary heart disease, diabetes, and obesity (Berlin & Colditz, 1990; Blair & Brodney, 1999; Helmrich, Ragland, Leung, & Paffenbarger, 1991; Lee & Skerrett, 2001; Warburton, Gledhill, & Quinney, 2001). Though many determinants of physical activity have been identified (e.g., Sallis, Prochaska, & Taylor, 2000; Sherwood & Jeffery, 2000), some scholars have suggested that the environment is a causal factor in the decline of physical activity (Hill, Wyatt, Reed, & Peters, 2003; Spence & Lee, 2003; Swinburn, Egger, & Raza, 1999; Wendel-Vos, Droomers, Kremers, Brug, & van Lenthe, 2007). For instance, people who reside in neighbourhoods that are deemed to be more *walkable* are more likely to be physically active (Frank, Sallis, Saelens, Leary, Cain, Conway, & Hess, 2009; Frank, Schmid, Sallis, Chapman, & Saelens, 2005; Saelens, Sallis, Black, & Chen, 2003) and less likely to be obese (Spence, Cutumisu, Edwards, Raine, & Smoyer-Tomic, 2009). Walkability defines the ease with which a person can navigate from one urban space to another (Sallis, 2009).

Thus, efforts to promote physical activity within or across populations should consider the role of the built environment or urban form (Killingsworth, 2003; Stokols, Grzywacz, McMahan, & Phillips, 2003). Both *objective* (actual) and *subjective* (perceived) urban form influence physical activity (Duncan, Spence, & Mummery, 2005; Humpel, Owen, & Leslie, 2002; Seefeldt, Malina, & Clark, 2002). *Objective* (or material) traits include the availability and distribution of facilities for physical activity and for commercial / service uses, as well as the availability of an adequate pedestrian structure. *Subjective* (or immaterial) traits include neighbourhood safety, comfort, aesthetics, and other aspects that pertain to the social functioning of built environment. However, it remains unclear whether objective or subjective measures are more effective in capturing the association of urban form with physical activity (Lin & Moudon, 2010). Moreover, because associations between objective and subjective assessments of urban form and physical activity often vary (Leslie, Saelens, Frank, Owen, Bauman, Coffee, & Hugo, 2005), and because it is still not known whether subjective urban form attributes have an independent, synergistic, or shared association with physical activity (Saelens, Sallis, & Frank, 2003), it is important to consider subjective along with objective urban form attributes to better understand physical activity (McGinn, Evenson, Herring, Huston, & Rodriguez, 2007).

For successful environment-based interventions to be developed, and for subsequent planning, it is necessary that valid and practical measures of the built environment be available. Unified, valid, and easy-to-employ objective measures of urban form are particularly necessary, since they offer the advantage of fast translation of the research findings into interventions (Lin & Moudon, 2010). Conversely, the perceptions of individuals living in the same environment may not necessarily be similar, thus making translation of research findings onerous (King, Belle, Brach, Simkin-Silverman, Soska, & Kriska, 2005). Because of this, the *objective* assessment of urban form (in particular of walkability) constitutes the focus of this research, though I recognize that both *objective* and *subjective* assessments need to be employed for a comprehensive approach to the association between urban form and physical activity.

Main Research Question

This dissertation combines a number of studies that seek to answer the following main research question: *What is the association between urban form and the physical activity of adults?* Specifically, this project aims to understand the association between urban form and physical activity in the context of

Edmonton, a medium-sized Canadian city, the capital of the Province of Alberta. This dissertation examines (a) methodological issues in assessing urban form *objectively*, (b) the association between *objective* and *subjective* urban form and physical activity, and (c) physical activity patterns in environments that contrast in terms of *objectively* assessed urban form walkability (i.e., higher versus lower walkability environments).

Definitions

An overview of the definitions of concepts used in my study is provided in Table 1-1.

Theoretical Framework

The first section of the theoretical framework discusses the *Social Ecological Models*, which are relevant to this dissertation due to their central focus on the role of environment in shaping behaviour. The second section describes the *Place-Centered Approach* that I adopted to analyze the association between urban form and physical activity from both an *objective* and a *subjective* perspective. The third section describes the *two main methods* used in *objectively* assessing urban form walkability, which are employed in the fields of public health (*the 3Ds of urban form method*) and architecture (*the space syntax method*). Finally, the fourth section revisits the *Social Ecological Models* framework and describes how it expands to accommodate public health and architectural research on physical activity.

Social Ecological Models

This dissertation is situated within the theoretical framework of the *Social Ecological Models* (Sallis & Owen, 1997). I am employing this theoretical framework because of its focus on understanding the role of environment in relation to behaviour. Within the multilevel social ecological paradigm, environment is conceptualized as a multilayered interplay of *intra-personal* influences (e.g., individual factors related to behaviour modification that operate at the level of the individual, such as beliefs and motivations) and *extra-personal* influences (e.g., factors external to the individuals, such as physical and social environments) on health behaviour (Spence & Lee, 2003). Because *intra-personal* factors only account for approximately 25% of the variance in physical activity behaviour, ecological models may provide a more comprehensive approach to the study of physical activity than theories focusing on *intra-personal* factors alone (Baranowski, Anderson, & Carmack, 1998).

In addition, social ecological models are also useful because they address both the *direct* and *indirect* (mediated by cognitions and perceptions) effects that environment exerts on behaviour. To date, the *direct* effect of environment on behaviour has been examined using deterministic models of location – that is, *theories of attraction* based on the assumption that individuals aim to optimize their spatial behaviour by minimizing distances in pursuit of any activity (Smale, 1999). However, some studies point out that the influences of urban form on behaviour are mediated by personal characteristics (Shriver, 1997), socio-economic status (SES; Brownson, Baker, Housemann, Brennan, & Bacak, 2001), and cognitive (Bandura, 1986) or decision-making factors (Cox, 1995) that exert an *indirect* effect of environment on behaviour. This *indirect* effect has been examined using cognitive models of spatial behaviour based on the assumption that the perception of the environment and the knowledge about environment influence choice behaviour (Golledge & Timmermans, 1990). Although there are situations in which the *direct* effect of physical environment may be a stronger determinant of choice than the cognitively mediated influences (Owen, Humpel, Leslie, Bauman, & Sallis, 2004), it has been a challenge to delimit ecological models from Bandura's (1986) Social Cognitive Theory (SCT) and to demonstrate direct, unmediated effects of the environment on physical activity (Spence & Lee, 2003).

I employed two compatible operational frameworks that were proposed by Spence and Lee (2003) and by King, Stokols, Talen, Brassington, and Killingsworth (2002), because they were developed specifically to study environmental effects on physical activity and, therefore, are crucial to an analysis of environmental influences on such activity. Within Spence and Lee's (2003) ecological model of physical activity (EMPA), behaviour is studied at various *extra-personal* environmental levels that exist outside the *intra-personal* level. *Extra-personal* environmental levels include *micro* (i.e., immediate proximity of an individual), *meso* (i.e., everyday environments), *exo* (i.e., environments that influence the individual, without requiring the individuals' presence), and *macro* (i.e., societal factors) scales of analysis. King and her colleagues propose a similar encompassing approach that presents environment as a multi-level continuum ranging from *intra-personal* to *extra-personal* levels of influence. To analyze physical activity, a large array of theories ranging from *intra-personal theories* (e.g., Theory of Planned Behaviour) to *extra-personal theories* (e.g., theories that address the physical and social environments) are appropriate to use at specific levels of analysis, based upon the realms of understanding and applicability of each theory. Due to its focus on the interplay between individual, behaviour, and environment, which is catalyzed by self-efficacy (defined as the sense of personal agency about one's ability to perform a specific behaviour; Bandura, 1986), SCT is one such *extra-personal* theory that was employed for this project. SCT posits that proximal environment influences physical activity only *indirectly*, through cognitions, beliefs, and perceptions; thus, SCT is a useful theory to employ in understanding the *indirect* effects of environment on physical activity.

Therefore, to better understand the nature of the relationships between place and physical activity, I used SCT in conjunction with the operational frameworks of Spence and Lee (2003) and King et al. (2002), incorporated within the theoretical perspective of the Social Ecological Models. These operational frameworks assisted in elucidating both *direct* and *indirect*, as well as both *intra-* and *extra-personal,* influences of environment on physical activity.

A Place-Centered Approach to Physical Activity

This research entails a place-centered perspective on physical activity. Within this perspective, it is necessary to study the *context* (i.e., the urban context or milieu) in which individual-environment interactions occur. Such a perspective is timely in light of the current urban policies and trends in public health that emphasize the role of the context (Bradford, 2005; Cantin, 2010; Capital Health, 2008; Canadian Institute for Health Information, 2006; Myres & Betke, 2002; Poland, Lehoux, Holmes, & Andrews, 2004). Such an approach is guided by an agenda of transdisciplinary health promotion models, such as the Social Ecological Models, whose central tenet is the environment. Because health promotion is an interdisciplinary endeavour, complex methodologies are required to tackle environment understood as a complex inter-layered entity within the Social Ecological Models of public health. Thus, a place perspective, supported by complex methodologies and technologies that are enabled by advancements in Geographic Information Systems (GIS), is necessary to better analyze *direct* and *indirect*, as well as *intra-personal* and *extra-personal,* influences posited to be associated with physical activity.

Researchers in urban theory have operationalized context as a *place* situated at the intersection of three concepts: *urban form*, *urban activities*, and *image* (Canter, 1977; Punter, 1991). Similarly, for Agnew (1987), place consists of three components: a *locale*, a *location*, and a *meaning*. *Locale* refers to the settings in which social relations emerge (Giddens, 1979). *Location* refers to the objective geographic position of the areas that contain the settings and the spatial distribution of the human activities that take place in these areas (Agnew & Duncan, 1989). *Meaning (or sense of place)* refers to an overarching tridimensional concept that captures the way environment is construed by individuals (Lim & Barton, 2010). According to Jorgensen and Stedman (2001), sense of place includes an affective dimension (place attachment), a cognitive dimension (place identity), and a relational dimension (place dependence). For this study, I considered only one dimension of the sense of place, the cognitive dimension, which is captured by assessing the perceptions of individuals about their environments in relation to physical activity.

It is the *location* that represents the key element of place; it functions as an interface between *local* and *global* contexts. *Location* implies simultaneously an *objective* and a *subjective* dimension. Furthermore, Gans (1968) proposed a two-fold perspective on *place,* viewing it as the interplay between the *potential environment* (the range of environmental opportunities or conditions for various activities available in a place) and the *resultant environment* (the range of activities that people perform in that particular place).

While recognizing that the three components of place proposed by Agnew cannot be dissociated, because the tension between the *location* and the *locale* generates a *sense of place* and a specific set of *perceptions* individuals may have about their environment, it seems useful to analyze the *objective* and *subjective* dimensions of place separately, to understand the influence of place on behaviour. Thus, I combined the approaches of Agnew and Gans to investigate the role of place in influencing physical activity as an *objective environment, a subjective environment,* and as a *resultant environment* (see Figure 1-1). While a place perspective recognizes that the *location-locale-sense of place* triad is indestructible, it proposes to operationalize place as *objective, subjective,* and *resultant environment* components that capture both the *objective* and the *subjective* dimensions of the context. *Objective environment (O)* is understood in terms of *location* (i.e., opportunities that neighbourhoods offer for physical activity) and *locale* (i.e., neighbourhood socio-demographics). *Subjective environment (S)* is understood in terms of *sense of place,* which includes individuals' *perceptions* about their environment's conduciveness to physical activity. *Resultant environment (R)* is understood in terms of activity patterns (i.e., *observed* and *self-reported* levels of physical activity). The relationship between *objective environment* and *resultant environment* is denoted as *OR*, whereas the relationship between the *subjective environment* and *resultant environment* is denoted as *SR* (see Figure 1-1).

I synthesized the theoretical frameworks relevant for this study (which were presented previously) into an ecological model of environmental opportunities for physical activity (EOPA) in order to describe *objective* and *subjective* physical environment at various scales: *micro*, *meso*, and *macro* (Figure 1-2). Specifically, the main geographical features studied were the urban form variables, such as accessibility to physical activity facilities, as well as urban form walkability (see Figure 1-1 and Figure 1-2), analyzed at *meso* and *macro* scales. Accessibility was operationalized by using the cost of pedestrian travel to facilities for physical activity. This was accomplished by employing calculations based on street network distance (Apparicio & Séguin, 2006; Nicholls, 2001; Witten, Exeter, & Field, 2003) and on the two-step floating catchment area method (Luo & Wang, 2003; Radke & Mu, 2000). Urban form walkability was operationalized in two ways, based on methodological techniques employed in the spatial planning disciplines (Cervero & Kockelman, 1997; Hillier & Hanson, 1984).

Data pertaining to residents and urban form was collected in Edmonton, which encompasses a land area of 700 square kilometres, and has a population of 712, 391 inhabitants living in 201 residential neighbourhoods that define the spatial extent of the study (City of Edmonton, 2005). Thus, this dissertation studied the influence of *objective* and *subjective* urban form on physical activity at the *macro* and *meso* scales of analysis, focusing on the *objective environment* and on the *OR* and *SR* relationships. In particular, *objective* measurement of urban form in relation to walking (objective urban form walkability) constitutes the central environment analyzed in this dissertation.

Objectively Measuring Urban Form Walkability

The objective measurement of urban form walkability has been heavily influenced by the fields related to spatial planning: urban design, transportation, and geography (see Boarnet & Sarmiento, 1998; King, Stokols, Talen, Brassington, & Killingsworth, 2002; Talen, 2003). Currently, two methods are being used to objectively assess urban form in relation to walking: *the 3Ds of urban form* developed in the field of public health (Cervero & Kockelman, 1997), and *space syntax,* developed in the field of architecture (Hillier & Hanson, 1984). These two methods are efficacious in capturing environmental influence on walking, and each produces consistent associations with self-reported and observed walking. The *3D* method emerged in the field of public health to assess the walkability of communities based on quantifying *Density* (residential density), *Design* (street network patterns), and *Diversity* (mixed land use) of an area. The space syntax method emerged in the field of architecture when the urban design literature appeared less concerned than public health research with documenting the links between urban form and physical activity. Although several valuable contributions for evaluating pedestrian environments have been elaborated (Gehl & Gemzøe, 1996; Whyte, 1980), architectural research has provided mainly normative frameworks, without offering empirical support for the relationship between built environment and pedestrian behaviour (Banerjee, 2001; Carmona, Heath, Oc, & Tiesdell, 2003). As an alternative, the theory of space syntax has generated a body of research that documents empirically the association between urban form and walking. Space syntax is now beginning to be considered by public health researchers (Raford, Chiaradia, & Gil, 2005; Raford & Ragland, 2006; Zimring, Joseph, Nicoll, & Tsepas, 2005) as a valid alternative for quantifying urban form influences on pedestrian movement. In particular, *angular analysis* is a space syntax method that is particularly suitable for use in conjunction with spatial layouts of rectangular street networks that are prevalent in North American cities (Turner, 2007).

The underlying paradigms, conceptual frameworks, and theoretical affiliations of the two methods used in assessing urban form objectively are presented next (see Table 1-2).

The 3Ds of Urban Form (3D)

This method reflects the *organism-environment paradigm,* which is the default position in analyzing environment as a background consisting of a set of clues and cues for behaviour (Hillier, 1996). From the perspective of this approach, an individual experiences the environment while being guided by his or her cognitive abilities (Porteous, 1977). As a system of elements recognized by the individual subject, environment exerts a direct or indirect (via cognitions) effect on behaviour. Based on stimuli perceived in their environment, individuals create mental maps as generalized and personalized images of the environment that depend on the physical environment's legibility, to guide behaviour (Lynch, 1960). The *3D* method belongs to the conceptual framework of the Social Ecological Models described in the first section of the theoretical framework. This method is theoretically affiliated with the *theories of attraction* (Hillier, Penn, Hanson, Grajewski, & Xu, 1993), which assume that movement is driven by the presence of *attractor-land uses* (e.g., commercial or recreational land uses that tend to attract more pedestrian movement than residential or industrial land uses). Using the *3D* approach, studies have documented associations between urban form and physical activity in both Australia (e.g., Owen et al., 2007; Saelens, Sallis, Black, & Chen, 2003) and the United States (e.g., Frank, Andresen, & Schmid, 2004; Frank, Sallis, Conway, Chapman, Saelens, & Bachman, 2006). The *3D* measures rely on the assumption that metric relations influence pedestrian movement strongly: the further the distance to spaces of interest, the less frequented the spaces; conversely, the shorter the distance to spaces, the more frequent their use.

Space Syntax

This method reflects the *space-machine paradigm* (Hillier, 1996; Hillier & Hanson, 1984). In this approach, an individual experiences environment mainly via spatial configuration, rather than only via the particular physical elements of the spatial configuration (Hillier, 2003). Some generic mental structures are crystallized in humans over many eras and are transmitted from generation to generation (Hillier, 1996). This set of mental structures is activated automatically and unconsciously when an individual navigates urban space. Human navigation in urban space is primarily guided automatically and unconsciously by the generic mental structures that detect the characteristics of the urban grid, rather than through the perception of individual environmental features. This method belongs to the *conceptual framework of Space Syntax* (Hillier & Hanson, 1984), a *theory of configuration* that assumes movement is driven mainly by the *spatial configuration* of a studied area (Hillier, Penn, Hanson, Grajewski, & Xu, 1993). Unlike research in public health and social psychology emphasizing the role of cognitions and indirect effects of environment, space syntax proposes that humans navigate urban space by decoding certain descriptors of the layout. These descriptors can be analyzed mathematically to predict spatial behaviour, such as pedestrian, cyclist, and vehicular movement (Hillier, 1999).

Although angular analysis is theoretically affiliated with space syntax, some differences exists between the two (see Table 1-3 and Figure 1-3). Space syntax relies on an analysis of the individual spaces in relation to the whole, urban space being represented as relational pattern of spaces, where every space is connected with every other space (Peponis & Wineman 2002). The spatial representation of layouts as *axial maps* is constructed using axial lines, which are defined as the fewest longest lines of sight or vistas (Hillier and Hanson, 1984). Graph Theory, an area of applied mathematics, is used to analyze axial maps (Barrat, Barthelemy, & Vespignani, 2008; Lin & Hsu. 2009). A graph can be created for an axial map, as a set of objects called vertices (or nodes) consisting of axial lines and a set of edges (lines or arcs) consisting of links between axial lines (Hillier & Hanson, 1984). Figure 1-3 [a] presents an axial map and its corresponding graph. Weights are created, which are associated with the position of the node within the system (Turner, 2000). Distance is, in fact, a weight associated with overcoming the cost of transfer from a node to another. In space syntax, weights are assigned based on topological distance (or the number of steps necessary to get from a node to another, or number of turns to get from an axial line to another (Hillier and Hanson, 1984).

Angular analysis is affiliated with space syntax, and represents an analysis of axial maps that considers the angular change in direction to get from one axial line to another (see Figure 1-3 [b]). The spatial representation in angular analysis involves *segment maps*, which are obtained either by fragmenting axial maps or by employing road-centreline maps (Turner, 2007). Weights are assigned in angular analysis based on geometric distance or the amount of angular turn from a segment to another (Turner, 2007; Dalton, 2001; Turner, 2000). Centrality measures of closeness (or integration) and betweenness (or choice) are employed by both space syntax and angular analysis. In space syntax, measures of centrality are calculated for axial maps by assessing the distance between nodes, which represents the cost of reaching a node from another node. In angular analysis, measures of centrality are calculated for segment maps and involve angular distance instead of topological distance (Turner, 2007; Hillier & Iida, 2005). Despite these methodological differences, angular analysis is considered a special case of space syntax.

A Joint Social Ecological Model - Space Syntax Framework

Although space syntax does not consider cognitions, we consider it to still be affiliated with the ecological models, because it views environment as exerting a direct effect without being mediated by immediate individual cognitions. Rather, its basic assumption is that environment in itself constitutes social behaviour, even before it is experienced by individual subjects, because social patterns are encrypted in the spatial configuration (Hillier, Burdett, Peponis, & Penn, 1986). In this way, individual cognitions are discounted.

Space syntax has a higher predictive value regarding pedestrian movement than other existing theories outside the architectural domain (Hillier, Penn, Hanson, Grajewski, & Xu, 1993). For instance, approximately 66% of variation in pedestrian movement is predicted by variations in the space syntax measure of integration (Hillier, 1996), which assesses the accessibility of a street segment as a destination for all other segments (Hillier, 2009). Since Turner (2007) proposed *angular analysis* as a particular case of space syntax that can easily be used in conjunction with current GIS databases, new opportunities are created for public health research to incorporate space syntax methodologies in the study of physical activity. Though other space syntax methods are currently being used in public health research (Baran, Rodriguez, & Khattak, 2008; Raford & Ragland, 2006; Zimring, Joseph, Nicoll, & Tsepas, 2005), angular analysis has yet to be applied to public health walkability research.

Due to the ability of space syntax to capture the direct effect spatial configuration exerts on movement, I argue that space syntax can, and should, be employed in conjunction with ecological models and SCT to assist in capturing both the *direct* and *indirect* effect the environment exerts on behaviour. Figure 1-4 illustrates the common conceptual framework of the Social Ecological Models that incorporates space syntax. As a synthesis of the two approaches, Figure 1-4 describes how individual cognitions mediate environment-behaviour relationships to exert both *direct* influences (mediated via unconscious cognition, resulting in an immediate behavioural response; e.g., when individuals unconsciously recognize the urban grid based on their innate mental structures) and *indirect* influences (mediated via conscious cognition, resulting indirectly in a behavioural response; e.g., when individuals consciously employ pre-existing beliefs and attitudes in understanding their environments) on behaviour.

Recent evidence in public health indicates that both *attractors* and the *neighbourhood generic environment* (the characteristics of the spatial configuration of the neighbourhood) influence physical activity (Sugiyama, Leslie, Giles-Corti, & Owen, 2009). For example, because a synergetic effect seems to occur between the presence of facilities and neighbourhood environment in terms of conduciveness to physical activity (Giles-Corti & Donovan, 2002;

Sugiyama, Leslie, Giles-Corti, & Owen, 2009), the presence of recreational facilities needs to be complemented by a supportive system of streetscapes and cultural facilities to create prerequisites for achieving recommended levels of physical activity. Thus, individuals walk more to facilities if attractors such as facilities and outdoor recreational settings are present and if the neighbourhood environment provides incentives for active lifestyles. However, generic neighbourhood environments are currently analyzed using operational frameworks affiliated with the *theories of attraction* only. An additional specific operational framework affiliated with the *theories of configuration* is necessary to address the generic neighbourhood environment, because both families of theories (*theories of attraction* and *theories of configuration*) should be employed *together* to better understand physical activity from a public health perspective. Their associated paradigms need to be joined to accommodate both an *organism-environment* and a *space-machine* conceptualization of individual-environment interaction. Consequently, I proposed a combined Social Ecological Models - Space Syntax framework that entails an analysis of the synergy of the constituent elements of the urban form.

Research Goals and Hypotheses

Three research objectives were selected for the purpose of answering the main research question: *What is the association between urban form and the physical activity of adults?*

Goal 1 was to explore and compare two methods of objectively assessing the conduciveness of urban form to walking: the *3D*s of urban form (informed by the *theories of attraction*) and the angular analysis method (informed by the *theories of configuration*).

Goal 2 was to assess the association between *objective* and *subjective* urban form and physical activity. It was hypothesized that urban form has a *direct*, as well as an *indirect*, effect on physical activity. It was also hypothesized that urban form variables describing walkability and accessibility to physical activity facilities would be independently associated with residents' self-reported walking levels and total physical activity above and beyond the variance explained by psycho-social and socio-demographic correlates.

Goal 3 was to compare the self-reported walking, as well as actual walking, of individuals living in higher and lower walkability environments. It was hypothesized that residents of higher walkability environments would walk more and participate in more total physical activity than their counterparts living in lower walkability environments, after adjusting for socio-economic status (SES), age, gender, and health status.

While *Goal 1* focuses on the objective environment (*O*), *Goals 2* and *3* focus on both relationships *OR* and *SR* (see Figure 1-5).

Thesis structure

This dissertation consists of four chapters (Chapters 2 to 5) describing studies that investigated the association between urban form and physical activity. Also, a final chapter (Chapter 6) presents a set of overall conclusions for the four studies and implications for future work. The research goals addressed by each study, the title and aims of each study, the units and the scales of analyses employed, as well as the type of analyzed relationship are presented in Table 1-4. In addition, Figure 1-5 illustrates how the four studies addressed the relationships between *O, S*, and *R* environments, while Figure 1-6 illustrates how the four studies addressed the research goals of this dissertation to answer the main research question.

Study 1 is entitled *"Figures of fit: Comparing a 3D walkability index to angular measures of pedestrian movement"*. It focused on an assessment of the objective environment *O*, analyzing objectively the location (or physical environment), measured at *macro* scale, using neighbourhood as the unit of analysis. Study 1 addressed *Goal 1* and represented a preliminary step in creating the measures used in Studies 2-4. Specifically, Study 1 aimed to compare two methodologies of assessing neighbourhood walkability: the *3Ds* of urban form (*3D*) measure and the *angular analysis (AA)* measures. This study investigated to what extent the two assessments fit (i.e., the compatibility of the assessments based on the two measures).

Studies 2 and 3 focused on both *OR* and *SR* relationships measured at both *macro* and *meso* scales (see Table 1-2 and Figure 1-6), using neighbourhood and buffers created around individuals' households as units of analysis.

Study 2 is entitled *"Fields of motion: Sports fields as potential catalysts for physical activity in the neighbourhood"*. The study addressed *Goal 2* of this dissertation. Specifically, it aimed to investigate whether individuals' self-reported physical activity is associated more strongly with the objective or subjective environment. It examined the association between the access to sports fields and the levels of physical activity.

Study 3 is entitled *"Forms of contrast: Urban form association with walking in Edmonton"*. Study 3 addressed both *Goals 2* and *3* of this dissertation. It aimed to investigate whether individuals' self-reported walking is associated more strongly with the objective or subjective environment, and whether individuals living in contrasting walkability environments display contrasting self-reported walking levels. More specifically, Study 3 aimed to investigate whether living in contrasting urban forms, such as higher versus lower walkability, translates to contrasting levels of physical activity, such as higher versus lower levels of physical activity.

Finally, Study 4 is entitled *"Fabric of movement: An observational study of pedestrian, cyclist, and vehicular movement in four neighbourhood environments"*. It focused on the *OR* relationship only, measured on the *meso* scale, using neighbourhood and street segments as units of analysis. This study addressed *Goal 3* of this dissertation. Study 4 aimed to compare the *observed walking* in four neighbourhoods stratified by SES and walkability assessed using *3D* measures. Also, it aimed to compare *observed walking* in each of the four neighbourhoods to an objective assessment of neighbourhood walkability based on an analysis of street networks (the *"fabric of movement"*) using *AA* measures.

Significance and Contributions

My dissertation has *theory relevance* because it aims to refine theoretical frameworks based on current paradigms in health promotion and architectural research regarding built environment and physical activity. An investigation of the built environment correlates of pedestrian movement, as revealed by space syntax research, may provide important contributions to the evidence on correlates of physical activity.

This dissertation also has *policy relevance* because its results are expected to elucidate whether newer measures of urban form could be employed in assessing urban form for physical activity. While approaches currently used in public health to analyze the effect of the built environment on walking are expensive and complicated, my study proposes to introduce to the field of walkability research a novel, simple, inexpensive, and feasible application of architectural methods. It is easier to use space syntax instead of currently used methods that often rely on inaccurate data, involve expensive fieldwork, and require complex database creation. This type of information would be useful for urban planning and for developing and targeting interventions to promote walking.

Finally, this study's *place relevance* needs to be noted. Because most of the space syntax research has been performed in older urban textures based on a distorted grid (e.g., London), more research is needed to elucidate the role of urban form in an urban texture based on a regular grid such as Edmonton's.

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Tables

Table 1-1. Definitions

Concept	Definition
Urban form	Physical structure and organization of cities: (1) A *material component* (also called physical environment) consists of the natural environment and the built environment (e.g., land uses, transportation systems, and urban design). (2) An *immaterial component* refers to psycho-social functioning aspects of the material component (e.g., urban aesthetics, comfort, and safety).
Physical activity (U.S. Department of Health and Human Services, 1996, p. 21)	The "bodily movement that is produced by the contraction of skeletal muscle and that substantially increases energy expenditure"
Walkability	A property of the built environment that measures the conduciveness to walking, running, biking, rollerblading, or other activities that involve non-motorized movement
Accessibility (Hansen, 1959)	The ease with which a person at a starting point (origin) can arrive at another point of interest (destination)

Geographic information systems (GIS; Melnick, 2002)	Computer-based systems for integrating and analyzing spatially-referenced data
Spatial configuration	The emergent spatial pattern of buildings and open space that describe urban space; It refers to relations between spaces, which are considered by taking into account other relations (Hillier, 1998)
Space Syntax (Hillier & Hanson, 1984)	A body of literature, a research program, a theory and a family of methodological techniques generated by the ideas formalized by Hillier and Hanson to capture and understand the relationship between spatial configuration and society. Space syntax considers solely the spatial configuration of an urban layout, which is represented, measured, mathematically analyzed, and interpreted, mainly based on relational measures (topological distances that are based on adjacency; e.g., a destination is located in terms of the number of turns in street direction, as opposed to a certain number of meters away from an origin), that is by viewing spatial configuration as a relational pattern of distinct spaces (Bafna, 2003; Peponis & Wineman, 2002, Hillier & Hanson, 1984).

Table 1-2. Methods of objectively measuring urban form walkability

	The *3D*s of Urban Form	Space Syntax
Paradigm	*Organism-environment paradigm*	*Space-machine paradigm*
Conceptual Framework	*Social Ecological Models*	*Space Syntax*
Theoretical Affiliation	*Theories of Attraction*	*Theories of Configuration*

Table 1-3. Comparison between Space Syntax and Angular Analysis

	Space syntax	Angular analysis
Spatial representation	*Axial map*	*Segment map*
Weights (cost of overcoming distance)	*Topological Distance*: number of turns from one node to another e.g., topological distance from *A* to *E* in Figure 1-3 is 3 (3 edges were traversed from *A* to *E*: *e1, e2, e3*)	*Angular (or Geometric) Distance*: amount of angular change in direction from a segment to another e.g., angular (geometric) distance from segment *A* to segment *E* in Figure 1-3 is $w(\varphi) + w(\theta) + w(\pi/2)$, where *w* denotes the weights. Weights are assigned using the convention of Hillier and Iida (2005), which assigns a value of 0 for a change of 0º, a value of 1 for a change of 90º, and a value of 2 for a change of 180º.

Measures	*Closeness (Integration):* potential for to-movement (or potential of a node/ segment to become a destination in the layout) *Betweenness (Choice):* potential for through-movement (or potential of a node/street segment to become a route in the layout) (Hillier, 2009; Hillier, Penn, Hanson, Grajewski, & Xu, 1993)

Table 1-4. Studies 1-4: Dissertation structure and focus

Study Title	Dissertation Goals	Study Aims	Unit of analysis	Scale	Focus
Study 1. "Figures of fit: Comparing a *3D* walkability index to angular measures of pedestrian movement"	*Goal 1*: Explore and compare two methods of objectively assessing urban form walkability	Compare two walkability methodologies: *3D* and *AA*	neighbourhood	macro	*O*
Study 2. "Fields of motion: Sports fields as potential catalysts for physical activity in the neighbourhood"	*Goal 2:* Assess the association between objective and subjective urban form and physical activity	Investigate whether individuals' *self-reported physical activity* is associated more strongly with the objective or subjective environment	neighbourhood buffers	macro meso	*OR* *SR*

Study 3. "Forms of contrast: Urban form association with walking in Edmonton"	*Goal 2:* Assess the association between objective and subjective urban form and physical activity	Investigate whether individuals' *self-reported walking* is associated stronger with the objective (assessed using both *3D* and *AA* measures) or subjective environment	neighbourhood buffers	macro meso	*OR* *SR*
	Goal 3: Compare self-reported and actual walking of individuals living in high- and low-walkability environments	Investigate whether individuals living in contrasting walkability environments (based on both *3D* and *AA*)			

		display contrasting *self-reported walking* levels			
Study 4. "Fabric of movement: An observational study of pedestrian, cyclist, and vehicular movement in four neighbourhood environments"	*Goal 3*: Compare self-reported and actual walking of individuals living in high and low walkability environments	Compare observed movement in four neighbourhoods that were stratified by walkability (assessed objectively using *3D* measures) and by SES Compare observed movement with the angular measure of walkability in four neighbourhoods that	neighbourhood street segments	meso	*OR*

were stratified by walkability (assessed objectively using *3D* measures) and by SES

Note: *3D* = Design, Diversity, Density; *AA* = Angular Analysis measures; *O* = objective environment; *S* = subjective environment; *R* = resultant environment; *OR* relationship = relationship between objective (*O*) and resultant (*R*) environments; *SR* relationship = relationship between subjective (*S*) and resultant (*R*) environments.

Figures

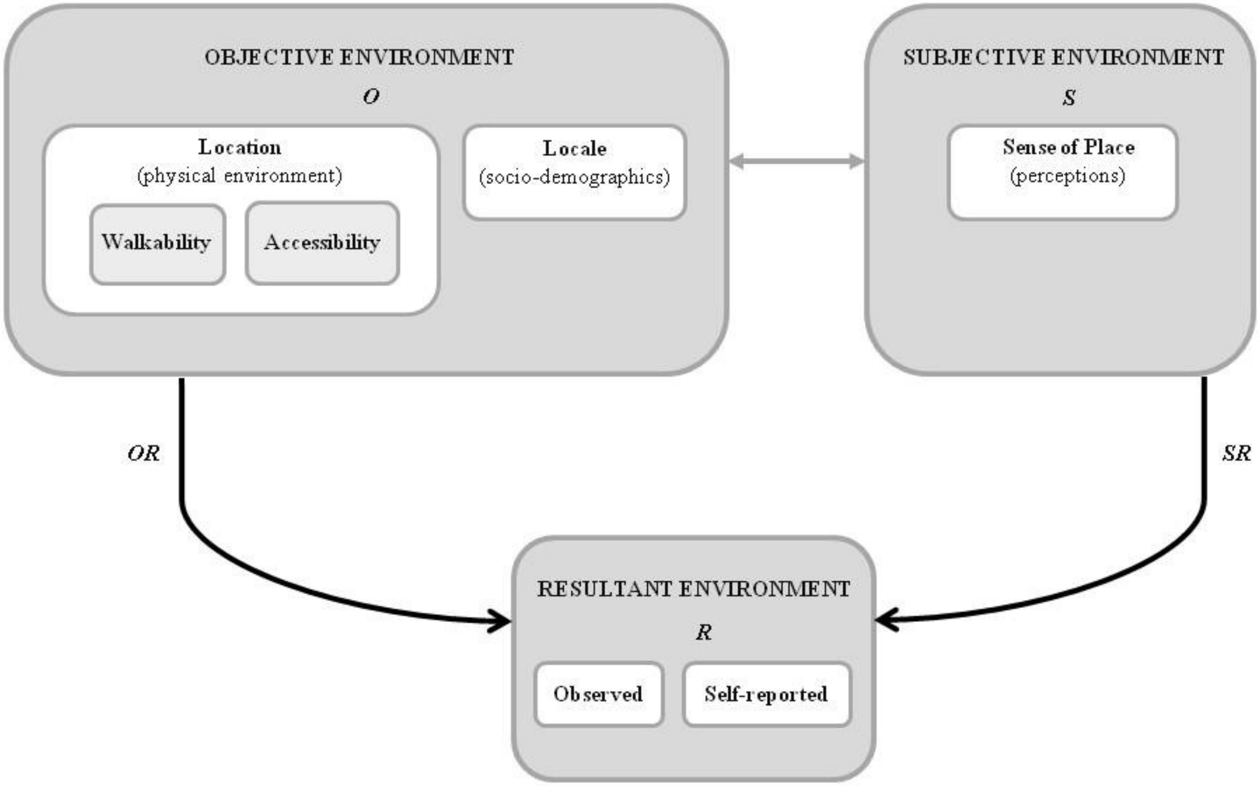


Figure 1-1. Objective, subjective, and resultant environment

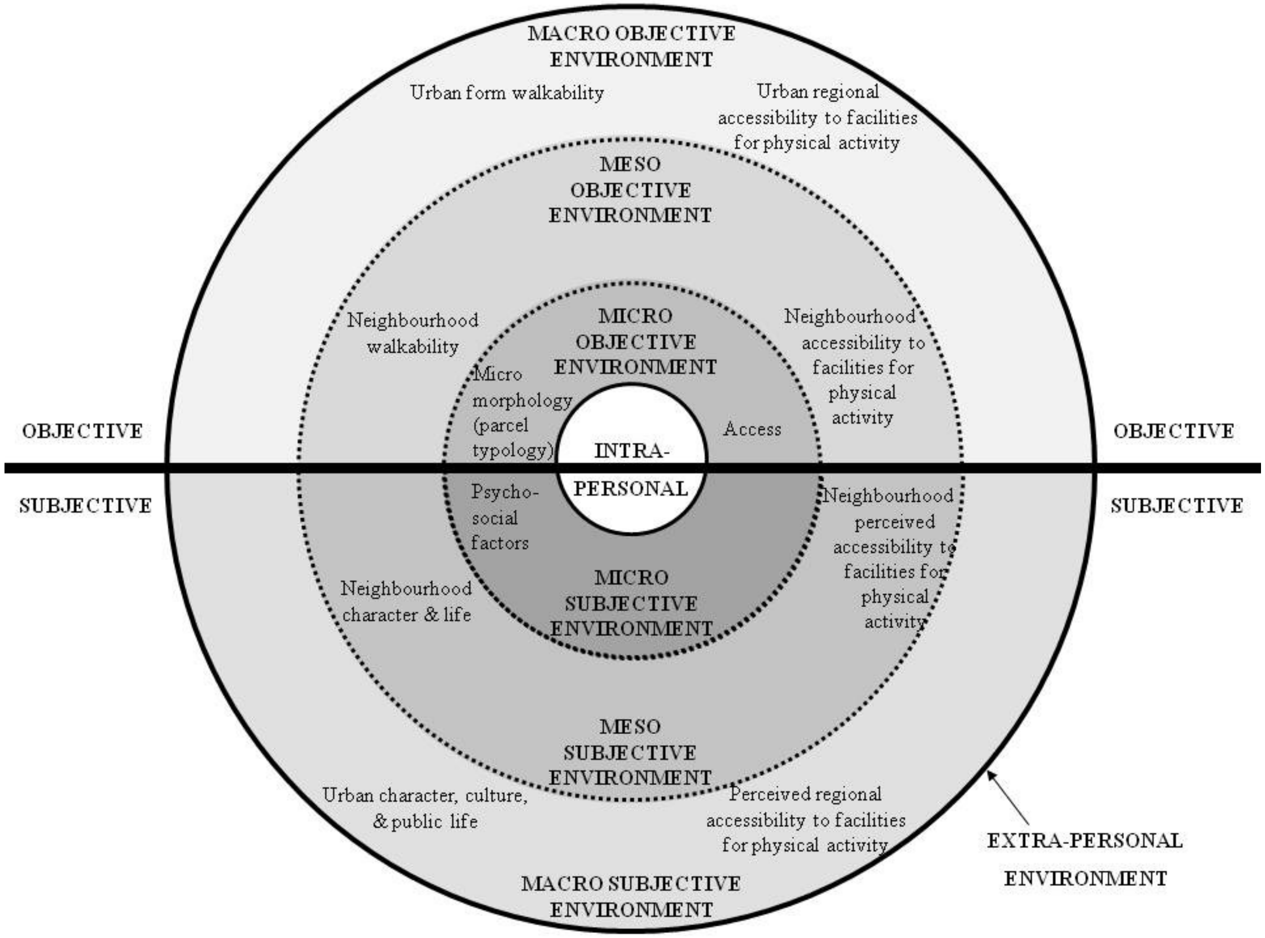
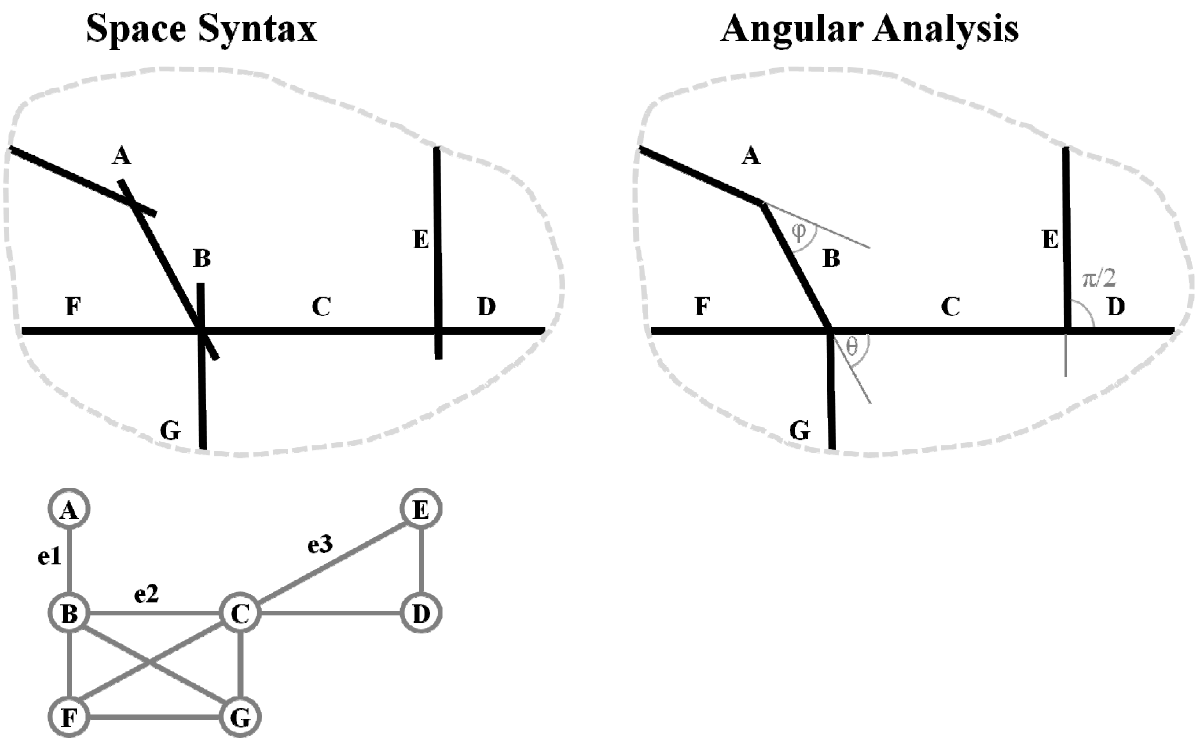


Figure 1-2. The Model of Environmental Opportunities for Physical Activity (EOPA)



[a]

[b]

Figure 1-3. Space Syntax and Angular Analysis

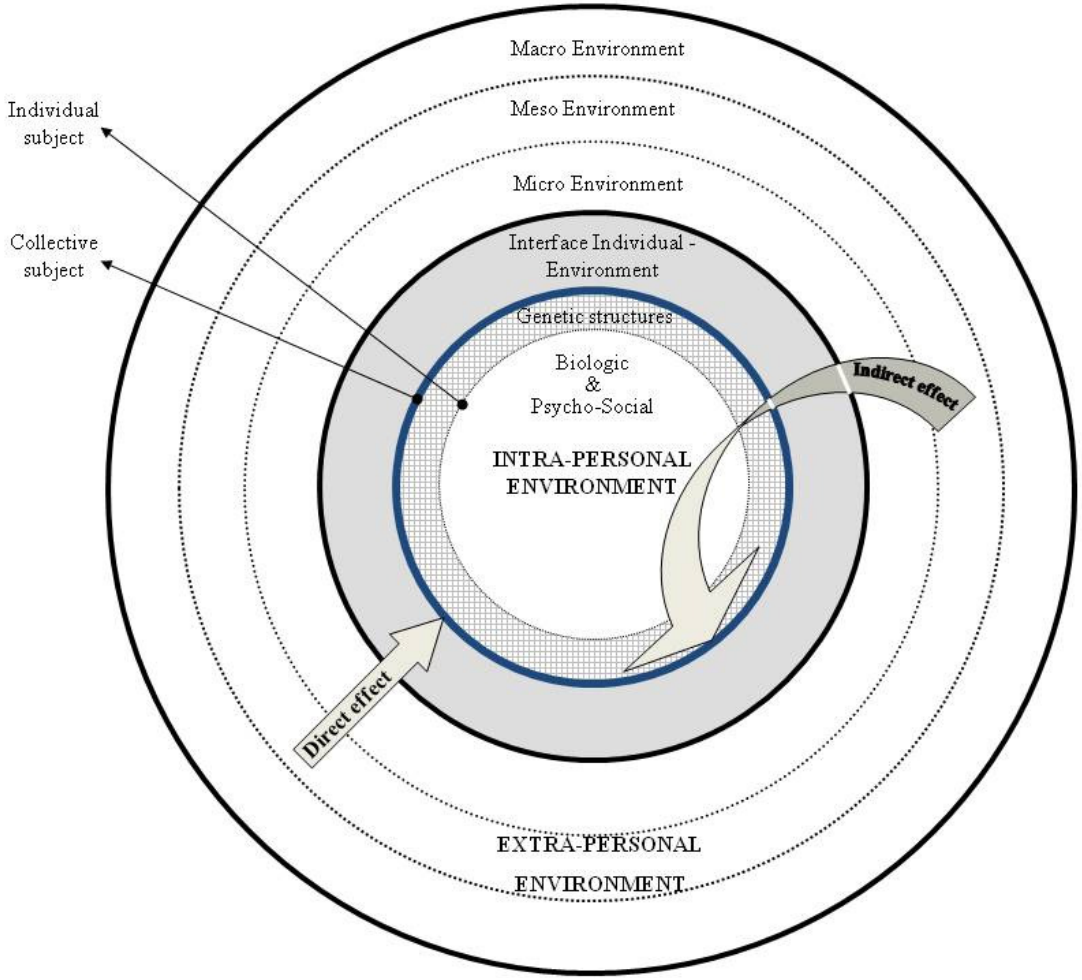


Figure 1-4. Common conceptual framework for Social Ecological Models and Space Syntax

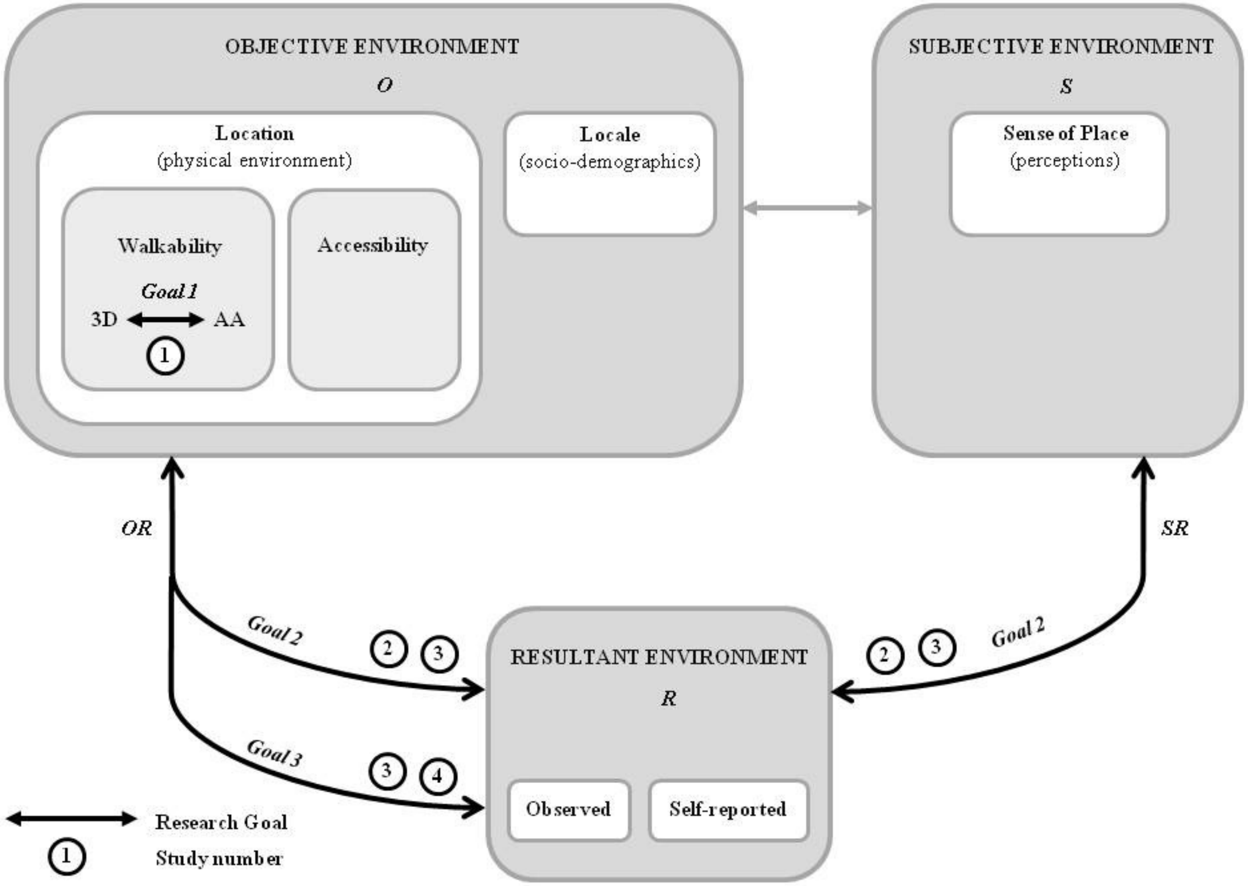


Figure 1-5. Objective, subjective, and resultant environment and the four studies

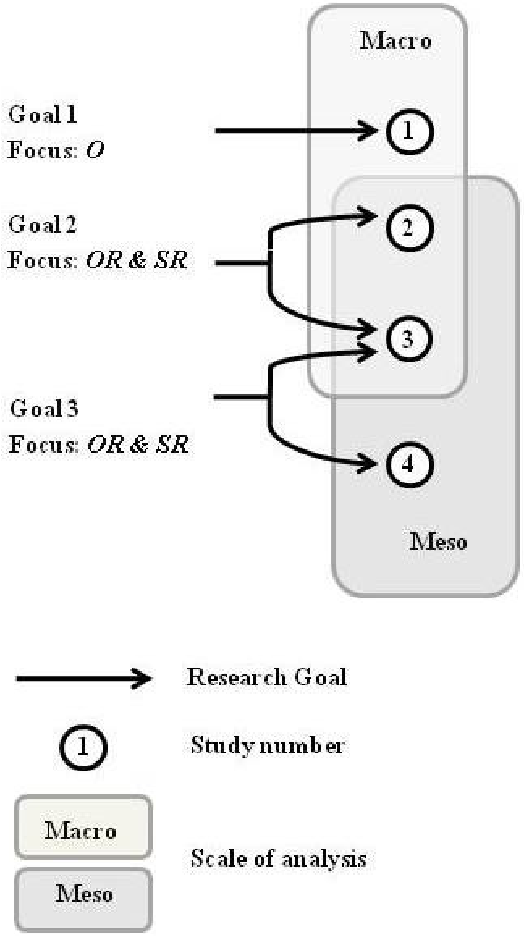


Figure 1-6. The relationship between the four studies and the goals of this dissertation

CHAPTER 2. FIGURES OF FIT: COMPARING A 3D WALKABILITY INDEX TO ANGULAR MEASURES OF PEDESTRIAN MOVEMENT (STUDY 1)

Background

The prevalence of obesity observed among populations around the world (World Health Organization, 2002) has been blamed on an imbalance in energy intake and energy expenditure (Hill, Wyatt, Reed, & Peters 2003). According to Lakdawalla and Philipson (2002), 60% of the growth in obesity rates is due to declining physical activity. This translates to a decrease in walking of approximately 15 to 30 minutes per day (Hill, Wyatt, Reed, & Peters 2003; Slentz et al., 2004). However, this decline in physical activity is not due to changes in leisure-time activity (Craig et al., 2003; Brownson, Boehmer, & Luke, 2005), but rather to declines in work-related activity, transportation activity, and activity in the home (Brownson, Baker, Housemann, Brennan, & Bacak, 2001).

Though many determinants of physical activity have been identified (e.g., Sherwood and Jeffery, 2000), the environment has recently been implicated as a causal factor in the decline of physical activity (Hill, Wyatt, Reed, & Peters 2003; Wendel-Vos, Droomers, Kremers, Brug, & van Lenthe, 2007; Handy, Cao, & Mokhtarian, 2008; Salmon, Spence, Timperio, & Cutumisu, 2008). In particular, it appears the built environment, also known as urban form, is influential for transportation activity (Handy, Boarnet, Ewing, & Killingsworth, 2002; Lee & Moudon, 2004; Sallis, Frank, Saelens, & Kraft, 2004; Ewing, 2005; Forsyth, Oakes, Schmitz, & Hearst, 2007; McCormack, Giles-Corti, & Bulsara, 2008; Saelens & Handy, 2008). Thus, efforts to promote physical activity within or across populations should consider the role of the built environment (Killingsworth, 2003; Stokols, Grzywacz, McMahan, & Phillips, 2003).

The measurement of the built environment has been heavily influenced by fields related to spatial planning, such as urban design, transportation, and geography (see Boarnet & Sarmiento, 1998; King, Stokols, Talen, Brassington, & Killingsworth, 2002; Talen, 2003). Self-report, observational and Geographic Information Systems (GIS)-based measures have been developed specifically for assessing the environment as it relates to physical activity (see Brownson, Hoehner, Day, Forsyth, and Sallis, 2009). The application of GIS, in particular, has revolutionized the measurement of urban form due to the ability of GIS to represent spatial data by linking location and attributes (Sallis, 2009). However, in the rush to use these measures, researchers have employed tools which they have not described in sufficient detail to allow for discussions of validity and reliability (Brownson, Hoehner, Day, Forsyth, & Sallis, 2009; Sallis, 2009). Recognizing this issue, a recent initiative focused on creating standardized definitions for built environment measures that are assessed with GIS (Forsyth, Schmitz, Oakes, Zimmerman, & Koepp 2006). Unified, valid, and easy-to-employ objective measures of urban form are particularly necessary, since they offer the advantage of fast translation of the research findings into interventions (Lin & Moudon, 2010). Because of this, the *objective* assessment of urban form constitutes the focus of our research.

Due in large part to contributions from the city planning field (Frank, Sallis, Conway, Chapman, Saelens, & Bachman, 2006; Lee & Moudon, 2006), the concept of walkability has become an integral component in the objective measurement of urban form in relation to physical activity. Walkability defines the ease with which a person can navigate from one urban space to another and expresses the conduciveness of an urban layout to pedestrian movement (Sallis, 2009). Public health research typically assesses walkability of urban form using some variation of the *3Ds of urban form*, which entails an assessment of the *Density*, *Design*, and *Diversity* of an urban layout (Cervero & Kockelman, 1997). Architectural research assesses the walkability of urban form using the *space syntax* method of quantifying urban form influences on pedestrian movement (Hillier & Hanson, 1984). More recently, a novel space syntax method of assessing walkability, named *angular analysis,* was proposed; it can easily be used in conjunction with current GIS databases, unlike most of the other space syntax measures. While other space syntax methods are currently being used in the study of urban layout influences on active transportation (e.g., walking – see Baran, Rodriguez, and Khattak, 2008; Raford and Ragland, 2006; cycling - see Raford, Chiaradia, and Gil, 2007), angular analysis has yet to be applied in public health research on walkability.

To date, no study has considered comparing angular analysis methods to the classic *3D* method in the context of walking. We believe such a comparison is valuable for the following reasons. First, urban design literature would benefit because angular analysis is not yet known outside the space syntax research community, particularly in the North American planning practice / research (Psarra, 2009; Raford, 2009). Second, active living literature would benefit because angular measures could be incorporated into current theoretical models of environmental influences on behaviour (Dara-Abrams, 2009) to document the direct effect of environment. These effects have been difficult to document using other measures employed within the framework of the social ecological models to understand environmental effects on physical activity. Angular analysis is of particular relevance to these models since it is believed to capture a certain cognitive distance in addition to capturing physical distance between places (Turner, 2009), unlike other built environment measures that are less efficacious in capturing this cognitive distance. Third, space syntax measures have demonstrated good validity and reliability, and they therefore may be useful for validating other built environment measures, which lack a *"gold standard"* (Forsyth, Schmitz, Oakes, Zimmerman, & Koepp, 2006). Fourth, space syntax measures have the ability to convey information about the system's conduciveness to movement at a very refined level of analysis (the level of the street segment) without requiring the complex databases the *3D* measures typically require. For instance, space syntax is capable of predicting about 70% of the movement observed in a layout solely by examining the configuration of the street networks and measuring it using syntactic descriptors of the layout to determine the movement potential of the layout (Hillier & Iida, 2005).

Determining the degree of agreement or *fit* between the *3D* and space syntax measures would contribute theoretically and practically to the literature examining direct and indirect effects of urban form on walking. This would constitute the first step for future studies that test both measures against actual and predicted movement. In this way, urban form influence on walking could be elucidated by building upon the merits of both families of measures.

Research Question

This study answered the following main research question: *What is the fit between the assessment of walkability based on the 3Ds of urban form method and the assessment of walkability based on the angular analysis (space syntax) method?*

This study addressed *Research Goal 1* of this dissertation: comparing two methods of assessing walkability using the neighbourhood as a unit of analysis. It was hypothesized that angular analysis measures are positively associated with the *3Ds* of urban form walkability index and its three individual components.

Research Focus

An ecological model of environmental opportunities for physical activity (EOPA) was developed to investigate direct and indirect effects of physical environmental elements at various scales (see Figure 1-1, Chapter 1). This study investigates the objective environment *(O)* that is understood in terms of *location* (i.e., opportunities that neighbourhoods offer for physical activity) and *locale* (i.e., neighbourhood socio-demographics). We focused on an assessment of a subset of the objective environment: the *location* or physical environment, which was objectively measured in terms of walkability on a macro-ecological scale, using neighbourhood as the unit of analysis. Neighbourhood walkability was assessed using two methods: *the 3Ds of urban form method* used in the field of public health and *the angular analysis method* used in the field of architectural research. These concepts will be addressed in the following sections.

The 3Ds of Urban Form

The most widely accepted urban form measure to assess walkability of neighbourhoods in the area of public health is the *"3Ds of urban form"* method (Cervero & Kockelman, 1997). This method is based on quantifying density (residential density), design (street network patterns), and diversity (land use mix) of an area. The *3Ds* rely on the assumption that metric relations strongly influence pedestrian movement: the further the distance to spaces of interest, the less frequented the spaces. Conversely, the shorter the distance to spaces, the more frequent their use.

Using the *3D* approach, studies have documented associations between urban form and physical activity in both Australia (Owen et al., 2007) and the United States (e.g., Frank, Andresen, & Schmid, 2004; Frank, Sallis, Conway, Chapman, Saelens, & Bachman, 2006). In a meta-analysis of the associations between the *3Ds* of urban form and travel, Ewing and Cervero (2001) found that pedestrian trips increase 0.45 % for every 1% increase in measures of design or density, with a smaller effect for diversity.

Although the *3Ds* are prevalent in the field of public health, they are disaggregate measures that do not capture relational properties at work within urban form. These relational properties essentially link local and global urban contexts and influence the way humans interact with their urban environments (Baran, Rodriguez, & Khattak, 2008).

Space Syntax (Angular Measures)

Space syntax, which focuses on the relational properties at work among urban form elements, is now being considered by public health researchers (Raford & Ragland, 2006; Zimring, Joseph, Nicoll, & Tsepas, 2005; Raford, Chiaradia, & Gil, 2007) as a valid alternative for quantifying urban form influences on pedestrian movement. Although recognized world-wide, space syntax is still unfamiliar to North American public health researchers (Raford, 2009). This approach emerged from the field of architecture and was inspired by Hillier and Hanson's (1984) theory of space syntax, which proposes that humans navigate urban space by decoding a set of spatial properties of the layout. Space syntax relies solely on the study of urban spatial configuration, ignoring information on origins, destinations, land uses, and to some extent metric distance, as well as the role of motivations and intentions (Penn, 2003).

Thus, whereas public health research that employs the *3D* measures relies on the assumption that a mix of land uses influences pedestrian movement, space syntax relies on the assumption that land uses are a by-product of the spatial layout. Basically, the layout creates a certain proportion of pedestrian movement. Moreover, as *"correlation detectors"* (Penn & Dalton, 1994), humans are able to assess the potential for encounter (or walkability) based on the spatial configuration, in a way that is not mediated by individual cognitions. Space syntax research found positive associations between spatial configuration and population density and design (Peponis, Bafna, & Zhang, 2008), as well as diversity (Mora, 2003). These associations are thought to capture the multiplicative effect exerted by the network on urban space functioning.

The spatial layout has been traditionally quantified in the space syntax community by using a set of descriptors (the spatial properties of the layout that individuals read while navigating urban space) which are captured by axial maps. The axial maps are created by dividing the spatial layout into convex spaces and covering these spaces with the fewest longest lines of sight (see Hillier, 1996). Afterward, layouts are represented using nodes (symbolizing the longest lines of sight) that are linked by edges (symbolizing intersections between lines of sight). Based on the configuration of nodes and edges, the layouts are objectively measured using relational measures (topological distances that are based on adjacency) and then analyzed mathematically to predict spatial behaviour, such as pedestrian and vehicular movement (Hillier, 1999), crime (Hillier, 2004), and sense of place (Dalton, 2007). In addition to such relational or *topological* distances, space syntax has more recently incorporated *metric* and *geometric distances* (Hillier, 2009). *Topological* relationships are based on changes in turns from a street segment to all others, assigning a value of 1 for a change in direction and a value of 0 if there is no change in direction. *Metric* relationships are based on metric distance between the midpoint of a street segment and the midpoint of another street segment. Finally, *geometric* relationships are based on changes in angles from a street segment to all others. Space syntax research used these types of distances to capture urban space and its conduciveness to movement.

In space syntax, urban space consists of a "*foreground network*", distinguishable at the global level as the main structure in the city, which is characterized by higher movement potential, and a "*background network*", distinguishable at the local level as a secondary structure in the city, which is characterized by lower movement potential (Hillier, Turner, Yang, & Park, 2007). The tension between these two structures explains the movement patterns in cities and represents the essence of the urban space (Hillier, 2009). Navigating urban space involves a process of negotiation between these global and local scales. It appears that urban space is mainly governed by metric relationships at the local level and by topological and geometric relationships at the global level. Thus, at the *local level*, the rules of conventional attractor-based theories that employ metric distance (e.g., distance decay of movement from an attractor) are stronger. At the *global level,* the rules of configurational theories (such as space syntax) that employ topologic and geometric distances are stronger. To better capture this dual structure, *topological, metric*, and *geometric* distances need to be employed.

Challenges in Space Syntax Research

Several challenges were noted with respect to the space syntax methodology. First, it appears that space syntax is successful in predicting movement mostly in spatial layouts characterized as *"distorted grids",* which represent departures from the ortho-rectangular grid. A perfect ortho-rectangular grid consists of a uniform network of perpendicular streets (which is a characteristic of urban form in most North American cities). Even though pedestrian densities in a uniform grid are generally lower than those in the distorted grids typically found in European cities, it is still characteristic of the network that the more integrated spaces attract more movement (Peponis, Ross, & Rashid, 1997). However, it appears that the syntactic properties of the layout have diminished predictive ability in terms of movement as the layout configuration approaches the uniform grid, because the uniform grid is characterized by relatively homogeneous syntactic descriptors (Hillier, Penn, Hanson, Grajewski, & Xu, 1993). In such networks, which lack a clear hierarchy and offer a multitude of choices for movement, other built environment factors become more influential for movement (these include the quality of the built environment, sidewalk width and continuity, the traffic lights presence). Second, the use of axial maps particularly in such spatial layouts based on a regular grid has been criticized (Ratti, 2004), because axial maps do not constitute a representation-free method of analyzing spatial configurations and they are sensitive to small changes in direction.

Refinements in Space Syntax Research: Angular Analysis

In response, Turner (2007) proposed angular system analysis as a particular instance of space syntax analysis that uses angular maps instead of axial maps, based on the street segment analyzed using geometric distance. Angular maps constitute an extension of axial maps that consider the angle between the edges that connect nodes, because individuals tend to minimize the angle of direction while walking (Turner, Chapman, & Penn, 2000; Turner, 2001). Thus, individuals appear to navigate along the shortest angular paths in a system. The measures of *angular betweenness* (also named *angular choice*) and *angular* *closeness* (also named *angular mean depth*) were adapted to assess the conduciveness of an urban layout to movement from Sabidussi (1966)'s graph measures of centrality. In space syntax research, betweenness is known as *choice*, a measure that assesses the *through-movement potential*, which denotes the probability that a segment lies on the shortcut from one segment to all others. Closeness is known as *integration*, a measure that assesses the *to-movement potential* of a segment, which denotes the accessibility of the segment as a destination for all other segments (Hillier, 2009).

Furthermore, Turner (2007) has introduced the idea of weighting angular measures by segment length to take into account the size of the urban system and to avoid any inconsistencies that might result from the way street segments were represented by the cartographer. Thus, angular measures weighted by segment length rely both on a system's *geometric* structure (i.e., by considering the degree of angular change on the route from one segment to all others) and on a system's *metric* structure (i.e., by considering the length of the street segments; Hillier, Turner, Yang, & Park, 2007). Angular measures are typically calculated for the urban system considered (radius *n*, or not restricted by a radius), or for a restricted radius. Radius may be defined as *topological radius* (based on a specified number of turns from a segment), as *angular radius* (based on a specified degree of angular change), or as *metric radius* (based on metric distance; Hillier, Turner, Yang, & Park, 2007). So far, angular measures restricted to a metric radius show the best correlations with observed pedestrian and vehicular movement (Hillier & Iida, 2005). Referring to the dual structure of urban space, Hillier and his colleagues noted that angular measures restricted to metric radii reveal the "*foreground network*", while metric measures restricted to metric radii reveal the "*background network*" (or "*patchwork*") of areas that are mainly residential in character (Hillier, Turner, Yang, & Park, 2007). Angular analysis can easily be used in conjunction with current GIS databases based on road centerlines (a widely used symbolic representation for street networks based on the geographic center of roads). Recent studies identify angular betweenness as the main correlate of pedestrian movement (Turner, 2009b; Turner, 2007; Hillier & Iida, 2005).

Neighbourhood as a Unit of Analysis

The *neighbourhood* has constituted the preferred unit of study for most of the health research on walkability. It seems that traditional neighbourhoods with a finer network generate shorter-than-average pedestrian trips and are considered more walkable than modern neighbourhoods, which generate longer-than-average pedestrian trips (Southworth & Owens, 1993; Ewing, Haliyur, & Page 1994; Cervero & Gorham, 1995; Cervero, 1996; Crane & Crepeau, 1998).

From a public health perspective, the use of spatial units such as administrative units (e.g., neighbourhoods) or census units (e.g., dissemination areas or census tracts) is unavoidable, although it is often criticized because these spatial units are considered units "*of convenience*" (Riva, Aparicio, Gauvin, & Brodeur, 2008). Practitioners and decision-makers are interested in finding out which urban neighbourhoods are higher or lower in walkability, in order to tailor programs directed towards increasing active transportation. Although there is agreement in the literature that identifying spatial units that are meaningful is not an easy task, and in many situations census or administrative units are not suitable because of their heterogeneity (Riva, Aparicio, Gauvin, & Brodeur, 2008), spatial units are routinely used in analyzing urban patterns of health behaviour. Since demographic data are summarized at the census or neighbourhood level, employing these spatial units with all the limitations associated with their use remains a necessary evil.

According to Lee, Moudon, and Courbois (2006), sampling is the source of many issues faced by researchers focusing on walkability. Consequently, to prevent such issues, many studies are increasingly employing *purposeful sampling* of neighbourhoods chosen to satisfy a set of criteria that would ensure the necessary variability in neighbourhood and individual level variables. Recent examples include studies affiliated with the IPEN project (http://www.ipenproject.org/index.htm), in which a set of neighbourhoods stratified by walkability and socio-economic status are selected for analysis. To benefit from the merits of both *3D* and angular measures, neighbourhoods can be categorized as high or low in walkability based upon both assessments. Researchers can then determine the characteristics of places that rank consistently high or low based on the two methods. For instance, a set of neighbourhoods could be ranked in terms of walkability based on a *3D*-affiliated method (denoted as *3D walkability*), as well as on angular analysis (denoted as *angular walkability*), to determine the degree of agreement of *3D* and angular walkability, as well as to identify the clusters of agreement*: high 3D walkability – high* *angular walkability* and *low 3D walkability - low angular walkability*. These clusters would then become future sampling pools. A first step, though, is an understanding of this relationship at the macro-ecological level, using neighbourhoods as spatial units.

Method

Data Acquisition and Sample

This study took place in Edmonton, Canada, which is the capital of the Province of Alberta. Edmonton includes 201 residential neighbourhoods, of which 90 are suburban (M = 1.05 km^2, SD = 0.34) and 111 are mature (M = 1.10 km^2, SD = 0.40). The average area of residential neighbourhoods is 1.08 square kilometres (SD = 0.38). Census data based on the 2001 Census by Statistics Canada was provided by the City of Edmonton for the residential neighbourhoods. The City's Infrastructure and Planning department provided shapefiles for neighbourhoods. Its Assessment and Taxation branch provided a tax assessment database that indicated the areas in residential, commercial, industrial, and other land uses in each neighbourhood. GeoEdmonton provided data on street networks.

Measures

According to Forsyth, Schmitz, Oakes, Zimmerman, and Koepp (2006), the absence of standards for the measurement of built environment variables is apparent in the literature; researchers very rarely present detailed formulae. Since such standards have yet to be finalized, we employed widely accepted methods and tools used in the literature.

The Components of the 3D Index

A walkability index affiliated to the *3Ds* of urban form methodology was devised. The *3D* components of diversity, density, and design were assessed employing GIS technologies, following the GIS protocol devised by Forsyth, Schmitz, Oakes, Zimmerman, and Koepp (2006). *Diversity* was assessed using the entropy index proposed by Frank, Sallis, Saelens, Leary, Cain, Conway, and Hess (2009), based upon five land uses: residential, retail, office, education / institutional (including religious establishments), and entertainment. The measure varies from 0 to 1, with a value of 0 indicating a homogeneous neighbourhood represented by a single land use and a value of 1 indicating a perfect mixture of the four land uses. *Density* was assessed by calculating the density of dwellings located in residential areas within each neighbourhood. *Design* was assessed by calculating the density of true intersections in each neighbourhood (Leslie, Saelens, Frank, Owen, Bauman, Coffee, & Graeme, 2005). We decided to define true intersections as intersections of four or more streets, since it appears that intersections of three or more streets are more characteristic of neighbourhoods with many curvilinear and cul-de-sac streets, while intersections of four or more streets are more characteristic of gridiron neighbourhoods (Cervero & Duncan, 2003). The *3D walkability index* for neighbourhoods was then calculated using a modified version of the Frank et al.'s (2009) weighted formula. We did not include the z score for the retail floor area ratio, because we only have access to data pertaining to the total building area in retail use summarized at the neighbourhood level, without parcel level information. Therefore the following formula was used to determine the 3D walkability index: $z_W = z_{D1} + z_{D2} + 2{*}z_{D3}$, where z_W represents the z scores for walkability, z_{D1} represents the z scores for density, z_{D2} represents the z scores for diversity, and z_{D3} represents the z scores for design.

Angular Analysis

The measures of angular weighted closeness (AWC) and angular weighted betweenness (AWB) were adopted from Alasdair Turner's (2007) protocol. The interested reader will find a detailed description of these measures provided by Turner. Angular measure calculations were based on the angular distance from each segment to all the others in the system, measured along the shortest angular path (i.e., the route with the lowest angular cost from a street segment to all the others in the system).

Angular weighted betweenness for a street segment *x* is calculated using the following formula: $B(x) = \sum_{i=1}^{n} \sum_{j=1}^{n} \sigma(i, x, j)$, where i≠j. The function σ takes the following values: $\sigma(i,x,j) = l(i){*}l(j)$, if the shortest path from *i* to *j* passes through *x*; this distance is divided in half if *x* is either an origin or a destination. Thus, angular weighted betweenness assesses how likely it is for a segment to be located along the shortest angular route from one segment to all others.

Angular weighted closeness for a street segment *x* is calculated using the following formula: $C\,(x) = \frac{\sum_{i=1}^{n} l(i)}{\sum_{i=1}^{n} d(x,i)l(i)}$, where *l(i)* represents the length of the segment *i* that is encountered along the shortest angular path from segment *x* to all others in the system and *D(x, i)* is the angular distance from segment *x* to segment *i*. Thus, angular weighted closeness assesses how accessible a segment is to every segment in the system.

To avoid the edge effect (Ratti, 2004; Turner, 2007), which is an inherent issue in space syntax analyses, angular weighted closeness and angular weighted betweenness were calculated for a radius R=1500 m (R_{1500}). A radius of 1500 m was chosen since the median size of a residential neighbourhood in Edmonton is 1.05 km^2; the smallest neighbourhood has an area of .207 km^2 and the largest neighbourhood an area of 2.56 km^2. Consequently, we considered the radius of 1500 m from the centroid (geometrical centre of the neighbourhood) to ensure that all of the segments present in the largest of the neighbourhoods were considered in evaluating the average angular weighted measures for a neighbourhood. In addition, we calculated the angular weighted measures for a radius R=1000 m (R_{1000}) that allows calculating these measures for all of the segments located within the *conceptual walkable neighbourhood* defined by Moudon et al. (2006) as a 1 km buffer around the households of individuals. Also, we calculated the angular measures for a radius R= 500 m (R_{500}). We chose R_{500} because we believed that it would capture the local properties of the spatial layout and would reflect distances that people are willing to walk in and around their neighbourhoods in Edmonton. This seems reasonable given that the median walking trip for commuting was about 756 m in a U.S. study (Schlossberg, Weinstein Agrawal, Irvin, & Bekkouche, 2007). Similarly, residents of Calgary, Alberta walk approximately 320 m to a commuter rail station and up to 643 m in suburban areas of the city, with an average of 482 m (O'Sullivan & Morrall, 1996). Therefore, R_{500} is a good choice for our Edmonton analysis.

Procedures

Measurement of built environment elements was performed using ArcGIS 9.2 (ESRI, 2008) and the Fnode extension (Solorzano, 2003) to calculate street lengths, number of true intersections, areas, and densities of residents. SPSS 17 (PASWSTAT, 2009) was employed for the statistical analyses. The UCL Depthmap 8.15 software (Turner, 2009a) was employed to calculate angular weighted betweenness and closeness for each street segment. The results of the angular analysis were exported into ArcGIS, and an overlay between the neighbourhoods' shapefile and angular analysis shapefile was performed to create a map of neighbourhood angular walkability (the values for each street segment within a neighbourhood were summarized). The level of statistical significance was set at $p < 0.05$.

Analysis

A preliminary examination of the data showed that the assumption of normality was not satisfied. Therefore, each neighbourhood was classified as high or low walkability based on *3D* and angular analysis measures using a median split for each variable. Also, the components of the *3D* walkability index were compared with each of the angular analysis measures. The analysis consisted of calculating Kendall's tau-b (τ) for all comparisons.

Results

Results are presented in Table 2-1 and Table 2-2.

Significant positive associations were found between the *3D* walkability index and angular weighted betweenness for R_{1500} ($\tau = .662$), R_{1000} ($\tau = .682$), and R_{500} ($\tau = .721$). Also, angular weighted betweenness showed significant positive associations with design for R_{1500} ($\tau = .642$), R_{1000} ($\tau = .662$), and R_{500} ($\tau = .761$), as well as with density for R_{1500} ($\tau = .284$), R_{1000} ($\tau = .264$), and R_{500} ($\tau = .184$). In addition, angular weighted betweenness showed significant positive associations with diversity for R_{1500} ($\tau = .413$), R_{1000} ($\tau = .393$), and R_{500} ($\tau = .333$).

Significant positive associations were found between angular weighted closeness and the *3D* walkability index for R_{1500} ($\tau = .403$) and R_{1000} ($\tau =.323$). Also, angular weighted closeness showed significant positive associations with design for R_{1500} ($\tau = .483$) and R_{1000} ($\tau = .363$), and with density for R_{1500} ($\tau = .144$), R_{1000} ($\tau = .184$), and R_{500} ($\tau = .264$). In addition, angular weighted closeness showed significant positive associations with diversity for R_{1500} ($\tau = .214$), R_{1000} ($\tau = .214$), and R_{500} ($\tau = .194$). No other statistically significant associations were found.

Discussion

In keeping with our hypothesis, the *3D* walkability index and most of its individual components were associated with angular weighted betweenness and closeness. With the exception of angular weighted closeness for R_{500}, we found that the association between all of the angular measures and the *3D* index (and its components) was as expected. Relatively high associations of the angular weighted betweenness were found with the *3D* index at all radii that were studied. Design showed the strongest association with the angular measures, as expected, since design and both angular measures capture the connectivity of the street network. Also, the associations of angular weighted betweenness and closeness with density were as expected.

Overall, this study found small to medium positive associations of diversity with the angular measures summarized at the neighbourhood level. According to Hillier and Iida (2005), the presence of magnet land uses creates a multiplicative effect on pedestrian movement, so it was expected that angular measures would be positively correlated with diversity. Recent space syntax research has found that the relationship between space syntax measures and pedestrian movement may vary according to the land use, with non-residential uses (specifically retail and service) attracting more pedestrian movement than residential uses (Ozer & Kubat, 2007; Ortiz-Chao & Hillier, 2007; Min, Moon, & Kim, 2007). Since our measure of diversity is a composite land use measure and does not consider individual land uses separately, an analysis of individual land uses (e.g., commercial, office, residential) might provide an additional explanation for the relationship between diversity and angular measures. In fact, some argue that it is promising to combine accessibility based on space syntax measures with density and diversity as assessed with conventional measures (Ståhle, Marcus, & Karlström, 2005; Marcus, 2006). Future studies should compare the *3D* index and place syntax accessibility, to investigate their potential use in conjunction.

Out of all components of the index, design displayed the most unexpected associations, ranging from a small positive association for radius 1500 to a small negative non-significant association for radius 500. It seems that radius 500 associations for angular weighted closeness describe a different situation compared to radius 1500 and 1000. It is possible that the presence of noise in the data (Peponis, Bafna, & Zhang, 2008) might contribute to the lack of association with diversity and to the relatively smaller associations found between all components of the walkability index and angular weighted betweenness at radius 500. In addition, density and diversity maintain their positive associations with angular measures observed at all studied radii.

Our findings reveal a very different relationship between closeness and betweenness with the walkability index at different radii of analysis. Typically, space syntax studies show high correlations between movement and both integration and choice, so we expected to obtain similar correlations between the walkability index and betweenness and closeness at all radii (1500 m, 1000 m, and 500 m). It is possible that using spatial units and summarizing the values for betweenness and closeness for these units could obscure the spatial signatures (i.e., particular spatial configurations) in terms of syntactic properties present in Edmonton's street networks. The chances are good that our layer of spatial units does not correspond to the configuration of spatial signatures present at global and local scales that characterize spatial differentiation (Hillier, Turner, Yang, & Park, 2007). Similarly, another recent study looking at vehicular traffic found that global betweenness and the measures of metric and directional reach shared about 10% of the variance (Scoppa, French, & Peponis, 2009). Therefore, betweenness and closeness may be associated differently at different scales of analysis. Further studies should elucidate the relationship between closeness and betweenness in various types of networks, because it is likely that the high correlations between choice and integration typically found in space syntax research are more characteristic of distorted grids.

Our results also suggest that global measures may be more suitable for use at the macro level, whereas local metric measures may be more suitable at the local level. This suggests that future studies should focus on topological and geometric relationships at the global (macro) level, while a more localized analysis should focus on metric relationships.

Though the compatibility of the two measures is limited and studies testing both these methods against actual and self-reported walking are still needed, the use of both measures in conjunction may provide a better explanation of pedestrian movement. In this respect, Alfonzo (2005) presents a hierarchical model of walking needs. Within this model, the first-order (and lowest) factor is feasibility, which includes personal characteristics and the limitations they may impose on the individual’s ability to walk. A number of other higher-order factors pertaining to urban form are organized in ascending ranks above feasibility. The most basic of the higher-order factors is accessibility, followed by safety, comfort, and pleasurability. Both *3D* and angular walkability indices address accessibility. Since space syntax measures have the additional capability of assessing the safety of an environment based on the spatial layout (Hiller, 2004), angular measures may be more useful for exploring the hierarchy of walking needs in relation to different populations and different types of walking. Though Raford and Ragland

(2006) explored the role of spatial syntax measures in relation to pedestrian safety, the only study employing angular measures was recently conducted on cycling (Raford, Chiaradia, & Gil, 2007). Similarly, because safety is an important determinant of children's physical activity (Carver, Timperio, & Crawford, 2008), Cutumisu and Spence (2008) argue that space syntax could be a useful tool for detecting associations between the environment and physical activity within this population group. Therefore, future studies of walkability indices should incorporate both *3D* and angular measures to explore associations with other determinants of walking than accessibility. Furthermore, an investigation of the associations between various syntactic descriptors and specific walking behaviour (walking for transportation, walking for recreation) is recommended (see Baran, Rodriguez, & Khattak, 2008).

Strengths and Limitations

One of the strengths of this study is the use of objective measures, such as the *3Ds* of urban form and space syntax measures. In addition, this study employed space syntax measures that have been previously validated. Another strength of this study is the inclusion of street alleys in calculating these objective measures of urban form.

Several limitations of this study need to be mentioned. Angular analysis measures are particularly sensitive to any boundary distortions (Turner, 2007). The cartography of the spatial layout in the databases provided by the City of Edmonton may influence the results of this analysis, although the dataset was tested and corrected for discontinuities in the road centerlines occurring during export from ArcGIS to DepthMap. In addition, we used the street segment to calculate angular measures; thus, our dataset contains a certain amount of *"noise"* because the line segments are artifacts of the way the street files were digitized, with certain road segments consisting of very short line segments, particularly representing curvilinear road segments. The use of road segments emerges as a better option for future studies (Peponis, Bafna, & Zhang, 2008). Finally, we believe that a limitation to conducting a comparison between angular and *3D* measures is the fact that *3D* measures are aggregations, while space syntax measures capture spatial layout in disaggregate detail (Raford, 2009).

Implications

One *practical implication* of our study is to use the two methods in conjunction, which might constitute a good avenue for understanding pedestrian movement. Though varieties of *3D* measures are generally accepted in the public health literature (e.g., Frank, Andresen, & Schmid, 2004; Frank, Sallis, Conway, Chapman, Saelens, & Bachman, 2006; Spence, Cutumisu, Edwards, & Evans, 2008), there are still inconsistencies in the assessment of *3D* measures using GIS that make cross-comparison studies difficult. Measures of density and land use mix vary across studies due to conceptual differences and issues around availability of data. For instance, several studies using *3D* measures (Leslie et al., 2005; Rundle, Field, Park, Freeman, Weiss, & Neckerman, 2008) employ Frank, Sallis, Conway, Chapman, Saelens, and Bachman (2006)'s formula of land use mix based on residential, education, entertainment, retail, and office uses, whereas others (Spence, Cutumisu, Edwards, & Evans, 2008) employ an alternative formula based on residential, commercial, industrial, and other uses (see Rajamani, Bhat, Handy, Knaap, & Song, 2003). Thus, creating walkability indices is complex and inconsistent. Instead, Depthmap provides a straightforward procedure for assessing angular measures. By using only street centerlines, angular measures may be used more easily to compare between contexts in terms of the association between built environment and walking behaviour. They do not involve access to extensive environmental data collected at various scales, nor do they require a variety of methodologies that are not formally validated.

One *theoretical implication* of our study is its potential contribution to refining and developing theoretical frameworks on the built environment and physical activity, given that the angular analysis method relies on the idea that spatial layout exerts direct influences on pedestrian movement, regardless of the role of individual cognitions and motivations. Therefore, angular analysis methods may be more useful when working within ecological models that propose direct influences of the built environment on physical activity (Spence & Lee, 2003). The majority of measures currently used in environmental models employ only metric relationships, whereas angular methods, which use topological and metric relationships, are able to capture cognitive distances and relational qualities of urban space. Understanding the topological relationships between spaces is the key to understanding the role of the two-level structure of the grid that represents the essence of space syntax analysis: the relationship between local and global contexts. Also, the use of angular measures would enable a more refined analysis moving away from a study of neighbourhoods towards disaggregate units (such as street segments as opposed to neighbourhoods), since spatial behaviour of individuals living is most often not homogeneous and smaller spatial units are more suitable for detecting existing relationships (Matthews, 2008). Therefore, more studies are necessary to elucidate how to use the two sets of measures together, particularly studies that explore a possible theoretical integration of the two methodologies.

Future Work

Our study represents just a first step toward future work that focuses on determining the characteristics of neighbourhoods that are higher or lower in walkability based on both *3D* and angular measures, as well as of understanding the similarities or differences in behaviour of individuals living in these neighbourhoods. Such clusters of high or low walkability could be used as sampling pools for future studies. Data collected in these clusters would be used for analyses that are to be performed at the disaggregate level. Such analyses would involve the description of *objective* and *subjective* built environment characteristics within buffers constructed around individual’s household, as well as the association of environment with *observed* and *self-reported* individual behaviour. A recent study (Moudon et al., 2006) provided evidence that an operational definition of a walkable neighbourhood refers to the geographic extent of a 1 km radius buffer around individuals’ households. Using this definition, city-wide studies of buffer *3D walkability* and *angular walkability* (assessed with angular measures restricted to a threshold metric radius of 1 km) may shed more light on the relationship between urban form and pedestrian movement, taking advantage of the main strength of angular measures - that is, their focus on the disaggregate level (Raford, 2009). Being able to determine what characteristics are common to areas that rank higher in walkability based upon both *3D* and space syntax measures would elucidate both direct and indirect effects of urban form on walking at various ecological levels of analysis, building upon the merits of both families of measures.

Conclusion

In summary, some support was found for the compatibility of the *3D* and angular analysis methods. The *figures of fit* we found between the two families of measures indicate promising potential uses for the *3D* and angular measures because it appears that the two methods measure independent aspects of the built environment, which can be used together to better explain walking behaviour. Studies testing both these methods against actual and self-reported walking are still needed. Angular analysis measures have the potential to contribute to refining current conceptual frameworks that analyze the association between urban form and walking.

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Tables

Table 2-1. Associations (Kendall's *tau*-b) between measures of *3D* walkability and Angular Weighted Betweenness for R_{1500}, R_{1000} and R_{500}

	NAWB 1500	NAWB 1000	NAWB 500
3D Walkability	.662**	.682**	.721**
Design	.642**	.662**	.761**
Density	.284**	.264**	.184**
Diversity	.413**	.393**	.333**

Note: NAWB = neighbourhood angular weighted betweenness

* $p < .05$, ** $p < .01$

Table 2-2. Associations (Kendall's *tau*-b) between measures of *3D* walkability and Angular Weighted Closeness for R_{1500}, R_{1000} and R_{500}

	NAWC 1500	NAWC 1000	NAWC 500
3D Walkability	.403**	.323**	.025
Design	.483**	.363**	-.015
Density	.144**	.184**	.264**
Diversity	.214**	.214**	.194**

Note: NAWC = Neighbourhood angular weighted closeness

* $p < .05$, ** $p < .01$

CHAPTER 3. FIELDS OF MOTION: SPORT FIELDS AS POTENTIAL CATALYSTS FOR PHYSICAL ACTIVITY IN THE NEIGHBOURHOOD

(STUDY 2)

Background

Physical environment plays an essential role in shaping population health (Brownson, Hoehner, Day, Forsyth, & Sallis, 2009). Neighbourhood environment and access to recreational facilities and public open spaces are associated with physical activity (Altschuler, Somkin, & Adler, 2004; Humpel, Owen, & Leslie, 2002; Jones, Bentham, Foster, Hillsdon, & Panter, 2007; McCormack, Giles-Corti, & Bulsara, 2008). The active living research agenda (Brownson et al., 2008; Moudon, 2005) has stimulated a generation of studies focusing on the provision, access, use, and features of recreational facilities that not only encourage various structured and unstructured physical activities at the site, but also encourage neighbourhood walking (Cohen, McKenzie, Sehgal, Williamson, Golinelli, & Lurie, 2007; Giles-Corti et al., 2005; Godbey, Caldwell, Floyd, & Payne, 2005). For instance, neighbourhood environments that are perceived as providing good access to facilities for physical activity are conducive to individuals being active (Bauman, Smith, Stoker, Bellew, & Booth, 1999; Duncan, Spence, & Mummery, 2005; Owen, Leslie, Salmon, & Fotheringham, 2000; Pikora, Giles-Corti, Bull, Jamrozik, & Donovan, 2003) and reporting physical activity at recommended levels (Duncan, Duncan, Stryker, & Chaumeton, 2002; Giles-Corti & Donovan, 2002b).

Public health literature focusing on access to recreational facilities typically investigates the role of the availability of facilities (defined as the number of facilities available to individuals) and of accessibility to facilities (defined as the ease of reaching desired activities and indicates both the distribution of activities offered by facilities and the travel to these activities; Handy & Clifton, 2001) in relation to the behaviour of various populations. It has been suggested that the provision of facilities for physical activity may not be egalitarian for all population groups (Diez-Roux et al., 2007; Powell, Slater, Chaloupka, & Harper, 2006). Some factors, such as the socio-economic status (SES) of areas, the quality of facilities, and the safety of areas, may restrict accessibility of facilities that may otherwise be spatially available. In the first place, some studies report that less affluent groups have less access to facilities (Aytur, Rodriguez, Evenson, Catellier, & Rosamond, 2008; Duncan, Duncan, Strycker, & Chaumeton, 2002; Estabrooks, Lee, & Gyurcsik, 2003; Hillsdon, Panter, Foster, & Jones, 2007), while others report better access for such groups (Giles-Corti & Donovan, 2002a; Timperio, Ball, Salmon, Roberts, & Crawford, 2007). Second, it appears that the patterns of access are different when the quality of facilities is incorporated in the assessment (Cutts, Darby, Boone, & Brewis, 2009; Smoyer-Tomic, Hewko, & Hodgson, 2004), with quality often being inversely correlated with the SES of the areas (Coen & Ross, 2006; Crawford et al., 2008). In addition, the relationship between access and SES may vary by the type of activity (e.g., facilities for team sports are more often found in less affluent areas and facilities for individual sports are more frequently found in more affluent areas; Cerin & Leslie, 2008). Third, neighbourhood safety, including concerns about crime, traffic injuries, and neighbourhood disorder, also seems to influence access to facilities (Foster & Giles-Corti, 2008). Feeling unsafe is reported as a barrier for physical activity, particularly among lower SES groups (Harrison, Gemmell, & Heller, 2007; Kirtland et al., 2003; Wilcox, Castro, King, Housemann, & Brownson, 2000), with perceived safety typically influencing behaviour more than actual safety (Kawachi & Berkman, 2003).

Consequently, availability may not translate into use if opportunities for physical activity are not perceived as having adequate quality or as being economically, socially, or culturally relevant for various users (Macintyre, McKay, & Ellaway, 2006). As a result, good spatial availability or accessibility of facilities may in fact translate into a low degree of actual accessibility. Because of this, not only *objective or actual* factors (e.g., material traits such as availability and characteristics of facilities for physical activity), but also *subjective or perceived* factors (e.g., immaterial traits such as neighbourhood safety, comfort, aesthetics) that influence physical activity need to be considered. In addition, not only *intra-personal level* factors (such as psycho-social and personal characteristics), but also *extra-personal level* factors (such as accessibility of facilities and neighbourhood safety) that influence physical activity need to be considered (Sallis, Bauman, & Pratt, 1998). An objective and subjective assessment of these environmental factors is also appropriate, because it is not clear yet whether *objective* or *subjective* environments exert a stronger influence on physical activity. Because current evidence shows that *extra-personal* influences on physical activity are mediated by *individual-level* factors, such as age, gender, SES and cognitive factors (e.g., perceptions, motivations, attitudes, normative beliefs; Bauman & Bull, 2007; Sherwood & Jeffery, 2000; Seefeldt, Malina, & Clark, 2002), both *extra-personal* and *intra-personal* influences need to be considered together in order to gain a better understanding of physical activity (Shriver, 1997; Brownson, Baker, Housemann, Brennan, & Bacak, 2001; Trost, Owen, Bauman, Sallis, & Brown, 2002). In particular, self-efficacy (defined as the sense of personal agency about one's ability to perform a specific behaviour; Bandura, 1986) is one cognitive factor that is most consistently positively associated with physical activity (Bauman & Bull, 2007) and that therefore merits consideration.

Moreover, it is not clear yet why inconsistent findings are reported with respect to the association between physical activity and access to facilities. Even though most studies report positive associations between access to various types of settings (such as parks, open spaces, and community recreational facilities) and physical activity levels in adults (see review by Kaczynski and Henderson, 2007), some studies report no association for access to parks (Duncan & Mummery, 2005; Hoechner, Brennan-Ramirez, Elliot, Handy, & Brownson, 2005), recreation centres (Foster, Hillsdon, & Thorogood, 2004), or swimming pools (Addy, Wilson, Kirtland, Ainsworth, Sharpe, & Kimsey, 2004). Generally, open areas show stronger associations with physical activity than built facilities, although findings are still inconclusive (Kaczynski & Henderson, 2007). It is likely that measurement of spatial accessibility to facilities is an explanation for these inconclusive findings. Therefore, more studies are necessary that employ better measures of spatial accessibility, in particular objective measures of assessing accessibility, to better understand physical activity patterns in urban populations.

Thus, from a population health perspective, it is essential to investigate whether the accessibility of recreational facilities (assessed objectively and subjectively) is associated with levels of physical activity in urban populations, after controlling for individual-level factors such as age, gender, SES, and self-efficacy. Understanding the role of accessibility to recreational facilities represents an important domain for health-promoting agendas, because it will help decision-makers to develop optimal environmental interventions that result in increased physical activity in urban populations. A better understanding of the association between the physical environment and physical activity will assist decision-makers in evaluating the spatial distribution of recreational services and in devising health-promoting programs, with a focus on underserved areas in terms of sport field provision.

Research Question

The purpose of this study was to investigate whether individuals' *self-reported physical activity* is associated more strongly with the *objective* or the *subjective* environment. This study addressed *Goal 2* of this dissertation. Specifically, it investigated the association between the objective and perceived accessibility of facilities for physical activity and the levels of physical activity among adults in Edmonton, Alberta, Canada. The facilities for physical activity considered for this study were complexes of various sport fields that are present in Edmonton.

We hypothesized that accessibility of sport fields would be independently associated with individuals' physical activity above and beyond the variance explained by psycho-social and socio-demographic correlates.

Conceptualization of Accessibility

Accessibility has been a subject of interest for researchers investigating spatial distribution of basic services such as health services (Fone, Christie, & Lester, 2006; Tanser, Gijsbertsenb, & Herbst, 2006), food establishments (Larsen & Gilliland, 2007; Smoyer-Tomic et al., 2008), gambling establishments (Gilliland & Ross, 2005), and recreational facilities and community services (Apparicio & Seguin, 2006; Gilliland, Holmes, Irwin, & Tucker, 2006; Smoyer-Tomic, Hewko, & Hodgson, 2004). Accessibility is conceptualized as a property of places, namely *place accessibility* (Talen, 2003), or of people, namely *individual accessibility* (Kwan, Janelle, & Goodchild, 2003). This study focuses on accessibility conceptualized as *place accessibility for pedestrian travel* (Talen, 2003). Within this approach, spatial access is assessed using physical distance and cost of pedestrian travel to facilities. An assessment of individual accessibility is outside the scope of this study. Hereafter we will refer to *place accessibility* only. In this context, accessibility is defined as a sum of relevant opportunities available within a selected area and an impedance function that assesses the spatial separation between origin and destination (Hansen, 1959). In most studies using this definition, origins and destinations are operationalized as either home-based postal code centroids or spatial units, such as census tracts, each carrying a different set of consequences for the results of analysis (Handy & Niemeier, 1997; Talen, 2003).

Separation between origins and destinations is operationalized most often using Euclidean distance (Fone, Christie, & Lester, 2006; Truelove, 2000) and street network distance (Apparicio & Séguin, 2006; Nicholls, 2001; Witten, Exeter, & Field, 2003).

Typically, the calculation of accessibility is restricted to an area of interest only. This means that particularly in an urban context, where individuals may be located in the service areas of multiple facilities, availability and accessibility should be considered simultaneously using the fusion concept of *spatial accessibility* (see Guagliardo, 2004). To perform accessibility calculations restricted to an area, a certain threshold distance is necessary to define that specific area of interest. Although it is clear that distance to facilities seems to influence associations between availability of facilities and levels of use, with more distant facilities being used less (Giles-Corti & Donovan, 2003; King, Belle, Brach, Simkin-Silverman, Soska, & Kriska, 2005), it is not clear what represents a threshold distance beyond which presence of facilities is not influencing use anymore (Kaczynski, Johnson, & Saelens, 2009). Therefore, it is not clear what threshold distance is optimal to use in defining the area of interest to calculate accessibility of facilities for physical activity.

Most studies have addressed the local availability of facilities to adults and have chosen a search radius varying between 400 m to 1500 m, based on walking distance (Heinrich et al., 2007; Hoehner, Brennan Ramirez, Elliott, Handy, & Brownson, 2005; Kaczynski & Henderson, 2008; Lackey & Kaczynski, 2009; McCormack, Giles-Corti, & Bulsara, 2008). Others have addressed regional availability of facilities and have chosen a search radius varying between 1500 m to 8000 m, based on driving distance (Ball, Jeffery, Crawford, Roberts, Salmon, & Timperio, 2008; Cohen et al., 2007; Cutts, Darby, Boone, & Brewis, 2009; Diez-Roux et al., 2007; McCormack, Giles-Corti, & Bulsara, 2008). For example, Diez-Roux and her colleagues (2007) suggest 1 mile as an appropriate distance for studying the availability of recreational facilities. It appears that associations at the local level (400 m – 800 m) are stronger for public open spaces and playgrounds, while associations at the regional level (beyond 800 m) are stronger for formal facilities for physical activity (such as fitness, sport, and recreational facilities) or for natural environment (such as beaches, rivers, and open spaces; Diez-Roux et al., 2007; Giles-Corti & Donovan, 2003).

The most frequently used operationalizations of accessibility include cumulative opportunity measures and gravity-based measures (Handy & Niemeier, 1997). Cumulative measures assess availability of destinations within a given travel cost from an origin (e.g., the number of sport facilities within a catchment of 500 m around an individual’s home). Gravity-based measures (or gravity potential measures) assess the availability of a set of destinations weighted by impedance (a function of travel cost from an origin to all destinations considered; also called a distance decay function), as well as by incorporating certain qualities of the destinations, to create friction coefficients (Hansen, 1959;

O'Kelly & Horner, 2003; Tiefelsdorf, 2003). Devising friction coefficients involves an assessment of destination characteristics pertaining to quality, type of service, and other factors that may influence facility attractiveness. For example, one study employed gravity potential measures that consider distance to public open space, attractiveness, and size of public open space (Giles-Corti et al., 2005). However, deciding upon which factors to include depends on the type of activities offered by the facilities and most likely will not result in relevant coefficients for everybody in every instance (Handy & Clifton, 2001). Also, the gravity potential model is complex and requires access to aggregate behavioural data to properly calibrate the friction coefficients used in the distance decay function (Luo & Qi, 2009). Moreover, the weights that may be assigned to destinations need to be tested against residents' surveys to ensure appropriate weighting is used (Handy & Niemeier, 1997).

Consequently, a basic-needs approach involving an assessment of distance and density may be appropriate for city-wide approaches, while a more sophisticated approach involving an assessment of attractiveness may be more appropriate when investigating subgroups of population on a local scale (Handy & Clifton, 2001). A recent new method that is easy to apply was proposed: *the two-step floating catchment area method* (2SFCA) of measuring potential spatial accessibility in public health (Luo & Wang, 2003; Radke & Mu, 2000). The 2SFCA method is a special case of gravity potential, in which the friction coefficient is 1 within the catchment and 0 outside the catchment. The 2SFCA method is more intuitive than the gravity potential method (Luo & Wang, 2003).

This measure ensures an assessment of a basic needs approach, but differentiates between areas where similar numbers of facilities serve zones with different population densities, thus providing a more realistic image of accessibility to facilities.

Research Focus

A place-centered approach employing Social Ecological Models (Sallis & Owen, 1997) was used to address this study's research question. Specifically, accessibility to sport field complexes was assessed objectively and subjectively, using a model of environmental opportunities for physical activity (EOPA; Figure 1-1, Chapter 1) which investigates place as an *objective environment (O), subjective environment (S),* and *resultant environment (R)*. *Objective environment (O)* refers to neighbourhood opportunities for physical activity (assessed as accessibility of sport field complexes) and to neighbourhood socio-demographics. *Subjective environment (S)* refers to individual perceptions of environment conduciveness for physical activity (assessed as perceived accessibility to sport field complexes). *Resultant environment (R)* refers to observed and self-reported levels of physical activity. The relationships between the objective and the resultant environment (denoted as *OR*) and between the subjective and the resultant environment (denoted as *SR*) were measured at *macro* and *meso* scales using neighbourhoods and buffers created around individuals' households as units of analysis.

Methods

Study Area

This study focused on 195 residential neighbourhoods located in the city of Edmonton, the capital of the Province of Alberta, Canada. Edmonton consists of 340 neighbourhoods, 201 of which are residential in character. A subset of 195 residential neighbourhoods was previously selected for this dissertation because data on SES and walkability was available for only 195 neighbourhoods, of which 84 are suburban (M = 1.06 km^2, SD = 0.34) and 111 are mature neighbourhoods (M = 1.10 km^2, SD = 0.40). Neighbourhood profiles based on Census 2001 data (Statistics Canada, 2003) were provided by the City of Edmonton. The Edmonton Police Service provided data on crime rates, and DMTI$^{\text{TM}}$ provided data on streetfiles. GeoEdmonton provided data on the locations of 362 sport field complexes comprising a total of 1,798 fields. Sports field complexes are defined as facilities for physical activity that include outdoor sports fields, such as diamonds, rectangular fields, and tracks. Some additional indoor facilities, such as school gyms and swimming pools, may be present, but most of the activities take place outdoors.

Participants

The original sampling frame for this study consisted of 4,175 adults living in the Capital Health region of Edmonton, Alberta, who took part in the Population Health Survey 2002 (PHS; Kaida et al., 2004). Data collection took place between October 28th and December 15th, 2002. The survey provided data on leisure-time physical activity levels, perceived environment, and socio-demographics. Individuals living in 195 residential neighbourhoods constituted the sampling population, resulting in a sample of 2,879 respondents. The location of the respondents' households was determined based on the postal code centroids for the addresses of the respondents, using the Postal Code Conversion Files (PCCF) produced by Statistics Canada (2004). It was assumed that each respondent's household was located in the postal code centroid corresponding to each household.

Measures

To capture the association between objective and subjective environments and physical activity, *individual* and *neighbourhood-level measures* were employed. Individual-level measures include individual socio-demographics, individuals' self-reported physical activity, individuals' self-efficacy, individuals' objective accessibility to sport field complexes, and individuals' perceptions of their neighbourhood environment (such as perceived access to facilities for physical activity, perceived risk from crime, and perceived risk from traffic). Neighbourhood-level measures include neighbourhood actual risk (from crime and from traffic), neighbourhood SES, and neighbourhood objective accessibility to sport field complexes (assessed as density of complexes).

Individual Socio-demographics

Participants in the 2002 PHS survey were asked to report their age (in years), gender, whether or not they had a health issue that would prevent them from taking part in physical activity, and whether any children under 18 lived in the household. Individual-level education and income were also recorded.

Self-reported Physical Activity

PHS 2002 employed the short form of the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003) to measure physical activity in various domains (e.g., leisure-time, domestic, and gardening activities). Good reliability ($r = 0.83$) and validity data correlated with accelerometer measurements ($r = 0.52$) are available for this scale (Craig et al., 2003). Sallis and Saelens (2000) found that typical IPAQ Spearman's *rho* correlations were 0.8 for reliability and 0.3 for criterion validity. In a more recent study (MäDer, Martin, Schutz, & Marti, 2006), moderate activities, walking, and vigorous activities measured by IPAQ short form indicated limited agreement ($r = 0.5$, $r = 0.48$, $r = 0.43$, respectively), and the reliability of total activities was $r = 0.54$. The criterion validity for total physical activity reported in IPAQ correlated with accelerometry (reported as total counts per minute) was $r = 0.39$. Questions about walking, moderate-intensity, and vigorous-intensity activities performed for at least 10 minutes during a week prior to the survey were the basis for calculating separate weekly duration scores for each type of activity. By weighting each type of activity according to its corresponding MET (multiples of the resting metabolic rate), a score in MET*minutes was calculated. Based on the recommendations of Haskell and colleagues (2007), respondents were assigned to one of two categories: *insufficient physical activity* or *sufficient physical activity.* Specifically, a cut-off value of 750 MET*minutes per week was used to determine level of activity. This reflects the recommendations that health benefits can be achieved by accumulating a minimum of between 450 and 750 MET*minutes per week of combined moderate and vigorous physical activity (Haskell et al., 2007).

Self-efficacy

Self-efficacy was assessed using a 100-point scale (divided into increments of 10 units), in which 0 means *Completely certain I cannot do it* (participate in regular physical activity) and 100 means *Completely certain I can do it* (participate in regular physical activity). Bandura (2006) recommends choosing a 100-point scale because it is a stronger predictor of performance than a 5-interval scale, as demonstrated by Pajares, Hartley, & Valiante (2001). This scale reflects a dual-judgment approach (Maibach & Murphy, 1995), which combines *level* (or magnitude) and *strength* into a single item to assess self-efficacy. *Level* involves a dichotomous response (yes/no) and indicates whether an individual can perform a certain activity. *Strength* involves a rating on a 0 to 10 scale of the confidence an individual has that they can perform a certain activity. Creating a composite measure of *level* and *strength* is based on Lee & Bobko's (1994) findings, in which this composite measure correlated better with the outcomes than the individual items of *level* and *strength*. The validity (McAuley, 1992, 1993; Resnick & Jenkins, 2000) and reliability (McAuley, Courneya, & Lettunich, 1991; McAuley, Lox, & Duncan, 1993; Morris, McAuley, & Motl, 2008) of this scale for exercise have been extensively documented.

Objective Accessibility of Sport Field Complexes

Two methods were employed to assess accessibility to complexes of sport fields: Method 1, based on street network distance calculations, and Method 2, based on the two-step floating catchment area method (SFCA). We chose both methods of assessing objectively accessibility to facilities because Method 1 is typically used in the public health literature, while Method 2 is a novel method that has recently been used in the literature on geography. A threshold of 1500 m was chosen for the accessibility calculations to reflect pedestrian distance based on the rationale that 1500 m represents the equivalent of a 15-minute pedestrian trip (see McCormack, Giles-Corti, & Bulsara, 2008; Giles-Corti, Timperio, Bull, & Pikora, 2005). Restricting our analysis to 1500 m should be appropriate, because distances between 800 m and 2000 m have been used to capture the relationship between access to facilities and physical activity for individuals who tend to rely more on local facilities, as well as for individuals who are willing to travel to multiple places located outside of their local environments (Diez-Roux et al., 2007; Giles-Corti & Donovan, 2003; Matthews, 2008).

Method 1 (street network distance) involved calculations based on the distance from the postal codes of the respondents to all sport complexes located within 1500 m of pedestrian travel along street networks.

Method 2 (2SFCA) involved calculations based on two floating catchments of 1500 m street network distance. A detailed description of the 2SCFA measure is provided by Wang (2006) and by Luo and Qi (2009). In the first step, the *complex catchment* (i.e., the catchment area of a sport field complex) was created for all complexes as a street network distance buffer of 1500 m from the centroid of each sport complex. The *complex-to-population ratio* at the location *j* of a sport complex was calculated using the formula $R_j = 1 / \sum P_k$, where P_k represents the population at census block *k* located within the catchment of the complex. A census block is an area equivalent to a city block bounded by intersecting streets (for a detailed definition see http://geodepot.statcan.ca/Diss/Reference/COGG). This represents an assessment of the ratio of *supply* (sport field complexes) to *demand* (census block population), restricting the number of complexes and census blocks that were taken into account (Luo & Qi, 2009). In the second step, the *population catchment* (the catchment area of a population location; e.g., the census block) was created. The 2SFCA accessibility was calculated as the *population-to-complex* value that represents the sum of *the complex-to-population* ratios (calculated in the first step) for all complexes located within the population catchment. The value for the 2SFCA accessibility of the census block at the location *i* was calculated using the formula $A^{CB}_i = \sum R_j$. Finally, the 2SFCA accessibility of the postal code of the respondents at location *p* was calculating by taking the average of the 2SFCA accessibility values for all census blocks present within 1500 m of street network distance from individuals' postal code centroids, using the formula $A^{PC}_p = (\sum Rj) / s$, where *s* represents the number of census blocks present within 1500 m of street network distance from the location *p* of the postal code centroid.

Perceptions of Neighbourhood Environment

The PHS survey included the International Physical Activity Prevalence Study's Environmental Survey Module (IPS; 2002), which was used in conjunction with IPAQ. Of the 20 countries participating in this study, 11 employed the environmental module (Sallis et al., 2009). Respondents' neighbourhoods were defined as areas around their homes to which they could walk in 10-15 minutes. The IPS survey included 17 items regarding the type of housing, access to neighbourhood facilities, access to public transit stops, presence of pedestrian infrastructure, access to free or low-cost recreational facilities, safety from crime and traffic, presence of active people in the neighbourhood, neighbourhood aesthetics, intersection density, and car ownership. Most questions from the IPS were adapted from previously-used instruments that demonstrated good validity and reliability (Addy et al., 2004; Brownson et al., 2004; Cerin, Saelens, Sallis, & Frank, 2006; Saelens, Sallis, Black, & Chen, 2003). One study addressing the test-retest reliability of this scale was conducted in a sample of Swedish adults; it reported interclass correlations larger than 0.7 for all variables except crime (Alexander, Bergman, Hagströmer, & Sjöström, 2006). A study of African adults reported moderate to excellent test-retest reliability of this scale (Oyeyemi, Adegoke, Oyeyemi, & Fatudimu, 2008). Another study of Japanese adults (Inoue et al., 2009) showed good test-retest reliability within a 7-day interval for perceived access (*kappa* coefficient of 0.75), perceived risk from crime (*kappa* coefficient of 0.71), and perceived risk from traffic (*kappa* coefficient of 0.69; $p < 0.001$).

Only variables measuring access to free or low-cost recreational facilities (*perceived access*) and safety from crime (*perceived risk from crime*) and from traffic (*perceived risk from traffic*) were employed. The questions regarding these items were rated using a four-point Likert response scale ranging from *strongly disagree* to *strongly agree*. In addition, a *don't know/ not sure* option was included for all variables. *Perceived access* (one item) responses ranged from *strongly disagree* to *strongly agree* with the statement *My neighbourhood has several free or low cost recreational facilities. Perceived risk* variables ranged from *strongly disagree* to *strongly agree* with the statements *The crime rate in my neighbourhood makes it unsafe to go for walk at night* (*perceived risk from crime;* one item) and *there is so much traffic on the streets making it difficult or unpleasant to walk in my neighbourhood* (*perceived risk from traffic;* one item).

Neighbourhood Actual Crime Levels (Risk)

Two variables were included to represent neighbourhood actual levels of risk from crime and traffic. Risk from crime was assessed based on the number of incidents in the following categories: violent crime (e.g., assaults and robbery) and property crime (e.g., break and entry, motor vehicle, and other theft), expressed as the percentage of violent and property crime incidents per neighbourhood population. Risk from traffic was based on the number of criminal code traffic violations (e.g., dangerous driving, failure to remain at the accident scene), expressed as the percentage of traffic violations incidents per neighbourhood population. Risk variables were dichotomized based on a median split as lower/higher levels of risk from crime and from traffic.

Neighbourhood Socio-economic Status (SES)

Neighbourhood-level SES was based on data extracted from the 2001 Canadian Census and compiled by the Edmonton Social Planning Council. Neighbourhood SES was calculated as a sum of z-scores of net educational level and median income of census families ($) minus the z score of the proportion of unemployed using Demissie, Hanley, Menzies, Joseph, and Ernst (2000) procedure.

Neighbourhood Density of Sport Complexes

This measure was calculated as the number of sport complexes per neighbourhood area.

Analysis

We used ArcGIS 9.3.1 (ESRI, 2009) and its Network Analyst extension to assess the 2SFCA accessibility to sport field complexes for buffer and neighbourhood levels. Street network distance buffers were created using the Street Logistics file by DMTI^{TM}. SPSS 17 (PASWSTAT, 2009) was employed for the statistical analyses. The level of statistical significance was set at $p < 0.05$.

Two hierarchical logistic regressions were performed, in which self-reported levels of physical activity (*sufficiently active* vs. *insufficiently active*) were regressed on individual socio-demographic variables, neighbourhood actual and perceived access to sport fields complexes, neighbourhood actual and perceived crime rates, neighbourhood SES, and self-reported self-efficacy. The logistic regressions were created separately for the two objective measures of access to sport fields.

Two models were created to examine the role of the selected predictors in influencing self-reported physical activity. In Model 1, we included only individual socio-demographic characteristics. In Model 2, we added buffer-level perceived and objective environment assessments. Finally, in Model 3, we added neighbourhood-level objective environment assessments. Separate analyses were conducted based on Method 1 (using 1500 m street network distance calculations) and on Method 2 (using the 2SFCA accessibility based on catchment calculations involving 1500 m street network distance).

Results

Descriptive statistics are provided in Table 3-1. About 23% of respondents were classified as reporting insufficient physical activity (sedentary and light activity) and 77% were classified as reporting sufficient physical activity (moderate and heavy activity). Table 3-2 presents the relationships between self-reported levels of physical activity and individual-, as well as environmental-level, variables. The Cox and Snell R^2 and Nagelkerke R^2 respectively indicate that 10% to 16% of variability in levels of physical activity was explained by this set of variables for both analyses in Model 1: Analysis 1 using street network distance and Analysis 2 using 2SFCA assessments of accessibility to sport fields for 1500 m. In Model 2, only street network distance accessibility to sport fields and 2SFCA accessibility showed significant associations with physical activity (insufficient/sufficient). Adding perceived and objective environment variables in Model 2 did not add to the proportion of variability explained in either of the analyses; the Cox and Snell R^2 and Nagelkerke R^2 indicate that about 11% to 17%

of variability in levels of physical activity was explained by this set of variables for both analyses in Model 2. Some of the individual-level variables were significantly associated with physical activity in the final model. Women were less likely to be sufficiently active than men. Being a woman decreased the likelihood of being sufficiently physically active by a factor of 0.6 (in both analyses). Model 3 did not explain any additional variability (11% to 18%).

Compared to the youngest group, the other age groups were less likely to be sufficiently physically active by a factor of about 0.5 for each group (in both analyses). Compared with the group with the least education, individuals who did not complete post-secondary education were less likely to be sufficiently physically active by a factor of 0.5 (in both analyses) and individuals who did complete non-university education were less likely to be sufficiently physically active by a factor of 0.6 (in both analyses). Post-bachelor level education also decreased the likelihood of being sufficiently physically active by a factor of 0.4 (in both analyses). Income was not associated with being sufficiently active. In addition, having a health condition that prevents individuals from engaging in physical activity was not associated with being sufficiently active. Respondents with higher levels of self-efficacy were 1.02 times more likely to be sufficiently active. Among environmental variables, only access was significantly associated with physical activity. Individuals having higher access to sport fields were 1.07 times (analysis 1) and 1.60 times (analysis 2) more likely to report sufficient physical activity.

Discussion

This study focused on the association between the presence of sport fields and physical activity for residents living in Edmonton, Alberta, Canada. Similar to previous research, we found that women were less likely and younger respondents more likely to be active as recommended in comparison to their counterparts (Cameron, Craig, & Paolin, 2005). Also, individuals who did not report having a health condition preventing them from undertaking physical activity were more likely to be sufficiently active. This suggests that health promoting interventions need to be tailored differently to men and women, as well as to different age groups, or groups with specific requirements.

Furthermore, compared to the least educated respondents, those with a higher educational attainment were less likely to be active as recommended. This conflicts with previous findings (Cameron, Craig, & Paolin, 2005), and may be due to the fact that total physical activity does not differentiate among various domains of physical activity. For instance, it is possible that respondents with a lower education have more physically demanding jobs, and that they thus report more total physical activity. Also, individuals with higher levels of self-efficacy are more likely to be sufficiently active than their counterparts, as expected; this is consistent with other findings (Ball, Timperio, Salmon, Giles-Corti, Roberts, & Crawford; Sherwood & Jeffery, 2000).

We found that access to facilities increased the likelihood of engaging in the recommended levels of physical activity. As one aspect of the general neighbourhood environment, recreational facilities for physical activity have been established to support engagement in physical activity by providing settings where individuals can be active and by providing opportunities for active lifestyles (Pearce, Witten, & Bartie, 2006; Witten, Exeter, & Field, 2003). For instance, recreational facilities are places to engage in individual or team-based sports. They may also contribute to changing norms and influencing individuals in adopting health-promoting behaviours, due to the visibility of physical activities in these facilities (Giles-Corti & Donovan, 2003).

Since studies on the accessibility of recreational facilities report mixed findings, perhaps because they rely on weak conceptualizations of place (Macintyre, Ellaway, & Cummins, 2002; Matthews, 2008; Pearce, Witten, & Bartie, 2006), more exploratory studies are necessary to determine the size of the area in which environmental characteristics seem to exert the most physical activity. Our study supports the definition of such an area using a street network distance radius of 1500 m (see Addy et al., 2004; Diez-Roux et al., 2007). Although the associations with physical activity are small, both accessibility measures showed significance. This confirms that, while proximity matters for some activities that are more locally-bound, for other activities people are willing to travel further to traverse spatial units, such as neighbourhoods and census tracts, displaying *"spatially polygamist"* behaviour (Matthews, 2008). Consistent with other studies in adults and children, including our previous work in Edmonton (Smoyer-Tomic et al., 2008; Spence, Cutumisu, Edwards, & Evans, 2008), our study confirms that the provision of recreational facilities within radii larger than 800 m is consistently associated with physical activity (Addy et al., 2004; Sugiyama, Leslie, Giles-Corti, & Owen, 2009). However, more exploratory studies are necessary to determine the extent to which distance influences the use of various types of facilities in various cultural contexts (Diez-Roux, 2007). It seems that 20 minutes of walking is the optimal travel distance to use in investigating the role of access to facilities on physical activity, because individuals may choose distant destinations if they are to meet current recommendations for a minimum of 30 minutes of daily physical activity (Sugiyama, Leslie, Giles-Corti, & Owen, 2009). This can be explained by the fact that formal places for physical activity are generally less frequently used than informal places such as open spaces, plazas, natural areas, and other community places in the neighbourhood where individuals can be physically active. For instance, sport facilities and tennis courts are amongst the least frequented formal physical activity facilities (Giles-Corti & Donovan, 2002a).

Like other researchers, we also found that factors measuring safety objectively (e.g., actual crime and traffic violations rates) and subjectively (e.g., perceived risk from crime and perceived risk from traffic) were not significantly associated with physical activity (Foster & Giles-Corti, 2008). However, our measures of actual crime and traffic violation rates were aggregates calculated at the level of neighbourhood as an administrative unit, while our measures of perceived risk were assessed for the neighbourhood conceptualized as a buffer constructed around individuals' postal codes. It is also possible that our respondents may underestimate distances and thus recall characteristics of areas that are smaller or larger than the buffers under discussion.

Strengths and Limitations

This study has several strengths that are worth mentioning. It involved a representative sample of the population residing in Edmonton, Alberta, providing information that was assessed by employing validated measures of physical activity and perceived environment. It also involved an analysis that considered both buffer- and neighbourhood-level variables and their association with physical activity. In addition, it involved an objective measurement of urban form, based on street network distance calculations of accessibility to facilities for physical activity, using Geographic Information Systems (GIS). As well, this study used a composite measure of SES, because neighbourhood income or education alone may not be adequate proxies of SES in the context of Edmonton.

Some limitations may affect the results of this study. First, our outcome measure is a total physical activity measure that does not specifically address various domains of physical activity (such as recreation, work-related, household-related; see Giles-Corti et al., 2005; Sugiyama, Leslie, Giles-Corti, & Owen, 2009). This measure, however, is suitable, given that our aim was to evaluate access to facilities based on distance and population demand as the most basic step in ensuring spatial equity. Therefore, access was considered a prerequisite for the use of opportunities / resources. Also, we did not incorporate a measure of attractiveness in our assessments of accessibility, because of the limited information available about sport fields. Thus, we assumed that all facilities are equally attractive (Giles-Corti & Donovan, 2002a). Since devising quality measures was not the scope of this study, future studies are required to personalize accessibility measures for different user groups, in order to investigate whether access to the facilities is relevant to various subpopulations. In particular, qualitative studies are necessary to investigate the preferences of various subgroups for certain activities and facilities, and their motivations in using those facilities, to assist in creating a basis for quality measures for attractiveness.

In addition, our study did not consider information on the use of facilities or on sports participation. Although we are aware that the presence of facilities does not necessarily imply their use (Riva, Gauvin, & Richard, 2007), an assessment of proximity is a measure of potential use: individuals who are active are more likely to use facilities available, while individuals with poor access are less likely to do so (van Lenthe, Brug, & Mackenbach, 2005). Also, buffer selection, ignoring facilities outside the catchment, and disagreement between measured and self-reported distance (Diez-Roux et al., 2007; Giles-Corti & Donovan, 2002b; Macintyre, Macdonald, & Ellaway, 2008; Riva, Gauvin, & Richard, 2007) are likely to have influenced these results. As well, because weather and seasonality seem to influence physical activity in outdoor settings (Carson, Spence, Cutumisu, Boule, & Edwards, 2010; Chan & Ryan, 2009; Tucker & Gilliland, 2007), it is likely that the date of the survey may have influenced the answers of the respondents.

Implications: Sport Fields as Catalysts for Physical Activity in the Neighbourhood

We found that environmental-level factors, such as access to facilities, together with individual-level factors such as age, gender, and educational attainment, influence the likelihood that individuals will undertake the recommended levels of physical activity. Although the presence of recreational facilities is a prerequisite for achieving recommended levels of physical activity, it needs to be complemented by a supportive system of streetscapes because they may influence the use of sport fields by offering opportunities to walk, run, or jog to relevant destinations (Giles-Corti & Donovan, 2002b). It appears that a synergetic effect occurs between the presence of good quality recreational facilities and a safe generic neighbourhood environment that encourages physical activity in the neighbourhood: individuals walk more to facilities if neighbourhood environment is conducive to walking. The presence of recreational facilities and of outdoor recreational settings encourages greater use of streets near home (Sugiyama, Leslie, Giles-Corti, & Owen, 2009) and may provide incentives for active lifestyles. Just as commercial facilities enhance pedestrian movement (Hillier & Iida, 2005), sport fields may exert a multiplicative effect as magnets for physical activity in the neighbourhood. Future research should consider sport fields in conjunction with their surrounding environments, because the negative or positive qualities of areas surrounding facilities may influence their use for physical activity (Kaczynski, Johnson, & Saelens, 2009).

Consequently, health-promoting strategies should concentrate on increasing the availability and accessibility of facilities for outdoor active recreation, as well as on increasing the quality of neighbourhood environments. In addition, a focus on providing relevant programs for various population groups is necessary to increase use of facilities, and it may contribute to sport fields becoming potential catalysts for physical activity. In this respect, sport fields may become *fields of motion* by generating movement both on the site and in the neighbourhood.

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Tables

Table 3-1. Sample characteristics

Sample characteristics		Total	Valid Percent
Gender			
	Female	1,464	50.9
	Male	1,415	49.1
		n = 2,879	
Age (years)			
	18-24	610	21.2
	25-34	605	21.0
	35-49	556	19.3
	50-64	553	19.2
	65+	555	19.3
		n = 2,879	
Education			
	Less than high school	405	14.1
	Completed high school	599	20.9
	Incomplete post-secondary	523	18.2
	Completed non university	597	20.8

	Completed university	533	18.6
	Post-Bachelor university	213	7.4
		n = 2,870	
Income			
	<$20,000	440	19.1
	$20-39,999	626	27.2
	$40-59,999	484	21.1
	$60-79,999	312	13.6
	$80-99,999	163	7.1
	$100,000+	273	11.9
		n = 2,298	
Health condition			
	Yes	1,092	38.0
	No	1,778	62.0
		n = 2,870	
Children under 18 at home			
	Yes	865	30.0
	No	2,011	69.9
		n = 2,876	

Neighbourhood has access to free/low cost facilities			
	Disagree	489	17.4
	Neither	363	12.9
	Agree	1,961	69.7
		n = 2,813	
Crime rate makes neighbourhood unsafe for walking at night			
	Disagree	1,499	54.4
	Neither	439	15.9
	Agree	819	29.7
		n = 2,757	
Traffic makes neighbourhood difficult/unpleasant for walking			
	Disagree	1,967	68.8
	Neither	364	12.7
	Agree	527	18.5
		n = 2,858	

Note: Some variables have missing cases.

Table 3-2. Contribution of predictors to explaining self-reported levels of physical activity

Predictors		Analysis 1500 m (1)					
		Model 1		Model 2		Model 3	
		OR	95%CI	OR	95%CI	OR	95%CI
Gender	Women	.62*	(.49, .78)	.62*	(.49, .78)	.62*	(.49, .79)
Age	25-34	.51*	(.34, .76)	.50*	(.34, .75)	.49*	(.32, .73)
	35-49	.57*	(.38, .87)	.55*	(.36, .84)	.55*	(.36, .84)
	50-64	.53*	(.35, .81)	.52*	(.34, .80)	.53*	(.34, .82)
	65+	.48*	(.30, .75)	.48*	(.30, .76)	.48*	(.31, .77)
Education	Completed high school	.84	(.55, 1.27)	.88	(.57, 1.34)	.87	(.57, 1.33)
	Incomplete post-secondary	.54*	(.35, .84)	.55*	(.35, .87)	.54*	(.34, .85)
	Completed non-university	.62*	(.41, .95)	.65*	(.43, .99)	.64*	(.42, .98)
	Completed university	.70	(.45, 1.09)	.74	(.47, 1.15)	.72	(.46, 1.12)
	Post-Bachelor university	.39*	(.23, .64)	.40*	(.24, .66)	.37*	(.22, .63)
Income	$20-39,999	.83	(.59, 1.17)	.83	(.59, 1.18)	.87	(.61, 1.23)

	$40-59,999	.97	(.67, 1.42)	1.03	(.70, 1.52)	1.10	(.75, 1.63)
	$60-79,999	.82	(.54, 1.26)	.86	(.56, 1.33)	.90	(.58, 1.38)
	$80-99,999	.87	(.52, 1.45)	.90	(.54, 1.52)	.97	(.58, 1.65)
	$100,000+	.92	(.58, 1.46)	.98	(.62, 1.58)	1.07	(.66, 1.72)
Health condition	No	.98	(.76, 1.27)	1.01	(.78, 1.31)	1.006	(.78, 1.30)
Self-efficacy		1.02*	(1.02, 1.03)	1.02*	(1.02, 1.03)	1.02*	(1.02, 1.03)
Children under 18	No	.85	(.65, 1.12)	.83	(.65, 1.12)	.81	(.62, 1.07)
Perceived access	Disagree			.89	(.47, 1.70)	.92	(.48, 1.75)
	Neither agree or disagree			.80	(.43, 1.50)	.80	(.42, 1.50)
	Agree			.95	(.52, 1.71)	.96	(.53, 1.74)
	Strongly agree			1.13	(.62, 2.03)	1.13	(.62, 2.04)
Perceived crime	Disagree			.78	(.55, 1.10)	.77	(.54, 1.10)
	Neither agree or disagree			1.12	(.74, 1.70)	1.12	(.74, 1.70)

	Agree	.83	(.56, 1.24)	.82	(.55, 1.22)
	Strongly agree	.93	(.58, 1.48)	.92	(.57, 1.47)
Perceived traffic	Disagree	1.16	(.84, 1.59)	1.16	(.84, 1.60)
	Neither agree or disagree	1.06	(.70, 1.60)	1.03	(.68, 1.56)
	Agree	1.47	(.95, 2.25)	1.45	(.94, 2.24)
	Strongly agree	1.11	(.63, 1.95)	1.05	(.60, 1.85)
Accessibility		1.05*	(1.003, 1.10)	1.07*	(1.02, 1.13)
NDC				.88	(.76, 1.01)
NSES				1.06	(.82, 1.36)
NRC				1.11	(.84, 1.45)
NRT				1.13	(.87, 1.46)

*Note: *p<0.05;* NDC = Neighbourhood density of sport complexes; NSES = Neighbourhood SES; NRC = Neighbourhood risk from crime; NRT = Neighbourhood risk from traffic

Analysis 1500 m (2)

Predictors		Model 1		Model 2		Model 3	
		OR	95%CI	OR	95%CI	OR	95%CI
Gender	Women	.62*	(.49, .78)	.61*	(.48, .77)	.62*	(.49, .78)
Age	25-34	.51*	(.34, .76)	.51*	(.34, .76)	.49*	(.33, .74)
	35-49	.57*	(.38, .87)	.55*	(.36, .84)	.56*	(.36, .85)
	50-64	.53*	(.35, .81)	.52*	(.34, .80)	.53*	(.34, .81)
	65+	.48*	(.30, .75)	.47*	(.30, .75)	.48*	(.30, .76)
Education	Completed high school	.84	(.55, 1.27)	.86	(.56, 1.31)	.86	(.56, 1.31)
	Incomplete post-secondary	.54*	(.35, .84)	.54*	(.35, .85)	.53*	(.34, .84)
	Completed non-university	.62*	(.41, .95)	.64*	(.42, .97)	.63*	(.41, .96)
	Completed university	.70	(.45, 1.09)	.73	(.47, 1.13)	.71	(.46, 1.11)
	Post-Bachelor university	.39*	(.23, .64)	.39*	(.23, .66)	.37*	(.22, .62)
Income	$20-39,999	.83	(.59, 1.17)	.82	(.58, 1.17)	.85	(.60, 1.21)
	$40-59,999	.97	(.67, 1.42)	1.01	(.69, 1.48)	1.07	(.73, 1.58)

	$60-79,999	.82	(.54, 1.26)	.84	(.55, 1.30)	.88	(.57, 1.35)
	$80-99,999	.87	(.52, 1.45)	.87	(.52, 1.47)	.94	(.56, 1.59)
	$100,000+	.92	(.58, 1.46)	.94	(.59, 1.51)	1.03	(.64, 1.65)
Health condition	No	.98	(.76, 1.27)	1.02	(.79, 1.32)	1.01	(.78, 1.31)
Self-efficacy		1.02*	(1.02, 1.03)	1.02*	(1.02, 1.03)	1.02*	(1.02, 1.03)
Children under 18	No	.85	(.65, 1.12)	.85	(.65, 1.12)	.82	(.62, 1.08)
Perceived access	Disagree			.89	(.47, 1.69)	.91	(.48, 1.73)
	Neither agree or disagree			.79	(.42, 1.49)	.79	(.42, 1.49)
	Agree			.93	(.52, 1.68)	.94	(.52, 1.71)
	Strongly agree			1.11	(.61, 2.00)	1.10	(.61, 2.00)
Perceived crime	Disagree			.78	(.55, 1.11)	.77	(.54, 1.10)
	Neither agree or disagree			1.13	(.75, 1.71)	1.12	(.74, 1.70)
	Agree			.84	(.57, 1.25)	.82	(.55, 1.22)
	Strongly agree			.95	(.60, 1.52)	.93	(.58, 1.49)

Perceived traffic	Disagree	1.16	(.84, 1.60)	1.16	(.84, 1.60)
	Neither agree or disagree	1.07	(.71, 1.62)	1.04	(.69, 1.57)
	Agree	1.48	(.96, 2.27)	1.46	(.95, 2.25)
	Strongly agree	1.13	(.64, 1.98)	1.07	(.61, 1.89)
Accessibility		1.40	(.96, 2.02)	1.59*	(1.05, 2.42)
NDC				.90	(.78, 1.03)
NSES				1.03	(.80, 1.33)
NRC				1.15	(.88, 1.50)
NRT				1.14	(.88, 1.48)

*Note: *p<0.05;* NDC = Neighbourhood density of sport complexes; NSES = Neighbourhood SES;

NRC = Neighbourhood risk from crime; NRT = Neighbourhood risk from traffic

CHAPTER 4. FORMS OF CONTRAST: URBAN FORM ASSOCIATION WITH WALKING IN EDMONTON (STUDY 3)

Background

The global prevalence of obesity is a complex public health problem that accounts for approximately 2-7% of total health care costs among developed countries (World Health Organization [WHO], 2000). In Canada, the mean Body Mass Index in all age groups and among both sexes is above the WHO overweight cut-point of 25 kg/m^2 (Shields, Tremblay, Laviolette, Craig, Janssen, & Connor Gorber, 2010). This increase in obesity rates has been attributed in part to declining physical activity (Lakdawalla & Philipson, 2002). Among Canadian adults, about 52% are living totally sedentary lifestyles (Canadian Fitness and Leisure Research Institute [CFLRI], 2009a). Canadian adults report an average of 8,881 steps/day (CFLRI, 2009b), which represents less than the 10,000 steps/day recommendation of Canada's Physical Activity Guide; this corresponds to a brisk daily walk of 30 to 60 minutes (Alberta Centre for Active Living, 2010). At the same time, 74% of Canadians are heavily reliant on cars and only 19% of Canadians walk or cycle predominantly (Turcotte, 2008a).

From an urban planning perspective, current levels of physical inactivity are a by-product of the postwar models that have been adopted in conceptualizing contemporary cities and have triggered urban sprawl, and, as a result, have induced important changes in the notions of place, proximity, and community (Moudon & Untermann, 1991). It was recently suggested that the quality of the generic neighbourhood environment influences walking and cycling (Garcia

Bengoechea, Spence, & McGannon, 2005; Sugiyama, Leslie, Giles-Corti, & Owen, 2009). Generic neighbourhood environment pertains to physical environment issues (such as presence of infrastructure for walking and cycling, proximity of shops and places to go to, and access to free facilities) and social environment issues (such as aesthetics, presence of active people exercising in the neighbourhood, neighbourhood safety, and neighbourhood socio-economic status - SES), which seem to be associated with walking in everyday environments (Harrison, Gemmell, & Heller, 2007; Humpel, Owen, & Leslie, 2002; McGinn, Evenson, Herring, Huston, & Rodriguez, 2008; Parks, Housemann, & Brownson, 2003). Researchers from the fields of health promotion, urban design, and transportation have focused on assessing the health-promotion potential of the neighbourhood environments in order to elucidate urban form influences on health within a joint research agenda (Killingsworth, 2003; Stokols, Grzywacz, McMahan, & Phillips, 2003). In particular, assessing the walkability of environments (i.e., the ease at which a person can navigate from one space into another; Sallis, 2009) has catalyzed recent public health research on physical activity, which is affiliated with the framework of the Social Ecological Models (Sallis & Owen, 1997). Within the framework of the Social Ecological Models, environment is conceptualized as a multilayered interplay of intra-personal and extra-personal influences on health behaviour (Spence & Lee, 2003). It appears that urban form influences on physical activity are mediated by personal characteristics, such as age, gender (Shriver, 1997), and socio-economic status (Brownson, Baker, Housemann, Brennan, & Bacak, 2001), as well as cognitive factors, such as self-efficacy (defined as the sense of personal agency about one's ability to perform a specific behaviour; Bandura, 1986), which is the most consistent correlate of physical activity (Bauman & Bull, 2007). To account for urban form influences on walking, both intra-personal and extra-personal influences need to be considered simultaneously.

Purpose

The purpose of this study was to assess the walkability of neighbourhood environments and to determine whether there was any association between neighbourhood walkability and the self-reported walking patterns of a sample of adults living in Edmonton, Alberta, after controlling for socio-demographic variables. In order to place this study in its conceptual context, it will be important first to consider various ways of objectively measuring walkability. Then we shall present our specific research goals, hypotheses, findings and conclusions in the sections that follow.

Walkability of Urban Layouts

Public health research documents the association of the generic neighbourhood environment with various domains of walking based on objectively and/or subjectively assessed urban form variables using metric distances (real and perceived). The variables most frequently used to describe the walkability of environments are the *3Ds of urban form* (Cervero & Kockelman, 1997). The *3Ds of urban form* is a method based on objective assessments of land use patterns (diversity), urban design characteristics (density), and transportation systems (design) within communities. The basic assumption of this approach is that individuals are constantly aware of their surroundings and make rational choices about walking and transportation based upon the attractiveness of destinations.

Alternatively, space syntax focuses on generic spatial layout and its influence on pedestrian, cyclist, and vehicular movement. This approach to quantifying urban form influences on movement was initiated by Hillier and Hanson's (1984) theory of space syntax, which aims to capture the way individuals read urban layouts. Space syntax assumes individuals are attracted to space. Thus, by studying the generic urban layout alone, it is possible to understand how individuals navigate through space (Penn, 2003). For example, pedestrian movement patterns can be explained simply by studying the integration of a spatial layout, which represents a syntactic property of the layout that assesses accessibility (Peponis & Wineman, 2002). More recently, a new direction within space syntax known as *angular analysis* (*AA*) enables the use of road centerlines existing in current Geographic Information Systems (GIS) databases; it may constitute a useful technique for the field of public health to employ in assessing the walkability of spatial layouts (Turner, 2007). For this study, a consideration of both methods (*3D* and *AA*) was proposed to differentiate urban form in terms of walkability into high versus low walkability (i.e., contrasting environments in terms of walkability).

We proposed to adopt a joint theoretical framework, by incorporating Space Syntax within the Social Ecological Models, in order to study the association between urban form and physical activity.

Contrasting Urban Forms in Terms of Walkability

Public health and space syntax research documented certain characteristics of environments that are conducive to pedestrian movement. Much public health research has compared the *self-reported walking* of individuals living in contrasting environments in terms of walkability (i.e., environments assessed objectively as higher in walkability versus environments assessed objectively as lower in walkability). Generally, residents of environments assessed objectively as higher in walkability report about 15-30 minutes more walking per week and are 2.4 times more likely to engage in the recommended 30 minutes of daily physical activity than their counterparts (Frank, Schmid, Sallis, Chapman, & Saelens, 2005; Sallis, Frank, Saelens, & Kraft, 2004). In addition, preferences for highly walkable environments are associated with more walking and walkability perceptions of individuals who reside in higher walkability environments (assessed objectively) rank consistently higher compared to the walkability perceptions of their counterparts (Leslie et al., 2005; Frank, Saelens, Powell, & Chapman, 2007).

Further, *objective measurement of walking* using accelerometers differs in environments that contrast in terms of walkability. Thus, living in an environment that is higher in walkability contributes to approximately 70 minutes more physical activity a week than does living in an environment that is lower in walkability (Saelens, Sallis, Black, & Chen, 2003).

Finally, *observed walking* differs in environments that contrast in terms of walkability, with fewer individuals being observed to be walking or cycling in less walkable areas such as suburban areas (an individual every 9.5 min; Suminski, Fritzsinger, Leck, & Hyder, 2008) than in urban areas (an individual every 7.5 min; Suminski, Petosa, & Stevens, 2006). In addition, space syntax research found that the relationship between observed walking and walkability of spatial layouts (as measured by integration) differs in urban and suburban areas. Urban and suburban networks display contrasting *spatial signatures* (e.g., different densities and lengths of street segments) and different syntactic properties (e.g., integration; Conroy-Dalton & Dalton, 2005). For instance, movement in urban areas is determined mainly by the presence of integration cores (i.e., areas of the layout with highest integration values), whereas movement in suburban areas is determined mainly by the presence of retail uses that constitute attractors for pedestrians (Hillier, Burdett, Peponis, & Penn, 1987). Moreover, observed average pedestrian density in urban areas is 2.6 people per 100 meters, whereas observed density in residential housing estates is between 0.4 and 0.7 people per 100 meters (Hillier, Burdett, Peponis, & Penn, 1987). In general, areas with more integrated streets, which are characteristic of traditional urban areas, attract more movement than do areas with less integrated streets, which are characteristic of most suburban areas (Penn, Hillier, Banister, & Xu, 1998; Raford & Ragland, 2006).

Therefore, it appears that contrasting degrees of walkability, measured objectively, are associated with contrasting patterns in terms of self-reported, objectively assessed, and observed walking.

Within the common theoretical framework of the Social Ecological Models, I proposed to operationalize contrasting environments in terms of walkability using *both* the *3D* and *AA* measures. Although the *3D* and the *AA* measures are based on different theoretical assumptions, they ultimately converge to capture both the role of the generic neighbourhood environment and the presence of attractors in influencing physical activity. Specifically, the *3Ds* were devised based upon the premise that the generic environment is a sum of individual built-environment elements that influence walking, whereas the *AA* measures were devised based upon the theoretical premise that the generic spatial layout as a whole generates walking. Because the two methods of assessing walkability are underpinned by complementary theoretical premises, and because the *AA* measures show good performance in predicting pedestrian and cyclist movement (Raford and Ragland, 2006; Turner, 2007), a classification of walkability based upon both measures was considered for this study. Thus, environments that were high in *both 3D and AA* walkability would be considered as high in walkability, and environments that were low in *both 3D and AA* walkability would be considered low in walkability.

Environments that contrast in terms of walkability are typically operationalized as high- versus low-walkability environments using the lowest and highest ranks of the walkability score calculated using a variety of the *3Ds* of urban form. However, selecting contrasting environments in this way is sometimes arbitrary (some researchers may classify the walkability data based on a median split or may classify the data into 3, 5, or 10 classes and choose the bottom and top classes in various ways to determine the high- versus low-walkability areas: e.g., the bottom four deciles and top four deciles of walkability; Frank et al., 2009). Moreover, because *both 3D and AA* variables are being used as criteria to classify areas as high versus low in walkability, spatial statistics tools are necessary to provide information on the location of spatial clusters of high and of low walkability based on *both 3D and AA* measures. Such tools, which include the Global Moran's *I* and the Local Indicators of Spatial Association (*LISA*; Anselin, 1995), are suitable. These tools are used in Exploratory Spatial Data Analysis (ESDA) to visualize and explore multivariate spatial correlation (Anselin, Syabri, & Smirnov, 2002). In this case, Global Moran's *I* and *LISA* are employed to investigate the bivariate spatial correlation between the *3D* and *AA* variables. Specifically, the bivariate Global Moran's *I* indicates the magnitude and direction of the association between the *3D* and *AA* variables and provides information about whether there is any degree of overall spatial clustering, whereas *LISA* indicate where the spatial clustering is located and the type of spatial association (Mitchell, 2005).

The bivariate Global Moran's *I* is visualized as a Moran Scatterplot, which represents a plot with one variable of interest on the *x* axis (in this case *AA* walkability) and the second variable of interest on the *y* axis (in this case *3D* walkability). The Moran scatterplot is centered on the mean values for *3D* and *AA* walkability, to obtain four quadrants: two quadrants of spatial clusters (*low 3D walkability* - *low AA walkability* and *high 3D walkability* - *high AA walkability)* and two quadrants of spatial outliers (*low 3D walkability – high AA walkability* and *high 3D walkability – low AA walkability)*, with all values standardized to the mean (Anselin, 2005).

LISA indicators are produced to understand how spatial association varies, because spatial association likely varies across space (Anselin, 1995). Local Moran's *I* indices are provided for each location (e.g., a given Edmonton neighbourhood in this case), to indicate the magnitude and direction of the association between the value of the *AA* variable observed at that location and the weighted average of the values of the *3D* walkability variable observed for the spatial neighbours of that given location (e.g., the Edmonton neighbourhoods that are adjacent to that particular neighbourhood). Thus, *LISA* indicators provide information about clusters (in this case walkability clusters based on both *3D* and *AA* measures) visualized with *LISA significance maps,* which depict those clusters that are statistically significant, and with *LISA cluster maps*, which classify those clusters by type of association between the two variables (as *high-high*, *low-low*, *high-low*, and *low-high*).

Research Questions

The aims of this study were: (1) to investigate whether individuals' *self-reported walking* is associated more strongly with objective environment (assessed using both *3D* and *AA* measures) or subjective environment; and (2) to investigate whether individuals living in contrasting walkability environments (environments that contrast in terms of walkability assessed using both *3D* and *AA* measures) display contrasting *self-reported walking* levels.

We hypothesized that residents of neighbourhoods with higher walkability would report more walking than their counterparts living in neighbourhoods with lower walkability. We also hypothesized that neighbourhood walkability variables were independently associated with residents' self-reported walking levels above and beyond the variance explained by psycho-social and socio-demographic correlates.

Research Focus

A model of environmental opportunities for physical activity (EOPA; Figure 1-1, Chapter 1) was employed to guide an investigation of place as interplay between the *objective environment (O), subjective environment (S),* and *resultant environment (R)*. *Objective environment (O)* is described by neighbourhood opportunities for physical activity and by neighbourhood socio-demographics. *Subjective environment (S)* is described by individuals' perceptions of the environment conduciveness for physical activity. *Resultant environment (R)* is described by observed and self-reported levels of physical activity.

This study addressed *Goals 2 and 3* of this dissertation. Thus, this study focused on the relationships between the objective and resultant environment (denoted as *OR*) and between the subjective and resultant environment (denoted as *SR*) – see Figure 1-2. The *OR* and *SR* relationships were measured at *macro* and *meso* scales using neighbourhood and buffers created around individuals' households as units of analysis.

Method

Data Acquisition and Sample

Built environment data for this study were compiled from several sources. Two hundred and one residential neighbourhoods located in Edmonton, Alberta, Canada, were selected. Ninety neighbourhoods were suburban (*M* = 1.05 km^2, *SD* = 0.34) and one hundred-eleven were mature neighbourhoods (*M* = 1.10 km^2, *SD* = 0.40). The average area of residential neighbourhoods is 1.08 square kilometres (*SD* = 0.38). Census data based on the 2001 Census (Statistics Canada, 2003), as well as tax data and spatial data provided by the City of Edmonton and GeoEdmonton, were used to characterize the built and social environment of the residential neighbourhoods. In addition, the Edmonton Police Service provided data on neighbourhood crime rates and the Alberta First Business Directory (http://www.albertafirst.com) provided data on facilities in various uses (Handy, Cao, & Mokhtarian, 2005). In addition, information on postal code centroids and population counts was based on data obtained from Statistics Canada (2004). It was assumed the spatial location of the respondents' households was their postal code's centroid.

Individual-level data were provided by Capital Health's Population Health Survey 2002 (PHS; Kaida et al., 2004), containing data on walking, perceived environment, and socio-demographics. The original sampling frame for this dataset consisted of 4,175 individuals living in the Capital Health region who were randomly selected by telephone (3,850 randomly selected individuals plus an additional sample of 325 residents of the North East area). For the purposes of the current study, the sampling frame consisted of 2,879 respondents living in 195 residential neighbourhoods that have complete data available on *3D* walkability, angular measures, and socio-economic status (SES).

Measures

Neighbourhood Walkability Measures

A neighbourhood *3D* walkability index was obtained by summing up the *z* scores for density, diversity, and design, with double weighting for design (see Frank et al., 2009 and Cutumisu and Spence, 2009). Because floor area ratio information was not available, our walkability index does not include the *z* score for the floor area ratio. As well, true intersections used in calculating design were defined as intersections of four or more streets which are more characteristic of gridiron neighbourhoods (Cervero & Duncan, 2003). In addition, a neighbourhood angular walkability index was based on Turner's (2007) measure of angular weighted betweenness (see Cutumisu & Spence, 2009). Angular weighted betweenness captures the potential of a street segment to be a route from a street segment to all of the others. Thus, this measure expresses the angular distance from each street segment to all of the others in the system measured along the shortest angular path (i.e., the route with the lowest angular cost from a street segment to all the others in the system) within a radius R=1000 m. This radius was selected to avoid the edge effect (Ratti, 2004; Turner, 2007). Also, Moudon et al. (2006) consider 1000 m as appropriate for defining a walkable neighbourhood. The neighbourhood angular walkability index was obtained by taking the average values for all street segments in the neighbourhood.

Buffer Walkability

Buffer *3D* and angular walkability of the physical environment for each respondent living in the 195 neighbourhoods was calculated based on streetfile data and facility location data. Density was calculated as the number of households per area within a 500 m radius aerial buffer (R_{500}). Design was calculated as the number of true intersections within the buffer. Diversity was calculated as the number of facilities in four categories (maintenance, institutional, eat out, and recreational; see Handy, Cao, & Mokhtarian, 2005) that are present in the buffer. Finally, the *3D* index for the buffer was calculated using Frank, Schmid, Sallis, Chapman, and Saelens' (2005) formula as a sum of z scores for the three components of the walkability index (design, diversity, and density), with a double weight being assigned to design. As well, information on angular analysis walkability, based on R_{500} calculations, was obtained for each buffer, as an average of values for angular weighted betweenness calculated for all street segments that were located within the buffer.

Demographics

Participants in the 2002 PHS survey were asked to report their age (in years) and their gender, and to indicate whether or not they had a condition that would inhibit them from taking part in physical activity.

SES

Neighbourhood-level SES was assessed based on neighbourhood socio-economic variables extracted from the 2001 Canadian Census and compiled by the Edmonton Social Planning Council. A procedure by Demissie, Hanley, Menzies, Joseph, and Ernst (2000) was used to determine neighbourhood SES by taking the sum of the *z*-scores of net educational level (the proportion of people with low education subtracted from the proportion of people with high education aged 20 and over) and median income of census families ($), and then subtracting the proportion of unemployed (unemployed people aged 15 and over as a percentage of people aged 15 and over who were in the labour force). Individual-level SES was based on survey data on income and education. The variable for education was collapsed into three groups, assigning respondents a value of 1 for high-school education or less, 2 for post-secondary education, and 3 for university-level education.

Neighbourhood Actual Crime Levels

Rates of risk from traffic were based on incidents of criminal code traffic violations (e.g., dangerous driving, failure to remain at the accident scene) per neighbourhood population. The variable was dichotomized based on a median split as lower/higher levels of risk.

Self-reported Walking

To measure walking, PHS 2002 employed the short form version of the International Physical Activity Questionnaire, which has good reliability and validity (IPAQ; Craig et al., 2003). Questions about walking performed for at least 10 minutes during a week prior to the survey were the basis for the calculation of separate weekly duration scores for walking, as well as for the calculation of a score in MET*minutes (multiples of the resting metabolic rate). Respondents were assigned to one of two categories: *insufficient walking* and *sufficient walking* according to Haskell et al.'s (2007) recommendation of 495 MET*minutes per week for moderate activity (e.g., walking). This amount of physical activity is attained by walking for 30 minutes at the speed of 3 miles per hour, 5 days per week, leading to an accumulation of 495 MET*minutes per week. Specifically, individuals accumulate 99 MET*minutes of physical activity in 30 minutes (3.3 MET * 30 minutes = 99 MET* minutes) and thus they accumulate 495 MET*minutes of physical activity in 5 days (99 MET*minutes * 5). This corresponds to the minimum amount of moderate activity recommended for health benefits.

Self-efficacy

Self-efficacy represents the confidence of respondents in their ability to participate in regular physical activity, including overcoming barriers to participation (Bandura, 1986). Self-efficacy was assessed using a 100-point scale, in which 0 means *Completely certain I cannot do it* (participate in regular physical activity) and 100 means *Completely certain I can do it* (participate in regular physical activity). Validity and reliability for this scale was noted previously (McAuley, 1992, 1993; McAuley, Courneya, & Lettunich, 1991; McAuley, Lox, & Duncan, 1993; Morris, McAuley, & Motl, 2008; Resnick & Jenkins, 2000).

Perceptions of the Built Environment

The PHS survey was based on the International Physical Activity Prevalence Study's Environmental Survey Module (IPS, 2002). Respondents' neighbourhoods were defined as areas around their homes that they could walk to in 10-15 minutes. The survey included one item regarding each of the following:

(a) the type of housing, (b) the access to neighbourhood facilities, (c) the access to public transit stops, (d) the presence of pedestrian infrastructure, (e) the presence of free or low cost recreational facilities, (f) the safety from crime and traffic, (g) the presence of active people in the neighbourhood, (h) the aesthetics of the neighbourhood, (i) the density of intersections, and (j) the ownership of cars. Four-point Likert response scales ranging from *strongly disagree* to *strongly agree* were used for all variables. In addition, one other option (*don't know/ not sure*) was included for all variables. This scale survey was based on seven core perceived physical and social environment items adapted from published surveys (Kirtland et al., 2003; Saelens, Sallis, Black, & Chen, 2003), which show good validity and reliability (Addy et al., 2004; Alexander, Bergman, Hagströmer, & Sjöström, 2006; Brownson et al., 2004; Cerin, Saelens, Sallis, & Frank, 2006; Saelens, Sallis, Black, & Chen, 2003). One study that addressed the test-retest reliability of this scale was conducted in a sample of Swedish adults; it reported interclass correlations larger than 0.7 for all variables except crime (Alexander, Bergman, Hagströmer, & Sjöström, 2006). Two other studies of Japanese and African adults, respectively, reported moderate to excellent test-retest reliability of this scale (Inuoe et al., 2009; Oyeyemi, Adegoke, Oyeyemi, & Fatudimu, 2008).

Only five variables (of one item each) measuring *the type of housing*, *the access to neighbourhood facilities*, *the access to public transit stops*, *the safety from traffic*, and *the aesthetics of the neighbourhood* were included in this study. The questions regarding these items were rated using a four-point Likert response scale ranging from *strongly disagree* to *strongly agree*. In addition, a *don't know/ not sure* option was included for all variables. The *strongly disagree* and *somewhat disagree* responses were collapsed into a *disagree* response, whereas the *somewhat agree* and *strongly agree* responses were collapsed into an *agree* response.

Procedures

ArcGIS 9.3.1 (ESRI, 2009) and its Network Analyst extension were used to assess neighbourhood *3D* walkability. The UCL Depthmap 8.15.00c software (Turner, 2009) was used to assess neighbourhood *AA* walkability. More detail about these procedures is reported elsewhere (Cutumisu & Spence, 2009). SPSS 17 (PASWSTAT, 2009) was employed to manage data and carry out aspatial analyses. The level of statistical significance was set at $p < 0.05$ for the aspatial analyses. A preliminary aspatial comparison found good correlations between the neighbourhood *3D* and angular weighted betweenness (Kendall's *tau* for R_{1000} was $\tau = .594$; Cutumisu & Spence, 2009). In this study we employed spatial techniques to determine clusters of high versus low walkability. Global Moran's I and *LISA* indicators were produced by the OpenGeoDa 0.98.13 software (Anselin & Syabri, 2003). To enable the use of global and local indicators of spatial association (Anselin, 1995), a set of row-standardized, distance-based spatial weights was created for the neighbourhood shapefile (see Mitchell, 2005). This approach accounts for spatial units that have unequal numbers of neighbours, given that neighbourhoods' spatial layout comprises of a conglomerate of residential neighbourhoods surrounded by non-residential neighbourhoods

(Smoyer-Tomic, Hewko, & Hodgson, 2004). Also, a spatial lag was generated for the *3D* walkability variable (Anselin, 1988). We selected a threshold distance of 2.8 km to ensure each neighbourhood had at least one spatial neighbour.

For this study's spatial analysis, tests of significance were conducted based on a permutation test produced for 999 random comparisons of the spatially random generated datasets with a reference distribution at the pseudo-significance level of 0.01 to ensure stabile clustering (e.g., to ensure that the clustering did not change for randomly generated datasets). Randomization envelopes (represented as dotted lines on the graph) indicate whether the Global Moran's *I* is significant, that is whether the clustering is statistically significant.

Analyses

First, an inspection of the areas of agreement between neighbourhood *3D* index and neighbourhood *AA* walkability was performed using bivariate *LISA* maps (Anselin, 1995) to determine the location of significant clusters of low and high walkability. Second, a binary logistic regression was performed for a city-wide comparison regarding the levels of walking of the residents. Third, a Chi-Square test was conducted to compare levels of walking for individuals living in contrasting neighbourhood environments.

Prior to our logistical regression analysis, we determined whether any nesting was present in the data, and we thus verified whether multilevel modelling was applicable, given that some of the respondents live in the same neighbourhood. An intraclass correlation coefficient (ICC) was calculated for the self-reported walking variable as the outcome variable and the neighbourhoods as the grouping variable. Because the ICC was 0.006, no nesting effect was present, and a binary logistic regression was employed to determine whether levels of self-reported walking are associated more strongly with objective or subjective elements of built environment.

About a half of the respondents (49.5%) were classified as reporting insufficient walking (of less or equal to 495 MET*minutes per week) and about a half (50.5%) were classified as reporting sufficient walking (of more than 495 MET*minutes per week). About 20.2% of respondents did not provide information on their income, so this variable was not included in our analysis. Therefore, we only included the questions regarding the following aspects: type of housing, access to neighbourhood facilities, access to public transit stops, presence of pedestrian infrastructure, safety from traffic, and neighbourhood aesthetics. As a result, 2,683 cases (93.2%) were included in our analysis, with 196 missing (6.8%). Descriptive statistics regarding our sample of respondents are provided in Table 4-1. Descriptive statistics regarding perceived and objective built environment are provided in Table 4-2 and Table 4-3. Four models were fitted for 2,683 respondents (see Table 4-4): Model 1 included only individual socio-demographic characteristics; Model 2 included perceived environment variables as additional predictors; Model 3 included buffer-level objective environment variables as additional predictors; and, finally, Model 4 included neighbourhood-level objective environment and SES variables as additional predictors.

Results

Agreement between 3D and Angular Walkability

The bivariate global Moran's *I* for the association between *3D* walkability (on the *y* axis) and *AA* walkability (on the *x* axis) was 0.6665 (999 permutations; p <0.01), indicating an overall positive spatial correlation of *3D* walkability and *AA* walkability (see Figure 4-1). The slope of the regression line indicates the presence of statistically significant clustering (the randomization envelopes encompassed the slope for the Global Moran's *I*). The bivariate *LISA* cluster map is shown in Figure 4-2 (for a 999 permutation test and a pseudo-significance level of $p = 0.01$). This map uses colour to differentiate the type of clustering detected in the data. The results for the *LISA* tests of significance and of clustering are presented in Figure 4-2 and Figure 4-3, respectively. Based on the *LISA* cluster maps, a subset of 88 neighbourhoods was selected for a study of the levels of walking of residents living in low-walkability neighbourhoods ($n = 40$) versus high-walkability neighbourhoods ($n = 48$) assessed using *3D* and *AA* walkability.

City-wide Comparisons

Results of the analysis are presented in Table 4-4. In Model 1, age, education and self-efficacy were associated with walking. About 3-4% of variability in walking was explained by individual-level socio-demographic variables. The inclusion of perceived environment variables in Model 2 did not markedly improve the amount of variability explained (6-8%). In addition, some of the perceived walkability variables were associated with walking. Model 3 did not add to the amount of variance explained by Model 2. None of the buffer-level variables were significant. Finally, the inclusion of neighbourhood-level variables in Model 4 did not explain much additional variability (7-10%). In this model, individuals aged 25 to 34 were less likely to be active by a factor of .77, individuals aged 50 to 64 were less likely to be active by a factor of .70, and individuals over 65 were less likely to be active by a factor of .60, compared to the youngest group. Compared with the group with the least education, individuals who completed university education were less likely to be sufficiently physically active by a factor of 0.8. Also, individuals with higher self-efficacy were 1.01 times more likely to be active as recommended. Respondents who lived in apartments of 4 to 12 storeys and of more than 12 storeys were 1.42 times and 2.03 times more likely to be sufficiently active, respectively. Also, compared to individuals who disagreed with the statement *There are interesting things to look at while walking in my neighbourhood,* individuals who agreed with the statement were 1.24 times more likely to be sufficiently active. Neighbourhood-level walkability and socio-economic status variables, along with neighbourhood actual crime rate variable were not significantly associated with walking as recommended.

Contrasting Environment Comparisons

A Chi-square was performed for self-reported walking (insufficiently versus sufficiently active) and location (low walkability versus high walkability) for 1,356 respondents living in low- versus high-walkability areas (see Table 4-5). Yates' Continuity correction (with χ^2 (1) = .210, p =.647) indicated there was no significant difference in self-reported walking for individuals living in contrasting walkability areas.

Discussion

This study focused on the association between the levels of self-reported walking of individuals and their neighbourhood environments. It aimed to investigate whether individuals' self-reported walking is associated more strongly with the objective (assessed using both *3D* and *AA* measures) or subjective environment. For this, we first investigated the agreement between *3D* and angular walkability (discussed in the first sub-section). We then conducted a city-wide analysis of the association between urban form and self-reported walking (discussed in the second sub-section).

This study also aimed to investigate whether living in areas with contrasting urban forms, such as higher versus lower walkability, translates to higher versus lower levels of self-reported walking. Using the results of the analysis on the agreement between the *3D* and angular walkability, we determined the areas of higher and lower walkability based upon both *3D* and *AA* measures. We then investigated whether living in areas with contrasting urban forms, such as higher versus lower walkability, translates to higher versus lower levels of self-reported walking (discussed in the third sub-section).

Agreement between 3D and Angular Walkability

We examined spatially the agreement between the *3D* and *AA* walkability variables and found an overall positive spatial correlation of *3D* walkability and *AA* walkability. To assess the spatial correlation between *3D* and *AA*, we used

LISA indicators, which constitute valuable tools to aid in analyzing spatial correlation of variables. Such techniques of exploratory spatial data analyses provide better ways of selecting contrasting environments that represent clusters of high versus low walkability which are statistically significant.

City-wide Comparisons

We investigated the association between objective and subjective environments and total walking in a city-wide analysis, in which age, education, self-efficacy, and some of the perceived walkability variables predicted total walking. Older adults were less likely to walk at recommended rates than the youngest age group. This is consistent with our previous work (Cutumisu & Spence, 2010) and with another large Canadian population-based study (Craig, Russell, Cameron, & Bauman, 2004). For instance, Craig, Russell, Cameron, and Bauman (2004) found that older individuals were 31% to 44% as likely to be active as younger individuals. Therefore, it seems evident that older adults engage in less overall physical activity and less total walking than younger adults, while the main source of physical activity for older individuals is leisure-time walking. This is consistent with the possibility that individuals may have a *physical activity budget,* which allows them to balance the amount of activity they engage in by undertaking various types of activity; for example, if individuals walk more, they will engage in less physical activity of other types, and conversely, if they walk less, they will engage in more physical activity of other types (Forsyth, Hearst, Oakes, & Schmitz, 2008). Also, we found that respondents with a higher education were more likely to report insufficient total walking, which was consistent with previous research on total walking levels (Reis, Macera, Ainsworth, & Hipp, 2008). Other studies that reported associations between higher educational attainment and higher levels of physical activity did not consider walking measured in all domains of physical activity (Bryan & Katzmarzyk, 2009). It is likely that respondents with higher education have less physically demanding jobs than respondents with lower education.

We found an association between total walking and features of the perceived neighbourhood environment, such as housing type and aesthetics. This is consistent with previous research, which shows positive associations between walking and environments that are perceived or are objectively assessed as densely-built, as well as between walking and environments that are perceived as aesthetically pleasing (see reviews by Bauman & Bull, 2007; McCormack et al., 2004; Owen, Humpel, Leslie, Bauman, & Sallis, 2004; Saelens & Handy, 2008; Saelens, Sallis, & Frank, 2003; Wendel-Vos et al., 2007). While there was an association between walking and neighbourhood environment in this study, some studies found no association between total walking and environment (Forsyth, Oakes, Schmitz, & Hearst, 2007; Rodriguez, Khattak, & Evenson, 2006). Forsyth, Oakes, Schmitz, and Hearst (2007) emphasize the possibility of a *zero-sum game,* with higher-density areas being associated with more walking for travel and lower-density areas being associated with more walking for leisure, although the overall physical activity and total walking might be the same. Consequently, less walking for transportation may result in more walking for recreation (Krizek, Birnbaum, & Levinson, 2004; Rodriguez, Khattak, & Evenson, 2006), while total walking is similar even for people living in environments with contrasting walkability (Forsyth, Hearst, Oakes, & Schmitz, 2008). Also, Baran, Rodriguez, and Khattak (2008) found that different space syntax properties are associated with walking for leisure and for utilitarian purposes in traditional (New Urbanist) versus conventional suburban neighbourhoods. Areas with higher integration are associated with more utilitarian walking, but less leisure walking. This may be explained because people living in suburbia may have a propensity towards walking for leisure in areas with less traffic.

A recent report (Cameron, Craig, & Paolin, 2005) indicates that safety concerns are relatively low amongst Canadians, with 83% disagreeing that safety from traffic is an issue. Therefore, the finding that perceived or actual risk from traffic did not predict total walking is consistent with previous research (see also Hoehner, Brennan Ramirez, Elliott, Handy, & Brownson, 2005). However, the most likely explanation for this finding pertains to inaccurate measurement. Our finding that perceived risk from traffic was not a significant predictor could be attributed to a mismatch in the ways respondents conceptualized the neighbourhood area. It could also be attributed to a mismatch between assessments of actual risk and perceived risk. Actual risk was calculated at the aggregate level, while perceived risk from traffic was calculated at the buffer level. Thus, our measures assessed risk in relation to two different spatial referents. In addition, our selection of a 500 m radius to define the neighbourhood environment may have been too small, as the residents in our study may in fact have walked longer distances. Therefore, this buffer selection might have not captured the differences in levels of walking (VanDyck, Deforche, Cardon, & DeBourdeaudhuij, 2009). Canadians typically walk for various purposes (e.g., recreation, transportation) a distance of about 3 km and cycle to work along distances of 5 km (Cragg, Cameron, & Craig, 2006). This indicates that future studies should consider larger areas around individuals' homes.

Furthermore, we found no association between buffer- and neighbourhood-built environment variables and recommended levels of walking, which may be explained by the lack of measurement specificity. Walking for transportation is associated with other environmental correlates than walking for recreation or total walking (the total amount of walking an individual accumulates in a week). Researchers have recently made calls for specificity (Cerin, Leslie, du Toit, Owen, & Frank, 2007; Giles-Corti et al., 2005). Different factors influence walking and cycling because these activities serve different purposes for individuals and raise different sets of issues for planning and design (Krizek, Handy, & Forsyth, 2009). It is possible that, by using a generic measure for walking, some of the relationships of environmental variables and walking were obscured. However, from a population health perspective, it is important to assess environmental potential for walking and for other physical activities entailed by active living in general, by focusing on those factors that are common to all types of walking / physical activity. This will help to guide interventions that are directed towards the promotion of active living within the community. It appears that the presence of a neighbourhood environment that is characterized by higher residential densities, mixed use, and good street connectivity, and of high-quality, safe, and convenient facilities, are pre-requisites for an environment that is conducive to active lifestyles (Sugiyama, Leslie, Giles-Corti, & Owen, 2009). It is, therefore, necessary to identify some generic traits of the neighbourhood environment that can be enhanced to support general physical activity. While enhancing access to all groups might not be feasible within a limited community budget, creating a basic level of access might be a starting point for communities. Future research should identify specific characteristics for specific domains and subgroups and then select commonalities to determine areas of priority for community action.

In addition, our walkability index may not be specific enough (VanDyck, Deforche, Cardon, & DeBourdeaudhuij, 2009) to capture some urban form elements that influence walking. For instance, a recent study found that residents of neighbourhoods with preponderant commercial-industrial uses reported significantly more walking for transportation than residents of neighbourhoods with preponderant recreational uses, although the land use mix index might be the same in these two types of neighbourhoods (Cerin, Leslie, du Toit, Owen, & Frank, 2007). The land use mix formula we used to assess walkability did not include recreational areas; this may be one of the explanations for not finding an association between total walking and walkability status. The use of floor space or land area in various uses may have yielded very different results, given that land area-based indices are more likely to assess those aspects of built environment that influence recreational walking (Cerin, Leslie, du Toit, Owen, & Frank, 2007). In addition, the make-up of the index does not include informal alleys and walkways that individuals might use in their daily trips. Although the walkability index we employed for this study included alleys (residential, commercial, and industrial), there are still many informal paths which are not captured in this tool of assessment. Chin, van Niel, Giles-Corti, and Knuiman (2008) recently reported that most walkability measures employ only street networks, which may not be representative for pedestrian networks, because pedestrian networks often incorporate informal paths. These researchers found connectivity was underestimated to a larger extent for conventional suburbs than for traditional neighbourhoods when using street networks as opposed to street networks and informal paths.

Contrasting Environment Comparisons

We compared the levels of self-reported total walking (sufficiently active versus insufficiently active) for individuals living in objectively assessed contrasting walkability environments, after we determined significant clusters of high and low walkability based upon both *3D* and *AA* variables. Our results found no difference in walking between individuals living in high- versus low-walkability areas. This is consistent with a recent Canadian study that did not find a difference between lower-density neighbourhoods (having the characteristics of conventional suburbs) and higher-density neighbourhoods (having the characteristics of traditional urban areas) in terms of moderate physical activity levels after controlling for socio-demographic factors (Turcotte, 2009). It is also likely that people living in higher-walkability areas walk more for transportation, but engage in less recreational physical activity, while people living in lower-walkability areas walk less and engage in more recreational physical activity. This may be because suburban neighbourhoods might offer more opportunities for leisure-time walking, as well as a safer environment. It is possible that various physical activities differ according to the type of neighbourhood, with more opportunities for active leisure in suburban neighbourhoods (Turcotte, 2009).

It is also possible that more specificity in our measure of walking (which does not distinguish between walking for recreation and walking for transportation) would have resulted in different findings regarding the association between urban form and walking, because it appears that other aspects may be more important to walking for recreation than to walking for transportation (Saelens & Handy, 2008). However, most of the previous studies that found differences between levels of walking for individuals living in contrasting walkability environments examined active transportation. For example, while finding differences in terms of active transportation, Handy (1996) found no difference in terms of walking for exercise and Rodríguez, Khattak, and Evenson (2006) reported no difference in the levels of physical activity.

A further explanation for the lack of association between self-reported walking and the type of objectively assessed neighbourhood is that other factors that are associated with walking may be more important for our sample of residents. While active transport is influenced primarily by proximity and connectivity, which are captured by the *3D* walkability index (Forsyth, Hearst, Oakes, & Schmitz, 2008), other elements that may influence walking, and which are not captured by the index, might be more important for our residents in terms of total walking (such as the attractiveness of the neighbourhood environment and of various destinations, the level of maintenance of the sidewalks, or presence of deterrent uses or other undesirable factors; Wells & Yang, 2008). Such qualities are important for our particular sample of respondents in relation to walking for various purposes, as revealed by our city-wide analysis, in which we found that individuals living in higher residential-density areas that are perceived as more interesting are more likely to walk sufficiently. The fact that we found a difference in terms of perceived environment suggests that individuals' perceptions may exert a stronger influence on total walking levels than does the objectively assessed environment. This finding is consistent with previous research that revealed significant differences in perceptions and preferences of individuals who live in contrasting walkability environments (Leslie et al., 2005).

The preferences of the residents of Edmonton may have also played a role in not finding differences in activity levels for individuals living in contrasting environments. Preference for single family dwellings, little traffic noise, and low municipal taxes are very strong and consistent across almost all population subgroups in Edmonton (Hunt, 2001). According to Hunt, residents are willing to decrease driving times to work and to increase commuting times to all types of destinations in favour of living in a single family dwelling. However, they are only willing to consider moving into higher density developments in the case of a dramatic decrease in the cost of commuting (Hunt, 2001). This likely reflects certain aesthetic and social values associated with living in suburban areas held by all population subgroups and may contribute to blurring differences in terms of walking. Thus, given the choice, most residents would choose to live in suburban areas; this suggests that a large proportion of the individuals who prefer to be active may perhaps perceive suburban areas as having less traffic and thus constituting safe environments for recreational activity. This is consistent with previous studies which indicated not only that residents of suburbia value safety more than accessibility, but also that residents of suburban streets that were protected from traffic have increased satisfaction and social interaction, as well as decreased accident rates (see Ben-Joseph, 1997).

Edmonton is Canada's second-fastest-growing major urban area, having experienced a population increase of 10% between 2001 and 2006 (Statistics Canada, 2008). As the city grows, distances from the centre of the city increase, and consequently, car reliance increases (Turcotte, 2008b). In 2001, 12% of Edmontonians lived in high density (or urban) neighbourhoods versus 58% who lived in low-density (suburban) neighbourhoods. Also, 18% of population lived within 5 km of the city centre, 35% within 5-9 km of the city centre, and 47% within more than 10 km of the city centre. Moreover, about 77% of the housing stock constructed in 1991 or later was low density, while only 7% was high density, indicating a rapid increase in suburbanization. The percentage of Edmontonians who are heavily reliant on cars is significantly higher in mixed areas (77%) and in suburban areas (80%) than in high-density areas. In addition, the proportion of central neighbourhood residents who travelled distances shorter than 5 km by car was 64% (Turcotte, 2008a). Such a prevalence of car trips is reflective of a highly reliant automotive culture, with Edmontonians living predominantly in low-density areas (with a total of 88% of population living in low-density areas and 82% of population living further than 5 km away from the city centre), where even distances that are shorter than 5 km (that could be cycled) are travelled by car. Because a typical distance for cycling is 5 km for Canadians (Cragg, Cameron, & Craig, 2006) and 6.44 km for Americans (Blanco et al., 2009), distances under 5 km can be travelled by bicycle instead of by car.

Therefore, due to the general preference for suburban living and to the disproportionate availability of suburban housing versus urban housing, it is possible that living in a certain type of archetypal urban environment (e.g., urban versus suburban) does not necessarily reflect a preference for living in such an environment. It is thus possible as Hunt (2001) suggested, that, given the chance, a majority of individuals might choose to live in lower-density developments. Future studies should specifically control for self-selection of the living environment by the residents and should consider residential preferences for living in certain archetypal environments.

Strengths and Limitations

The strengths of this study include the use of a representative sample of the population residing in Edmonton, Alberta, as well as the use of both objective and subjective assessments of urban form, employing GIS and a joint Social Ecological Models - Space Syntax perspective. The use of both buffer- and neighbourhood-level variables allowed for an understanding of the relationship between urban form and physical activity at various scales of analysis. As well, the inclusion of back street alleys in the assessment of built environment measures helped to ensure a better assessment of connectivity. In addition, this study used a composite measure of SES, which is a better proxy of SES in the context of Edmonton, where only neighbourhood income or education would not properly quantify SES in isolation.

Several limitations need to be noted. Because weather is associated with outdoor physical activity patterns in various populations (see systematic review by Tucker and Gilliland, 2007) and, in particular, among Edmontonians (Chan & Ryan, 2009; Carson, Spence, Cutumisu, Boule, & Edwards, 2010), it is likely that the season in which the survey was completed may have influenced the individuals' answers. Another limitation is the potential mismatch between perceived and objective measures of the physical activity environment (Ball, Jeffery, Crawford, Roberts, Salmon, & Timperio, 2008), due to the buffer selection. Other limitations include the use of self-reported data as opposed to objective data on behaviour measured by accelerometers, the lack of specific measures for different domains of walking, and the use of aggregated built environment and risk data (actual data on safety or risk from crime and from traffic) at the neighbourhood level. Finally, this study cannot infer causality, due to its cross-sectional design. In addition to considering self-selection and individuals' preferences, future studies should incorporate informal paths that individuals might use and which are not typically included, determine the appropriate buffers and employ specific measures of physical activity (e.g., walking for recreation, walking for transportation).

Conclusion

Although individuals living in objectively-assessed *urban forms of contrast* did not display different walking levels, we found that perceived environment plays a stronger role in the likelihood that individuals will meet the recommended levels of walking than the objective environment, after controlling for socio-demographic variables. Our study supports the idea of a budget for physical activity. Even though the physical activity budget of individuals living in contrasting environments may be the same, it is likely distributed differently, with people living in higher walkability areas walking more for transportation and possibly less for leisure.

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Tables

Table 4-1. Sample characteristics

Sample characteristics		Total	Valid Percent
Gender			
	Female	1,464	50.9
	Male	1,415	49.1
		n = 2,879	
Age (years)			
	18-24	610	21.2
	25-34	605	21.0
	35-49	556	19.3
	50-64	553	19.2
	65+	555	19.3
		n = 2,879	
Education			
	Low	1,004	35.0
	Medium	1,120	39.0
	High	746	26.0
		n = 2,870	
Health condition			
	Yes	1,092	38.0
	No	1,778	62.0
		n = 2,870	

Note: Some variables have missing cases.

Table 4-2. Descriptive statistics for subjective built environment variables

Sample characteristics		Total	Valid Percent
Type of housing			
	Detached single family	1,588	55.3
	Attached or Mixed housing	1,284	44.7
		n = 2,872	
Many shops, stores, or other places to buy things I need are within easy walking distance of my home			
	Disagree	737	25.7
	Neither	265	9.3
	Agree	1,862	65
		n = 2,864	
It is within a 15-minute walk to a transit stop from my home			
	Disagree	149	5.2
	Neither	35	1.2
	Agree	2,659	93.3
		n = 2,843	

There is so much traffic on the streets making it difficult or unpleasant to walk in my neighbourhood			
	Disagree	1,499	54.4
	Neither	439	15.9
	Agree	819	29.7
		n =2,858	
There are many interesting things to look at while walking in my neighbourhood			
	Disagree	1,005	35.4
	Neither	571	20.1
	Agree	1,262	44.5
		n = 2,838	

Table 4-3. Descriptive statistics for the objective built environment variables

Sample characteristics	N	Mean (SD)	Median
Buffer *3D* walkability	2,879	-.006 (3.12)	-.51
Buffer angular walkability	2,879	1.74 (.87)	1.68
Neighbourhood *3D* walkability	2,879	1.02 (.01)	3.64
Neighbourhood angular walkability	2,879	12.01 (6.39)	11.24
Neighbourhood socio-economic status	2,879	-.38 (1.87)	-.33

Table 4-4. Contribution of predictors to explaining self-reported levels of walking

Predictors		Model 1		Model 2		Model 3		Model 4	
		OR	95%CI	OR	95%CI	OR	95%CI	OR	95%CI
Gender	Men	Reference category							
	Women	.90	(.77, 1.05)	.89	(.76, 1.04)	.89	(.76, 1.04)	.89	(.76, 1.04)
Age	18-24	Reference category							
	25-34	.80	(.63, 1.01)	.78*	(.61, .99)	.78*	(.61, .99)	.77*	(.61, .99)
	35-49	.86	(.67, 1.09)	.89	(.69, 1.14)	.90	(.70, 1.15)	.89	(.70, 1.14)
	50-64	.68*	(.53, .87)	.70*	(.54, .90)	.70*	(.54, .90)	.70*	(.54, .90)
	65+	.61*	(.46, .80)	.61*	(.46, .80)	.60*	(.46, .80)	.60*	(.45, .79)
Education	High school or less	Reference category							
	Post-secondary	.87	(.72, 1.04)	.86	(.71, 1.04)	.86	(.71, 1.04)	.87	(.72, 1.05)
	University	.80*	(.65, .98)	.78*	(.63, .96)	.78*	(.63, .96)	.80*	(.64, .99)
Health condition	Yes	Reference category							
	No	.96	(.81, 1.15)	.98	(.82, 1.18)	.98	(.82, 1.18)	.98	(.82, 1.18)
Self-efficacy		1.01*	(1.007, 1.01)	1.01*	(1.007, 1.01)	1.01*	(1.007, 1.01)	1.01*	(1.007, 1.01)

Main type of housing	Detached single family	Reference category					
	Town/row houses	1.16	(.89, 1.52)	1.18	(.90, 1.54)	1.17	(.89, 1.54)
	Mixed housing	1.04	(.86, 1.26)	1.04	(.86, 1.26)	1.04	(.86, 1.26)
	Apt 4-12 storeys	1.43*	(1.01, 2.03)	1.42*	(1.002, 2.01)	1.42*	(1.001, 2.02)
	Apt >12 storeys	2.04*	(1.28, 3.25)	1.97*	(1.23, 3.16)	2.03*	(1.26, 3.28)
Facilities within walking distance	Disagree	Reference category					
	Neither	.81	(.60, 1.08)	.81	(.60, 1.09)	.81	(.60, 1.09)
	Agree	1.10	(.92, 1.33)	1.10	(.91, 1.32)	1.10	(.91, 1.33)
Transit stop within 15 min	Disagree	Reference category					
	Neither	.82	(.38, 1.76)	.82	(.38, 1.76)	.82	(.38, 1.77)
	Agree	.86	(.61, 1.22)	.86	(.60, 1.22)	.86	(.60, 1.22)
Traffic	Disagree	Reference category					
	Neither	1.12	(.89, 1.43)	1.12	(.88, 1.42)	1.11	(.88, 1.42)
	Agree	1.14	(.92, 1.40)	1.12	(.91, 1.39)	1.12	(.90, 1.38)
Interesting things	Disagree	Reference category					
	Neither	1.02	(.82, 1.27)	1.02	(.82, 1.27)	1.03	(.83, 1.28)
	Agree	1.23*	(1.03, 1.47)	1.23*	(1.03, 1.47)	1.24*	(1.03, 1.48)

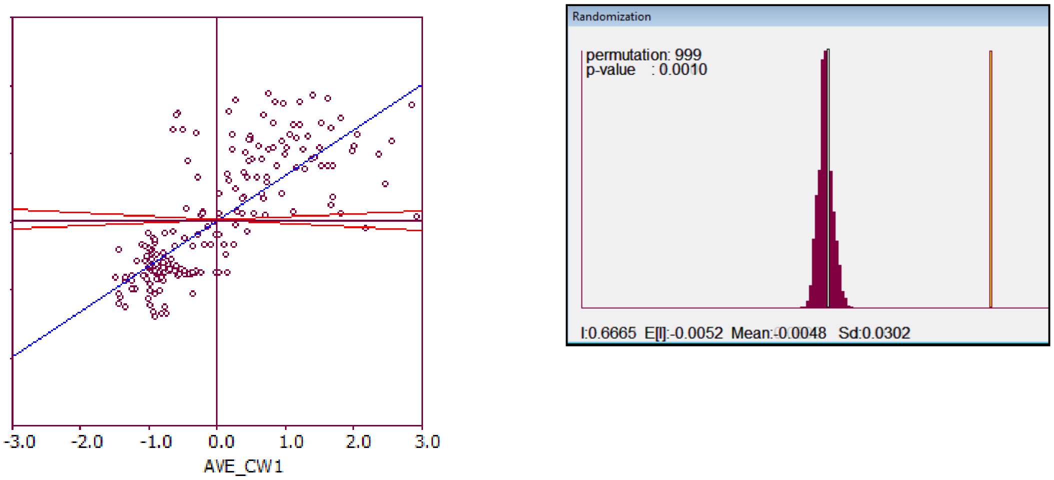
Buffer *AA*	Low	Reference category					
	High			1.02	(.81, 1.28)	1.15	(.79, 1.67)
Buffer *3D*	Low	Reference category					
	High			1.07	(.85, 1.35)	1.09	(.86, 1.38)
Actual risk traffic	Low	Reference category					
	High					.97	(.81, 1.16)
Neighbourhood angular index	Low	Reference category					
	High					.83	(.54, 1.28)
Neighbourhood *3D* index	Low	Reference category					
	High					1.05	(.77, 1.44)
Neighbourhood SES	Low	Reference category					
	High					.94	(.80, 1.11)
Cox & Snell R^2		.03	.06	.06			.07
Nagelkerke R^2		.04	.08	.08			.10

*Note: *p<0.05*

Table 4-5. Cross-tabulation of self-reported levels of walking and walkability

		Walkability		
		Low	High	Total
Walking	Insufficient	250	421	671
	Sufficient	246	439	685
Total		496	860	1,356

Figures



```
permutation: 999
p-value   : 0.0010
I:0.6665  E[I]:-0.0052  Mean:-0.0048   Sd:0.0302
```

Figure 4-1. Bivariate global Moran's *I* for the association between *3D* walkability (the spatial lag variable) and angular walkability R=1000 m (for the sample of 195 neighbourhoods; 999 permutations, *p* <0.01)

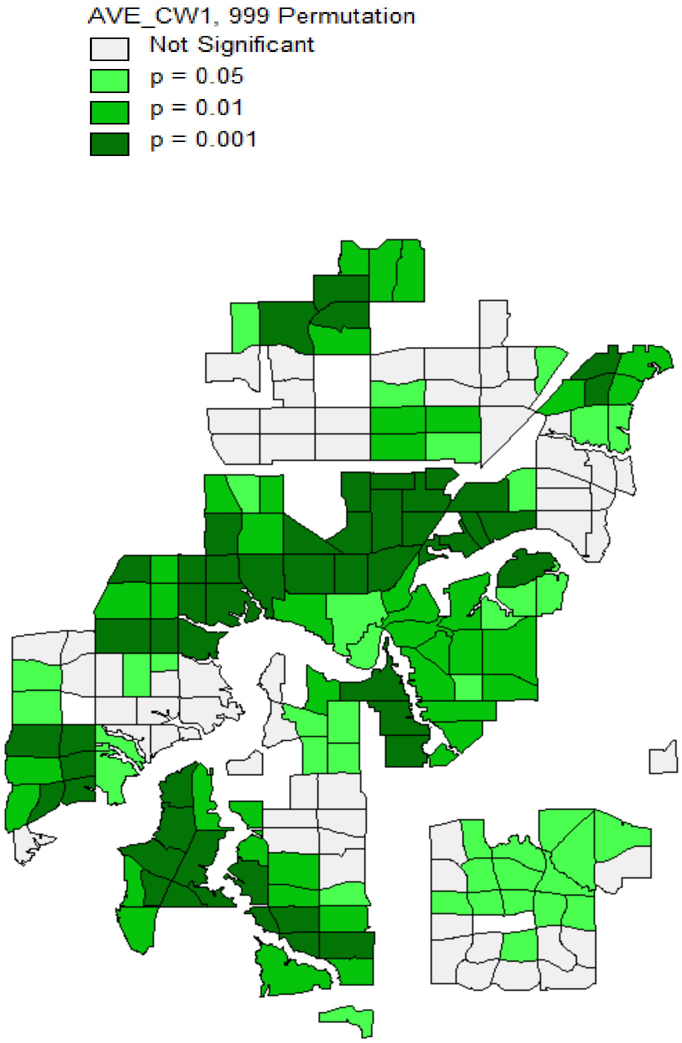


Figure 4-2. Map of significance - Bivariate global Moran's *I* for the association between *3D* walkability (the spatial lag variable) and angular walkability R=1000 m (for the sample of 195 neighbourhoods; 999 permutations, $p < 0.01$)

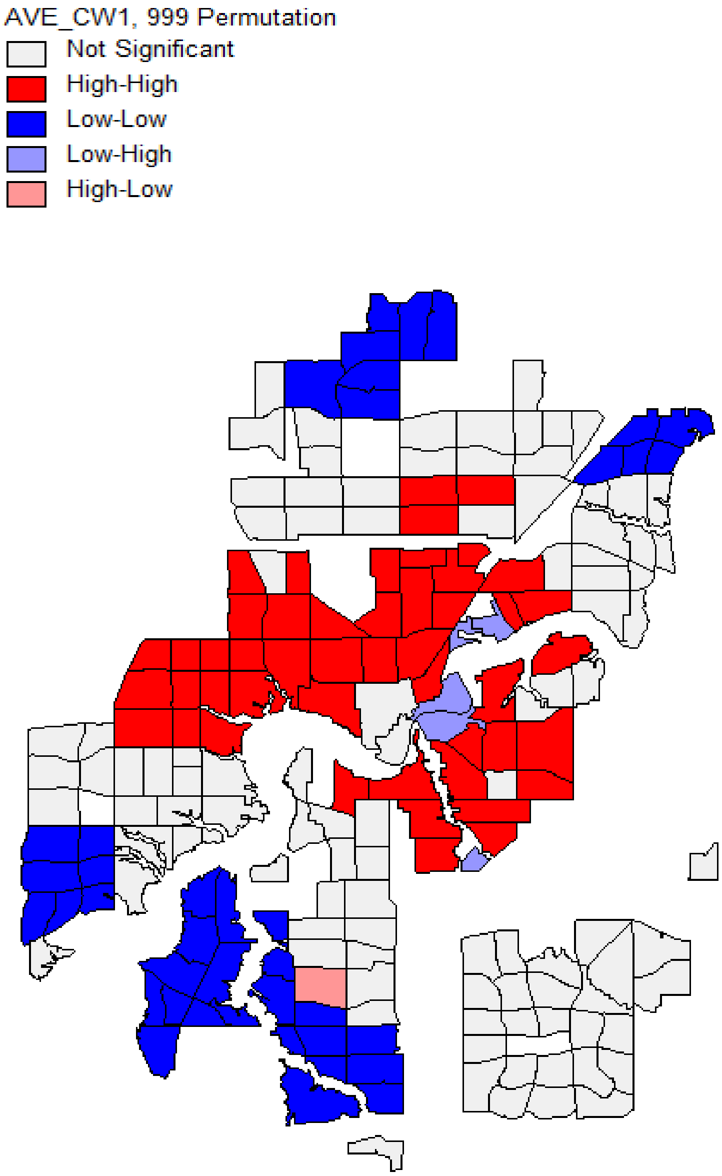


Figure 4-3. Map of clustering - Bivariate global Moran's *I* for the association between *3D* walkability (the spatial lag variable) and angular walkability R=1000 m (for the sample of 195 neighbourhoods; 999 permutations, $p < 0.01$)

CHAPTER 5. FABRIC OF MOVEMENT: AN OBSERVATIONAL STUDY OF PEDESTRIAN, CYCLIST, AND VEHICULAR MOVEMENT IN FOUR NEIGHBOURHOOD ENVIRONMENTS (STUDY 4)

Background

The global epidemic of obesity is caused by an imbalance in energy intake and energy expenditure, which is facilitated by a proliferation of everyday obesogenic environments (Hill, Wyatt, Reed, & Peters, 2003; Swinburn, Egger, & Raza, 1999). Two-thirds of the industrialized world does not achieve minimum physical activity guidelines (U.S. Department of Health and Human Services, 1996). Thus, physical inactivity constitutes a major public health concern with related social and economic costs (Bouchard, Shephard, & Stephens, 1994; Katzmarzyk, Gledhill, & Shephard, 2000; Katzmarzyk & Janssen, 2004). This is, in part, a consequence of the way we design our cities, with adverse repercussions for public health (Filion, Bunting, & Warriner, 1999; Moudon & Untermann, 1991). As a result, the role of the built environment and related policy has become a topic of great interest in the public health domain. Urban form measurement is a focus for current physical activity research, catalyzing efforts from the spatial-planning-related fields (Boarnet & Sarmiento, 1998; King, Stokols, Talen, Brassington, & Killingsworth, 2002).

Research in public health and space syntax provides evidence that living in environments that are objectively contrasting in terms of walkability (hereafter referred to as *contrasting environments*; e.g., environments that are high versus low in walkability) is associated with contrasting walking levels. For instance, individuals living in higher walkability neighbourhoods engage in about six times more walking trips and about 50% fewer automobile trips than individuals living in neighbourhoods that are characterized by lower walkability (Frank et al., 2009). Also, residents of neighbourhoods that are lower in walkability are about two and a half times less likely to accumulate the recommended 30 minutes of physical activity (Frank, Schmid, Sallis, Chapman, & Saelens, 2005). Higher pedestrian and cyclist volumes were observed in higher walkability (an individual every 7.5 minutes; Suminski, Petosa, & Stevens, 2006) versus lower walkability (an individual every 9.5 minutes; Suminski, Fritzsinger, Leck, & Hyder, 2008) areas. Space syntax research found an observed average density of 2.6 people per 100 meters in urban areas and of 0.4 to 0.7 people per 100 meters in residential housing estates (Hillier, Burdett, Peponis, & Penn, 1987).

Likewise, perceptions about the built environment held by individuals living in higher walkability environments are also associated with physical activity and walking at recommended levels (Duncan, Duncan, Stryker, & Chaumeton, 2002; Giles-Corti & Donovan, 2002) and rank consistently higher compared to their counterparts (Leslie et al., 2005). Neighbourhood environments perceived as providing opportunities for physical activity facilitate such activity (Bauman, Smith, Stoker, Bellew, & Booth, 1999; Giles-Corti & Donovan, 2002; Owen, Leslie, Salmon, & Fotheringham, 2000; Pikora, Giles-Corti, Bull, Jamrozik, & Donovan, 2003; Sallis, Johnson, Calfas, Caparosa, & Nichols, 1997). However, it appears that the availability, perception, and use of facilities in neighbourhoods is moderated by socio-economic status (SES; Brownson et al., 2000; Estabrooks, Lee, & Gyurcsik, 2003; Huston, Evenson, Bors, & Gizlice, 2003). As a result, SES should also be considered an important factor for understanding the role of the environment in relation to physical activity.

The measurement of urban form has been dramatically redefined, particularly in the public health context (Sallis, 2009), due to the rise of Geographic Information Systems (GIS) technologies, which have sparked theoretical debate about the various conceptualizations of urban form measurement specific to each field. However, much effort is needed to develop standardized urban form measures (Forsyth, Schmitz, Oakes, Zimmerman, & Koepp, 2006). Along with urban form measures based on an assessment of the *3Ds* of urban form (design, density, and diversity; see Cervero and Kockelman, 1997) and conventional accessibility measures that have the underlying assumption of rational choice (the default position in conceptualizing environmental influences on physical activity), other measures have caught the attention of researchers in the field of public health. The space syntax family of methods (see Hillier & Hanson, 1984) has proven very efficacious in capturing a cognitive distance in addition to physical distance between urban places (Turner, 2007b).

It appears that walking levels are influenced by both the quality of the neighbourhood environment and the availability and quality of neighbourhood facilities (Humpel, Owen & Leslie, 2002; Sallis, Kraft, & Linton, 2002; Sugiyama, Leslie, Giles-Corti, & Owen, 2009). While *3D*-affiliated measures rely on the assumption that individual urban form elements are attractors for pedestrian movement, space syntax measures rely on the assumption that the spatial layout determines primarily the patterns of movement. We proposed to investigate the association of urban form assessed objectively with physical activity within a Social Ecological Models framework (Sallis & Owen, 1997) that incorporates Space Syntax.

Our previous work has found good agreement of urban form assessed objectively using *3D* and space syntax measures (Cutumisu & Spence, 2009; Cutumisu & Spence, 2010). However, it is not clear whether *3D* or space syntax measures perform better in relation to self-reported or observed movement patterns (pedestrian, cyclist, and vehicular). However, a wealth of evidence supports the strength of the space syntax methodology in predicting observed movement patterns (Hillier, Burdett, Peponis, & Penn, 1987; Hillier & Iida, 2005; Penn, Hillier, Banister, & Xu, 1998; Turner, 2007a). Since space syntax has strong predictive value for observed movement patterns, it would be opportune to investigate the relationship between space syntax built environment measures (in particular angular analysis measures - *AA*) and observed pedestrian, cyclist and vehicular movement in contrasting environments classified objectively using *3D* measures. For this study, contrasting walkability environments are neighbourhood environments that are classified as either high or low in walkability based on *3D* measures.

Research Questions

The purpose of this study is to elucidate whether levels of observed movement of individuals living in contrasting walkability environments in

Edmonton, Alberta, are different. This study answered *Goal 3* of this dissertation. Specifically, Study 4 had two aims.

Aim 1 of this study was to compare observed movement in four neighbourhoods that were stratified by walkability and SES. We hypothesized that more pedestrians and cyclists and fewer vehicles would be observed in higher walkability neighbourhoods (assessed using *3D* measures) compared to lower walkability neighbourhoods.

Aim 2 of this study was to compare observed movement with the angular measure of walkability in the four neighbourhoods that were stratified by walkability (assessed objectively using *3D* measures) and by SES.

Research Focus

A social ecological model of environmental opportunities for physical activity (EOPA; Figure 1-1, Chapter 1) was employed to study the association between the physical environment and walking. Environment was conceptualized as place, which consists of an *objective environment* (referring to neighbourhood opportunities for physical activity and neighbourhood socio-demographics; denoted as *O*), a *subjective environment* (referring to individuals' perceptions of the environment conduciveness for physical activity; denoted as *S*), and a *resultant environment* (referring to observed and self-reported levels of physical activity; denoted as *R*). The relationship between objective and resultant environment (denoted as *OR*) was measured on *meso* scale using neighbourhood and street segments as units of analysis.

Methods

Data Sources

Though Edmonton includes a total of 340 neighbourhoods, information on neighbourhood socio-economic characteristics and walkability based on the 2006 Canadian Census of Statistics Canada was available for 238 neighbourhoods. A database that indicated areas in residential, commercial, industrial, and other land uses per neighbourhood was obtained from the Assessment and Taxation branch of the City of Edmonton. Spatial data on neighbourhoods were provided by the Infrastructure and Planning department of the City of Edmonton. In addition, GeoEdmonton and DMTI^{TM} provided data on street networks. Additional information based on observations in the field, such as pedestrian, cyclist, and vehicular counts, was collected. A set of 238 neighbourhoods with *3D* walkability and SES data available was selected for this study. The neighbourhoods were stratified by *3D* walkability and SES into four categories: *high walkability-high SES*, *high walkability-low SES*, *low walkability-high SES*, and *low walkability-low SES*. One neighbourhood in each category was then chosen for an analysis of observed movement. Location of selected neighbourhoods is presented in Figure 5-1. Data on angular walkability were also available for each neighbourhood. A total of 9,314 individuals reside in these four selected neighbourhoods. Descriptive statistics for the neighbourhoods are provided in Table 5-1.

Measures

Neighbourhood 3D Walkability

ArcGIS 9.3.1 (ESRI, 2009) and the Fnode extension (Solorzano, 2003) were employed to assess *3D* walkability using the Twin Cities GIS protocol (Forsyth, Schmitz, Oakes, Zimmerman, & Koepp, 2006). A *3D* walkability index was calculated using a modified version of Frank et al.'s (2009) weighted formula. The index was calculated using the formula: $z_W = z_{D1} + z_{D2} + 2*z_{D3}$, where z_W represents the z scores for walkability, z_{D1} represents the z scores for density, z_{D2} represents the z scores for diversity, and z_{D3} represents the z scores for design. Because information on retail floor area ratio was unavailable, we did not include the z score for the retail floor area ratio. *Diversity* was assessed using residential, retail, office, education/institutional (including religious establishments), and entertainment land uses. *Density* was calculated as the neighbourhood density of dwellings located in residential areas. *Design* was calculated as the neighbourhood density of intersections of four or more streets.

Angular Analysis

Angular walkability (*angular weighted betweenness*) using the UCL Depthmap 8.15.00c software (Turner, 2009; see Figure 5-2, Figure 5-3, Figure 5-4, and Figure 5-5) was calculated for every segment in the selected neighbourhoods. Angular betweenness assesses how often a street segment is encountered on the route from each segment to all possible segments in the studied layout. Angular betweenness calculations rely on the angular distance from each segment to all the others in the system, measured along the shortest angular path (i.e., the route with the lowest angular cost from a street segment to all the others in the system). Angular weighted betweenness incorporates the length of the origin and destination segments to account for longer segments that may generate more origins and destinations (Turner, 2007a). To avoid the edge effect (Ratti, 2004; Turner, 2007a), angular walkability was calculated for a radius R = 1000 m (R_{1000}), with 1 km being the average walking trip length in Edmonton (City of Edmonton, 2005). Angular weighted betweenness was calculated for each street segment of the network constituted by the road centerlines, as well as by the main pedestrian network paths in the neighbourhood.

Neighbourhood Socio-economic Status (SES)

Neighbourhood-level SES was assessed based on neighbourhood socio-economic variables extracted from the 2006 Canadian Census by the City of Edmonton. A procedure by Demissie, Hanley, Menzies, Joseph, and Ernst (2000) was used to determine neighbourhood SES composite indices. Specifically, neighbourhood SES was calculated as a sum of z-scores of net educational level and median income of census families ($) minus the z score of the proportion of unemployed.

Procedures

An observational study of pedestrian, cyclist, and vehicular movement was performed in the selected neighbourhoods using a modified version of the protocol of Penn and Dalton (1994). The movement structure of Edmonton consists of streets (or roads) and back alleys (which are mainly used for vehicular traffic, and only occasionally for pedestrian and cyclist traffic). For this study, observation gates were located only on streets (or roads). Pedestrian, cyclist, and vehicular movement on the back alleys was not observed. Location of the observation gates in each neighbourhood is presented in Figure 5-6, Figure 5-7, Figure 5-8, and Figure 5-9. Counts were taken by stationary observers at observation points (or gates), which were located, where possible, at the midpoint of each street segment that was observed.

Every street segment was observed for 10 minutes during each of three observation-time periods. Instead of taking counts on the same day at five observation-time periods (8-10 a.m., 10-12 a.m., 12-2 p.m., 2-4:30 p.m., and 4:30-6:30 p.m.) for all observation points as in Penn and Dalton (1994)'s protocol, this study involves only three observation time periods: morning (8-10 a.m.), noon (12-2 p.m.), and evening (4-6 p.m.). Each observer recorded the movement that was observed at the assigned gate on the street segment during an observational period of 10 minutes during each assigned observation-time slot (e.g., morning, noon, or evening). This resulted in 30 minutes (10 minutes * 3 observations = 30 minutes) of total coverage per street segment during a typical day (including the morning, noon, and evening observational time slots). Movement in both directions was recorded for each observed street segment. Total pedestrian, cyclist, and vehicular volumes (counts) were calculated for each street segment. The mean for the recorded pedestrian, cyclist, and vehicular movement during all three observational time slots (e.g., morning, noon, and evening) was calculated for each street segment. Then, the mean for each type of movement (e.g., pedestrian, cyclist, vehicular movement) for each street segment was weighted by the total number of street segments observed in each neighbourhood.

The observations were taken on the same day or, in situations when observations were taken on different days, it was ensured that the observations were conducted in similar weather conditions. The protocol was performed from May 27 to August 7, 2009. The average mean temperature was 17.66 degrees Celsius. No observations were conducted on rainy days. Observations were conducted by a team of graduate students. In addition to gaining the experience of being involved in a research project, the observers were remunerated for their time.

Analysis

SPSS 17 (PASWSTAT, 2009) was employed for data analysis. The level of statistical significance was set at $p < 0.05$. A preliminary exploratory analysis of the variables detected departures from normality for the walkability and the observed movement variables. Consequently, variables were transformed following the procedure by Turner (2007a). First, each variable was divided by the largest value. Then, a cube root was applied to the new variable. Since all variables approached normality after transformation, parametric statistics were further employed. For descriptive purposes, Neighbourhood 1 has low walkability and high SES (LWHS), Neighbourhood 2 has low walkability and low SES (LWLS), Neighbourhood 3 has high walkability and high SES (HWHS), and Neighbourhood 4 has high walkability and low SES (HWLS). The statistical procedures that were used are as follows. First, three *ANOVA*s were employed to compare the four neighbourhoods in terms of observed pedestrian, cyclist, and vehicular movement. Second, bivariate correlations were conducted for observed pedestrian, cyclist, and vehicular movement in relation to the angular measure within neighbourhoods. Finally, bivariate correlations were conducted for observed pedestrian, cyclist, and vehicular movement in relation to the angular measure in lower versus higher walkability neighbourhoods. The *alpha level* was set to 0.05.

Results

Across the four neighbourhoods, n = 520 observations of pedestrian, cyclist, and vehicular movement were made. The mean pedestrian, cyclist, and vehicular volumes in the four neighbourhoods, as well as in lower versus higher walkability areas, are presented in Table 5-2. The mean pedestrian volume (weighted by neighbourhood size based on the number of segments in each neighbourhood) was 0.03 per 10 minutes in lower walkability areas and 0.05 pedestrians per 10 minutes in higher walkability areas. Three one-way *ANOVAs* were conducted for observed movement for a dataset containing all observations for each street segment observed in the four neighbourhoods (n = 520), weighted by the size of each neighbourhood (by the number of segments in each neighbourhood). In the analysis of the observed pedestrian movement (Table 5-3), Levene's test indicated a violation of the assumption of homogeneity of variance. Therefore, Welch (F'(3,162.93) = 5.39, p = .001) and Brown-Forsythe (F^*(3, 294.413) = 7.47, p = .000) tests were consulted; both indicated a significant difference for the four neighbourhoods. Post-hoc comparisons using the Games-

Howell test indicated that the mean scores for the LWLS (*M* = 0.23, *SD* = 0.17) and LWHS (*M* = 0.21, *SD* = 0.15) neighbourhoods did not differ significantly. However, the mean scores for the HWHS (*M* = 0.23, *SD* = 0.12) and HWLS (*M* = 0.31, *SD* = 0.22) neighbourhoods were significantly different. Although the mean score for the LWHS neighbourhood (*M* = 0.21, *SD* = 0.15) was not significantly different from the mean scores for the HWHS (*M* = 0.23, *SD* = 0.12), the LWLS (*M* = 0.23, *SD* = 0.12) was significantly different from the HWLS (*M* = 0.31, *SD* = 0.22). Overall, significantly more pedestrian movement was observed in the HWLS neighbourhood compared to all others.

Similarly, Table 5-4 and Table 5-5 present the results of the *ANOVAs* for observed cyclist and vehicular movement, respectively. Significantly lower volumes of cyclist movement were observed in Neighbourhood 2 (LWLS) than in the rest of the neighbourhoods (Welch *F'*(3,175.122) = 15.75, *p* = .000 and Brown-Forsythe *F**(3, 317.742) = 13.51, *p* = .000). More cyclist movement was observed in the LWHS neighbourhood versus the LWLS, and in the HWHS neighbourhood versus the HWLS. Although more cyclist movement was observed in the HWLS neighbourhood versus the LWLS, no difference in cyclist movement was observed in the HWHS neighbourhood versus the LWHS. Vehicular movement was different in the four neighbourhoods, as well (Welch *F'*(3,177.831) = 3.773, *p* = 0.012 and Brown-Forsythe *F**(3, 278.630) = 4.079, *p* = .007). More vehicular movement was observed in the HWLS neighbourhood than in the HWHS. However, no differences were found in terms of vehicular movement in any of the lower walkability neighbourhoods compared to any of the higher walkability neighbourhoods, or between LWLS and LWHS neighbourhoods.

We then analyzed the correlations between our angular measure and observed movement in each of the four neighbourhoods (Table 5-5). The angular measure was significantly correlated with observed pedestrian movement in Neighbourhoods 1 (r_{LWHS} = .319), 3 (r_{HWHS} = .323), and 4 (r_{HWLS} = .389). The angular measure was also significantly correlated with observed cyclist movement in Neighbourhoods 1 (r_{LWHS} = .359), 3 (r_{HWHS} = .442), and 4 (r_{HWLS} = .340). Finally, the angular measure was significantly correlated with observed vehicular movement in Neighbourhoods 1 (r_{LWHS} = .311), 2 (r_{LWLS} = .645), 3 (r_{HWHS} = .509), and 4 (r_{HWLS} = .432).

In addition, we analyzed the correlation between our angular measure and observed movement in low versus high walkability neighbourhoods (Table 5-6). The angular measure was significantly correlated with observed pedestrian movement in low-walkability neighbourhoods (r_{LW} = .221) and high-walkability neighbourhoods (r_{HW}= .338). Furthermore, we tested the statistical significance of the difference between the correlation coefficients obtained for the association between observed movement and low versus high walkability (Pallant, 2007). We converted the *r* value into *z* scores for the two obtained correlations r_{LW} and r_{HW} and we used the following formula to calculate the observed value of *z* (z_{obs}): $z_{obs} = (z_1 - z_2) / \sqrt{(\frac{1}{N1-3} + \frac{1}{N2-3})}$. The obtained value was z_{obs} = -1.04, indicating the correlation coefficients in the low- versus high-walkability neighbourhoods were not statistically different. Similarly, we compared the correlation coefficients for cyclist and vehicular movement, respectively, in low- versus high-walkability neighbourhoods and found no difference in the strength of association between the angular measure and movement in the two walkability contexts.

Discussion

We found that observed pedestrian movement was significantly higher in volume in higher versus lower walkability neighbourhoods, but only in neighbourhoods with a lower SES. This is consistent with previous work investigating urban form influences on non-motorized transportation (Saelens, Sallis, Black, & Chen, 2003; Handy, Cao, & Mokhtarian, 2005). Residents of higher walkability neighbourhoods walk twice as much as their counterparts (Saelens, Sallis, Black, & Chen, 2003), with active transportation accounting for most of this difference. One study found that 18% of the residents of the lowest walkability areas walked as recommended compared to 37% in the highest walkability areas (Frank, Schmid, Sallis, Chapman, & Saelens, 2005). Also, areas higher in density (Ewing & Cervero, 2001; Cervero & Kockelman, 1997), land use mix (Lee & Moudon 2004; Frank, Sallis, Conway, Chapman, Saelens, & Bachman, 2006), street connectivity (Frank, Schmid, Sallis, Chapman, & Saelens, 2005), and intense retail land use (Rodriguez, Evenson, Diez-Rouz, & Brines, 2009) are associated with increased physical activity.

In addition, no differences were observed in pedestrian movement between lower walkability neighbourhoods that differ in terms of SES. Our suggested explanation is the prevalence of a car culture in Edmonton. According to the City of Edmonton’s Household Travel Survey (2005), approximately 77%

of Edmontonians are car drivers (57%) or passengers (20%), while the other 23% use more activity friendly transportation modes such as public transit (9%), walking (11%), and cycling (1%). Also, Edmonton is the second-fastest-growing Canadian city, with its largest increase in population being witnessed in suburban areas (City of Edmonton, 2005). Another explanation for this finding might lie in the difference in terms of the type of physical activity residents undertake in these neighbourhoods. Residents of higher SES neighbourhoods appear to be engaging in more recreational physical activity than their counterparts living in lower SES neighbourhoods (Parks, Housemann, & Brownson, 2003; Wilson, Kirtland, Ainsworth, & Addy, 2004), while residents of lower SES neighbourhoods appear to walk more. However, we suspect that this may not be the case in our lower walkability neighbourhoods. While LWHS residents are expected to walk less than the residents of LWLS, it is possible that education and awareness about the benefits of a healthier lifestyle may play a role. In addition, the proximity to green space and the character of the LWHS (e.g., premium housing, well maintained streetscapes) makes this area attractive for recreational walks. Quality of streetscapes and public spaces (Owens, 1993b), neighbourhood imageability, legibility, transparency, coherence, and linkage (Ewing, Handy, Brownson, Clemente, & Winston, 2006) are positively associated with walking. Therefore, it is possible that residents of the two higher SES neighbourhoods have positive perceptions of their neighbourhoods, which makes them more likely to engage in physical activity (Hoehner, Brennan Ramirez, Elliott, Handy, & Brownson, 2005; Humpel, Owen, Iverson, Leslie, & Bauman, 2004).

However, lower volumes of pedestrian movement were observed in higher walkability neighbourhoods that were higher in SES, compared to higher walkability neighbourhoods that were lower in SES. Regarding our higher walkability neighbourhoods, our HWLS neighbourhood has good access to low cost recreational facilities, and this may contribute to increased walking levels in the neighbourhood. It is also possible that the residents of the HWLS neighbourhoods are more aware of the benefits of a healthy lifestyle, particularly since we found that individuals living in HWLS neighbourhoods also cycle more. Also, it is possible that certain economic constraints (such as price of gas or parking fees) may influence the choice of transportation mode.

We found cyclist volumes in Neighbourhood 2 (LWLS) to be significantly lower than in the other neighbourhoods. Even though we expected higher rates in the LWLS neighbourhood than in the LWHS neighbourhood, it is possible that the character (e.g., the general pleasant atmosphere for being in the neighbourhood) of the LWHS makes that neighbourhood more attractive for cycling.

Finding no difference in vehicular movement for the higher versus lower walkability neighbourhoods is not surprising, due to the prevalence of cars in Edmonton and to the fact that street connectivity is conducive to both vehicular and pedestrian traffic. Therefore, the more walkable neighbourhoods have better connected street networks and are better connected to the street networks on the larger scale, thus attracting more through movement.

When we compared the correlation between our angular measure and observed movement in lower versus higher walkability neighbourhoods, we found no statistically significant difference. Previous work acknowledged the difficulty of space syntax methods in providing good correlations in areas such as many of the suburban neighbourhoods with curvilinear street networks that lack intelligibility, i.e. their global structure cannot be easily understood by reading the local proprieties of the layout (Hillier, Burdett, Peponis, & Penn, 1987). Turner (2007a) found better associations ($R^2 = .82$ was the best association at radius R=1500 m) for the angular measure and vehicular traffic in an organic urban texture in London. Another space syntax work conducted in London yielded an average correlation of .75 in four urban areas between the syntactic measures and pedestrian volumes (measured in pedestrian counts per 100 m per minute that are recorded by observers moving at a rate of 3.5 km/h; Hillier, Burdett, Peponis, & Penn, 1987). Previous space syntax work conducted in Boston explained 81% of pedestrian movement (Raford & Ragland, 2006). However, the character of the neighbourhood analyzed was very different from the character of our Edmonton neighbourhoods, which are predominantly residential. Space syntax work conducted in Atlanta found average pedestrian volumes of one person per 5 minutes, with downtown volumes of 13.6 persons per 5 minutes and 5.62 pedestrians per 5 minutes in the 10% most used space (Peponis, Ross, & Rashid, 1997). They found correlations between syntactic properties and pedestrian movement ranging from .20 to .59.

Another more recent study conducted in Atlanta produced two R^2 of about .33 and .53 for two syntactic measures and pedestrian movement in an analysis of 38 gates in one of the most pedestrian friendly neighbourhoods in the city (Peponis, Bafna, & Zhang, 2008). They found a mean number of 25 pedestrians per 20 minutes, or 12.5 pedestrians per 10 minutes. We found a mean pedestrian volume of 8.74 pedestrians per 10 minutes for a typical day of observation in our study, in the higher walkability neighbourhoods. Our best correlation of pedestrian volume and the syntactic measure is .39, so our correlations for Edmonton are much weaker and our pedestrian volumes are lower compared with the results from the Atlanta study. Typically, encounter rates observed are about 0.6 to 0.8 pedestrians per 100 m per minute in housing estates and about 2.6 pedestrians per 100 m per minute in urban areas (Hillier, Burdett, Peponis, & Penn, 1987). Even though pedestrian volumes found in Edmonton are much smaller than in European cities, areas that are better connected (i.e., have higher angular measures) display higher pedestrian volumes. However, as Peponis, Ross and Rashid (1997) note, some pedestrians observed in downtown areas might be walking to parking lots.

We did not include informal alleys and walkways that individuals might use in their daily trips in our *3D* and angular measure. A recent study pointed out that current walkability measures do not include such informal alleys; hence they may be biased assessments of connectivity. In addition, sidewalk continuity and quality influences pedestrian volumes (Chin, van Niel, Giles-Corti, & Knuiman, 2008). Aspects such as sidewalk continuity and maintenance, the presence of trees, and the presence of physical and social incivilities warrant further investigation because the perceived presence of functional pedestrian infrastructure was associated with walking and vigorous activity. The perceived availability of sidewalks (Addy et al., 2004; Brownson, Baker, Housemann, Brennan, & Bacak, 2001; Giles-Corti & Donovan, 2002c; King, Castro, Eyler, Wilcox, Sallis, & Brownson, 2000; Sallis, Johnson, Calfas, Caparosa, & Nichols, 1997; Wilcox, Castro, King, Housemann, & Brownson, 2000) and the perception of adequate walking surfaces (Pikora, Giles-Corti, Bull, Jamrozik, & Donovan, 2003) influence physical activity. A lack of sidewalks is reported in Edmonton for 45% of all potential sidewalks along roadways (City of Edmonton, 2008), along with many curb ramps along the existing sidewalks; this posits adverse consequences for accessibility. Moreover, about 1,700 bus stops throughout Edmonton are not properly connected with adequate hard-surfaced links to the sidewalk network. Since Edmonton's Sidewalk Strategy proposes addressing discontinuities in the sidewalk network, a natural experiment can be conducted before and after absent elements are restored/built, to better understand how pedestrian volumes differ in areas with different degrees of connectivity.

We did, however, include alleys and driveways in our analysis. While they contribute to overall connectivity, they represent spaces that are less likely to be used for pedestrian movement compared to the main streets with sidewalks. Since other space syntax studies were not conducted in areas where such alleys are present, this may constitute an explanation for the weaker correlations we found between the angular measure and observed volumes, compared to the correlations other studies found.

Strengths and Limitations

The main strength of this study is the use of GIS to objectively assess urban form in relation to the observed level of walking, within a joint Social Ecological Models - Space Syntax perspective. Using street segments as units of analysis offer an opportunity to analyze the association between walking and urban form on a disaggregate scale.

Several study limitations need to be mentioned. Self-selection is likely a contributor to the differences we found between contrasting environments (Krizek, 2003; Mokhtarian and Cao, 2008). It may also have played a role in our observed patterns of movement. Also, this study cannot establish causality. Although the space syntax method is considered a theoretical proxy for the direct effect of environment on walking (which is built on the premise that spatial layout exerts a direct effect on movement), there is not enough evidence to establish a direct effect of the layout on movement. Other limitations include potential database inaccuracies and the selection of observation time slots. Space syntax studies have typically observed movement in five time slots, capturing more of the pedestrian volume for each segment. Also, we did not compare weekday versus weekend pedestrian volumes.

Our results add to the literature documenting the differences in physical activity patterns in contrasting environments in terms of walkability. Future work should compare weekday versus weekend pedestrian volumes and should conduct studies that incorporate informal links in the pedestrian network, as well as qualitative information regarding the quality of the sidewalks, into analyses. Moreover, qualitative research is necessary to understand the analyzed locales, in conjunction with more observational studies and audits of the built environment. Further work should also analyze land uses adjacent to each street segment and evaluate the presence of attractors in influencing observed movement patterns. Finally, considering both observed and self-reported pedestrian movement in conjunction will result in a better understanding of the association between urban form and physical activity in contrasting environments.

In conclusion, understanding the association between the *fabric of movement* and the patterns of walking, cycling, and vehicular movement in urban environments, as well as how this fabric might differ in contrasting environments, might help elucidate the association between urban form and physical activity.

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Tables

Table 5-1. Descriptive statistics for the selected four neighbourhoods

Neighbourhood	1	2	3	4
Number of residents	1,130	1,763	2,972	3,449
Number of households	585	616	1,291	1,529

(source: City of Edmonton, Municipal Census, 2005)

Table 5-2. Mean movement per 10 minute observation slots of each street segment on a typical day in the four neighbourhoods and in the low versus high neighbourhoods, weighted by number of observed streets segments in each neighbourhood

Neighbourhood	*N*	Weighted observed pedestrian movement *M (SD)*	Weighted observed cyclist movement *M (SD)*	Weighted observed vehicular movement *M (SD)*
Neighbourhood 1 (LWHS)	77	0.02 (0.02)	0.01 (0.02)	0.83 (1.96)
Neighbourhood 2 (LWLS)	62	0.03 (0.04)	0.006 (0.01)	1.92 (4.67)
Neighbourhood 3 (HWHS)	256	0.02 (0.03)	0.01 (0.02)	0.88 (1.57)
Neighbourhood 4 (HWLS)	125	0.09 (0.19)	0.01 (0.01)	1.55 (2.86)
Low walkability	139	0.03 (0.03)	0.01 (0.02)	1.32 (3.47)
High walkability	381	0.05 (0.11)	0.01 (0.02)	1.10 (2.10)

Table 5-3. Mean differences for observed pedestrian movement in the four selected neighbourhoods, weighted by neighbourhood size (by the number of observed street segments in each neighbourhood)

		Mean difference	Std.	95% Confidence Interval	
		(*I* - *J*)	Error	Lower bound	Upper bound
(*I*)	(*J*)				
Neighbourhood 1	Neighbourhood 2 (LWLS)	- 0.014	0.028	- 0.089	0.060
(LWHS)	Neighbourhood 3 (HWHS)	- 0.019	0.019	- 0.069	0. 031
	Neighbourhood 4 (HWLS)	- 0.100*	0.027	- 0.170	- 0.030
Neighbourhood 2	Neighbourhood 1 (LWHS)	0.014	0.028	- 0.060	0.089
(LWLS)	Neighbourhood 3 (HWHS)	- 0.004	0.023	- 0.067	0.058
	Neighbourhood 4 (HWLS)	- 0.085*	0.030	- 0.165	- 0.006
Neighbourhood 3	Neighbourhood 1 (LWHS)	0.019	0.019	- 0.031	0.069
(HWHS)	Neighbourhood 2 (LWLS)	0.004	0.023	- 0.058	0.067
	Neighbourhood 4 (HWLS)	- 0.081*	0.021	- 0.138	- 0.024
Neighbourhood 4	Neighbourhood 1 (LWHS)	0.100*	0.027	0.030	0.170
(HWLS)	Neighbourhood 2 (LWLS)	0.085*	0.030	0.006	0.165

Neighbourhood 3 (HWHS)	0.081*	0.021	0.024	0.138

*The mean difference is significant at the 0.05 level.

Table 5-4. Mean differences for observed cyclist movement in the four selected neighbourhoods, weighted by neighbourhood size (by the number of observed street segments in each neighbourhood)

		Mean difference (*I* - *J*)	Std. Error	95% Confidence Interval	
				Lower bound	Upper bound
(*I*)	(*J*)				
Neighbourhood 1 (LWHS)	Neighbourhood 2 (LWLS)	0.131*	0.039	0.027	0.235
	Neighbourhood 3 (HWHS)	- 0.070	0.031	- 0.153	0.012
	Neighbourhood 4 (HWLS)	0.016	0.036	- 0.078	0.111
Neighbourhood 2 (LWLS)	Neighbourhood 1 (LWHS)	- 0.131*	0.039	- 0.235	- 0.027
	Neighbourhood 3 (HWHS)	- 0.201*	0.030	- 0.282	- 0.122
	Neighbourhood 4 (HWLS)	- 0.114*	0.035	- 0.207	- 0.022
Neighbourhood 3 (HWHS)	Neighbourhood 1 (LWHS)	0.070	0.031	- 0.012	0.153
	Neighbourhood 2 (LWLS)	0.201*	0.030	0.122	0.282
	Neighbourhood 4 (HWLS)	0.087*	0.026	0.019	0.154
Neighbourhood 4	Neighbourhood 1 (LWHS)	- 0.016	0.036	- 0.111	0.078

(HWLS)	Neighbourhood 2 (LWLS)	0.114*	0.035	0.022	0.207
	Neighbourhood 3 (HWHS)	- 0.087*	0.026	- 0.154	- 0.019

*The mean difference is significant at the 0.05 level.

Table 5-5. Mean differences for observed vehicular movement in the four selected neighbourhoods, weighted by neighbourhood size (by the number of observed street segments in each neighbourhood)

		Mean difference	Std. Error	95% Confidence Interval	
		(*I* - *J*)		Lower bound	Upper bound
(*I*)	(*J*)				
Neighbourhood 1 (LWHS)	Neighbourhood 2 (LWLS)	- 0.052	0.034	- 0.141	0.037
	Neighbourhood 3 (HWHS)	0.018	0.021	- 0.037	0.074
	Neighbourhood 4 (HWLS)	- 0.046	0.026	- 0.114	0.021
Neighbourhood 2 (LWLS)	Neighbourhood 1 (LWHS)	0.052	0.034	- 0.037	0.141
	Neighbourhood 3 (HWHS)	0.0470	0.031	- 0.011	0.152
	Neighbourhood 4 (HWLS)	0.005	0.034	- 0.085	0.096
Neighbourhood 3 (HWHS)	Neighbourhood 1 (LWHS)	- 0.018	0.021	- 0.07	0.037
	Neighbourhood 2 (LWLS)	- 0.070	0.031	- 0.152	0.011
	Neighbourhood 4 (HWLS)	- 0.064*	0.022	- 0.123	- 0.006
Neighbourhood 4 (HWLS)	Neighbourhood 1 (LWHS)	0.046	0.026	- 0.021	0.114
	Neighbourhood 2 (LWLS)	- 0.005	0.034	- 0.096	0.085

Neighbourhood 3 (HWHS)	0.064*	0.022	0.006	0.123

*The mean difference is significant at the 0.05 level.

Table 5-6. Correlations between R_{1000} angular weighted betweenness and observed movement in the four neighbourhoods

Neighbourhood	*N*	Observed pedestrian movement	Observed cyclist movement	Observed vehicular movement
Neighbourhood 1 (LWHS)	77	.319**	.359**	.311**
Neighbourhood 2 (LWLS)	62	.098	.129	.645**
Neighbourhood 3 (HWHS)	256	.323**	.442**	.509**
Neighbourhood 4 (HWLS)	125	.389**	.340**	.432**
Low walkability	139	.221**	.263**	.467**
High walkability	381	.338**	.401**	.487**

** Correlation is significant at the .01 level.

Figures

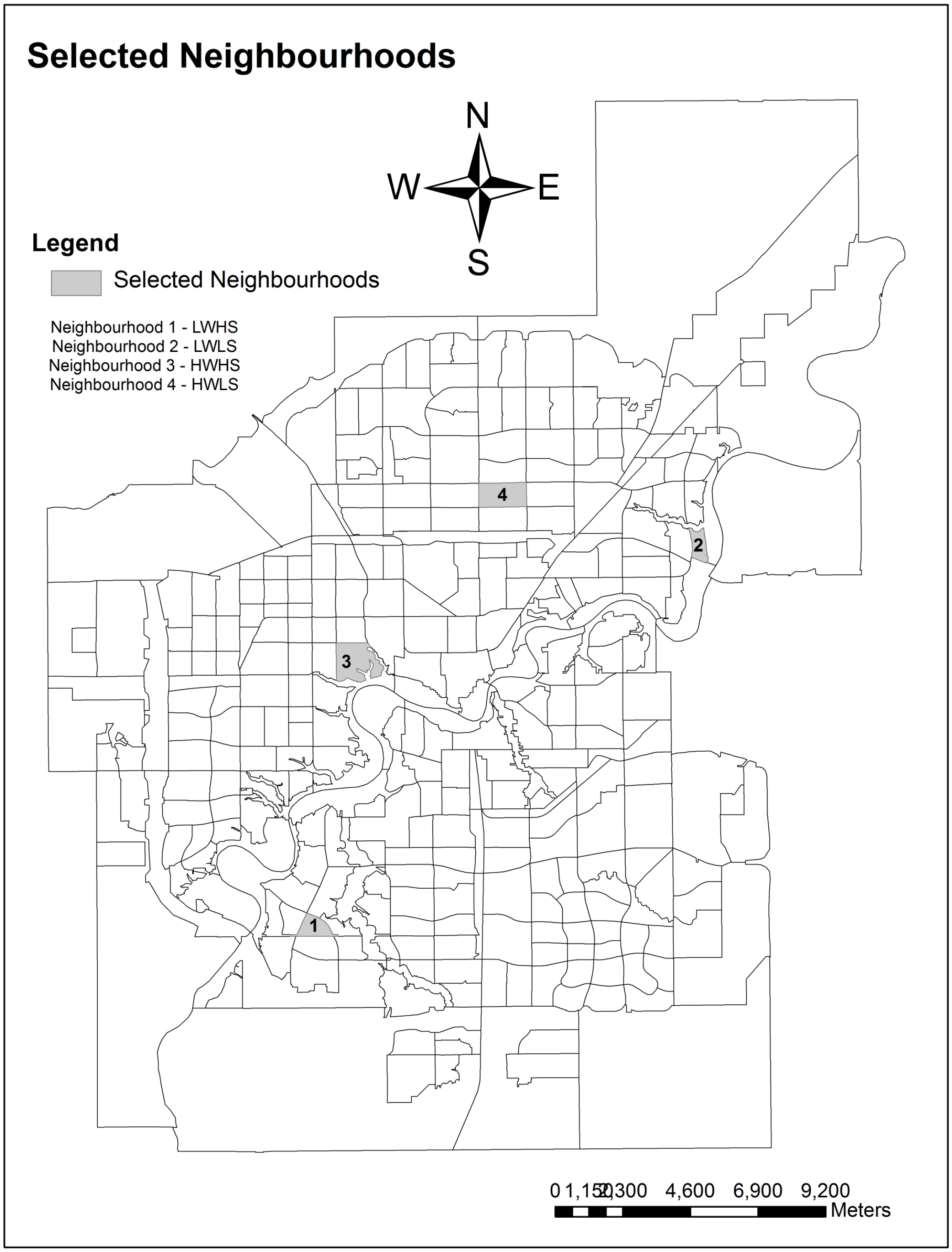

Figure 5-1. Selected Neighbourhoods

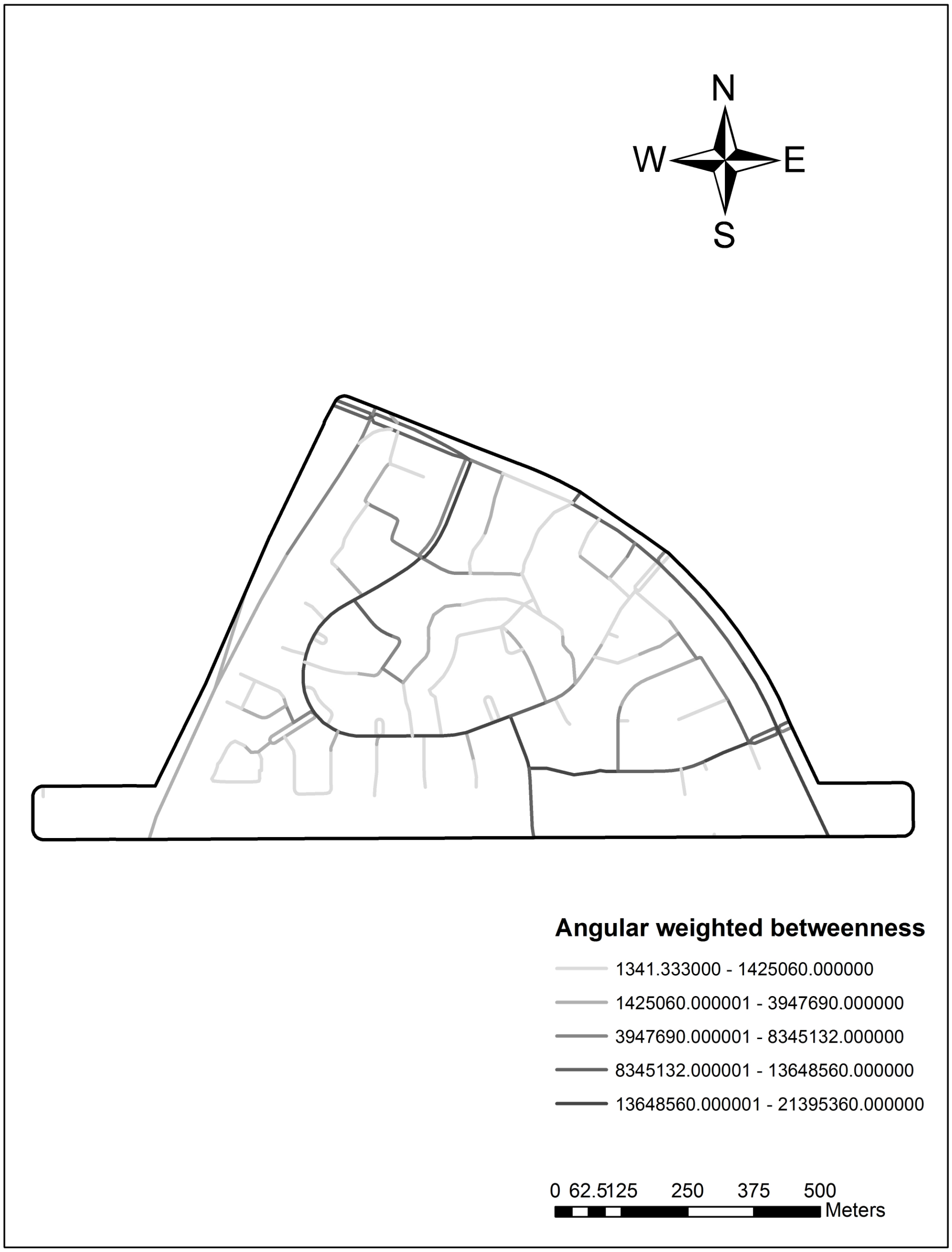

Figure 5-2. Angular Walkability - Neighbourhood 1 (LWHS)

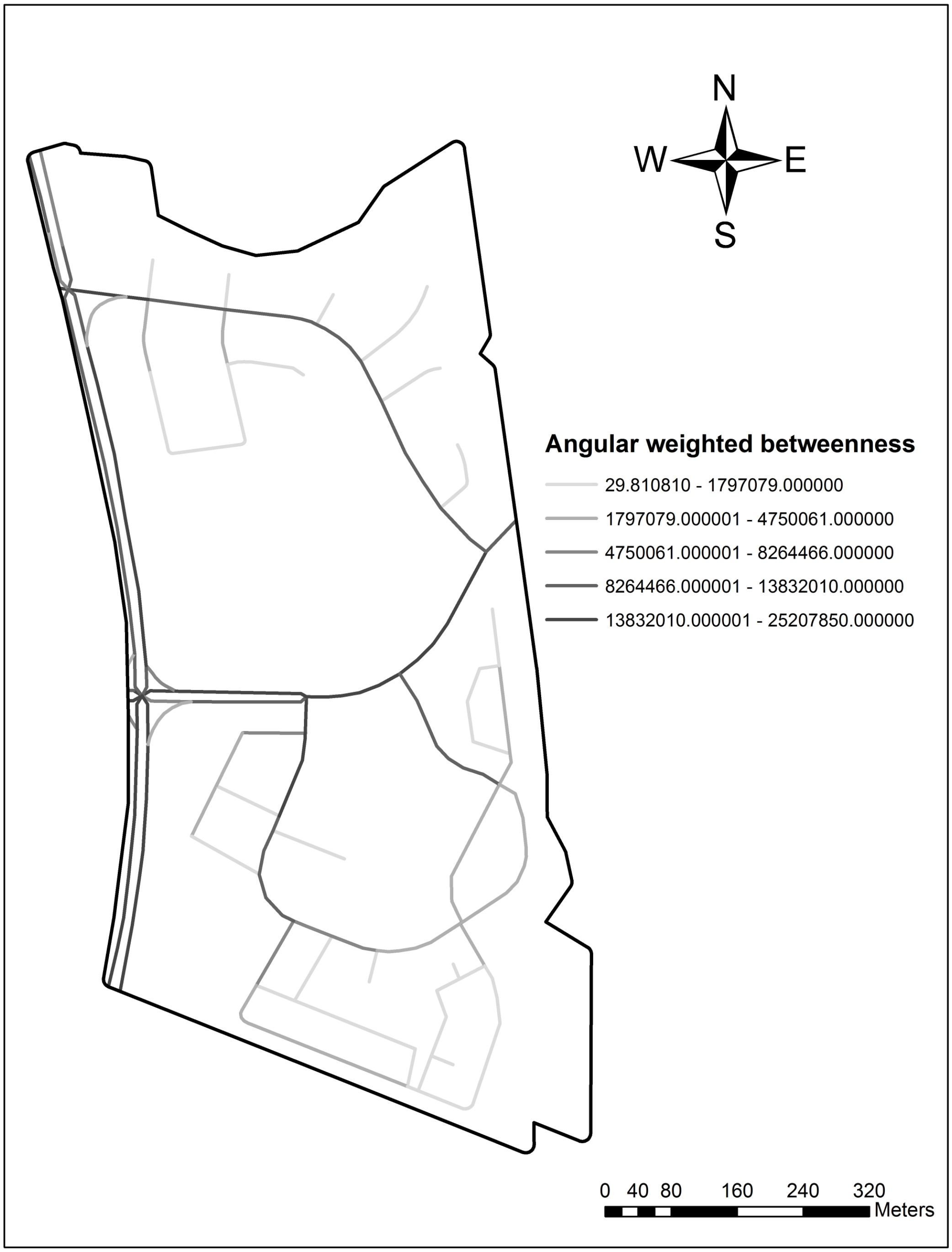

Figure 5-3. Angular Walkability - Neighbourhood 2 (LWLS)

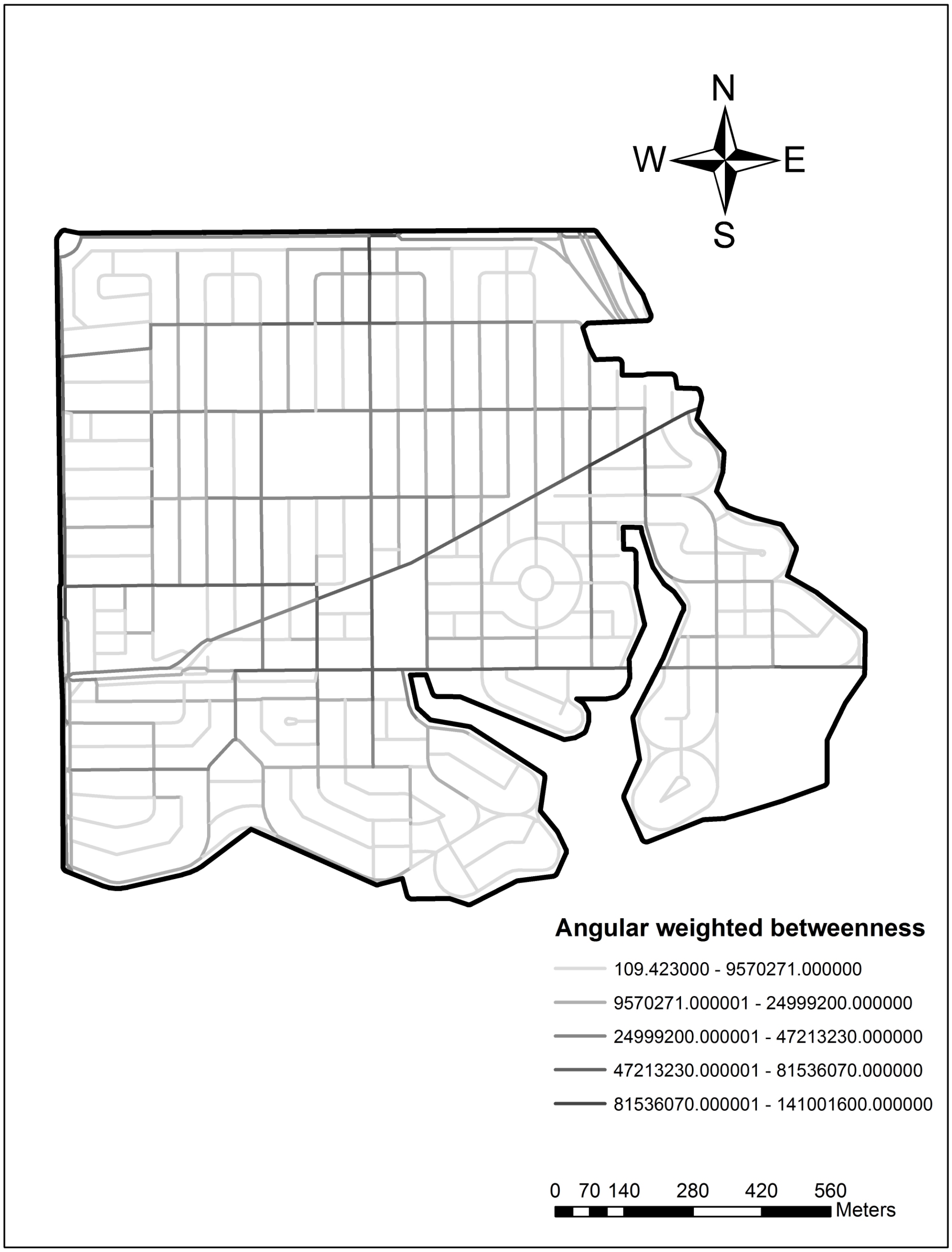

Figure 5-4. Angular Walkability - Neighbourhood 3 (HWHS)

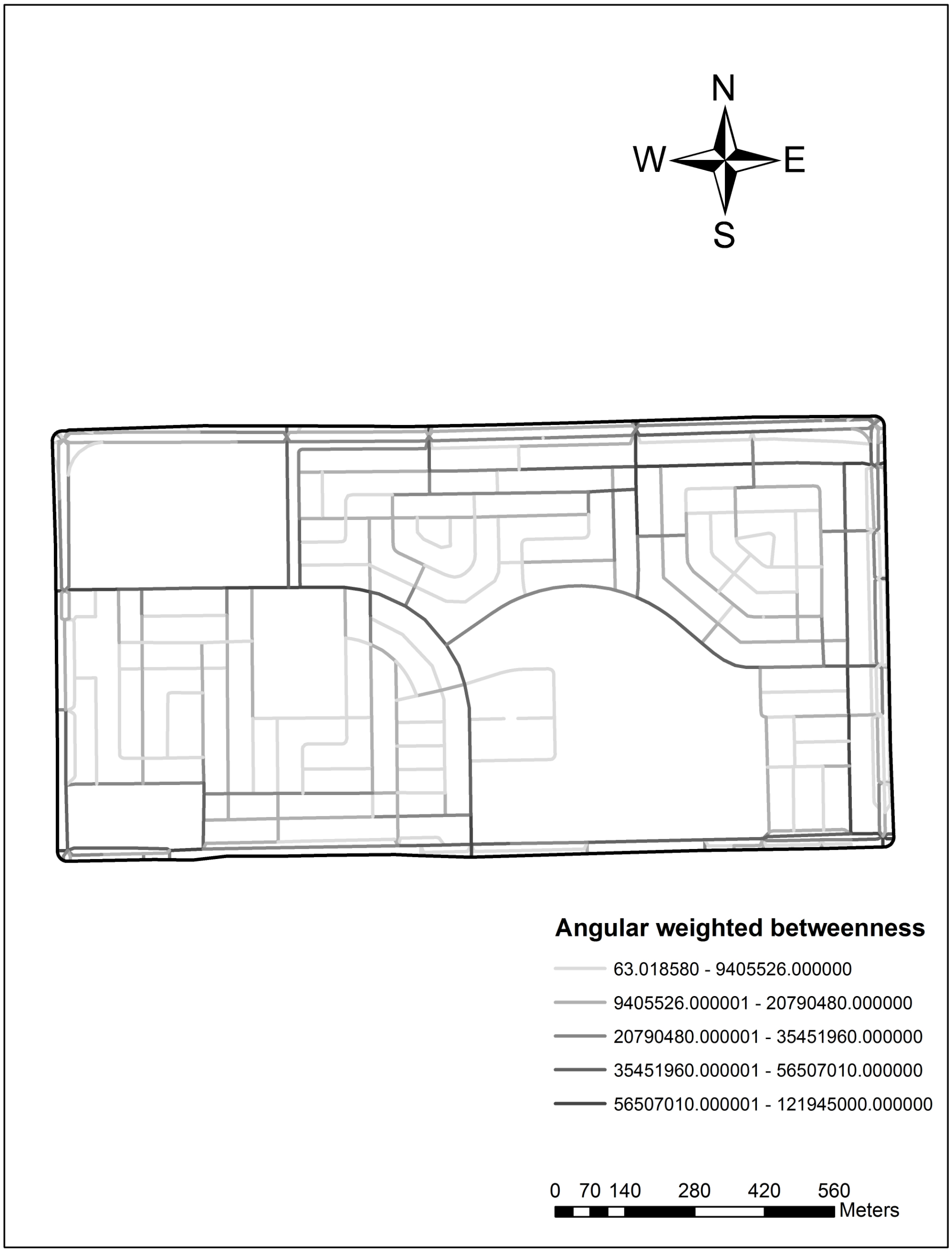

Figure 5-5. Angular Walkability - Neighbourhood 4 (LWLS)

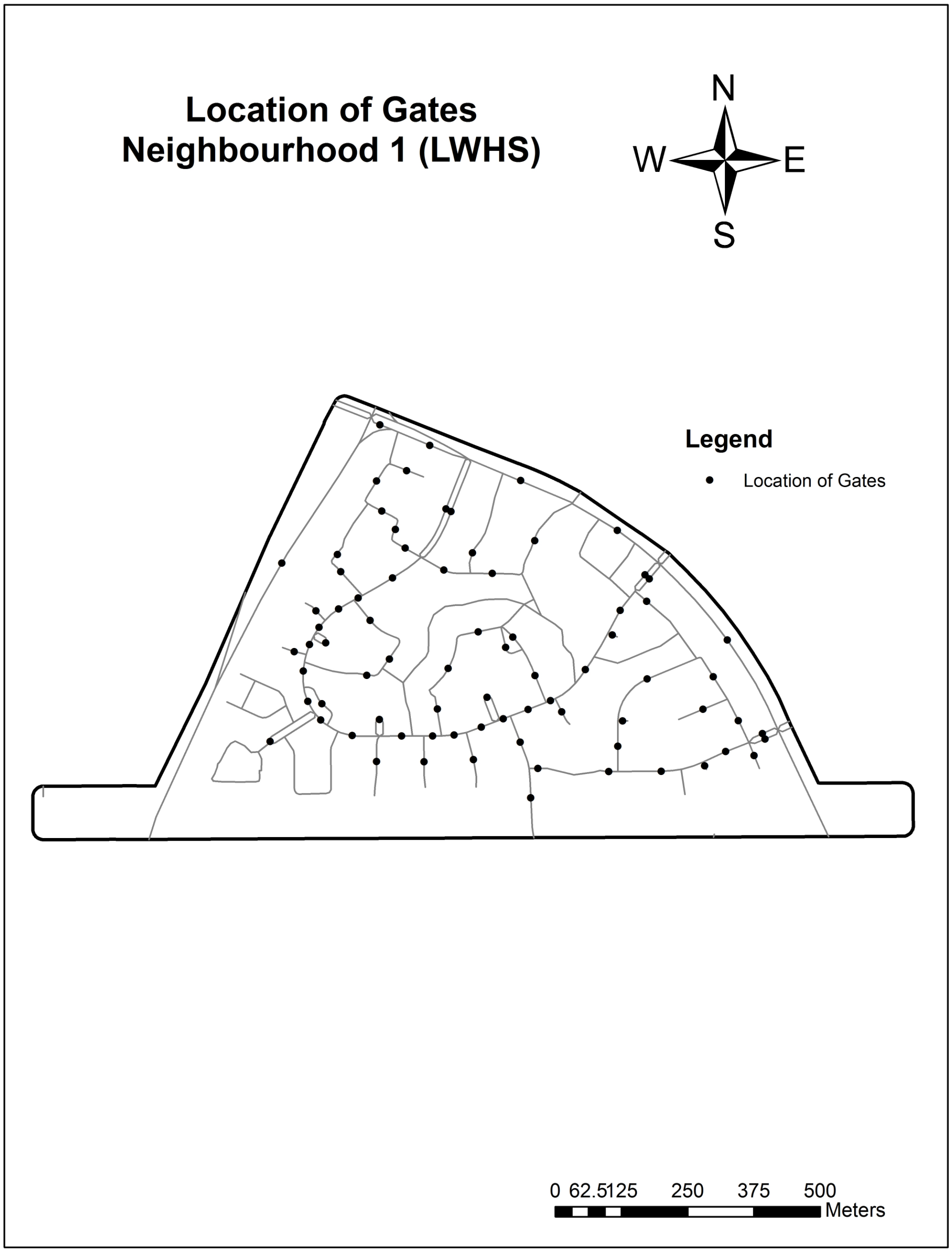

Figure 5-6. Location of gates - Neighbourhood 1 (LWHS)

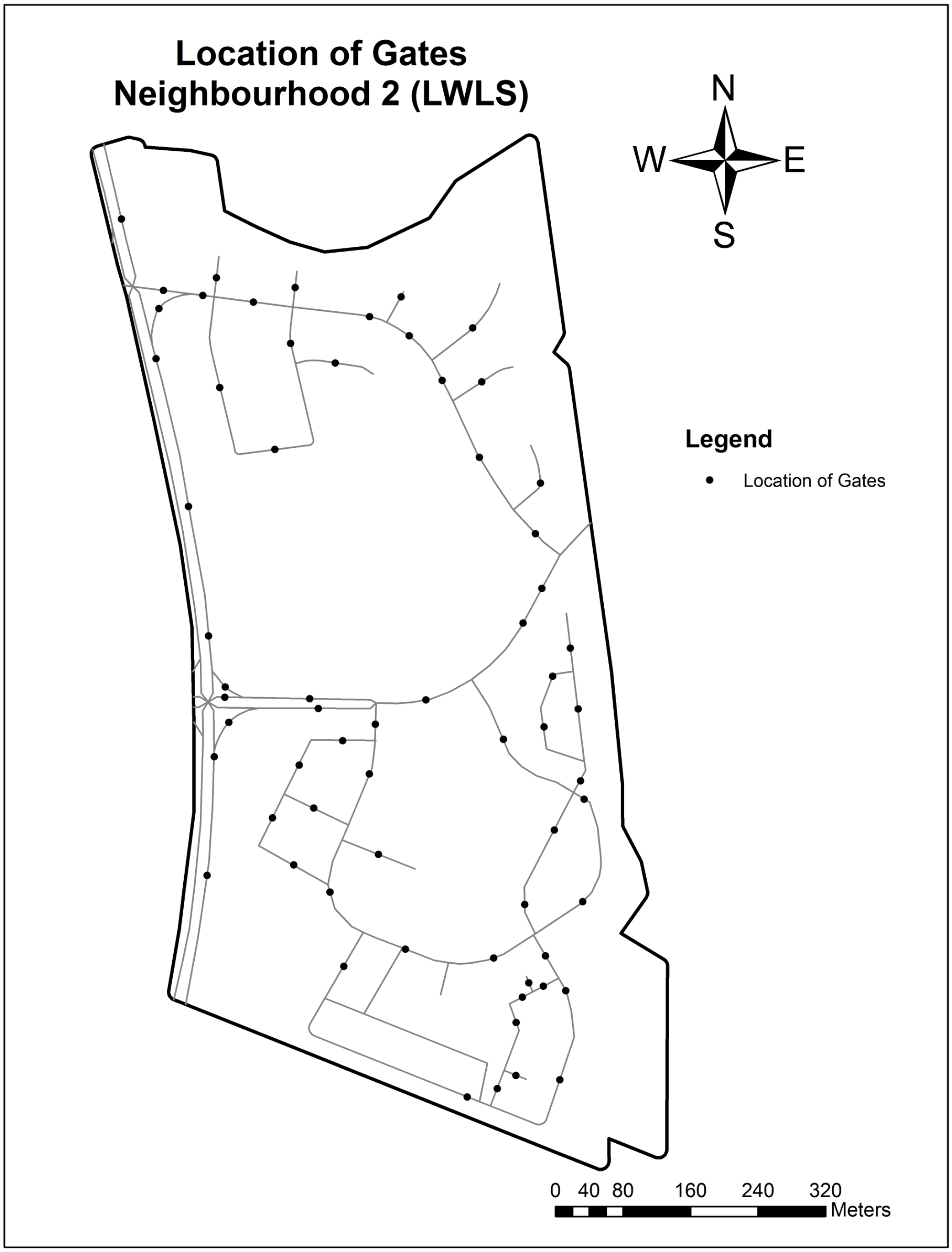

Figure 5-7. Location of gates - Neighbourhood 2 (LWLS)

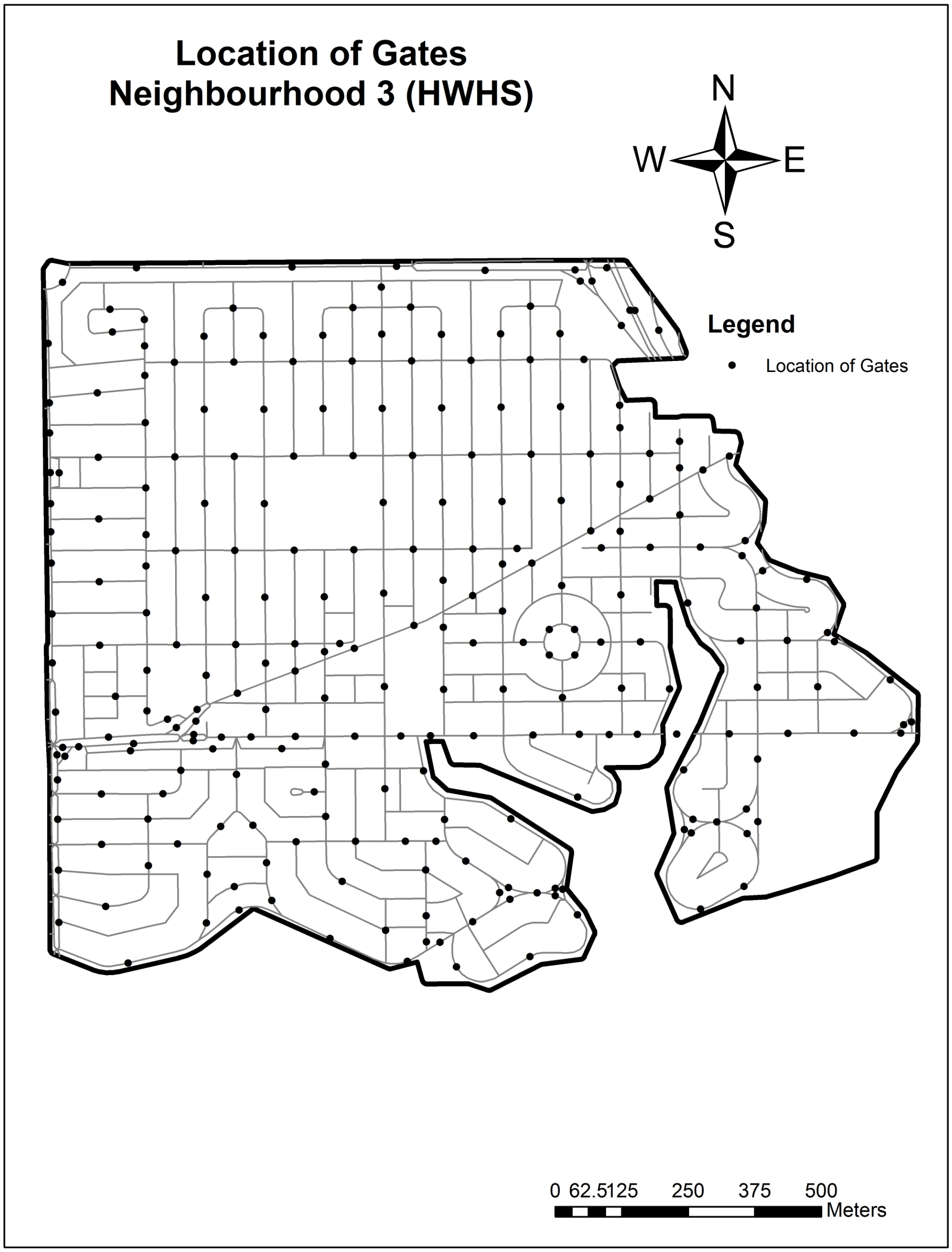

Figure 5-8. Location of gates - Neighbourhood 3 (HWHS)

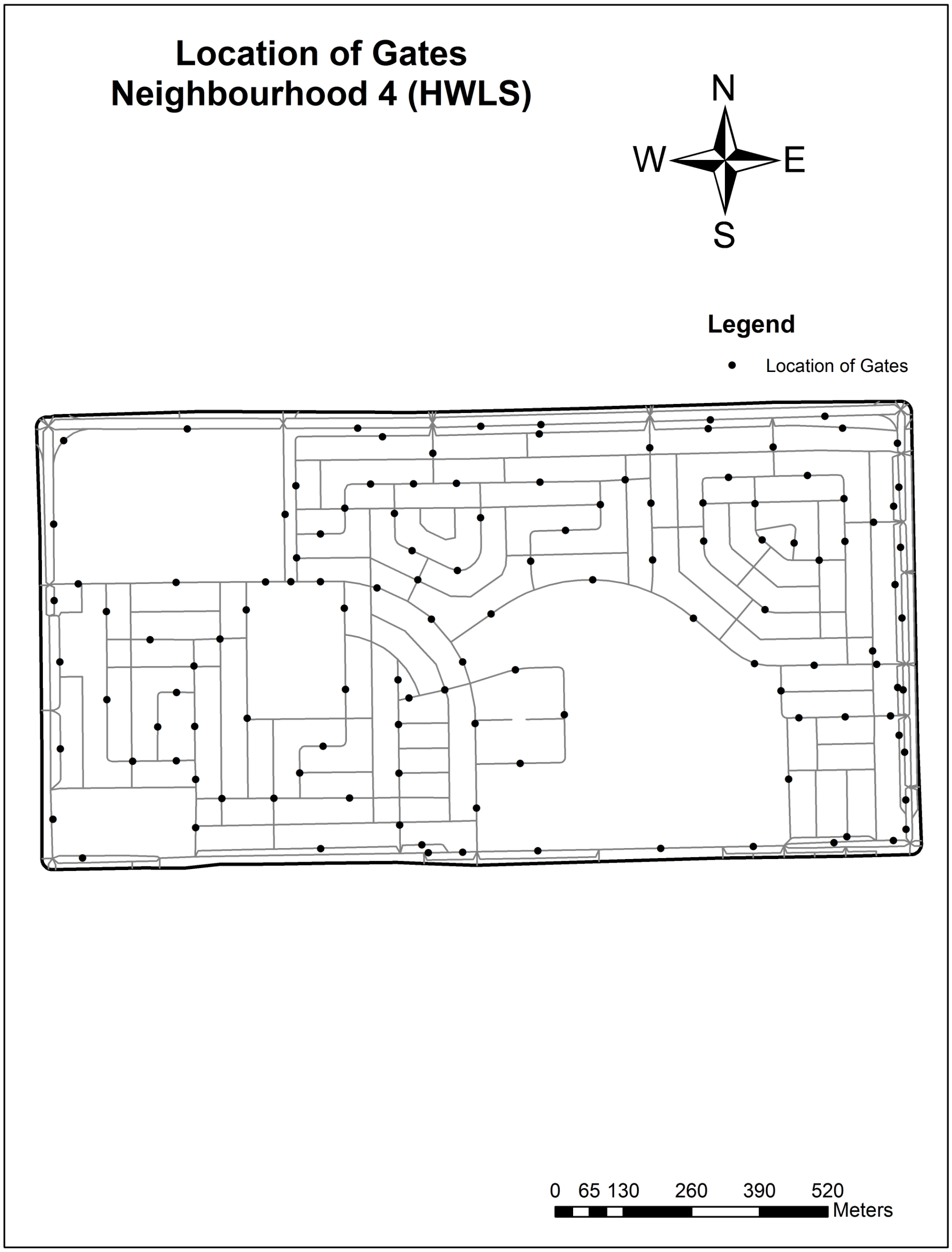

Figure 5-9. Location of gates - Neighbourhood 4 (HWLS)

CHAPTER 6. CONCLUSIONS AND IMPLICATIONS FOR FUTURE WORK

Conclusions

This dissertation comprises of four studies that seek to answer the following main research question: *What is the association between urban form and the physical activity of adults?* This dissertation examined three specific research goals, as follows. *Goal 1* was to explore and compare the *3Ds* of urban form with the angular analysis method. *Goal 2* was to assess the association of *objective* and *subjective* urban form with physical activity. *Goal 3* was to compare the self-reported walking and total physical activity, as well as actual walking, of individuals living in higher and lower walkability environments.

In response to calls for improving theoretical conceptualizations of place effects on physical activity and measurement of urban form at multiple levels of analysis (Matthews, Vernez-Moudon, & Daniel, 2009), I proposed a joint Ecological Models-Space Syntax framework for my program of research. Within this joint framework, conventional public health approaches (Cervero and Kockelman, 1997) and space syntax methodology (Hillier & Hanson, 1984) were employed to address both the direct and indirect effects that environment exerts on physical activity at various urban scales. An analysis was conducted of place understood as a triad consisting of the *objective environment* (pertaining to locale and location), *subjective environment* (pertaining to sense of place), and *resultant environment* (pertaining to the range of activities that individuals perform in urban space, as described by the self-reported and observed physical activity) in the specific case of physical activity. Within this place perspective, I explored various methods to elucidate whether objective or subjective environments influenced walking (self-reported and actual) and physical activity.

Study 1 investigated the *3D* and the angular analysis methods in assessing neighbourhood walkability, answering *Research Goal 1* of this dissertation. It found good agreement based on various radii calculations for the angular measures (i.e., Kendall's τ between .642 and .721 for associations between neighbourhood *3D* walkability and angular walkability). Therefore, an investigation of the environmental correlates of pedestrian movement as revealed by space syntax research may provide important contributions to the evidence on the correlates of physical activity.

Study 2 investigated the predictors of self-reported total physical activity, answering *Research Goal 2* of this dissertation. It found that spatial proximity to recreational facilities such as sports fields (radius 1500 m) increases the likelihood of being sufficiently physically active (i.e., accumulating a minimum of 750 MET*minutes per week), after controlling for socio-demographic factors. Although awareness about the presence of attractive opportunities for physical activity has been associated with greater physical activity (Humpel, Owen, & Leslie, 2002), my study found no such associations. I speculated that the way individuals conceptualize perceived environment within the immediate proximity of their residence may have played a role in these findings.

Study 3 investigated the predictors of self-reported total physical activity, answering *Research Goals 2* and *3* of this dissertation. It found that only aspects pertaining to the perceived environment predict the likelihood of walking sufficiently (a minimum of 495 MET*minutes per week). In addition, no difference was found in the self-reported total walking as recommended between individuals who live in neighbourhoods that were assessed using both the *3D* and angular measures as lower versus higher walkability. I speculated that our sample of residents living in contrasting environments is more likely to show smaller differences in the number of self-reported walking trips, because of the prevalence of a car-oriented culture in Edmonton (City of Edmonton, 2005), the possibility of a *zero-sum game* (Forsyth, Oakes, Schmitz, & Hearst, 2007), and/ or the lack of specificity of our outcome measure (Giles-Corti et al., 2005). I also compared areas of low versus high walkability assessed with *3D* and angular measures. Various neighbourhood categorizations proposed in the past (see Krizek, 2003 for a review) were criticized for being based on intuition rather than empirical testing (Handy, Boarnet, Ewing & Killingsworth, 2002) or for being distortions of reality, since usually the neighbourhoods are positioned within a continuum developed along two dimensions (Etzioni & Lehman, 1967). Better categorizations for neighbourhoods are required to elucidate the influence of built environment on physical activity. Perhaps such categorizations could include *3D* and angular walkability as studied dimensions.

Finally, Study 4 investigated the volumes of observed pedestrian, cyclist, and vehicular movement in four neighbourhoods that contrast in terms of SES and objectively-assessed walkability; it answered *Research Goal 3* of this dissertation. Study 4 found higher pedestrian volumes in neighbourhoods that were objectively assessed as higher in walkability than in neighbourhoods that were objectively assessed as lower in walkability. This is consistent with public health and space syntax research showing that, generally, residents of environments that rank higher in objectively-assessed walkability report more non-motorized transportation than residents of environments that rank lower in objectively-assessed walkability (Frank, Sallis, Conway, Chapman, Saelens, & Bachman, 2006; Turcotte, 2009; Peponis & Wineman, 2002; Penn, Hillier, Banister, & Xu, 1998; Cervero & Duncan, 2003). Although some differences were found in the cyclist movement between the four neighbourhoods, no difference was observed in terms of vehicular movement, except for the high walkability areas, with more vehicular movement found in the high walkability low SES neighbourhood compared to the high walkability high SES neighbourhood. As well, moderate agreement was found between angular weighted betweenness and observed pedestrian and cyclist movement, except in the street segments in the neighbourhood that was lower in walkability and lower in SES.

In conclusion, I found good *figures of fit* between the *3D* and angular analysis measures (*AA*). I also found that the likelihood to be physically active as recommended was higher for individuals living in areas with higher accessibility to facilities which can become *fields of motion* in the neighbourhood (if access to facilities is complemented by a high quality neighbourhood environment) and for individuals living in neighbourhoods they perceived as more interesting environments. Although I found no difference in terms of total walking between the two urban *forms of contrast* (higher versus lower walkability environments), I found differences in observed pedestrian and cyclist movement between higher and lower walkability environments and no difference in vehicular traffic. Also, the *fabric of movement* (the street network) was consistently associated with observed movement in the four different neighbourhoods. These findings support the idea that a *zero-sum game* exists and the idea that environments supportive in terms of walkability may in fact be supportive for all kinds of activities, including vehicular activity. This is consistent with the research of Handy (1992) and Cervero and Gorham (1995), which suggest that walking trips do not replace driving trips, but occur in addition to the driving trips. Furthermore, we found that the *3Ds* of urban form, spatial layout, access to facilities, and various aspects related to aesthetics, influenced physical activity (Baran, Rodriguez, & Khattak, 2008; Godbey, Caldwell, Floyd, & Payne, 2005; Humpel, Owen, & Leslie, 2002; Raford & Ragland, 2006). Therefore, our results confirm that the *Magnet (Movement Attractors and Generic Neighbourhood Environment Traits) perspective* is suitable for analyzing the influence of urban form on physical activity, by considering both attractors and the general neighbourhood environment.

A cautionary note is in order here: because of the cross-sectional nature of the studies conducted for this dissertation, no conclusive statements can be made about causality. However, my work supports the convincing evidence that objective assessments of walkability and accessibility to physical activity facilities are associated with levels of increased walking and physical activity. It also adds to the body of the convincing evidence that subjective assessments of walkability and accessibility to physical activity (such as perceived urban form character and aesthetics) are associated with levels of walking and physical activity. Based on the current work and evidence, a clear statement cannot be made whether objective or subjective assessments of urban form show consistently better associations with walking and physical activity levels.

Implications for Future Work

This work has theoretical, methodological, practical, and policy implications for future research. These implications are to be considered when tackling physical inactivity in various contexts from an integrated perspective.

Several *theoretical implications* need to be mentioned. Along with other recent research (Baran, Rodriguez, & Khattak, 2008; Raford & Ragland, 2006; Raford, 2009), this study indicates the usefulness of incorporating space syntax, and in particular angular analysis, in public health research. This likely contributes to strengthening the instruments that are used to assess urban form within a joint framework provided by the ecological models for the theories of attraction and the theories of configuration. Further theoretical study is necessary to investigate both the role of urban attractors (Hillier, Penn, Hanson, Grajewski, & Xu, 1993) and neighbourhood accessibility for physical activity (Krizek, 2003), to elucidate to what extent spatial layout and the attractors influence observed pedestrian movement. Further theoretical work is also necessary for a better conceptualization of the effects of urban form on physical activity from a place perspective, coupled with better operationalizations of the measurement of urban form (Matthews, Vernez-Moudon, & Daniel, 2009; Sallis, Frank, Saelens, & Kraft, 2004).

The reported mismatch between objective and perceived renderings of urban form (Ball, Jeffery, Crawford, Roberts, Salmon, & Timperio, 2008) and the lack of unified, validated, consistent, and easy-to-employ measures to assess urban form objectively using GIS are still challenges for the measurement of urban form (Forsyth, Schmitz, Oakes, Zimmerman, & Koepp, 2006). It is necessary to conduct more research that considers the non-stationarity of the relationships between urban form and physical activity across space (research that considers the fact that relationships vary across space), employing models such as geographical weighted regression (Fotheringham, Charlton, & Brunsdon, 2002). Finally, while specificity is necessary and future work investigating specific domains of physical activity is required (Giles-Corti, Timperio, Bull, & Pikora, 2005; Sallis, Bowles, Bauman, Ainsworth, Bull, Craig, et al., 2009), it is also necessary to analyze total walking and total physical activity as an outcome, from a spatial equity perspective (Cutts, Darby, Boone, & Brewis, 2009), which considers urban form as a container for all types of physical activity of all urban populations. Furthermore, other issues worth exploring in addition to the influence of the distribution of land uses on the travel mode include individuals' preferences for different environments and individuals' allocation of time for activities. These issues are worth exploring because there seems to exist a difference in time use allocation (e.g., weekend versus weekday) by individuals living in neighbourhoods with different urban characters (Lee, Washington, & Frank, 2009).

Further studies should consider the triad of *objective*, *subjective*, and *resultant* environments, as well as analyze observed versus self-reported environments for individuals who are observed on street segments located in areas selected for a study. The relationships between the triad environments also need further exploration. The relationship between *locale*, *location*, and *sense of place* should be investigated (e.g. a spatial analysis of the relationship between neighbourhood walkability and neighbourhood SES, as well as of the relationship between sense of place and levels of physical activity in the neighbourhood). In addition, it is necessary to conduct qualitative research on the subjective environment (e.g., preferred places, meaningful places) and the resultant environment (e.g., preferred types of physical activity).

The triad of environments influences the decision to walk via each of the constitutive elements of these environments, as well as via the accumulation of the constitutive elements that interact to create a particular character (Frank, Sallis, Conway, Chapman, Saelens, & Bachman 2006). Therefore, neighbourhood environment is more than the sum of various elements that likely influence walking and, consequently, it is important to understand the *relative influence* of each group of urban elements in influencing walking. One way to analyze the triad of environments using the *Magnet perspective* in future studies is by considering the hierarchy of walking needs (Alfonzo, 2005). This hierarchy encompasses progressive levels that entail objective and subjective dimensions which allow researchers to investigate walkability (*3D* and *AA*) and accessibility to facilities at a basic level, then investigate safety at a higher level, then to consider comfort and finally pleasurability, in order to create generic neighbourhood environments that satisfy all walking needs (e.g., Franzini, 2010).

Several *methodological implications* also need to be mentioned. Better designs are necessary to account for the self-selection and the preferences of individuals living in neighbourhoods that contrast in terms of walkability. Future studies should adopt designs (e.g., natural or quasi-natural experiments) that allow for the elucidation of whether self-selection plays a role in individuals' physical activity patterns. In addition, it is necessary to adopt mixed methods that enable the linking of data from various sources (e.g., census; audit data; qualitative surveys; focus groups; hermeneutical research in neighbourhood environments which contrast in terms of walkability). Also, obtaining better or more refined data (e.g., level of quality and maintenance of sidewalks) is necessary for improved accessibility measures. Studies that focus on the objective measurement of urban form should include informal alleys, and should conduct buffer sensitivity analyses for both *3D* and angular analysis measures in relation to walking, as well as for the 2SFCA measure in relation to physical activity. In addition, better ways of defining the area of study are required (Brennan-Ramirez et al., 2006).

Some *practical implications* are derived from this work. Practitioners should collaborate with researchers and conduct natural experiments in newer suburban areas, as well as in inner city areas considered for revitalization (e.g., The RESIDE study; Giles-Corti et al., 2008), to take advantage of the fact that new residential areas are created so quickly in Edmonton. For example, given that a strategy to complete absent sidewalks in Edmonton is in place, observational baseline studies such as our Study 4 can be conducted to determine whether any change occurs in observed pedestrian behaviour or self-reported walking after environmental changes are implemented. In addition, interventions are necessary to increase the quality of facilities and of the generic neighbourhood environment (such as increasing the connectivity of the informal alleys which constitute untapped neighbourhood resources for connectivity).

Our findings are consistent with empirical evidence showing that perceived attractiveness of spaces suitable for physical activity is associated with increased physical activity and walking for exercise (Booth, 2000; Brownson, Baker, Housemann, Brennan, & Bacak, 2001; Craig, Brownson, Cragg, & Dunn, 2002; Giles-Corti & Donovan, 2002). Aspects such as street scale and aesthetic qualities are important in addition to the *3Ds* (Handy, Boarnet, Ewing, & Killingsworth, 2002), although network connectivity influences active travel the most (Badland, Schofield, & Garrett, 2008; Butler, Orpana, & Wiens, 2007; Schlossberg & Brown, 2004). Consequently, more efforts are required to increase the environmental knowledge of individuals, to improve quality of spaces and, as a result, to improve users' perceptions and use of everyday spaces for physical activity. For example, local initiatives such as *Adopt a Sidewalk* (City of Edmonton, 2008) can help individuals make a difference in their communities by identifying barriers to walking and can contribute to changes that would make environments more conducive to physical activity.

Our results also indicate that not only improving the perceived attractiveness of facilities/spaces, but also improving the quality of streetscapes, are potentially useful approaches of enhancing the kinaesthetic urban experience (Carmona, Health, Oc, & Tiesdell, 2003). Practitioners should seek and improve several aspects of the streetscapes, such as urban imageability and meaning (Lynch, 1960; Ramadier & Moser, 1998), and should seek to address aspects such as urban disorder (King, Stokols, Talen, Brassington & Killingsworth, 2002), to create favourable conditions for healthy lifestyles and effervescent public life to flourish (Rapoport, 1991). Interventions should target features of the physical environment that influence physical activity (such as safety, comfort, pleasurability, and aesthetics) and features of the social environments (such as collective efficacy and social capital), which seem to support physical activity (Franzini et al. 2010, Zhu and Lee, 2008; Kim et al., 2006).

Although very few of these aspects have been documented empirically and very few studies measured them consistently within an active living context (Handy, Boarnet, Ewing, & Killingsworth, 2002), the association between these aspects and walking, urban healthy lifestyles, and quality of life (Demerath & Levinger, 2003; Gehl, 1987; Gehl & Gemzøe, 1996) has long been established in the normative research in planning and architecture (Rapoport, 1991). Also, sociological studies argue that the existence of third places (i.e., familiar places of transition between home and public spaces, such as local shops; Oldenburg, 1997) is essential for modern flaneurism (i.e., strolling the city; see Benjamin, 1973) and city walkability. More studies are needed to provide practitioners with empirical evidence regarding the role of such aspects in relation with physical activity in everyday environments. The *Magnet perspective* would constitute a first step in targeting neighbourhood environments, attractors for walking, and possible detractors from walking (e.g., incivilities, bad areas, other physical barriers) to create a local supportive atmosphere for physical activity.

Such practical measures are suitable because a recent survey (Cragg, Cameron, & Craig, 2006) indicated that about 17% of Canadians live within 2.5 km of their workplaces (a reasonable walking distance) and 41% live within 5 km (a reasonable cycling distance). Although only 23% of Edmontonians currently use active transportation on a regular basis (City of Edmonton, 2005), it is possible that more individuals may consider adopting active transportation modes if environmental changes are made to support such options.

Finally, a few *policy implications* emerge from this study. While there is consensus on the fact that urban form influences physical activity, the degree of this influence is still unknown: although evidence on walkability indicates a weak association, evidence on accessibility indicates a stronger association (Barton, 2009). Although the role of place in relation to individuals has been documented (Sallis, Moudon, Linton, & Powell, 2005), specific Canadian place-based policy targets have not been developed yet (Frohlich, Ross, & Richmond, 2006; Shugart & Townsend, 2010). It has been recently suggested there is a need for an integrated approach to environment that encompasses both place-based (local) and structural approaches with policy (Bradford, 2005). That is why it is necessary to conduct more place-based research, which focuses on city and neighbourhood levels (Duranceau & McCall, 2007). As an example of place-based research, my study provides evidence that can be useful in creating context-specific indicators that can help decision makers at the local levels (Kahn et al., 2002; Brennan-Ramirez et al., 2006).

Due to the complexity of the influences of urban form on physical activity and the magnitude of the problems created by inactivity, both individual-level and community-based programs and supports are clearly necessary (Bauman, Finegood, & Matsudo, 2009). Bauman and his colleagues identified four domains of action to tackle physical inactivity: individual-level programs, social norms (via mass media campaigns), environmental supports, and policy (national strategies and regulation). Understanding perceptions and environmental supports could help target media interventions, as well as environmental (physical and social) interventions at both the local and national levels. In the first place, as my study found, individual-level factors are strongly associated with individuals' physical activity, suggesting that interventions seeking to increase individuals' self-efficacy levels are potentially valuable. Second, campaigns directed at modifying the preferences of individuals for automobile-oriented environments in Edmonton, in conjunction with campaigns directed at increasing awareness about the benefits of a healthy lifestyle, are suitable. I speculated that preference for car-oriented environments may have played a role in our findings. Third, enhancing the existing opportunities for physical activity in the neighbourhood (e.g., improving quality of recreational facilities, replacing absent portions of sidewalks) and creating programs that are culturally, socially, and economically attractive to various population subgroups are appropriate. I found that both objective and subjective environmental factors are associated with physical activity, so local programs and policies to implement physical environment changes designated to support active lifestyles are essential, because lifestyles are a key determinant of health (Lalonde, 1974). Finally, concerted local and national policies focusing on physical activity (e.g., concerning active transportation) are appropriate; these should involve better communication channels and cross-sectoral cooperation. Similarly, allocating funds to create infrastructure for active transit should be supported by local initiatives that educate citizens about the benefits of active lifestyles. For example, one study found that trips to the public transit stops enabled 29% of individuals using public transit to be active as recommended (Besser & Dannenberg, 2005). Policies that support active transportation and a better quality of life in the neighbourhoods are necessary in order to enforce the character of spaces that are conducive to physical activity and strengthen the sense of place, which, in turn, increases walkability (Wood et al., 2008).

Consequently, projects of physical revitalization of neighbourhoods, corroborated with programs of building social capital, should be implemented, using a vision to create *Magnet Places* as high quality public spaces (e.g., the politics of urban space adopted in Barcelona in the 1990s). Such a coherent policy of urban spaces is necessary to ultimately strengthen the sense of place and the social capital of the residents in relation to their neighbourhood and their city. In this way, light will likely be shed on strategies for shaping perceptions and characteristics of actual spaces with the purpose of transforming urban spaces into magnets for physical activity.

In conclusion, it appears that physical activity is influenced by urban form elements that constitute attractors for pedestrian movement, such as commercial land uses and areas that are densely populated, which are accessible via highly connected street networks. It also appears that urban spatial layouts that are higher in accessibility influence physical activity. Because both attractors and configuration matter in understanding physical activity in an urban context, I proposed an integrative place-based framework for analyzing the environmental contextual influences on physical activity. Studying these *Magnets* and their *magnetic lines of force* in relation to physical activity will help provide evidence that will ultimately lead to building healthier communities for healthier urban lifestyles.

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APPENDIX A. LITERATURE REVIEW

In this section, I shall provide a review of issues pertaining to the influence of urban form on physical activity, as they are covered within the disciplines concerned with urban form and its influence on human behaviour, such as the disciplines of health promotion, planning, geography, urban design, architecture, sociology, and environmental psychology. This review is guided by the question: *What are the elements of urban form that are associated with the physical activity of adults?*

Because physical activity is influenced by *individual* (or intra-personal) and *environmental* (or extra-personal, such as urban form) factors (Spence & Lee, 2003), which are known as the correlates of physical activity, it is important to examine the full range of these factors, even though this review is concerned mainly with environmental (or urban form) factors. Thus, in the first section, entitled *Factors Associated with Physical Activity: Current Evidence*, I shall present a brief *overview of the key correlates of physical activity*, followed by a more detailed overview of the *environmental correlates of physical activity*. Environmental correlates, in particular *physical environmental correlates*, represent the focus of this thesis because they have the potential to be easily modified and to simultaneously influence large populations; consequently, interventions that target physical environmental correlates have the potential to increase physical activity in populations.

In the second section, entitled *Theoretical Perspectives on Environment*, I shall present two *theoretical perspectives* that underpin two ways of conceptualizing the relationship between individual and the physical environment, as categorized by Hillier (1996) in the field of architectural theory. Understanding these two theoretical perspectives has implications for the way we conceptualize the individual-environment interactions within the context of public health research, because I argue that combining the two perspectives into a common framework is valuable to aid in elucidating urban form influences on physical activity within a public health context.

In the third section, entitled *Urban Form Influences on Physical Activity: A Place Perspective*, I shall provide an overview of the *conceptualization* and *operationalization of urban form and of its association with physical activity* from a place perspective. Within this perspective, it is necessary to study the *context* (i.e., the urban context or milieu) in which individual-environment interactions occur. Because a place perspective entails an objective and a subjective assessment of urban form, I shall then focus on the association between physical activity and the *objective* and *subjective measurement of urban form.*

Factors Associated with Physical Activity: Current Evidence

Correlates of Physical Activity

To date, research on physical activity has identified several correlates of physical activity, which are variables that consistently show associations with physical activity (Baranowski, Anderson, & Carmack, 1998; Sherwood & Jeffery, 2000). These correlates pertain to several domains: demographic, biological, psychological, cognitive and emotional, behavioural attributes and skills, social, cultural, physical environments, and physical activity characteristics (Humpel, Owen, & Leslie, 2002; Sallis & Owen, 1997). Some correlates are *individual* (or intra-personal) and others are *environmental* (or extra-personal) - see Sallis, Johnson, Calfas, Caparosa, and Nichols (1997). Also, some correlates (such as age, gender, race, and ethnicity) are *invariable*, while others (such as behavioural, personal, and environmental characteristics) are *modifiable* (see Seefeldt, Malina, & Clark, 2002). *Individual* factors include health risk profile, body weight / appearance, enjoyment, stress, social interaction, skill development, achievement, satisfaction, self-efficacy, and exercise history (Sherwood & Jeffery, 2000). *Environmental* factors include social environment influences, physical environment influences, and health policy influences. Current theories have identified environmental variables as having various influences in terms of barriers, facilitating conditions, and contextual influences (Godin, 1994). While a small percentage of variables constitute the focus of the theories of health promotion, many environmental variables consistently associated with physical activity are not accounted for by the theories (Bauman, Sallis, Dzewaltowski, & Owen, 2002). Such environmental variables are worth investigating within a Social Ecological Models framework (Sallis and Owen, 1997) because intra-personal factors only account for approximately 25% of the variance in physical activity behaviour and, consequently, it appears that an additional focus on environmental factors could explain a larger proportion of the variance in physical activity (Baranowski, Anderson, & Carmack, 1998).

The role of environmental factors in influencing physical activity, body weight, and diet was investigated in a recent report (Raine et al., 2008) that used Swinburn et al. (2003)'s ANGELO framework of analyzing obesogenic environments. The ANGELO framework, which is a Social Ecological Models framework, operationalizes environments in a 2x4 matrix organized in terms of the geographic *scale of environment* (micro or *setting level* and macro or *sector level*) and the *nature of the environment* (physical, socio-cultural, economic, and policy). Raine et al. (2008) found that economic, physical, and socio-cultural *settings* are consistently associated with physical activity, while policy *settings* and *sectors* are less convincingly associated with physical activity. The report revealed that, based on experts' opinions, built environment changes seem most likely to result in greater positive impacts on physical activity. Because of their documented influence on physical activity, their quality of being modifiable and their potential to influence large populations, social and physical environmental correlates constitute the focus of this study. Therefore, a more detailed overview of the social and physical environmental correlates is presented in the following section.

Environmental Correlates of Physical Activity

Social Environmental Correlates

Social support has been consistently associated with modest improvements in physical activity (e.g., Trost, Owen, Bauman, Sallis, & Brown, 2002), varying across populations in terms of age, gender, and ethnicity (Seefeldt, Malina, & Clark, 2002). Also, factors such as having access to health care, seeing other active people in the neighbourhood, being members of a club, and having a companion to exercise with were positively associated with increased walking (e.g., Brownson, Baker, Housemann, Brennan, & Bacak, 2001). Neighbourhood socio-economic status (SES) seems to be the most important social environmental factor associated with physical activity. Thus, it seems that residents of lower SES neighbourhoods have less access to adequate facilities for physical activity (Estabrooks, Lee, & Gyurcsik, 2003; Moore, Diez-Roux, Evenson, McGinn, & Brines, 2008) and they face more environmental barriers (Cameron, Craig, & Paolin, 2005). Residents of higher SES neighbourhoods appear to be engaging in more physical activity than their counterparts living in lower SES neighbourhoods (Parks, Housemann, & Brownson, 2003; Wilson, Kirtland, Ainsworth, & Addy, 2004). In turn, residents living in lower SES neighbourhoods appear to walk more due to the higher residential densities of their neighbourhoods (Heinrich et al., 2007) and the use of public transit or non-motorized transportation (Bhat & Guo, 2007).

Some other factors often reported as perceived barriers to physical activity show strong correlations with decreased physical activity. These factors include: being too tired, having physically demanding jobs, or lacking motivation for physical activity (Brownson, Baker, Housemann, Brennan, & Bacak, 2001; King, Castro, Eyler, Wilcox, Sallis, & Brownson, 2000). However, it appears that people who exercise more frequently are more likely to report barriers (Humpel, Owen, Iverson, Leslie, & Bauman, 2004).

Physical Environmental Correlates

Both actual and perceived physical environmental circumstances and community settings influence physical activity (Seefeldt, Malina, & Clark, 2002). Thus, the availability and distribution of facilities for physical activity and for commercial/service uses, the availability of an adequate pedestrian structure, the safety of neighbourhoods, and the aesthetics of neighbourhoods are associated with physical activity (Duncan, Spence, & Mummery, 2005; Humpel, Owen, & Leslie, 2002). The *3Ds* of urban form (Design, Density, and Diversity; see Cervero & Kockelman, 1997) and the quality of environments (such as aesthetics, interesting scenery, presence of sidewalks, and access to facilities; see Pikora, Giles-Corti, Bull, Jamrozik, & Donovan, 2003; Garcia Bengoechea, Spence, & McGannon, 2005; Humpel, Owen, & Leslie, 2002; Spence, Plotnikoff, Rovniak, Martin-Ginis, Rodgers, & Lear, 2006) are variables that are typically employed to describe the walkability of environments.

Another factor showing associations with physical activity is neighbourhood safety (Harrison, Gemmell, & Heller, 2007; Humpel, Owen, & Leslie, 2002; McGinn, Evenson, Herring, Huston, & Rodriguez, 2008), which includes issues such as crime, traffic injuries, neighbourhood disorder, and the presence of unattended dogs. Safety from traffic has been reported as one of the main safety concerns, given that heavy traffic conditions reduce the livability of streets (Appleyard, Gerson, & Lintell, 1981) and that 55% of all pedestrian deaths by automobile occur on neighbourhood streets (Cohen, Wiles, Campbell, Chen, Kruse, & Corless, 1997). Adults who feel unsafe are three times less likely to engage in leisure-time physical activity than adults who feel safe in their neighbourhoods (Morbidity and Mortality Weekly Report, 2005). By contrast, adults (particularly women) who feel safe in their neighbourhoods are walking more (Li, Fisher, Brownson, & Bosworth, 2005; Powell, Martin, & Chowdhury, 2003).

Certain neighbourhood features, such as housing age, value, and type (Berrigan & Troiano, 2002) are also crucial in influencing physical activity. For example, it appears that newer neighbourhoods with many cul-de-sac streets attract premium housing values compared with neighbourhoods based on a grid street network (Asabere, 1990), and that cul-de-sacs are associated with less walking in adults (Crane & Crepeau, 1998; De Bourdeaudhuij, Sallis, & Saelens, 2003). In addition, it appears that urban and suburban residents of houses built before 1974 are more likely to walk a mile or more at least 20 times per month than are newer home residents (Berrigan & Troiano, 2002).

While most public health studies look at discrete elements of the physical environment in isolation, space syntax research (generated by the work of Hillier and Hanson, 1984) focuses on relationships between spaces and their influences on walking. Since the decision to walk depends on the accumulation of various elements that interact to create a particular character (Frank, Sallis, Conway, Chapman, Saelens, & Bachman, 2006), and because neighbourhood environment is more than the sum of various elements that likely influence walking, it is important to understand the *relative influence* of each group of urban elements with regard to walking. For example, safety may not influence physical activity when studied in isolation, but it can contribute to environmental quality and can influence physical activity as part of the composite measure of environmental quality, based on safety and neighbourhood character (Alfonzo, 2005). In addition, it may be the case that various environmental correlates influence walking based on a hierarchy of needs (Alfonzo, 2005), with accessibility being the most fundamental aspect of built environment with regards to taking a decision to walk, as a first-order correlate of walking, and with safety being a second-order correlate.

To date, only few studies have examined multiple determinants simultaneously from multiple perspectives, to shed light on the *relative* importance of personal, social, and physical environmental influences on physical activity behaviour (e.g., Ball, Timperio, Salmon, Giles-Corti, Roberts, & Crawford, 2007; Giles-Corti & Donovan, 2002b). These studies have found that personal influences show the strongest association with physical activity, compared to social and environmental influences. This suggests that simply having access to environments supportive of physical activity may not be enough for achieving recommend levels of recreational physical activity in the community. To address some of the above-mentioned issues, better measurement of environmental correlates is necessary within the framework of the Social Ecological Models because this framework provides an integrative account of the complex pattern of possible correlates of physical activity, both individual and environmental, as well as their interaction. Better theoretical perspectives affiliated with the Social Ecological Models are needed to study individual and environmental variables in a way that reflects the complexity of predicting physical activity behaviour (Sherwood & Jeffery, 2000). The following section examines such perspectives in order to establish a better framework for assessing the influences of urban form on physical activity.

Theoretical Perspectives on Environment

As Hillier (1996) noted, research focusing on built environment reflects two conceptualizations of individual-environment interactions. After presenting these two conceptualizations, I shall consider how to combine them into a joint approach that can be fruitful in analyzing the association between physical activity and urban form within a public health context.

Individual – Environment Interactions

The Organism-Environment Position (Position 1)

Position 1 is the default position in analyzing environment as a background consisting of a set of clues and cues for behaviour. Environment exerts a *direct* effect or an *indirect* effect (via cognitions) on the behaviour of an *individual subject*. Whether it is the case that individuals perceive separate elements as stimuli (e.g., the systems approach) or as a whole (e.g., the transactional approach), where a system cannot be divided into discrete relationships among elements (Bell, Greene, Fisher, & Baum, 2001), it seems that people are more likely to notice stimuli that are of significance to them (Kaplan & Kaplan, 1982). Based on these stimuli, individuals create mental maps as generalized and personalized images of the environment that depend on the physical environment's legibility (Lynch, 1960) and guide behaviour.

Environmental perception in Position 1 is based on stimulus-response (Hull, 1943), involving cognitive, affective, interpretive, and evaluative components that operate simultaneously (Ittelson, 1978). A stimulus from the extra-personal environment, located in a subset called *phenomenal environment,* is internalized into an intra-personal environment, *the experiential environment* (see Figure A-1). Within the experiential environment, individuals perceive (visually distinguish) and apperceive (identify) the stimuli. A subset of the experiential environment is *the contextual environment*, where previous cognitions contextualize the stimuli. At the contextual environment level, a decision is made: when an overt response is emitted, an action takes place in *the behavioural environment* (a subset of extra-personal environment); when a response is repressed, it is consequently stored in the experiential environment, to be activated at a later time by a similar stimulus.

The Space-Machine Position (Position 2)

Position 2 posits that environment influences the behaviour of an *objective subject* mainly via spatial configuration, rather than only via the particular physical elements (such as alleys, sidewalks, buildings) of the spatial configuration. This objective subject is a generic and abstract subject, not an individual. It is a collective entity that synthesizes commonalities of multiple individuals in the way they interact with their environment. The idea of such a collective subject (based on multiple individuals) is based on Gibson's (1986) *ecological perception approach,* which proposes that the ecological properties of environmental stimuli are important. Rather than perceiving individual features and organizing them into recognizable patterns, people detect meaning that already exists in an ecologically structured environment. Thus, people perceive functional properties, named *affordances*, which are invariant. Such functional properties are ecologically-relevant functions of the environment (e.g., a rock is sittable, and sitting is an invariant associated with the rock). Thus, over many historic eras, certain information about environment is synthesized as some generic mental structures associated with the spatial layout. These mental structures capture some essential properties of the spatial layouts; based on these mental structures, which are inherited from generation to generation, human beings are able to automatically recognize the urban grid as associated with walking, as an affordance for walking; this recognition is not mediated by individual cognitions.

Therefore, the spatial layout generates *a field of probabilistic encounter*, which can be assessed by analyzing the properties of the spatial layout (Hillier, Burdett, Peponis, & Penn, 1986). This makes it possible to predict movement based on an assessment of spatial relationships discernable within the urban layout. The proportion of pedestrian movement that is generated by the spatial configuration is termed *natural movement* (Hillier, Penn, Hanson, Grajewski, & Xu, 1993). This proportion of pedestrian movement is derived based on the spatial layout characteristics only, independent of the presence of any attractor-land uses, such as commercial or recreational land uses that attract more pedestrians than other land uses. The presence of attractor-land uses generates additional pedestrian movement, as a multiplicative effect on pedestrian movement. Through their generic mental structures, humans are able to assess the potential for encounter, or walkability, that arises based on the spatial configuration of an urban layout only. This potential for encounter can be captured by analyzing the properties of the spatial layout using space syntax methodologies.

A Joint Framework (Position 1- Position 2)

Environmental perception in Position 1 is based on the idea of environment as a system of elements recognized by an individual subject. According to Hillier (1996), the Mechanism of perception 1 is not contradicted by the Mechanism of perception 2, but the generic informational structures are the central factors in influencing behaviour with respect to pedestrian movement in built environment. Building on a framework proposed by Porteous (1977), a basic representation of the environmental perception mechanism is illustrated in Figure A-1, which unifies positions 1 and 2. It appears that the Space Syntax framework can be affiliated to the Social Ecological Models framework, as a special case for analyzing the direct effect of the built environment on behaviour – see Figure A-1, Figure A-2, Figure A-3, and Figure A-4. Position 1 was adopted in ecological models to describe the physical environment's two-fold influence on physical activity behaviour (see Figure A-2): a *direct effect* and an *indirect effect.* The direct effect is based on direct (or visual) perception, which refers to the process of becoming aware of the presence of the stimuli without interpretation (Porteous, 1977). The indirect effect is based on perception (distinguish the stimuli visually), apperception (identify the stimuli), and cognition (interpret the stimuli). Although Position 2 explains behaviour solely in the basis of configuration, it recognizes the existence of other factors that explain the rest of variance in behaviour. This position places emphasis on the direct effect, but it acknowledges the weak influence of other indirect effects (see Figure A-3). Both positions, thus, posit an environmental deterministic influence on behaviour, emphasizing that physical environment directly shapes behaviour. Although determinism has gained much support (Bargh & Chartrand, 1999) in public health research, no causal direction has been established yet (Krizek, 2003). More research is needed to elucidate what kind of influences the built environment exerts (Craig, Brownson, Cragg, & Dunn, 2002). It might be possible that the effects of urban form could be insignificant once other latent factors (e.g., preferences, learned behaviour, and lifestyles) are considered (Krizek, 2003). For its part, my study proposes that Position 2 is compatible with Position 1. I decided to incorporate Position 2 into Position 1 to study the direct influences of physical environment on walking, because Position 1 has a larger scope (see Figure A-4).

As a synthesis of the two approaches, the joint framework is illustrated in Figure A-5. This figure describes how individual cognitions mediate the relationship between environment and behaviour, and are moderated by personal and other unknown factors (according to Bargh & Chartrand, 1999) at various moments during the process. Perception and cognition are indissolubly linked and together they act as a filter that mediates the relationship between environment and behaviour. Visual perception (represented as a crescent shape in grey shade) is part of the perception-cognition continuum (area delimited by a dotted line). This continuum includes: the process of visual perception that takes place at the interface with environment, and the process of indirect perception, through cognition, whether conscious or not. Therefore, individual cognitions mediate both direct and indirect environmental influences on behaviour. Direct influences are influences due to environment that are in fact mediated by individual cognitions via unconscious cognition (resulting in an immediate behavioural response). Indirect influences are influences due to environment that are mediated by individual cognitions via conscious cognition (e.g., resulting indirectly in a behavioural response). Since recent evidence (Bargh & Chartrand, 1999, Bargh & Ferguson, 2000) shows that there might be some other unexplained factors influencing unconscious and conscious behaviour, it is likely that moderators linked to individual characteristics or other unknown factors act upon the relationship between environment and behaviour. In this study, public health and space syntax methods are employed to capture direct and indirect influences of environment on individual behaviour.

Urban Form Influences on Physical Activity: A Place Perspective

In this section, I will first address several issues pertaining to the conceptualization of the urban form elements and their influences within a place perspective. I will then address issues pertaining to the operationalization of urban form elements, which involves objective and subjective measurement of urban form elements on various scales of analysis.

Conceptualization

As noted in the previous section, environment is not only a physical construction, but also a mental construction (Carmona, Health, Oc, & Tiesdell, 2003). Therefore, both objective and subjective environments influence physical activity. A place perspective on spatial context, namely urban form, posits that a sense of place emerges when urban environments satisfy certain objective and subjective qualities of urban form (Project for Public Spaces, 2007). Their synergy results in a *place potential*, which represents the likelihood that a particular environment is considered significant and meaningful by individuals (Carmona, Health, Oc, & Tiesdell, 2003). Architectural studies have shown that urban areas with place potential attract pedestrian movement (Gehl, 1987; Gehl & Gemzøe, 1996; Gehl & Gemzøe, 2000).

A place perspective on urban form will thus be adopted for this study, in order to consider each environmental element from an objective and subjective perspective. Such a perspective recognizes the existence of a place potential for physical activity, as well as of a place effect on physical activity. To capture such effects, this perspective employs *input* (supply: e.g., availability of opportunities for physical activity) and *output* (demand: e.g., use of opportunities for physical activity) area-based measures in the study of environmental influences, with an accent on the dynamics between supply and demand, as Macintyre, Ellaway, and Cummins (2002) recommend. This study considers both direct and indirect effects (via perceptions and cognitions) of urban form, by studying urban form conduciveness to opportunities for physical activity operationalized in terms of (1) *walkability* (spatial accessibility to opportunities for physical activity); and (2) *accessibility of physical activity facilities*. These aspects are studied on the global scale (e.g., city-wide) and on the local scale (e.g., in the proximity of respondents' households).

Taken individually, neither type of urban element guarantees pedestrian movement. In addition, it is also extremely difficult to disentangle each of the separate influences of elements on travel behaviour, e.g., to separate proximity and connectivity measures (Frank, 2000). Connectivity may be more important for walking, while proximity may be more important for the frequency of trips to community's physical activity facilities; but they have both shown consistent associations of environmental variables with active living. The combination of variables that produces conducive environments for active transportation (Krizek, 2003; Sallis, Frank, Saelens, & Kraft, 2004) remains to be determined.

Operationalization (objective and subjective measurement at various scales of analysis)

Urban form influences operate via urban form elements of objective and subjective nature. The bodies of literature on public space, environmental psychology, and sociology have focused mainly on understanding the more *subjective* qualities of urban form (such as city imageability and liveability, perceptions, quality of life) and their influences on walking. In contrast, spatial syntax has concentrated on *objective* elements of urban form that may influence pedestrian movement. Similarly, the planning and transportation literature has focused on the influences of various objective urban form variables on walking as a mode of travel, as well as on neighbourhood accessibility in general. In addition, geography literature was concerned mainly with the supply and demand of urban amenities and recreational resources, with a particular interest in the effects of distance and accessibility on the use of amenities and resources (Smale, 1999).

Within my study, I aimed to be integrative and to consider both objective and subjective urban form within a place perspective, informed by evidence from all the disciplines concerned with the study of the way urban form. The sections entitled *Objective Measurement of Urban Form* and *Subjective Measurement of Urban Form* present the way urban form influences are operationalized by the various relevant disciplines.

To elucidate urban form influence on physical activity, urban form elements need to be studied objectively and subjectively at various ecological scales of analysis (e.g., city scale - *macro* level, neighbourhood scale - *meso* level, and home scale - *micro* level). Various urban form elements influence physical activity differently (Berrigan & Troiano, 2002). For instance, automobile trips are more influenced by the *regional* structure (Boarnet & Crane, 2001), while walking trips are more influenced by the characteristics of the *local* neighbourhood (Frank, 2000; Greenwald & Boarnet, 2001). Also, Ewing (2005) argues that land use patterns mainly affect travel (via accessibility to various activities), while the proximity and quality of recreational facilities mainly affect leisure-time physical activity. Addy, Wilson, Kirtland, Ainsworth, Sharpe, and Kimsey (2004) have pointed out that the *neighbourhood (local)* facilities were stronger predictors of physical activity than the *community (regional)* facilities. Objective and subjective measures need to be employed to clarify the role of urban form elements at each level of analysis (Figure A-6). Walkability and accessibility based upon *3D* and space syntax (angular analysis) measures are calculated similarly at macro and meso levels, with small differences that are discussed later. The next sections provide an overview of the operationalization of the urban form elements from an objective and a subjective perspective.

Objective Measurement of Urban Form

Objective factors associated with physical activity include the *walkability* and *accessibility to facilities for physical activity*. The following two sub-sections present the operationalization of these two concepts.

Walkability

Two directions in operationalizing walkability will be presented: neighbourhood walkability as a *3D* concept and walkability of the urban layout as a space syntax concept. I shall discuss walkability based on angular analysis (*AA*) measures in this section, although the main assumption in space syntax research is that the spatial layout, not its separate elements, influences pedestrian movement. This is because *AA* walkability is operationalized using the street segment as an urban element of analysis.

Walkability based upon 3D measures. Urban environment influences physical activity via its degree of spatial accessibility or walkability. The measurement of walkability at the regional and local scales is based on diversity, density, and design. To date, the neighbourhood has often constituted the unit of study for most of the health research on walkability. Many studies on urban form have attempted to characterize neighbourhoods thoroughly, since the ways neighbourhoods are operationalized and compared may influence the research findings (Talen, 2003). Several studies have compared the pedestrian trip frequencies in binary contrasting neighbourhoods (e.g., high- vs. low-walkability neighbourhoods). Categorizations were proposed (Krizek, 2003) in terms of geographical scale (urban vs. suburban), of internal characteristics (traditional or non-traditional, transit oriented vs. car oriented, mixed use vs. single use), and of construction era (prewar vs. postwar etc). Seemingly, trips are shorter than average in traditional neighbourhoods and longer than average in non-traditional neighbourhoods (Cervero & Gorham, 1995; Ewing, Haliyur, & Page, 1994). Also, walking levels are higher in the traditional neighbourhoods than in non-traditional neighbourhoods. In response, some researchers have raised the concern that some neighbourhood categorizations are based on intuition rather than empirical testing (Handy, Boarnet, Ewing, & Killingsworth, 2002). Neighbourhood categorizations are viewed by some (Etzioni & Lehman, 1967) as a serious distortion of reality, since the neighbourhoods are usually positioned within a continuum developed along two dimensions. Most of the neighbourhoods are composite, display heterogeneity, or have characteristics that are variable (e.g., some areas may be traditional and others suburban). To address this problem, a conceptualization of hybrid neighbourhoods is proposed based on scores accumulated for suburban and traditional aspects (Bagley, Mokhtarian, & Kitamura, 2002). Another approach is to compare similar neighbourhoods (Ewing, 1994; Handy, 1996; McNally & Kulkarni, 1997), having the advantage of a restricted sample size and of using individual urban form variables to group neighbourhoods, although this may in turn hinder the ability to assess the independent effect of urban form (Krizek, 2003).

Density measures refer to the distribution of either population, residences, or density (Churchman, 1999). Density most strongly influences the number of individual work trips and the frequency of walking and biking, with people walking more in high density neighbourhoods and relying less on automobiles than others (Cervero & Kockelman, 1997). *Diversity measures* employ various types of land uses (e.g., residential, institutional, commercial, open areas; Cervero & Kockelman, 1997; Hess, Moudon, & Logsdon, 2001). *Diversity measures* frequently used in public health research include: land use balance, entropy (heterogeneity), and dissimilarity (degree of overall land use mixing). *Design measures* refer to the layout and character of transportation networks - e.g., block size and circulation network (Cervero & Kockelman, 1997). Siksna (1998) proposes that 30-40% of a given urban area is optimal to be used as circulation area. Also, a circulation network of 80-100 m is optimal, often with an over-imposed finer grid of pedestrian alleys. For cities with small blocks, a convenient network size is less than 200 m (Carmona, Health, Oc, & Tiesdell, 2003). To account for the connectivity of the street network, the design measure most often used in public health research is density of intersections of more than two streets, named true intersections (Leslie et al., 2005).

Neighbourhood street patterns (e.g. traditional, modern, neo-traditional) are configured differently, with traditional neighbourhoods having a finer network (Southworth & Owens, 1993) and being considered more walkable than modern neighbourhoods (Cervero, 1996; Crane & Crepeau, 1998; Handy, 1996). The development of cul-de-sac neighbourhoods has impacted pedestrian life, making the neighbourhoods less walkable. In response, neo-traditional neighbourhoods aim at creating mixed pedestrian friendly neighbourhoods with connected sidewalks and higher density development (Duany, Plater-Zyberk, & Speck, 2000). For instance, a study (Cervero & Gorham, 1995) found that transit neighbourhoods produced fewer single-occupant automobile trips and lower trip generation rates than their auto-oriented counterparts. However, there is little evidence that street patterns influence significantly travel mode after controlling for individual and land use characteristics (Crane & Crepeau, 1998). Motivation to walk and distance to destinations seem to be more important factors (Handy, 1996) than street patterns.

Walkability of the urban layout in Space Syntax. Space syntax operationalizes the continuous space into a set of discrete units (Bafna, 2003), represented using axial lines. However, since the use of axial lines is problematic (Ratti, 2004), several researchers have developed compatible measures to use the equivalent of axial lines in GIS (Dalton, Peponis, & Dalton, 2003; Peponis, Allen, Haynie, Scoppa, & Zhang, 2007). *Angular analysis* shows the best results in terms of compatibility with axial map analysis, and it performs better than the axial map analysis in terms of predicting pedestrian movement (Turner, 2007). Angular analyses are conducted based on graphs using street segments as nodes; the distance between segments is then measured by analyzing the angular changes of direction. Several studies have shown associations between predicted and observed pedestrian traffic and volumes. Raford and Ragland (2006) applied space syntax in Boston and found a correlation ($R^2 = 0.77$) between predicted and observed pedestrian volume. Raford, Chiaradia, and Gil (2005) conducted an angular analysis of cycling trips in two areas located in central London and found strong and statistically significant relationships between angular mean depth and aggregate cyclist volume in two areas, with streets of lower angular mean depth showing higher traffic volumes. In addition, other space syntax measures were employed in conjunction with Geographic Information Systems (GIS) databases, showing associations between predicted and observed pedestrian movement (Ozbil & Peponis, 2007; Peponis, Allen, Haynie, Scoppa, & Zhang, 2007). One such measure used is metric reach, which represents the total length of streets accessible from one point of a system to all possible directions taking all available streets. Metric reach is correlated with movement (pedestrian density) as a measure of directional change, showing moderate correlations in area 1 ($r = 0.51$) and 2 ($r = 0.73$), and no correlation in area 3 ($r = -0.19$).

Accessibility of Physical Activity Facilities

In geographical research, accessibility involves individuals (i.e., origin location), activities (i.e., destinations available), and links between individuals and activities (i.e., travel patterns; Handy & Clifton, 2001). Various measures have been presented with various degrees of complexity, which require various amounts of data and reveal different associations (Talen, 1998; Talen & Anselin, 1998). Many researchers question the necessity of devising complicated models when simpler approximations could be successfully employed. However, some

(Kwan, Murray, O'Kelly, & Tiefelsdorf, 2003) point out that simple models do not always reflect the studied phenomena (e.g., use of centroids in calculating distances, see Hewko, Smoyer-Tomic, & Hodgson, 2002). Consequently, a thorough analysis is necessary to ensure the accuracy of measurement.

Straight line distance, street network distance, and amenity potential measures are used to assess the separations between origins and destinations. Objective indicators and opportunity-based indicators of accessibility are the most popular measures of accessibility (Kwan, 1998).

The most common objective indicators of accessibility to facilities are: (a) The Container Measure (Church & Marston, 2003; Handy & Niemeier, 1997), which involves counting the number of destinations specific for a targeted activity that are available within a predefined distance, time, or cost of travel from a given location or point *i* (Wachs & Kumagai, 1973); (b) The Coverage Measure (Church & Marston, 2003; Ingram, 1971; Murray & Wu, 2003), which involves calculating the sum of distances from a given location to all other locations (e.g., sum of distances from a household to all facilities for physical activity located throughout the city); and (c) The Nearest Neighbour Index (Church & Marston, 2003), which involves calculating the distance to the closest available destination from a given location. A more sophisticated version of this measure is *the average distance measure,* representing the average of distances to a given number of amenities, or to all amenities city-wide.

Opportunity-based models, also called gravity potential models, quantify the potential of various opportunities for interaction, based on the size of the attractiveness of the places and the travel impedance between them (Bruinsma & Rietveld, 1998; Horner, 2004; O'Kelly & Horner, 2003; Tiefelsdorf, 2003). Incorporating certain qualities of the destinations, like attractiveness, requires the creation of friction coefficients (Hansen, 1959; O'Kelly & Horner, 2003; Tiefelsdorf, 2003). Deciding upon which factors to include depends on the type of activities offered by the facilities and most likely will not result in relevant coefficients for everybody at any time (Handy & Clifton, 2001). The gravity potential model is complex and requires access to aggregate behavioural data to properly calibrate the friction coefficients used in the distance decay function (Luo & Qi, 2009). Moreover, the weights that may be assigned to destinations need to be tested against residents' surveys to ensure appropriate weighting is used (Handy & Niemeier, 1997). Consequently, a basic-needs approach involving an assessment of distance and density may be appropriate for city-wide approaches, while a more sophisticated approach involving an assessment of attractiveness may be more appropriate when investigating subgroups of population at a local scale (Handy & Clifton, 2001).

A newer, simplified measure is the two-step floating catchment area method (2SFCA) of measuring potential spatial accessibility in public health (Luo & Wang, 2003; Radke & Mu, 2000). The 2SFCA method is a special case of gravity potential, in which the friction coefficient is 1 within the catchment and 0 outside the catchment. This method is more intuitive than the gravity potential (Luo & Wang, 2003). It assesses accessibility using two floating catchments. In the first step, a facility's catchment area is assessed by calculating the facility-to-population ratio within a threshold distance (e.g., population in all census blocks that are present within the facility catchment). In the second step, a population location's catchment is assessed by calculating the sum of the facility-to-population ratios (calculated in the first step for each facility) for all facilities located within a threshold distance from the population location (e.g., census block). This represents an assessment of the ratio of supply (facilities) to demand (population), restricting the number of facilities and population locations that are taken into account (Luo & Qi, 2009). Therefore, the accessibility measure varies with location, and it accounts for areas of overlap where a population location has access to multiple facilities.

Spatial proximity and accessibility of facilities for physical activity are associated with increased physical activity (Giles-Corti et al., 2005; Huston, Evenson, Bors, & Gizlice, 2003; Krizek, 2003; Powell, Martin, & Chowdhury, 2003). In particular, spatial accessibility to attractive public open space (Giles-Corti & Donovan, 2002a) makes residents 50% more likely to achieve high levels of walking to places, including walking to work (Giles-Corti et al., 2005). Similarly, people who used private recreational facilities, parks, playgrounds, sports fields, but also shops, were more likely to be regularly active (Addy et al., 2004). Objective measures of attractive features were positively associated with higher recreational physical activity (Hoehner, Brennan Ramirez, Elliott, Handy, & Brownson, 2005). Conversely, distance to trails was negatively associated with biking (Troped, Saunders, Pate, Reininger, Ureda, & Thompson, 2001), and lack of facilities was positively associated with lower physical activity (Sternfeld &

Ainsworth, 1999). Other studies found that residential density, availability of bike lanes, sidewalks, street connectivity, and recreational facilities were not related to physical activity (De Bourdeaudhuij, Sallis, & Saelens, 2003; Hoehner, Brennan Ramirez, Elliott, Handy, & Brownson, 2005) and walking (Cervero & Duncan, 2003).

Subjective Measurement of Urban Form

Subjective elements, such as urban imageability and meaning (Lynch, 1960; Ramadier & Moser, 1998), privatization and commodification of the urban environment (Mandanipour, 1996), level of environment stress and complexity, culture, urban lifestyles, and public life (Rapoport, 1991) pertain to urban character and identity. Several studies have addressed issues related to the indissoluble relation between city culture, public life, walking, and urban healthy lifestyles, as well as quality of life (Demerath & Levinger, 2003; Gehl, 1987; Gehl & Gemzøe, 1996). These studies argue that the existence of third places (i.e., familiar places of transition between home and public spaces such as local shops; Oldenburg, 1997) is essential for modern *flaneurism* (i.e. strolling the city; Benjamin, 1973) and city walkability. However, few empirical researchers have studied the association of these concepts with physical activity. Most researchers have usually relied only on normative prescriptions (Rapoport, 1991). Owens (1993) proposed some operative subjective qualities for describing walkable neighbourhoods: the study of the zone structure (e.g., concentrations of functions), the formative process (e.g., land use zones), the zone boundaries, and the connectivity (e.g., streets, public-private spaces, and degree of complexity).

Perceived aesthetics of the urban form has also been associated with physical activity. Quality of streetscapes, public spaces, street design, diversity, complex edges, incidental space, and diversity were indicated as important factors (Owens, 1993). Also, neighbourhood imageability, legibility, transparency, coherence, and linkage (Ewing, Handy, Brownson, Clemente, & Winston, 2006) were associated positively with walking. Although aesthetic qualities are often described, very few studies measure them in a consistent manner (Handy, Boarnet, Ewing, & Killingsworth, 2002). Empirical evidence has shown that perceived attractiveness of spaces suitable for physical activity is associated with physical activity and walking for exercise (Booth, 2000; Brownson, Baker, Housemann, Brennan, & Bacak, 2001; Craig, Brownson, Cragg, & Dunn, 2002; Giles-Corti & Donovan, 2002b). Residents who report positive perceptions of their neighbourhoods are more likely to engage in recommended physical activity than their counterparts with less positive perceptions (Hoehner, Brennan Ramirez, Elliott, Handy, & Brownson, 2005; Humpel, Owen, Iverson, Leslie, & Bauman, 2004).

Safety, security, and comfort are also associated with physical activity. In general, sidewalks in communities that reported less sedentary activity were safer than the sidewalks in other communities (Spangler-Murphy, Krummel, Morrison, & Gordon, 2005). Comfort and protection from weather (Gehl, 1987; Gehl & Gemzøe, 1996), as well as perceived neighbourhood safety from crime and traffic were significantly associated with physical activity and walking in the neighbourhood (Craig, Brownson, Cragg, & Dunn, 2002; Hovell, Hofstetter, Sallis, Rauh, & Barrington, 1992; Owen, Humpel, Leslie, Bauman, & Sallis, 2004; Pikora, Giles-Corti, Bull, Jamrozik, & Donovan, 2003). For example, men who report traffic as less of a problem are 61% less likely to increase walking, whereas women who report traffic as less of a problem are 76% more likely to increase walking (Humpel, Marshall, Leslie, Bauman, & Owen, 2004). However, one study (Hoehner, Brennan Ramirez, Elliott, Handy, & Brownson, 2005) found that neither the survey or audit measure of traffic safety was clearly associated with physical activity.

Other factors have also shown associations with walking and physical activity. Several studies found that perceiving people in the neighbourhood as active and friendly was associated with achieving sufficient levels of physical activity (Addy et al., 2004; Duncan & Mummery, 2005; Hovell, Hofstetter, Sallis, Rauh, & Barrington, 1992; King et al., 2000). Also, perceived non-inhibiting weather (Humpel, Marshall, Leslie, Bauman, & Owen, 2004), presence of unattended dogs (Huston, Evenson, Bors, & Gizlice, 2003; King et al., 2000; Wilcox, Castro, King, Housemann, & Brownson, 2000), and neighbourhood cleanliness (Duncan & Mummery, 2005) presented associations with the likelihood of being active. In addition, maintenance and physical disorder presented consistently a strong inverse relationship with active transportation (Hoehner, Brennan Ramirez, Elliott, Handy, & Brownson, 2005).

Perceived spatial accessibility of recreational resources for physical activity in neighbourhoods is significantly positively associated with residents' reports of their physical activity and walking at recommended levels (Duncan,

Duncan, Stryker, & Chaumeton, 2002; Giles-Corti & Donovan, 2002b; Sallis, Johnson, Calfas, Caparosa, & Nichols, 1997). Moreover, residents who met recommended physical activity levels perceived they had better access to recreational facilities, unlike the ones who did not (Kirtland et al., 2003). Also, reported positive changes in convenience and access to local facilities were twice as likely to increase walking (Humpel, Marshall, Leslie, Bauman, & Owen, 2004).

Awareness of the presence of opportunities for physical activity and satisfaction with these opportunities are associated with greater physical activity (Humpel, Owen, & Leslie, 2002), with associations that are stronger for men than for women (Brownson, Baker, Housemann, Brennan, & Bacak, 2001). Also, a positive correlation was found between the sum of destinations within a walking distance of home and physical activity levels in older women (King, Belle, Kriska, Brach, Killingsworth, & Fenton, 2003), college students (Sallis, Johnson, Calfas, Caparosa, & Nichols, 1997), and general population (Hoehner, Brennan Ramirez, Elliott, Handy, & Brownson, 2005). Walking and physical activity self-reported levels are associated with perceived availability of various destinations and walking routes (Craig, Brownson, Cragg, & Dunn, 2002; Wilcox, Castro, King, Housemann, & Brownson, 2000), as well as of natural relief forms (King et al., 2000; Troped et al., 2001; Wilcox, Castro, King, Housemann, & Brownson, 2000). Conversely, perceived long distance to facilities (Troped et al., 2001) and perceived lack of access to convenient facilities and safe environments (Trost, Owen, Bauman, Sallis, & Brown, 2002) were indicated as major barriers to physical activity.

Neighbourhood environments perceived as providing opportunities for physical activity facilitate people being active (Owen, Leslie, Salmon, & Fotheringham, 2000; Pikora, Giles-Corti, Bull, Jamrozik, & Donovan, 2003). Residents living in counties with low risk for sedentary behaviour indicated a more conducive environment than other residents (Spangler-Murphy, Krummel, Morrison, & Gordon, 2005). Duncan, Spence, and Mummery (2005) found that the likelihood of being active was explained by perceived access to physical activity facilities in neighbourhood (28%), presence of sidewalks (23%), presence of commercial destinations in proximity (15%), and traffic intensity not posing a problem (15%). Also, people who perceived their environments as conducive to physical activity were slightly more likely to meet recommendations for physical activity (Hoehner, Brennan Ramirez, Elliott, Handy, & Brownson, 2005), although the difference was not statistically significant. Several studies have found that the perceived presence of functional pedestrian infrastructure was associated with walking and vigorous activity: sidewalks (Addy et al., 2004; Brownson, Baker, Housemann, Brennan, & Bacak, 2001; Giles-Corti & Donovan, 2002a; King et al., 2000; Sallis, Johnson, Calfas, Caparosa, & Nichols, 1997; Wilcox, Castro, King, Housemann, & Brownson, 2000) and bike lanes (Booth, 2000; Brownson, Baker, Housemann, Brennan, & Bacak, 2001). Also, perceived functional factors, such as perceived walking surfaces, trail characteristics (Brownson et al., 2000; Huston, Evenson, Bors, & Gizlice, 2003; Pikora, Giles-Corti, Bull, Jamrozik, & Donovan, 2003), as well as perception of public space design and streetscapes (Hoehner, Brennan Ramirez, Elliott, Handy, & Brownson, 2005) were positively associated with physical activity.

Categories of Distances Used in Capturing Urban Form Influences on Physical Activity

It is unclear yet whether the environmental influences of behaviour depend more on the real or on the perceived qualities of the spatial context. However, mental representations are organized hierarchically corresponding to the physical world (Golledge, 1999). Thus, humans create their mental representations based on certain *topological*, *geometric*, *metric*, and *cognitive* relationships that characterize urban space and capture the essence of that particular environment. It appears that the topological relationships predict the accuracy of mental representations that humans create about their environments. These topological relationships are assessed using certain descriptors of environment such as legibility (Lynch, 1960) and intelligibility (Hillier, 1996).

Specifically, topological, geometric, metric, and cognitive distances play an essential role in the perception of environment as part of the kinaesthetic experience of urban space (Carmona, Health, Oc, & Tiesdell, 2003), namely the *visual* and *aesthetical* experience of city, influences movement patterns in urban space (Lynch, 1960; Whyte, 1980; Zacharias, 2001; Zimring, Joseph, Nicoll, & Tsepas, 2005). The kinaesthetic experience is based on what Cullen (1961) called serial visions that arise from the tension between the existing and emerging views / visual experiences. First, *visual experience* of spaces is influenced by distance and by the informational process of seeing (Hillier, 2003). Therefore, visual experience involves knowledge on physical accessibility (i.e., metric integration, based on real universal distance to express the effort to get from any point to all the others) and visual accessibility (i.e., visual integration, based on the informational effort to see each point from all the others). Second, *aesthetical experience* of spaces is influenced by stimuli and individual-level factors, such as preferences and cognitions. Aesthetical experience has an influence on visual experience, because it exerts a distorting effect on assessing distances and physical configuration of spaces by individuals (Golledge & Stimson, 1997; Lynch, 1960; Walmsley & Jenkins, 1992). This effect influences individuals in selecting various choices in urban space. For example, a real 500 m distance would represent a different experienced distance according to the characteristics of that specific route: if the environment is not perceived as being stimulating, experienced distance seems longer; if the environment is perceived as being stimulating, experienced distance seems shorter.

Therefore, different types of distances, including *topological, geometric*, *metric,* and *cognitive,* concur in the kinaesthetic experience of the urban layout. Each type of distance has constituted the focus of several disciplines that study the built environment.

Topological distance represents the focus of space syntax research that relies on the assumption that topological relationships (i.e., relationships based on adjacency) of the spatial layout dictate movement; Hillier and others have recently considered incorporating to some extent metric distance into space syntax analysis. Topological distance relies on considering the fewest turns from a line (e.g., street segment) to another line in the system.

Geometric distance is defined as the amount of angular change from a line (e.g., street segment), using a convention by Hillier and Iida (2005), which assigns a value of 0 to a turn of 0 degrees, a value of 1 to a turn of 90 degrees, and a value of 2 to a turn of 180 degrees. Geometric distance relies on considering the least angle from a line to another line in the system.

Metric distance represents the focus of public health research that relies upon the assumption that people are rational and try to optimize spatial behaviour by minimizing distances between origins and destinations. A large body of transportation and urban geographical research on location models has been developed based on this assumption, viewing location as a main determinant of spatial behaviour. Metric distance represents universal distance that is measurable between a point of origin and a spatial object. This distance may be real (as measured) or perceived, depending on the visual abilities of an individual subject.

Cognitive distance (or subjective distance, i.e., perceived cost of overcoming distance) is different from perceived distance (which represents a visual estimation of a specific metric distance to a certain spatial object); it represents an estimation of a spatial object made in the absence of the spatial object (Walmsley & Jenkins, 1992). Cognitive distance is the focus of environmental psychology and of geography. Cognitive distance is the basis of mental maps; it synthesizes the spatial experience (Downs & Stea, 1977). An assessment of the cognitive distance represents a modality of capturing some of the aspects of the perceived environment that influence behaviour. It is believed that mental maps (routinely employed to assess the way individuals perceive their environments), along with axial maps, are economic representations of space that allow for investigating social and cognitive aspects of spaces based on the use of cognitive distance. To better assess the association between urban form and physical activity, my study employs topological, metric, and cognitive distances.

Summary of the Literature Review

This review revealed that several environmental characteristics of urban form, as well as contextual area characteristics, appear to be associated with physical activity. Intra-personal correlates consistently associated with physical activity are SE and individual SES, whereas social environmental correlates consistently associated with physical activity are neighbourhood SES, neighbourhood housing type, housing value, and housing age. Physical environmental correlates consistently associated with physical activity include walkability and accessibility to opportunities for physical activity, as well as neighbourhood safety.

It appears that better theoretical approaches are needed to study the relative influence of various correlates of physical activity. A place perspective on urban form influences of physical activity is necessary, which entails the study of the influences exerted by both urban form elements and contexts. Urban contexts need to be described in terms of material infrastructure and collective functioning, using input and output area-based measures. Incorporating Space Syntax theory into the Social Ecological project may shed better light into evidence on direct and indirect influences of built environment on physical activity, enabling a study of each environmental element while considering the contribution of the spatial layout. An investigation of the environmental correlates of pedestrian movement as revealed by space syntax research (e.g., angular measures) may provide important contributions to the evidence on correlates of physical activity. It also appears that better measurement of urban form elements and contexts is necessary because some of the inconclusive evidence showing associations between physical activity and urban form may be attributed to inaccurate measurement. Despite issues created by measurement, there is some convincing evidence that objective assessments of elements pertaining to walkability (such as density, diversity, design, and angular measures) and accessibility to physical activity facilities are correlated with levels of walking and physical activity. Also, there is some convincing evidence that subjective assessments of walkability and accessibility to physical activity (such as urban form character, perceived aesthetics, safety, comfort, perceived presence of functional pedestrian infrastructure, awareness and satisfaction about the accessibility to physical activity facilities, perceived active and friendly neighbours, good weather, unattended dogs, as well as neighbourhood cleanliness) are correlated with levels of walking and physical activity.

However, it is still unclear whether objective or subjective assessments of urban form show consistently better correlations with walking and physical activity levels. One of the reasons for the lack of evidence is the lack of unified, validated, consistent, and easy-to-employ measures to assess urban form at various scales of analysis based on both objective and subjective geographies. Thus, studies are needed to explore various methods to elucidate whether objective or subjective environments influence walking and physical activity, within a place-based perspective on the association between urban form and physical activity.

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Figures

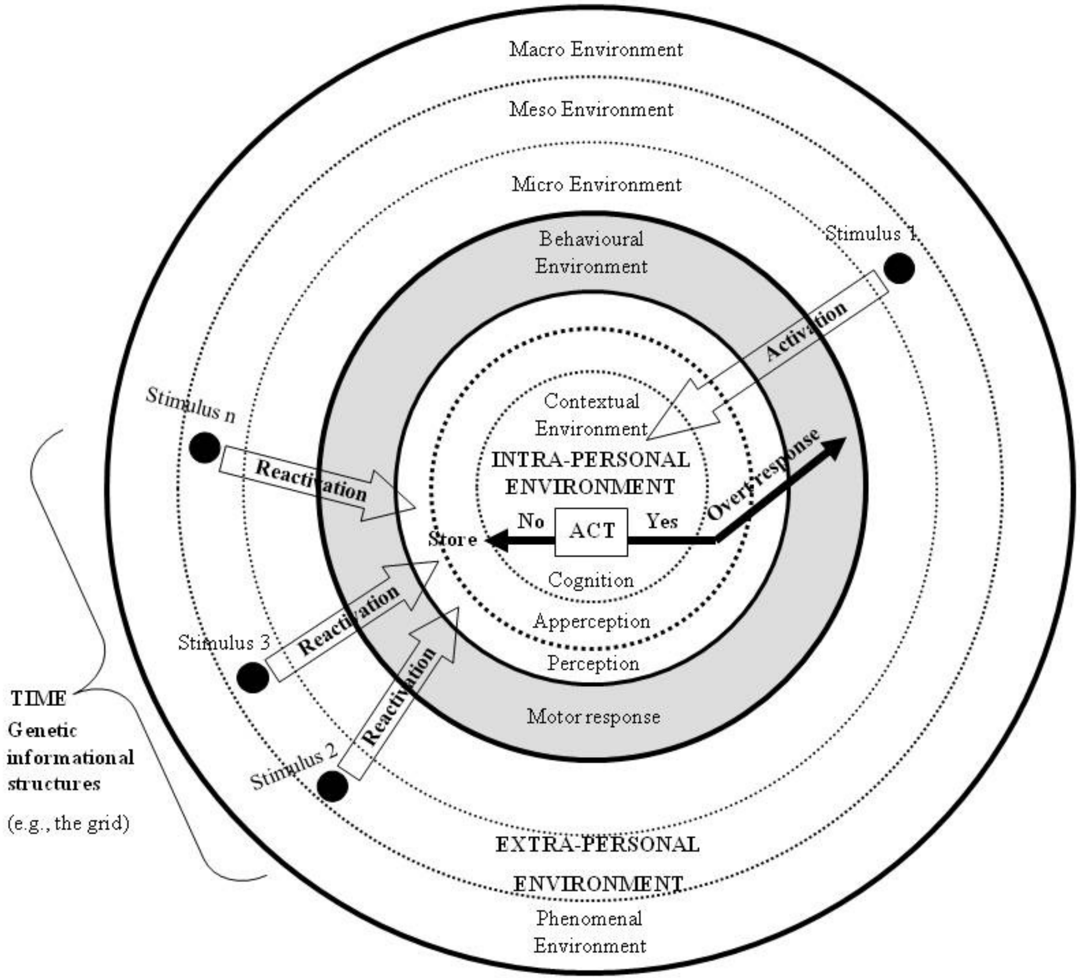

Figure A-1. Environmental Perception: direct and indirect effects of urban form on behaviour - adapted from Porteous (1977)

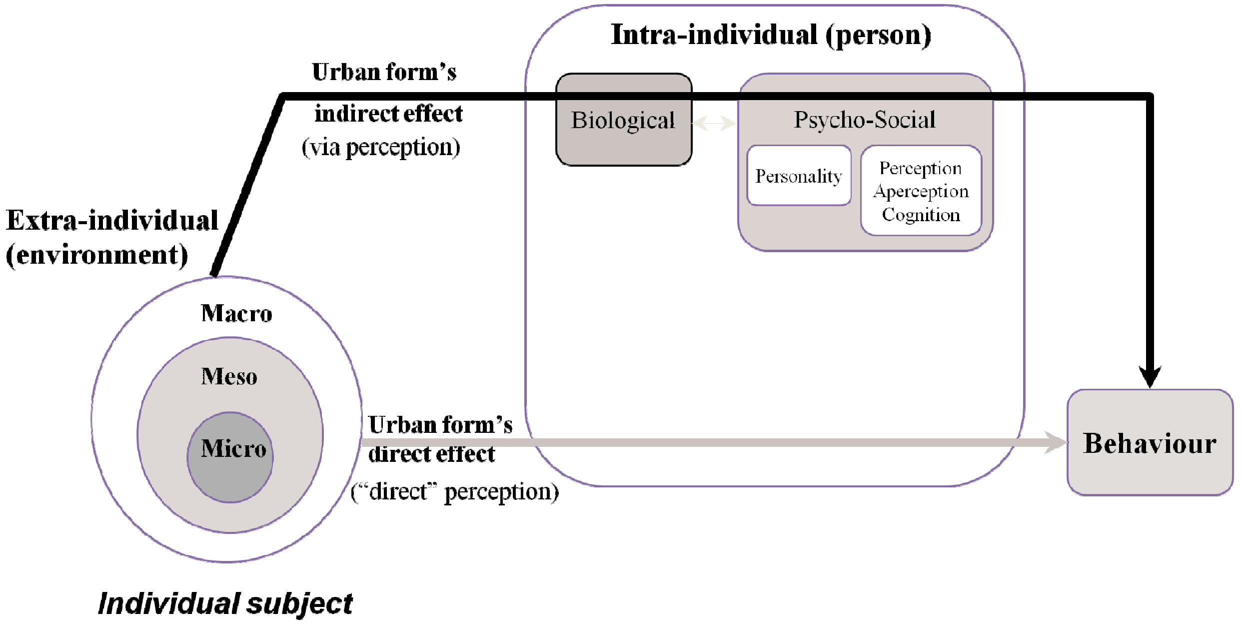

Figure A-2. Direct and indirect effects of built environment on physical activity as conceptualized by ecological models

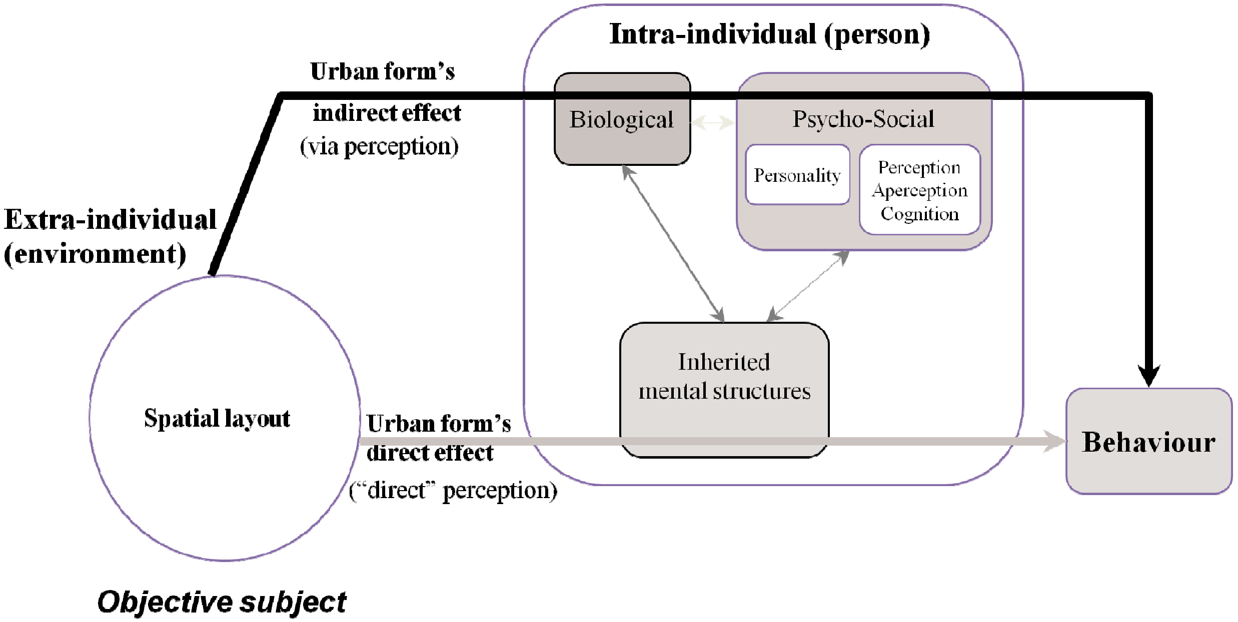

Figure A-3. Direct and indirect effects of built environment on pedestrian behaviour as conceptualized by space syntax

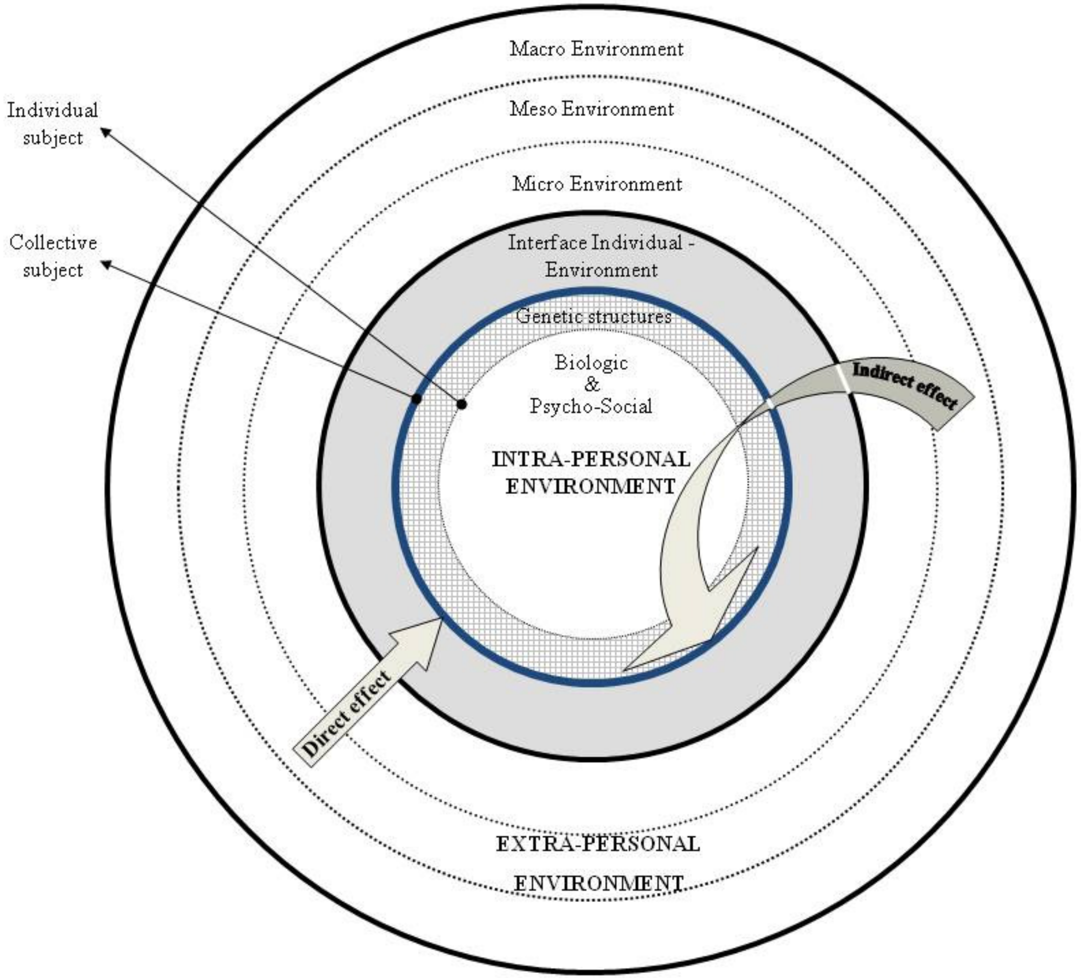

Figure A-4. A unified framework: Ecological Models and Space Syntax

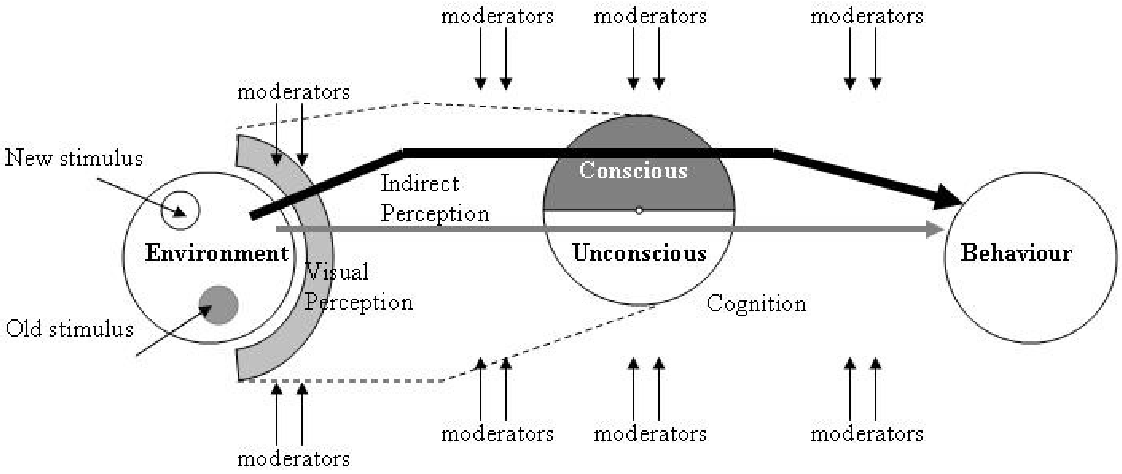

Figure A-5. Individual cognitions: Mediation of the relationship between environment and physical activity

City (Macro)	*Macro-objective elements:* o Urban form walkability • 3D • Space Syntax (Angular Analysis) o Urban accessibility to facilities for physical activity	*Macro-subjective elements:* o Urban character & public life • Urban typology • Urban culture & public life o Perceived urban accessibility to facilities for physical activity
Neighbourhood (Meso)	*Meso-objective elements:* o Neighbourhood walkability • 3D • Space Syntax (Angular Analysis) o Neighbourhood accessibility to facilities for physical activity	*Meso-subjective elements:* o Neighbourhood character • Neighbourhood typology • Neighbourhood life o Neighbourhood perceived accessibility to facilities for physical activity
Urban Design (Micro)	*Micro-objective elements:* o Micro morphology (parcel typology) o Access - public-private interaction; Building related issues	*Micro-subjective elements:* o Psycho-social factors

Figure A-6. Urban form elements that influence physical activity