Do Characteristics of the Built Environment Influence Walking Behaviour Among Urban Adults? A Conceptual Framework, Systematic Review, and Research Plan

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Abstract

Objectives were to improve conceptualization of associations between built environment characteristics (BECs) and walking, synthesize evidence on associations, and propose future research that addresses limitations in existing studies. I designed a conceptual framework of hypothesized BEC - walking associations. I conducted a systematic review, searching MEDLINE, EMBASE, PsycINFO, and TRID for studies investigating BEC - walking associations. Two reviewers screened articles for inclusion. I assessed methodological quality and extracted data from included studies. I used the framework's hypothesized associations to categorize and synthesize results, then analyzed study limitations and proposed future research that would address many limitations. The review identified 13 studies with 64 estimates that met all criteria. None of the framework's hypothesized associations had a statistically significant majority of estimates that were statistically significant. Evidence is lacking on BEC – walking associations and more research is needed that addresses methodological issues such as heterogeneous BEC measures and geographic homogeneity.

Authors' Contributions

Justin Thielman (JT), Dr. David Moher (DM), Dr. Ian McDowell (IM), and Dr. Elizabeth Kristjansson (EK) comprise the research team for this thesis. JT conceived the project, planned and carried out the design, performed the analyses, and drafted and edited the final report. DM helped refine the concept, provided ongoing input into the design, methodology, and analysis, aided with interpretation, and edited the final report. IM helped refine the concept, provided analytical input, aided with interpretation, and edited the final report. EK helped refine the concept and aided with interpretation. All authors read and approved the final report.

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Glossary of Terms

Low to middle income population: A low to middle income population is operationally defined as a majority of study participants having an annual household income below $60,000 (i.e., median household income < $60,000).

Built environment characteristic (BEC): A physical component of a neighbourhood that is part of the built form, including man-made structures and man-made natural settings. E.g., Parks, trails, streets, density of shops and services.

Conceptual framework: A diagram that depicts a concept by illustrating relationships between various domains or constructs, and often includes sub-domains and/or items within each domain [1]

Health determinant: According to the Center for Disease Control and Prevention: "Factors that contribute to a person's current state of health. These factors may be biological, socioeconomic, psychosocial, behavioral, or social in nature." [2]

Fundamental (macro) level determinant: A determinant of health that operates at a very broad scale and affects a large and dispersed population, such as an entire country. E.g., Natural environment factors such as climate, or macrosocial factors such as historical context.

Intermediate (meso) level determinant: A determinant of health that operates at a more local scale and affects smaller, more localized groups of people than fundamental-level determinants, such as an urban neighbourhood. E.g., built environment factors such as land use mix, or social environment factors such as community cohesiveness.

Proximate (micro) level determinant: A determinant of health that operates at a very localized level and affects only small groups of people, such as households or workplaces. E.g., Interpersonal factors such as social support from family members, or physical factors such as workplace ventilation systems.

Individual level determinant: A determinant of health that operates at the person scale and affects each person individually. E.g., Biological factors such as genetic predisposition, or psychological factors such as mood.

Health outcome: The state of one or more components of well-being or illness, indicators of well-being or illness, or risk of illness. E.g., BMI, blood pressure, risk of diabetes.

High income population: A high income population is operationally defined as a majority of study participants having an annual household income at or above $60,000 (i.e., median household income ≥ $60,000).

Measurement, objective: Recording a variable using an impartial method that is not influenced by the observer's recall or judgment. E.g., GIS-based measures of the built environment, neighbourhood audits, accelerometer counts.

Measurement, subjective: Recording a variable using a method that is partially influenced by the observer's recall or judgment. E.g., Self-reported minutes spent walking in the past week, self-reported nearby neighbourhood amenities.

Metabolic equivalents (METS): From Jette et al. "One metabolic equivalent (MET) is defined as the amount of oxygen consumed while sitting at rest and is equal to 3.5 ml oxygen per kg body weight per minute" [3].

Neighbourhood: From the World Health Organization (WHO): "The term neighbourhood usually refers to a local area which is defined in some way physically (for example, an estate or an area bounded by major roads) or by people's perceptions of what constitutes their local area. Neighbourhoods are usually fairly small. For example, neighbourhoods designated for New Deal for Communities funding are usually made up of around 4,000 households or around 10,000 people." [4]

Scoping review: From Petticrew and Roberts: A scoping review "involves a search of the literature to determine what sorts of studies addressing the systematic review question have been carried out, where they were published, in which databases they have been indexed, what sorts of outcomes they have assessed, and in which population." [6]

Study designs, experimental: From Deeks et al: "A study in which the investigator has control over at least some study conditions, particularly decisions concerning the allocation of participants to different intervention groups." [7].

Randomised controlled trial (RCT): From Deeks et al: "Participants are randomly allocated to intervention or control groups and followed up over time to assess any differences in outcome rates. Randomisation with allocation concealment ensures that on average known and unknown determinants of outcome are evenly distributed between groups." [7].

Cluster randomized trial: From the Cochrane Collaboration: "A trial in which clusters of individuals (e.g. clinics, families, geographical areas), rather than individuals themselves, are randomised to different arms." [5].

Non-randomised trial/quasi-experimental study: From Deeks et al: "The investigator has control over the allocation of participants to groups, but does not attempt randomisation (e.g. patient or physician preference). Differs from a 'cohort study' in that the intention is experimental rather than observational." [7].

Study designs, observational: Studies that examine participants' variation in exposure(s) to particular factors to explore associations between the exposure(s) and health outcomes [7]. The study investigator has no influence over allocation of participants to exposure and comparison groups.

Controlled before-and-after study: From Deeks et al: "A follow-up study of participants who have received an intervention [exposure] and those who have not, measuring the outcome variable both at baseline and after the intervention [exposure] period, comparing either final values if the groups are comparable at baseline, or change scores. It can also be considered an experimental design if the investigator has control over, or can deliberately manipulate, the introduction of the intervention.” [7].

Concurrently-controlled cohort study: An observational study where participants who have received an exposure and those who have not received the exposure are followed over time to compare development of the outcome(s) of interest. Exposure and comparison groups are assessed during the same time period [7]. A prospective study begins before the outcomes have developed, whereas a retrospective cohort study begins after the outcomes have occurred.

Historically-controlled cohort study: A variation of the concurrently-controlled cohort study where the exposure group and the comparison group are not assessed at the same time. Typically, outcome assessment in the comparison group occurs during an earlier time period than outcome assessment in the exposure group [7]. (This is different from a retrospective cohort study where exposure and comparison groups are assessed over the same period of time, but the study is initiated after the outcomes have occurred).

Case–control study: From Deeks et al: “Participants with and without a given outcome are identified (cases and controls respectively) and exposure(s) between the two groups compared.” [7].

Before-and-after study: From Deeks et al: “Comparison of outcomes from study participants before and after an intervention [exposure] is introduced. The before and after measurements may be made in the same participants, or in different samples. It can also be considered an experimental design if the investigator has control over, or can deliberately manipulate, the introduction of the intervention." [7].

Cross-sectional study: From Deeks et al: "Examination of the relationship between disease and other variables of interest as they exist in a defined population at one particular time point [7]. Participants are not followed-up over time.

Case series: From Deeks et al: "Description of a number of cases of an intervention and outcome (no comparison with a control group)." [7].

Type II error: From The Cochrane Collaboration: "A conclusion that there is no evidence that a treatment works, when it actually does work. The risk of a Type II error is often called beta. In a statistical test, it describes the chance of not rejecting the null hypothesis when it is in fact false. The risk of a Type II error decreases as the number of participants in a study increases. (Also called false negative.)" [5]

Urban area: From Statistics Canada "A contiguous built-up area with a population of at least 1,000 and a population density of at least 400 people/km^2 [8].

Walking for transportation: Moving on two feet with at least one foot on the ground at all times with the purpose of reaching a destination. E.g., walking to the store, walking to work.

Walking for recreation/exercise/leisure: Moving on two feet with at least one foot on the ground at all times for personal enjoyment or with the intention of improving/maintaining physical fitness. E.g., walking in the park, walking the dog, walking with neighbours after dinner.

CHAPTER 1: Rationale and Thesis Objectives

1.1 Issue to be Addressed

Chronic diseases, such as cardiovascular disease, cancer, and diabetes, are responsible for the majority of mortality in most countries [9,10]. The magnitude of this issue has grown dramatically over the twentieth century. Statistics Canada's data show a sharp increase in body mass index (BMI) and obesity rates over the past several decades and point to a clear association between a higher BMI and increased risk of high blood pressure, diabetes, and heart disease [11]. A review article published in the New England Journal of Medicine is perhaps even more alarming as it predicts a potential decline in life expectancy in the United States due to the increased risk of type 2 diabetes, coronary heart disease, and cancer among obese people [12].

If there is a silver lining to this enormous issue, it is that major contributory factors to many common chronic diseases are alterable lifestyle factors, such as low physical activity levels [13-20]. Indeed, the dramatic increases in chronic disease over recent decades are paralleled by decreases in physical activity levels [21]. The U.S. Department for Health and Human Services cites a study that has linked sedentary lifestyles to 23% of deaths due to chronic disease, and reports that physical activity has been shown to decrease the risk of heart disease, diabetes, colon cancer, and high blood pressure [22]. Globally, the World Health Organization estimates that insufficient physical activity was responsible for 3.2 million deaths in 2004 [23]**.** However, while there is considerable evidence that being more physically active decreases the risk of chronic disease, evidence on effective methods of increasing common physical activity behaviours such as walking is more equivocal [24-

29]. Therefore, ongoing research should continue attempting to identify effective methods of increasing physical activities such as walking among the population.

1.2 Rationale for Focus on Built Environment and Walking

Walking is a physical activity that warrants special focus because it has several advantages over other types of physical activity. For one, it is free; no equipment is required and walking facilities do not require membership fees, so walking is not restricted to higher income populations. Walking is also very convenient and can be done almost anywhere at any time. And finally, walking requires no special skill or expertise and can be done by almost everyone [30]. The fact that walking is accessible to such a wide range of people means that interventions that increase walking have the potential to increase physical activity levels among a wide range of the population. Given that research has shown that even moderate-intensity physical activities can have substantial health benefits, increasing walking may have far-reaching health benefits across a very broad population [29].

In recent years, both health research and public policy have increasingly focused on how characteristics of the neighbourhood built environment may limit or encourage walking and other physical activity behaviours [31-37]. Built environment characteristics (BECs) are operationally defined as man-made physical components of neighbourhoods; they include both built structures, such as buildings and streets, and natural features, such as parks and trails. (Characteristics of the social environment, by contrast, are intangible features such as social support or socioeconomic status). The idea underlying BEC research is that some neighbourhoods are more conducive to walking than other neighbourhoods due to differences in BECs. For example, a neighbourhood with a variety of nearby shops is thought to encourage walking more than a neighbourhood that has very few stores within walking distance.

A major advantage of targeting the neighbourhood-level built environment is that it is something policy makers have the potential to influence directly. At the household or workplace level, environmental changes may be harder to implement because these settings are primarily under the influence of individuals or workplace management. Public policy can have a greater effect at the neighbourhood level, as community planning is directly regulated by local and regional governments in many countries [38-40]. If relationships between BECs and walking are identified, these may have important health implications and should therefore be considered in health policies, as well as urban and transportation policies.

Further impetus for studying the built environment comes from the fact that physical changes are relatively permanent compared to changes that concern psychological, social, or economic influences on walking behaviour [41]. Individual-level physical activity behaviour changes that show beneficial effects are often not sustained in the long term [41,42]. Furthermore, beneficial policy changes that alter social or economic environments can be reversed after budget cuts or changes in government [43]. Built environment changes, while still alterable, are more difficult to reverse due to their physical nature. If changes to the built environment have an effect on walking behaviour, it may result in a far-reaching, long-lasting increase in walking with resulting improvements in overall health [44].

Some of the studies that have focused on BECs and walking have identified associations; however, these studies are far from conclusive [24-27]. Several systematic reviews have proposed that if an association exists between BECs and walking, the inconclusive state of the scientific evidence may be due to methodological issues in the existing studies, such as small sample sizes, heterogeneous exposure and outcome measures, and a need for improved conceptualization of hypothesized relationships [27,45-47]. Despite the equivocal state of the evidence, reports and policy papers from governmental and international organizations have increasingly cited the health benefits of walkable neighbourhoods [33-37]. Reports that cite the physical activity and health benefits of walkable BEC configurations include the Center for Disease Control and Prevention's Healthy Community Design Initiative; the Heart and Stroke Foundation of Canada's Position Statement on Community Design, Physical Activity, Heart Disease and Stroke; and a recent report titled Improving Health by Design in the Greater Toronto-Hamilton Area (GTHA) by the Medical Officers of Health in the GTHA [33,34,36]. Given that public health, urban planning, and transportation policies are increasingly citing the physical activity benefits of certain BECs, there is a pressing need for research to determine whether this evidence exists in order to ensure that resources are being directed to the most useful policies and programs.

1.3 Need for Improved Conceptualization of Built Environment Research

Before further research into the relationships between BECs and walking is conducted, it is prudent to ensure that such research is based on logical hypotheses. This is a daunting task, however, given the complexity and interconnectedness of the relationships between determinants of health and health outcomes [21]. In order to facilitate identification of logical research hypotheses, it is useful to refer to a conceptual framework. A conceptual framework is a diagram that depicts a concept by illustrating relationships between various domains or constructs, and often includes sub-domains and/or items within each domain [1]. Conceptual frameworks can be used to represent relationships between various health determinants and outcomes. Similar health determinants can be grouped together as items within constructs; likewise, similar health outcomes can be grouped into separate constructs. Associations or causal links between the constructs and the items they comprise can be represented by lines connecting constructs together [48].

A number of reviews that have synthesized research on BECs and physical activity have described a need for improved conceptualization of the hypothesized relationships between BECs and physical activities such as walking. For instance, a review by Humpel et al. pointed out that the theory behind BEC research is not yet well developed and that more detailed and refined constructs are needed for characterizing the influence BECs have on physical activities [49]. Similarly, a systematic review by Wendel-Vos et al. suggested that null associations in many studies may have been the result of environmental determinants that were not defined and measured in a way that matched the physical activities being studied [24]. Wendel-Vos et al. also observed that more positive and negative associations were identified for more narrowly defined combinations of environmental determinants and physical activities, suggesting that more narrowly defined constructs are needed [24].

1.4 Thesis Objectives

The ultimate goal of researching BECs and walking is to determine whether making changes to the built environment will increase physical activity behaviour and thus result in downstream reductions in chronic disease risk. This thesis does not directly achieve this goal; however, it addresses the need for improved conceptualization of relationships between BECs and walking, as well as some methodological issues in the existing research. The issues with conceptualization and methodology are a reflection of the fact that relationships between BECs and physical activities have only recently come into focus in public health research [49]. Given the importance of improved conceptualization and methodology in achieving the eventual goal of determining whether a causal relationship between BECs and walking exists, this thesis has the following objectives:

1. Improve conceptualization and understanding of relationships between BECs and walking
2. Assess the present level of evidence in the scientific literature on associations between BECs and walking
3. Propose a plan for appropriate future studies of relationships between BECs and walking

I achieve these three research objectives using the following methods: 1. I develop a new conceptual framework specific to relationships between BECs and walking to help achieve the first objective of improving conceptualization of these relationships. 2. I then investigate the present level of evidence on these relationships by conducting a systematic review, thereby achieving objective two. The conceptual framework developed in objective one is used to guide this systematic review. 3. Lastly, I use the information produced from the previous two objectives for objective three, developing a research plan for future studies of the relationships between BECs and walking.

This thesis is structured into five chapters. The present chapter, Chapter 1, outlines the project's rationale and research objectives. Chapter 2 focusses on objective one, improving conceptualization of the relationships between BECs and walking; I describe two existing conceptual frameworks, followed by the development of my own framework. In Chapter 3, I focus on objective two, assessing the current scientific evidence on BECs and walking associations. I describe the systematic review of the literature I conducted to achieve this objective. In Chapter 4 I propose a research plan for a future study that will address the research gaps identified in previous chapters, which allows me to achieve objective three. Lastly, in Chapter 5, I summarize the conclusions and suggested next steps.

CHAPTER 2: Conceptualization of Existing and Future Research

2.1 Breadth of Focus

Numerous types of conceptual frameworks exist in public health and these range in their breadth of scope [50]. At one end of the spectrum, there are comprehensive frameworks that attempt to encompass most or all determinants of overall health. At the other end, there are narrowly-focused frameworks that zoom in on a specific group of health determinants and one or several closely-related health outcomes. The various scopes each have strengths and weaknesses and the optimal breadth of focus often depends on the subject matter and specific research objectives.

Broadly-focused conceptual frameworks are very useful for depicting the overall context for health, as well as relationships between high-level constructs such as 'social context' and 'built environment'. Often, such models attempt to include all types of hypothesized determinants of health outcomes, from biological to psychosocial to environmental determinants (see Glossary for definitions of health determinants and outcomes). An example of a broadly-focused conceptual framework is Schulz and Northridge's framework of Social Determinants of Health and Environmental Health Promotion [51] (Figure 1). In their model, a wide range of health outcomes and health determinants are grouped into constructs, which are represented by boxes. The constructs are organized into four columns according to the scale or level at which the components of the constructs operate: fundamental, intermediate, proximate, and health & well-being columns. The arrows represent relationships between health determinants and health outcomes as well as between health determinants and other health determinants. Most of the arrows travel in two directions, illustrating the reciprocal nature of many relationships. This diverse group of constructs, operating at scales ranging from individually-focused to globally-focused, demonstrates the broad, encompassing objective of Schulz and Northridge's conceptual framework.

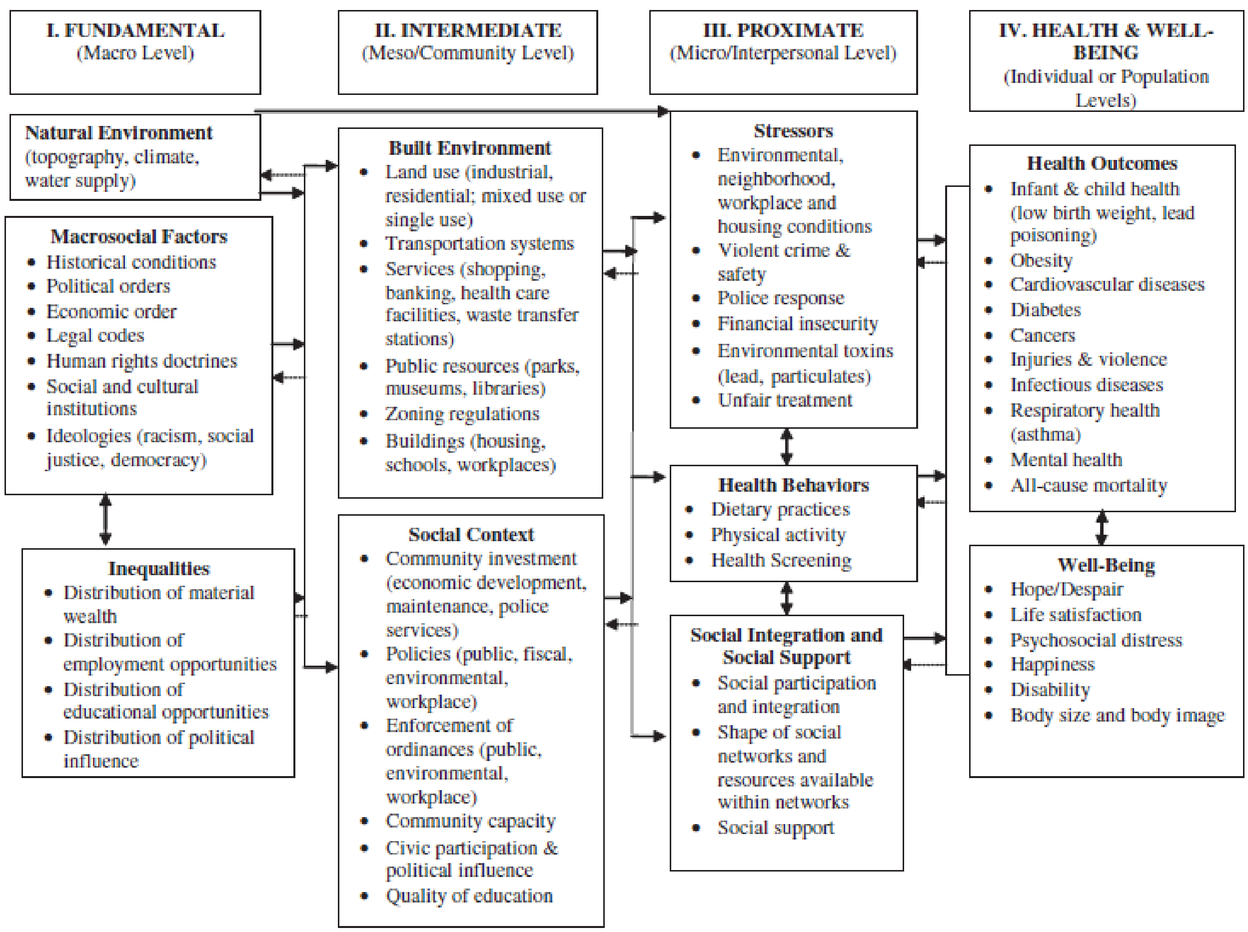

Figure 1: "Social determinants of health and environmental health promotion"
Reprinted with permission from SAGE Publications and John Wiley & Sons, Inc. from: Schulz A, Northridge ME. Social determinants of health: implications for environmental health promotion. Health Education & Behavior. 2004; 31(4):455-471.

A major strength of broadly-focused frameworks is that they can facilitate an understanding of the overall context of a particular issue or research question. This is important during the planning stages of a study, as understanding the context can inform researchers if their research question is feasible and ultimately useful and beneficial. Understanding the context is also important when interpreting research findings. If a broad framework does, in fact, encompass all hypothesized determinants of an outcome, it can help inform researchers whether their study groups are comparable with respect to unmeasured potential confounders, as well as whether their results might be generalizable to other populations.

A weakness of broadly-focused conceptual models is that they may not be useful for identifying associations between specific exposures and specific outcomes. As mentioned in section 1.4, the ultimate goal of researching BECs and walking is to determine whether making changes to the built environment will increase physical activity behaviours such as walking and thus result in reductions in chronic disease risk. Therefore, a useful conceptual framework should drill down to specific components of the built environment and walking. If a broadly-focused framework illustrated this level of detail for each of its constructs it would become cluttered with arrows and boxes. Such complexity may detract from the purpose of the framework, which is to enhance conceptualization of the hypothesized relationships.

A narrower framework can zoom in on one set of health determinants and health outcomes without becoming so complex that it defeats its purpose as a conceptual aid. The conceptual framework by Owen et al., shown in Figure 2, focuses specifically on the built environment and physical activity behaviours. This framework is able to go into more detail on the different types of built environments and different types of physical activities.

A weakness of Owen et al.'s framework is that restricting the scope to BECs and physical activity means that other determinants of physical activity are excluded. Thus, the model is not well suited to understanding the broader context of relationships between BECs and physical activity. Additionally, important covariates that may influence potential associations between BECs and physical activity are excluded from the model, likely because including these would take away from the model's detailed illustration of specific connections between BECs and physical activity. As a result, the model is limited when planning future research, although it can still be used to effectively categorize existing research on BECs and physical activity.

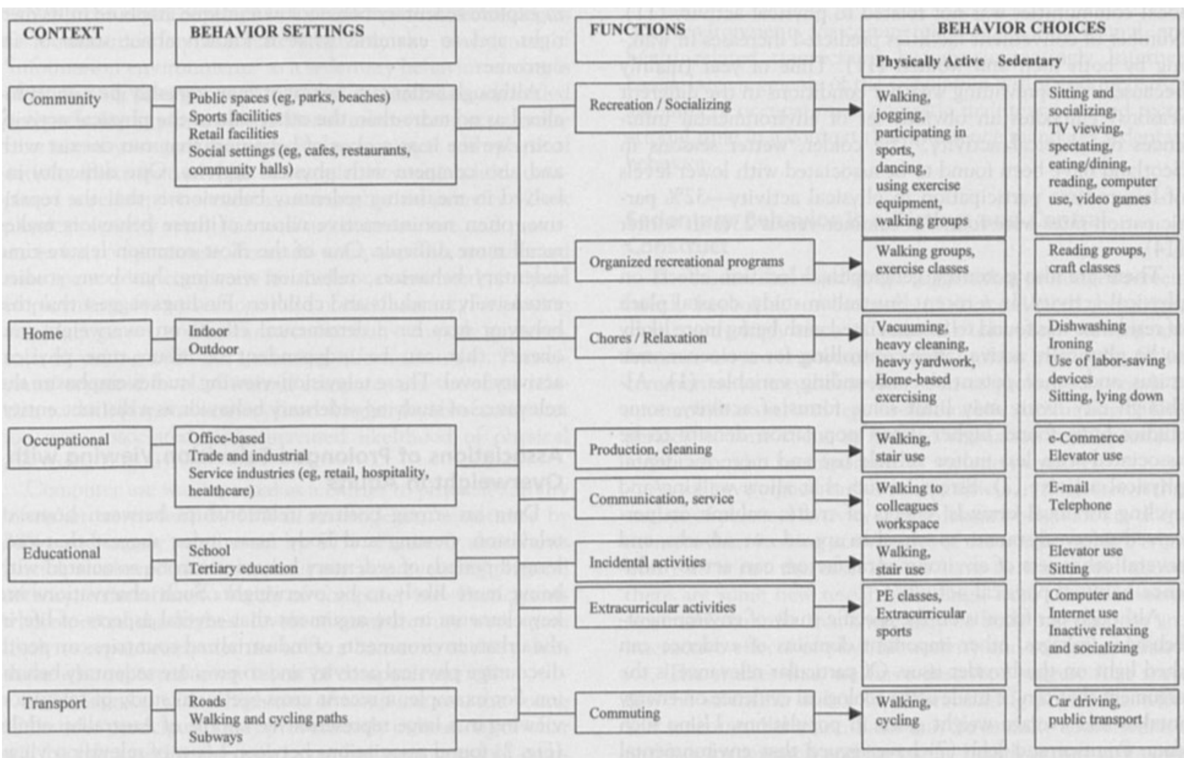

Figure 1 Potential influences of behavior settings and their functions on examples of physically active and sedentary choices.

Figure 2: "Potential influences of behavior settings and their functions on examples of physically active and sedentary choices"
Reprinted with permission from Wolters Kluwer Health from: Owen, N., Leslie, E., Salmon, J., Fotheringham, J. (2000). Environmental Determinants of Physical Activity and Sedentary Behavior. Exercise and Sport Sciences Reviews. 28(4)153-158.

Given that broadly focused and narrowly focused models have different strengths and weaknesses, choosing the appropriate level of scope often depends on one's research objectives. For instance, if the objective is to fit a regression model that best predicts an outcome, a broad framework that attempts to include all possible covariates is likely more useful. However, if the objective is more etiologically focused, where the researchers are investigating whether an association exists between a specific exposure and a specific outcome, a more narrowly focused framework that drills down to the specific hypothesized associations may be more useful. Covariates must also be considered in etiologically focused research because they may be confounders, effect modifiers, or mediators of the association of interest; however, the conceptual framework may illustrate relationships between exposures and outcomes of interest more clearly ifit does not include these covariates.

The choice of scope may also depend on the present state of scientific evidence on the research question being asked. Generally, preliminary evidence should be used to justify additional research that is very costly. In public health research, low-cost narrowly-focused studies are well-suited to generate this preliminary evidence, as they can identify which hypothesized relationships warrant further study in more resource-intensive, comprehensive studies. In such an approach, results from narrowly-focused research can be used to decide which variables should be included in more comprehensive studies, so studies move from a narrow to a more comprehensive focus as the evidence accumulates. Hence, a narrowly focused conceptual framework may make sense in new areas of study, such as BEC - walking research, where evidence of associations is lacking and conceptualization of the various relationships is under development [27,45].

Considering the strengths and weaknesses of different breadths of focus, I decided to use a narrowly-focused conceptual framework to achieve objective one. Research on BECs and walking is still in the early stages and my focus is etiological, so I decided to use a framework that focused specifically on relationships between BECs and walking. My rationale for choosing a narrow focus was that the inclusion of variables other than BECs and walking would distract from the concept I wanted the framework to convey: hypothesized relationships between BECs and walking. The purpose of this framework is not to identify all potential determinants of walking, nor is it to describe the different dynamics at play in the various hypothesized associations. Rather, its purpose is to facilitate visualization of the hypothesized associations to improve clarity and understanding, as well as provide a reference and basis for classifying existing scientific literature.

2.2 Existing Conceptual Frameworks on BECs and Walking

I performed a scan of the scientific literature to determine whether an existing conceptual framework would effectively conceptualize relationships between BECs and walking. I identified 15 relevant conceptual frameworks in this scan, which are listed in Table 1. None of these frameworks were ideally suited to objective one due to at least one of the following reasons: 1) the framework included proximate-level BECs such as characteristics of the home or workplace and did not focus solely on neighbourhood-level BECs 2) the framework included characteristics other than the built environment as potential exposures (e.g., biological, demographic, social characteristics) and therefore was not focused specifically on BECs as exposures, 3) the framework included multiple types of physical activity as potential outcomes and therefore was not focused on walking as an outcome, 4) the framework did not include objectively-measured BECs and therefore relied upon subjective assessments of BECs, which depend on study participants' perceptions of the built environment. Table 1 lists each of the 15 articles identified in this scan according to the reason(s) each article's conceptual framework was not used in this project. I elaborate on each of these reasons below.

Table 1: BEC and walking articles according to reasons their conceptual frameworks were not used

Includes many/all types of physical activity or doesn't specify what types	**Includes social and other non-BEC characteristics**	**Includes characteristics at individual and proximate levels**	**Does not include objectively-measured BECs (subjective only)**
Baker, 2011 [52]	Baker, 2011 [52]	Baker, 2011 [52]	
Foster, 2008 [53]	Foster, 2008 [53]	Foster, 2008 [53]	
Rodruiguez, 2006 [54]	Rodruiguez, 2006 [54]	Rodruiguez, 2006 [54]	
Grant-Savela, 2010 [55]	Grant-Savela, 2010 [55]	Grant-Savela, 2010 [55]	
	Pikora, 2003 [56]	Pikora, 2003 [56]	
	Panter, 2008 [57]	Panter, 2008 [57]	
	Molina-Garcia, 2010 [58]	Molina-Garcia, 2010 [58]	
		Lemieux, 2009 [59]	
	Lee, 2007 [44]		
Aytur, 2007 [60]			
Owen, 2000 [61]		Owen, 2000 [61]	
	Saelens, 2003 [62]	Saelens, 2003 [62]	
			Handy, 2006 [63]
		Rhodes, 2006 [64]	Rhodes, 2006 [64]
Cerin, 2008 [65]	Cerin, 2008 [65]	Cerin, 2008 [65]	Cerin, 2008 [65]

Many of the potentially relevant models I identified were excluded for focusing on all types of physical activity or not specifying the type of physical activity they focused on. For example, the conceptual framework used by Owen et al. focuses on a variety of physical activities ranging from housework to exercise classes, rather than targeting walking specifically (Figure 2) [61]. Similarly, many frameworks were not used because they included determinants of walking other than BECs. An example is the model by Saelens et al. shown in Figure 3 [62]. Saelens' framework includes 'safety' as a determinant of walking and cycling. While safety from traffic, crime, and animals undoubtedly has an impact on walking behaviour, safety is not a characteristic of the built environment. If I wish to focus solely on the effect of BECs, safety should be considered as a potential effect modifier or mediator of associations between BECs and walking, rather than a construct of primary focus. Frameworks were also excluded if they focused on BECs at a level other than the neighbourhood level. Owen et al.'s framework is an example of this as well (Figure 2) [61]. Some of the BECs in Owen's framework are office-based, which are at the proximate level and therefore outside this project's narrow scope.

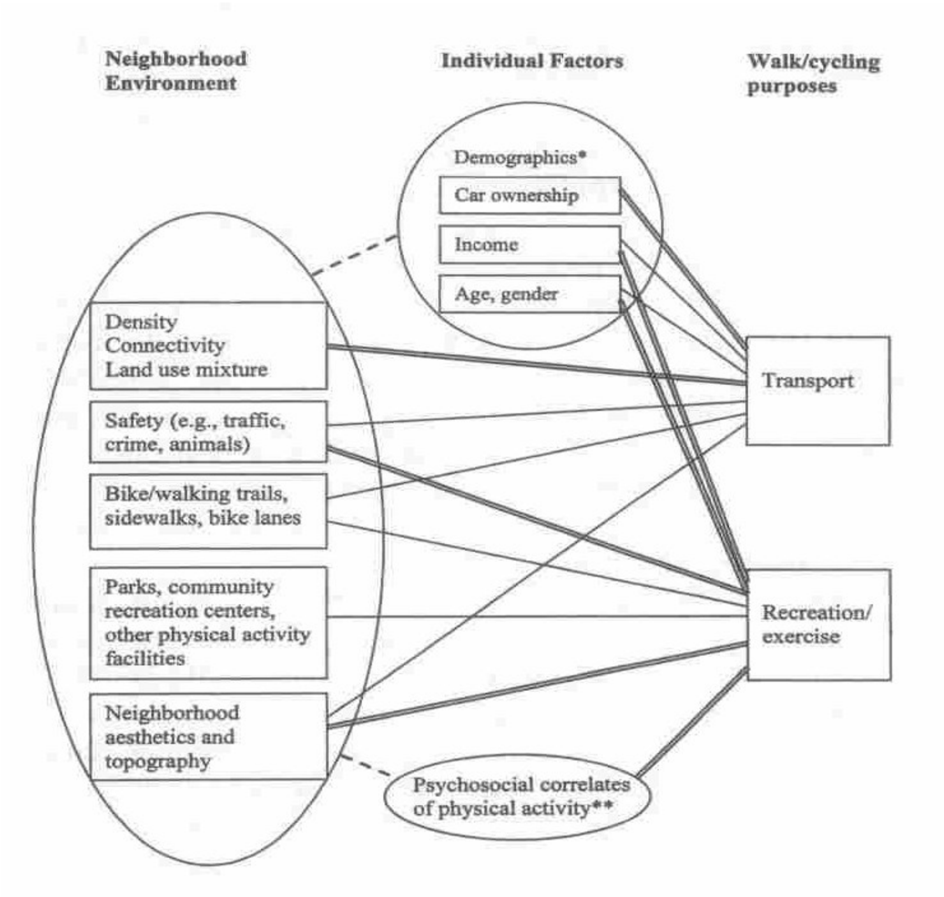

Figure 3: ”A proposed ecological model of neighbouhood environment influence on walking and cycling”
Reprinted with permission from Springer Science and Business Media from: Saelens, B.E., Sallis, J.F., Frank, L.D. (2003). Environmental Correlates of Walking and Cycling: Findings From the Transportation, Urban Design, and Planning Literatures. Annals of Behavioral Medicine. 25(2):80-91. Figure 2.

Inclusion of subjective measurements of BECs was another reason I excluded existing frameworks from use in this project (see Glossary for definitions of subjective and objective measurement). Unlike objectively-measured BECs, subjectively-measured BECs depend on people’s perceptions, which are influenced by psychosocial factors such as knowledge of nearby amenities, attitudes, motivation, or socioeconomic status [66,67]. The framework used by Handy et al. includes perceived (subjectively-assessed) BECs (Figure 4) [63]. As shown in their model, perceived BECs are influenced by attitudes and preferences. However, my thesis objectives aim to contribute to the eventual goal of determining whether changes to the built environment are associated with increases in walking. Additionally, the policies cited in section 1.2, Rationale for Focus on Built Environment and Walking, are attempting to change the actual BECs in neighbourhoods, not residents' perceptions of them. As perceptions are not my exposure of interest, I considered subjectively-measured BECs only as potential mediators, confounders, or effect modifiers of associations between objectively-measured BECs and walking, and sought a framework restricted to objectively-measured BECs.

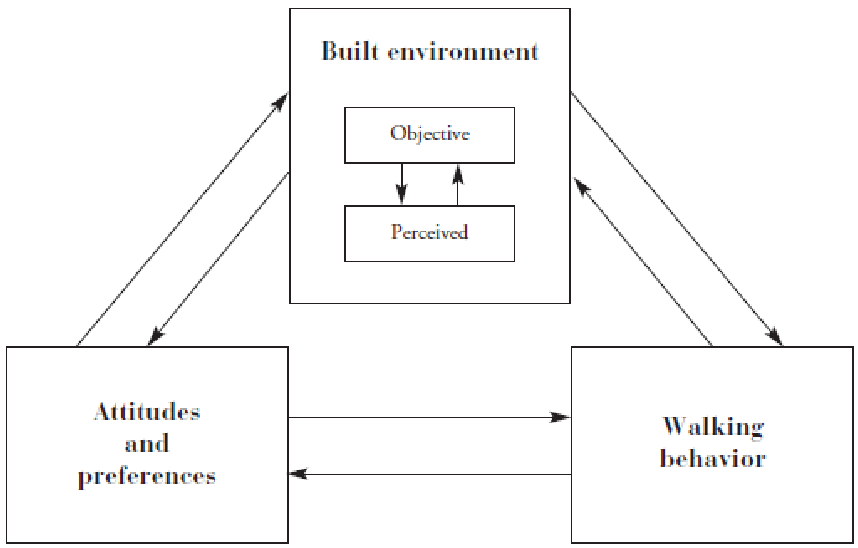

Figure 1. Conceptual model of relationships between built environment, attitudes and preferences, and walking behavior.

Figure 4: "Conceptual framework of relationships between built environment, attitudes and preferences, and walking behavior"
Reprinted with permission from Taylor & Francis from: Handy S, Cao X, Mokhtarian PL. Self-Selection in the Relationship between the Built Environment and Walking. Journal of the American Planning Association. 2006; 72(1):55-74.

2.3 Development of Conceptual Framework

I decided that designing a new conceptual framework that focusses only on intermediate-level objectively-measured BECs would better facilitate objective two, assessing the evidence on BECs and walking. The proposed framework is shown in Figure 5. The walking behaviour column on the right contains two constructs defined according to the purpose of walking: walking for transportation or walking for recreation (see Glossary for definitions of each purpose). I identified the walking constructs based on two of the four domains of active living that have been identified in previous research [47,68]. Walking and other physical activities have been shown to depend on the context in which they occur, which is illustrated by the following four domains of active living: recreational, transportation, occupational, and household physical activity [47,68]. These four domains attempt to cover all of the possible situations in which individuals engage in physical activity. The occupation and household activity domains are not included because they are affected by workplace and household-level aspects of the physical environment and are therefore beyond the scope of the model, which focuses on the neighbourhood level. One can imagine that the influence of BECs on walking behaviour varies according to the domain of active living. For example, nearby shops and services are likely to influence walking in the transportation domain, but may have little effect on recreational walking. Conversely, nearby parks may influence walking for recreation, but have no effect on walking for transportation. Thus, an effective conceptual framework should specify the domain or the purpose of walking.

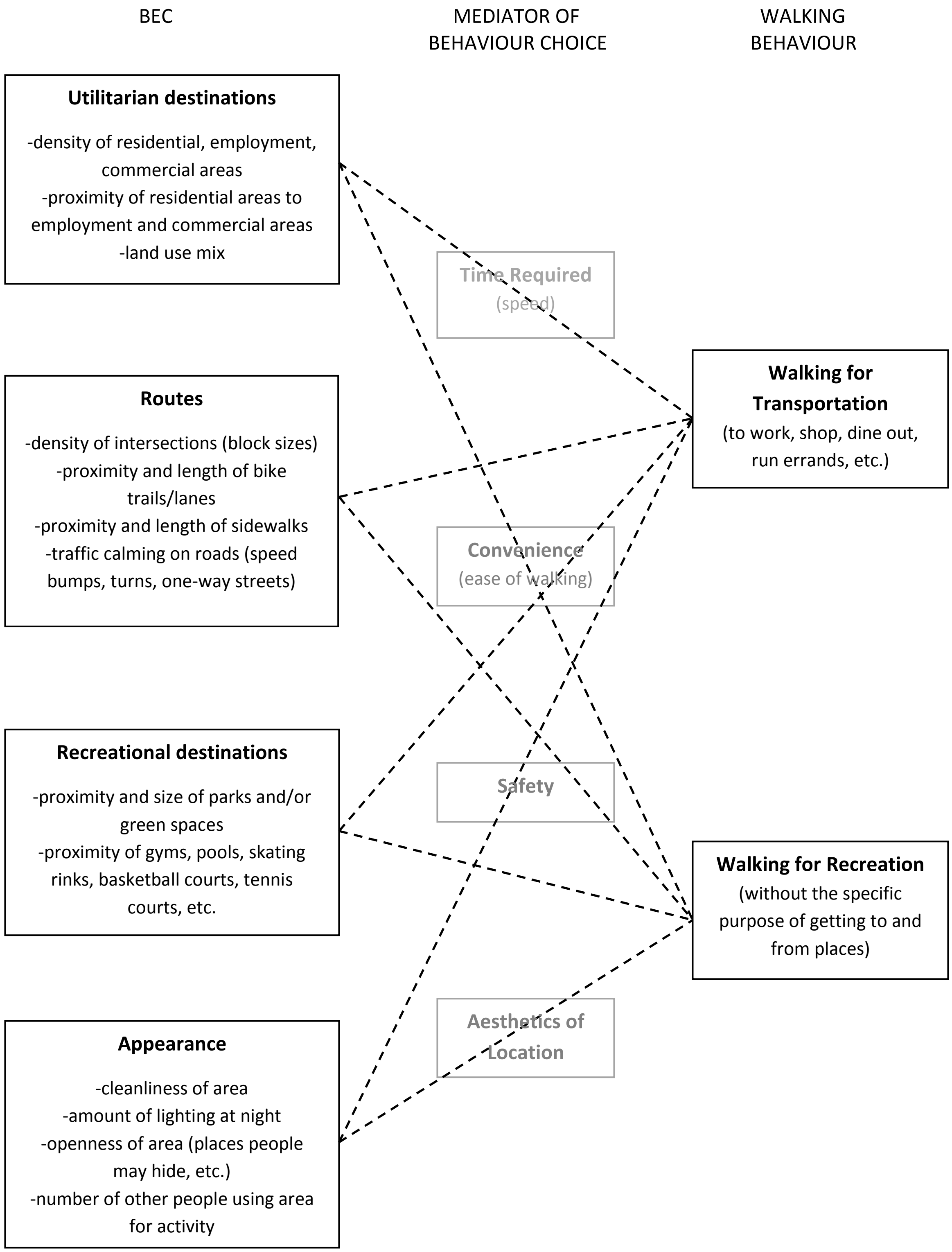

Figure 5: Initial conceptual framework of BECs and walking behaviour

The left-hand column consists of constructs that group together neighbourhood built environment characteristics. I was unable to identify a comprehensive categorization scheme for BECs as I did for physical activity, so I created the BEC constructs using a different method. First, I performed a scoping search for published systematic reviews that investigated BECs and walking (see section 3.1.2, Recent Systematic Reviews and Research Gaps for scoping methods). I then made a list of variables analyzed by the reviews and their primary studies that met the definition of BEC (see Glossary). If a study analyzed multiple BEC variables simultaneously, I listed each unique BEC separately. I then grouped the listed BECs with others if I hypothsized they would have a similar effect on walking. For instance, both the cleanliness and the openness of an area might affect walking by influencing perceptions of safety, so these are grouped together in the 'appearance' construct. Addtionally, groupings often brought together BECs that were highly correlated with each other. For example, in the utilitarian destinations construct, residential density would be correlated with a variety of retail destinations in close proximity because a high population density is needed to support a variety of shops and services, and in turn, a variety of shops and services are needed to service a high population density.

After grouping BECs I hypothesized to have similar influences on walking, the following four BEC constructs emerged. The 'utilitarian destinations' construct comprises built structures in the neighbourhood other than those intended for recreational use. It includes residential or commercial density and proximity of residential areas to commercial and industrial areas. The 'routes' construct encompasses the layout of streets, sidewalks, and other trails and paths. The 'recreational destinations' construct consists of parks, green spaces such as conservation areas, as well as gyms and other areas designed for sports and recreational activities. The 'appearance' construct considers visual neighbourhood components that can be quantified and measured objectively, including factors such as cleanliness, openness, lighting, and the number of other people using the area.

The middle column of the conceptual framework contains four hypothesized mediators of associations between BECs and walking: the time required for walking, convenience or ease of walking, safety of walking, and aesthetics of the walking location. I hypothesize that these mediators lie on the pathway between BECs and walking; that is, they are directly influenced by BECs and, in turn, directly influence walking behaviour. The constructs are based on factors that have been identified in previous studies as having an influence on activity behaviour [46,49,56]. Mediators of behaviour are only included if they have the potential to be affected by BECs. Many other behavioural mediators exist, but are influenced by other categories of constructs. For instance, personal values affect behaviour, but influences on personal values fall under 'psychological state' or 'socioeconomic/cultural environment'. As this thesis focuses specifically on objectively-measured BECs and walking, mediators are only considered where they are relevant to the interpretation of specific relationships between BECs and walking. Additionally, while the mediators are based on hypothesized causal pathways, the conceptual framework is not meant to illustrate causal relationships. The focus of this particular project is on whether or not BECs and walking are related, regardless of whether these are direct or indirect relationships. Future investigations may investigate the dynamics of how they are related.

I included mediators in the framework because they assist in conceptualizing the hypothesized relationships between BECs and walking. On the other hand, I did not include potential confounders and effect modifiers because I felt this would detract from the framework's clarity. Relationships between BECs and walking are likely complex and multifaceted and therefore have many potential confounders and effect modifiers. An attempt to list all hypothesized confounders and effect modifiers would clutter the framework, which would not fit with the goal of facilitating clear visualization of the hypothesized associations. Instead, such covariates have been left out, but should be considered when assessing existing evidence or planning future research. Perhaps additional constructs and items will be added and others modified in future iterations of the conceptual framework. This framework is a starting point for conceptualization that focusses specifically on BECs and walking. While a formal evaluation was beyond the scope of the current project, future research may evaluate and modify the framework.

CHAPTER 3: Systematic Review of the Literature

3.1 Background

3.1.1 Relationship between Conceptual Framework and Systematic Review

I conducted a systematic review of the scientific literature on associations between BECs and walking in order to achieve objective two, which is to assess the current evidence on these associations. I used the conceptual framework outlined in Chapter 2 to guide this systematic review. Generally speaking, the systematic review involved searching for studies that fit into the conceptual framework's hypothesized associations (a detailed explanation of this process is given in section 3.2 Methods). This allowed the systematic review to identify which of the relationships hypothesized in the framework are supported by evidence in the scientific literature.

I chose a systematic review as the methodology to achieve objective two because systematic reviews are widely considered an optimal method of synthesizing existing scientific evidence [69]. A systematic review attempts to identify all of the scientific literature pertaining to a research question. Systematic reviews also typically include a methodological quality assessment, which provides an evaluation of the risk of bias, reporting quality, and external validity of the included studies. Quality assessment can indicate the level of confidence that can be placed in the conclusions of the studies.

3.1.2 Recent Systematic Reviews and Research Gaps

Prior to the full systematic review of primary studies, I conducted a preliminary scoping search for similar systematic reviews to ensure that I was not duplicating an existing review. I searched Scopus using the following combined search terms: neighbo?rhood AND walk* AND "systematic review". I then hand searched the references from each relevant review article for additional systematic reviews. I also searched for articles that cited the relevant reviews using Scopus' forward citation feature. The following three reviews were the most similar to my planned systematic review.

A 2004 review by Owen et al. looked at environmental influences on walking behaviour and grouped the outcomes according to type of walking: walking for exercise or recreation, walking to get to and from places, and total walking [46]. Aesthetic attributes of the environment were found to be associated with walking for exercise. Convenience of walking facilities and accessibility of destinations were found to be related to walking to and from places. Associations were identified with perceptions about traffic for both walking purposes. While the outcomes were restricted to walking and were therefore narrowly focused, outcome measures included both perceived and objectively measured outcomes, instead of focusing solely on objective measures [46].

A more recent systematic review was conducted by Saelens and Handy in 2008. They looked at previous reviews in addition to individual studies, although not all reviews were systematic and many did not look specifically at walking. Saelens and Handy described consistent positive relationships between walking for transportation and density, land use mix, and distance to non-residential destinations; inconsistent evidence for relationships between walking for transportation and route connectivity, parks and open spaces, and safety; and inconsistent evidence of any relationships between recreational walking and the physical environment. The authors included both objective and perceived measures of the environment, measures at different scales, and both rural and urban areas [27].

While Owen at al.'s and Saelens et al.'s reviews included studies that measured perceived BECs only, a systematic review by McCormack and Shiell restricted studies to those that included objective BEC measures [70]. McCormack and Shiell also restricted their review to studies that addressed the issue of neighbourhood self-selection; that is, bias introduced when study participants have a pre-existing preference for walking and move to a neighbourhood that fits this preference. Their review found that most of the BEC – physical activity associations identified were in the expected direction or null. They also observed that BECs were more likely to be associated with transportation physical activity than recreational physical activity. Interestingly, they noted that accounting for neighbourhood self-selection seemed to attenuate BEC – physical activity associations, but did not eliminate them altogether. Unfortunately, McCormack and Shiell's review looked at total physical activity and did not focus on walking specifically [70].

This project's systematic review will be somewhat similar to the aforementioned reviews, but will have a narrower focus as it will be restricted to studies occurring in urban areas, using walking outcomes, and using objective measures of neighbourhood-level BECs. The reviews by Owen and Saelens included subjectively measured BECs. Additionally, these two reviews did not report specific inclusion criteria and neither listed the included and excluded studies, so reproducibility is difficult

[27,46]. McCormack and Shiell's review focused on objectively measured BECs only, but they looked at all types of physical activity, whereas the present review will focus specifically on walking [70]. I therefore conducted a new systematic review rather than updating an existing one. I developed the following research question to be answered by the systematic review based on the objectives and the population of interest. I then answered this research question by implementing the methodology described in the next section.

Research Question: According to the available scientific literature, which BECs are associated with walking for transportation and/or walking for leisure among able-bodied adults in urban areas in Australia, Canada, New Zealand, and the United States?

3.2 Methods

The planned methods for the systematic review were initially outlined in a protocol that was submitted to the Department of Epidemiology and Community Medicine. The methods I undertook are described in detail in the following sections.

3.2.1 Eligibility Criteria

I based the eligibility criteria on the research question and used the conceptual framework to guide refinement of these criteria. To be included in the systematic review, a study's total population or population subgroup with separate effect estimates had to meet the following criteria: 1. able-bodied/able to walk without assistance; 2. adult/aged 18 or older; 3. residing in an urban area (according to definition in Glossary); and 4. residing in Australia, Canada, New Zealand, or the

United States. In establishing these criteria, I aimed for the populations across studies to be relatively homogenous with regard to the various BECs that influence them and the type and amount of walking outcomes they engage in. This goal of increasing clinical homogeneity across the included studies was to allow for meaningful synthesis of the study results. The relationship between BECs and walking is likely to be very different in populations such as children, rural residents, and people with mobility problems. For instance, the proximity of trails may have little to no effect on walking if their limited mobility prevents them from using these trails, a well-connected street network may be less likely to influence children if they are less likely to walk to run errands and more likely to walk while playing outside, and nearby parks probably have little impact on rural residents as their residences are already surrounded by open, natural environments.

Improving clinical homogeneity across studies was also the motivation for restricting studies to those with populations residing in Australia, Canada, New Zealand, or the United States. The type and distribution of BECs within cities in these countries is similar, as well as the type and distribution of walking behaviours [71]. This is because the majority of urban growth in these countries occurred at a time when private automobiles were available and most of the population was able to afford their own car. The result was that much of the urban landscape is designed to accommodate cars, and people's transportation activities generally involve cars [72]. A strong car culture has developed in North America and Australasia that appears to extend beyond the influence of BECs. This is indicated by the preference to drive for short-distance trips in the United States, whereas in Europe active transportation is more common for short-distance trips [71]. European countries have additional factors that may confound associations between BECs and walking, such as a higher cost of owning and operating automobiles [71]. To avoid potential confounders such as these, eligible studies were restricted to Australia, Canada, New Zealand, or the United States.

The exposures that were eligible for the study were the presence of anything that fit the definition of BECs (see Glossary) and were measured using objective methods. The overall study or at least one subgroup (with separate effect estimates) had to include an exposure measure that was restricted to an objectively-measured BEC, or a combination of BECs that were all measured objectively. I used the subcomponents of each BEC construct in the framework as a guide, but if studies examined neighbourhood characteristics that were not in the framework they were still included, as long as they met the definition of objectively-measured BECs. In the protocol I stated that I would revise the framework if included studies examined BECs that did not fit into any of the constructs.

I used the framework to assess outcome eligibility as well; however, in this case I excluded outcomes that did not fit into one of the two predefined walking constructs: walking for transportation or walking for recreation. A study, or at least one study subgroup with a separate effect estimate, had to specify that they examined either walking for transportation or walking for recreation, leisure, or exercise. If the study or relevant subgroup did not specify the type of walking, looked at both types of walking combined, or looked at another type of walking (e.g., occupational walking), the study was excluded.

Eligible study designs were those involving a comparison between two or more groups with different exposures or between two or more time periods. Studies that did not include a comparison group, such as case reports or case series, were excluded. I used study design characteristics to assess eligibility instead of the study design labels used by individual articles because non-randomized studies are not consistently labelled [73]. For instance, one study may label itself a case-control study, while another study may label the exact same design a retrospective cohort study. I also excluded studies that were not reported in English. I based this exclusion criterion entirely on resource considerations. English is the only language I understand, and recruiting individuals to translate the non-English articles is beyond the resource limitations of this thesis project. The eligibility criteria discussed here were the basis of the literature search strategy described in the next section.

3.2.2 Literature Search Strategy

I developed the search strategy in MEDLINE. I began by identifying all of the Medical Subject Heading (MeSH) terms (the controlled vocabulary in MEDLINE/PubMed) used in the review articles retrieved in the preliminary scoping search I conducted prior to the full systematic review. I used the MeSH browser in PubMed to identify additional MeSH terms that appeared relevant to the population, exposures, and outcomes of interest. I supplemented the controlled vocabulary with keywords, using the conceptual framework as a guide (Figure 4). I used the items within each construct, as well as the construct names themselves, as a starting point; I then identified keywords in the review articles that were retrieved in the preliminary scoping search. I entered the keywords from the conceptual framework and the scoped articles into a dictionary and a thesaurus to identify additional keywords and alternate spellings. The full MEDLINE search strategy can be found in Appendix A.

After identifying relevant terms, I structured the search strategy by dividing the eligibility criteria into the following categories: 1. Population of interest, 2. Exposures of interest, and 3. Outcomes of interest. It is often thought that including the 'outcomes' category in a search strategy, as I have done, sacrifices too much sensitivity and should be avoided. Indeed, this is the recommendation from the Cochrane Collaboration [73]. However, traditional systematic reviews are usually concerned with the effectiveness of an intervention. If the goal of the research is to determine effectiveness, it is important for the search to capture all possible outcomes, including adverse events. It therefore makes sense to exclude the outcome category from the search because it is nearly impossible to identify all possible outcomes studied, so restricting the search to specific outcomes would exclude potentially relevant studies. This research project, on the other hand, poses an etiological research question. I wish to identify which BECs are associated with walking, which is a specific outcome. I am not attempting to determine the effectiveness of an intervention such as a change to the physical environment. If I did not include outcomes in the search I would have retrieved a massive number of irrelevant studies.

In order to restrict the number of irrelevant articles (i.e., improve specificity), search limits or search filters are usually applied to the search strategy. I used search limits to limit the search results to humans, adults, and articles published in the year 2000 or later. I chose 2000 as the date limit because relationships between BECs and walking are an area of research that has only recently come into focus and very few studies were done before 2000 [31,32]. Therefore, this date limit eliminated the time and resources that would have been required to screen many additional articles without sacrificing much search sensitivity. The search was therefore limited to studies published between January 1st, 2000 and March 2nd, 2012. I did not apply language limits to the search, despite the fact that I only included English-language studies in the systematic review. I did not apply language limits because I wanted to identify the number of studies excluded due to language. I also did not apply study design search filters. Design filters are commonly used to reduce irrelevant search results in systematic reviews of RCTs [74]; however, I anticipated that most or all studies on relationships between BECs and walking would use non-randomized study designs, since it is very difficult to randomize people to live in different neighbourhoods. Compared to RCTs, study design filters are much less accurate at capturing the various non-randomized study designs, due, in part, to the issue of inconsistent labelling mentioned previously [73]. This inability to filter by study designs generally results in systematic reviews of non-randomized studies having a much larger volume of articles to screen and, usually, a larger proportion of irrelevant articles [73].

After designing the search strategy, I did several checks to ensure the validity of the search. The search strategy was peer reviewed by an information specialist, who used the PRESS checklist to analyze the quality of the search (Appendix B) [75]. I revised the search strategy according to feedback from the information specialist. I also verified the search by checking whether the review articles identified in the preliminary scoping search were retrieved in the full systematic review search strategy. Each of the articles from the scoping review was identified by the search except for one, which was not retrieved because it was not indexed in MEDLINE (the scoping search used Scopus). These checks demonstrate that the search is sensitive enough to retrieve almost all relevant articles.

After verifying the search in MEDLINE, I adapted the search strategy to three additional databases: EMBASE, PsycINFO, and TRID (Transportation Research International Documentation). I then uploaded the search results from all four databases to the reference management software RefWorks. However, I moved the references from RefWorks to DistillerSR, which is another reference management platform that facilitates and tracks systematic reviews. I then used DistillerSR to identify and remove duplicate articles. I verified that each set of duplicates identified by DistillerSR were true duplicates before removing them.

3.2.3 Study Screening

I used DistillerSR for study screening as well. In order to apply the eligibility criteria to the studies in a systematic, minimally biased fashion, at least two reviewers screened each article. We screened articles at three separate levels, using the forms shown in Appendix C. We screened titles and abstracts at level one. Before screening began, all reviewers met to pilot the level one screening form. I revised the form to improve clarity based on the feedback at this meeting. At level one, we excluded articles that were not in English, clearly did not evaluate BECs and walking, or did not compare two or more groups or two or more time points. For a title/abstract to be passed on to level two, it had to be included by only one reviewer; however, to be excluded at level one, it had to be excluded by two reviewers. In cases where the reviewers disagreed about whether the study should be excluded, the two reviewers met to discuss the abstract. In each case, consensus was reached on whether or not the article should be excluded.

Level two screening focused on the study population, exposures, and outcomes, as can be seen in the level two screening form (Appendix C). As was done for level one, reviewers met to pilot the level two screening form and I revised the form based on feedback from the meeting (Appendix C). During level two screening, two reviewers were required to exclude each article, as was done during level one screening. However, unlike level one screening, two reviews were also required to pass the article to level three during level two screening. Again, all disagreements about eligibility were resolved through the reviewers meeting and achieving consensus.

In the third and final level of screening, the full texts of the articles were again assessed by two reviewers, independently. The level three screening form repeated the three population criteria questions from level two regarding whether the population was able-bodied, adult, and urban (Appendix C). However, at level two, we passed articles on to level three if they received a response of 'Unclear' on these three questions, whereas at level three a response of 'Unclear' resulted in the article being excluded. Hence, articles had to report all of these population characteristics to be included in the systematic review. At level three we also excluded systematic reviews, which could have been included up to this point if they met all criteria. My reasoning for excluding systematic reviews was that any primary studies included in the systematic reviews that met the criteria should have been picked up in the search and screening. As I did not want to double count any comparisons in the analysis, I excluded articles that reported a comparison from another study. Again, we resolved disagreements about inclusion through consensus. The articles that remained after level three were all reports of primary comparative studies that explicitly met the population, exposure, and outcome criteria.

3.2.4 Data Extraction

I extracted data from the studies that met the inclusion criteria using the data extraction form shown in Appendix D. Another reviewer checked a 10% random sample of the articles for accuracy of the extracted data. I extracted data on relevant exposures, outcomes, and estimates of association between the two. If an article stated that relevant measures were done, but the estimates were not reported, I contacted the first author to request these data. I extracted study characteristics that are typically extracted during systematic reviews such as first author, year of publication, study objective, study location, start and end dates, and source of funding. In addition to these characteristics, I extracted study design characteristics such as the group allocation method, group comparison method, and methods used to control for confounding at the study design stage. It is particularly important to extract these additional study design characteristics when non-randomized studies are included in a systematic review so that each study's design and risk of selection bias can be assessed.

Selection bias requires special attention when analyzing non-randomized studies because it is of particular concern when allocation to study groups is not random. It is important to note that selection bias can refer to two separate issues. Selection bias sometimes refers to external validity, in which case it is bias due to important differences between the study sample and the target population [7]. This type of selection bias affects a study's generalizability. Selection bias can also refer to internal validity. In this case it is bias due to important differences between the study groups. This type of selection bias affects a study's internal validity, as it causes the study groups to be less comparable on key prognostic factors [7]. If these prognostic factors are associated with the exposure and outcome of interest they will confound the estimate of association [7]. From this point on, when I refer to selection bias I am talking about the second type: selection bias in relation to internal validity/comparability.

I was careful to extract data on which confounding variables were considered in each study and how the study controlled or adjusted for these variables. I recorded all techniques used in each study to control for confounding at the design stage and adjust for confounding at the analysis stage. Furthermore, if studies reported effect estimates that were adjusted for confounders as well as estimates that were unadjusted, I recorded both estimates. There were two potential confounders I thought warranted special attention: 1. whether the study attempted to control for neighbourhood self-selection (people who walk more choosing more walkable neighbourhoods) and 2. whether it attempted to control for varying amounts of time spent in participants' neighbourhoods of residence. These two potential confounders are specific to BEC and walking relationships and are discussed in detail in section 3.4.3, Strengths and Limitations of Included Studies. I also extracted all of the reported characteristics concerning the studies' designs, populations, and effect estimates in order to conduct the analyses and to allow for readers of the review to gauge the methodological quality of each study.

3.2.5 Methodological Quality Assessment

I assessed the methodological quality in each included study using the Downs and Black checklist, which can be used for all study designs [76]. The checklist evaluates methodological quality in the following five domains: 1. Reporting quality, which includes ten separate items; 2. External validity (generalizability), including three items; 3. Internal validity – Bias, with seven items; 4. Internal validity – Confounding (selection bias), with six items; and 5. Power, with one item. I altered the question about statistical power so that studies received a score of one if they reported a power or sample size calculation and a score of zero if they did not. This adaptation has been done in a number of other systematic reviews using the Downs and Black checklist [77,78]. I modified the power question because the heterogeneity in outcome measures and wide variation in effect sizes and variability measures precluded estimation of accurate sample sizes [79,80]. The main drawback to this modification was that an in-depth analysis of the risk of type II error was no longer possible.

As shown by the various domains, the Downs and Black checklist is very comprehensive, assessing methodological quality over a diverse range of areas. Another advantage of the Downs and Black checklist is that it has been validated by the authors [7,76]. The Downs and Black authors found that validity and reliability were good in all of the checklist's domains except for the external validity domain [7]. It is also one of six tools recommended for non-randomized studies in a health technology assessment by Deeks et al [7], and one of two checklists recommended for non-randomized studies by the Cochrane Collaboration [73].

3.2.6 Analysis

After assessing each study's methodological quality, I analyzed the data extracted from the studies. I anticipated from the beginning that I would not be able to conduct a meta-analysis on any of the extracted data because I expected that most or all studies would be non-randomized. Non-randomized studies are generally more heterogeneous than RCTs and a pooled summary statistic from a heterogeneous group of studies may not be meaningful.

Perhaps the biggest source of heterogeneity among non-randomized studies is methodological. There are a number of various non-randomized study designs, ranging from controlled clinical trials with no randomization, to observational studies such as cohort, case-control, and cross-sectional studies. A meta-analysis should not combine studies of different designs if the goal is a meaningful pooled effect estimate [73]. Even if a meta-analysis is restricted to studies that share one non-randomized study design, studies use a variety of methods to reduce selection bias and control for a variety of different potential confounders. All of this adds significant methodological heterogeneity between studies and often precludes a meaningful pooled effect estimate.

Non-randomized studies also tend to have more clinical heterogeneity than RCTs. RCTs need to recruit eligible participants who consent to the study. Populations such as pregnant women and children are typically excluded due to safety and ethical concerns. Non-randomized studies, and observational studies in particular, do not pose the same ethical issues since people usually choose their exposure groups freely. The result is that a broader, more generalizable study population is often included in non-randomized studies with observational study designs. While observational studies may have improved external validity over RCTs, the less restricted study populations result in more clinical heterogeneity between studies and greater difficulty pooling these studies in a meta-analysis.

Knowing that a meaningful meta-analysis would be unlikely, I sought an alternative means of synthesizing the data and decided on the vote counting method [81] (i.e., conducting counts of statistically significant effect estimates), as well as a narrative synthesis. I used the conceptual framework to guide both of these. For the counts of statistically significant effect estimates, I grouped the relevant comparisons from the included studies into the hypothesized associations represented by lines in the conceptual framework (Figure 5). I did this by categorizing the exposure into one of the BEC constructs and the outcome into one of the walking constructs. In doing this, the effect estimate from the comparison is represented by the line joining the BEC construct to the walking construct (see Figure 5). All relevant outcomes should fit into one of the two walking constructs because studies had to specify whether the outcome was walking for transportation or walking for recreation/leisure/exercise in order to be included. On the other hand, all relevant exposures did not necessarily have to fit into one of the BEC constructs to be included in the review, they just had to meet the definition of BEC (see Glossary). If a relevant exposure did not fit into an existing BEC construct I created a new construct.

After categorizing the relevant comparisons into the conceptual framework's relationships, I counted the number of comparisons that fit along each of the lines connecting BEC constructs to walking constructs. I also counted how many of these were statistically significant at $p < 0.05$. Dividing the number of statistically significant estimates by the total number of estimates in each category gave the proportion of effect estimates that were statistically significant for each of the hypothesized relationships. For each of these proportions, I conducted an exact chi square goodness of fit test to calculate statistical significance. I tested the null hypothesis that the proportions of statistically significant and null associations in each category were equal. I did this for each of the lines in the model, with the intention of changing lines from dashed to solid if they had a statistically significant (at $p < 0.05$) goodness of fit test. Despite the fact that some estimates came from the same studies and were therefore correlated, I did not include a Rao Scott adjustment of the goodness of fit test to account for clustered data. The reason was that the number of estimates and number of clusters in the categories were so small that a Rao Scott adjustment may have produced unstable estimates [82].

In addition to the overall analysis, I stated in the protocol that I would conduct the following subgroup analyses if enough studies were included in the review. I planned potential subgroups based on geographical region, body mass index (BMI), and income level. I also planned to do a sensitivity analysis comparing studies with high methodological quality scores to studies overall.

3.3 Results

3.3.1 Search Results

Our search strategy identified 14,867 potentially relevant articles in MEDLINE, EMBASE, PsycINFO, and TRID. For each database, Table 2 shows the number of articles retrieved, the number of articles remaining after removing duplicates, and the proportion of articles remaining after removing duplicates. During duplicate removal, I gave first priority to MEDLINE articles. That is, if one of the duplicates was from MEDLINE, I kept that one and deleted the articles from the other databases. The exception to this was when another article provided more information in the abstract. Likewise, I gave second priority to EMBASE, third to PsycINFO, and fourth priority to TRID. Therefore, the fact that only 48.0% of the articles retrieved in EMBASE remained after duplicates were removed shows that there was a lot of overlap between MEDLINE and EMBASE. TRID, on the other hand, had 95.3% of its articles retained after duplicate removal, despite being given last priority. This shows that there was very little overlap between TRID and the other databases. Table 2 also shows that approximately half of the 11,509 articles remaining after I removed duplicates came from TRID.

Table 2: Number of articles retrieved before and after removing duplicates

Database	Pre de-dup	Post de-dup	Post/Pre de-dup
MEDLINE	3196	2925	91.5%
EMBASE	4410	2118	48.0%
PsycINFO	1464	941	64.3%
TRID	5797	5525	95.3%
Total	14867	11509	77.4%

3.3.2 Screening Results

The 11,509 articles that remained after removal of duplicates were screened during level one screening. 986 of these remained after level one screening, 96 remained after level two, and 13 remained after level three and were ultimately included (Figure 6). The 11,496 excluded articles are categorized according to reasons for exclusion in Table 3 (studies excluded during full-text screening are listed in Appendix E).

Table 3: Reasons for exclusion and number of articles excluded

Reason for Exclusion	**Number Excluded**
Not written in English	330
Does not evaluate BECs and walking	9,932
Does not compare two groups or two time periods	550
Full text not available	214
Not in Australia, Canada, New Zealand, or United States	124
Study population (or subgroup) not entirely able-bodied	28
Study population (or subgroup) not entirely older than 18	76
Study population (or subgroup) not entirely urban residents	21
BECs not measured objectively	73
Walking for transport and recreation not reported separately	77
Systematic Review	14
Did not report mobility status of study population	57
Total	11,496

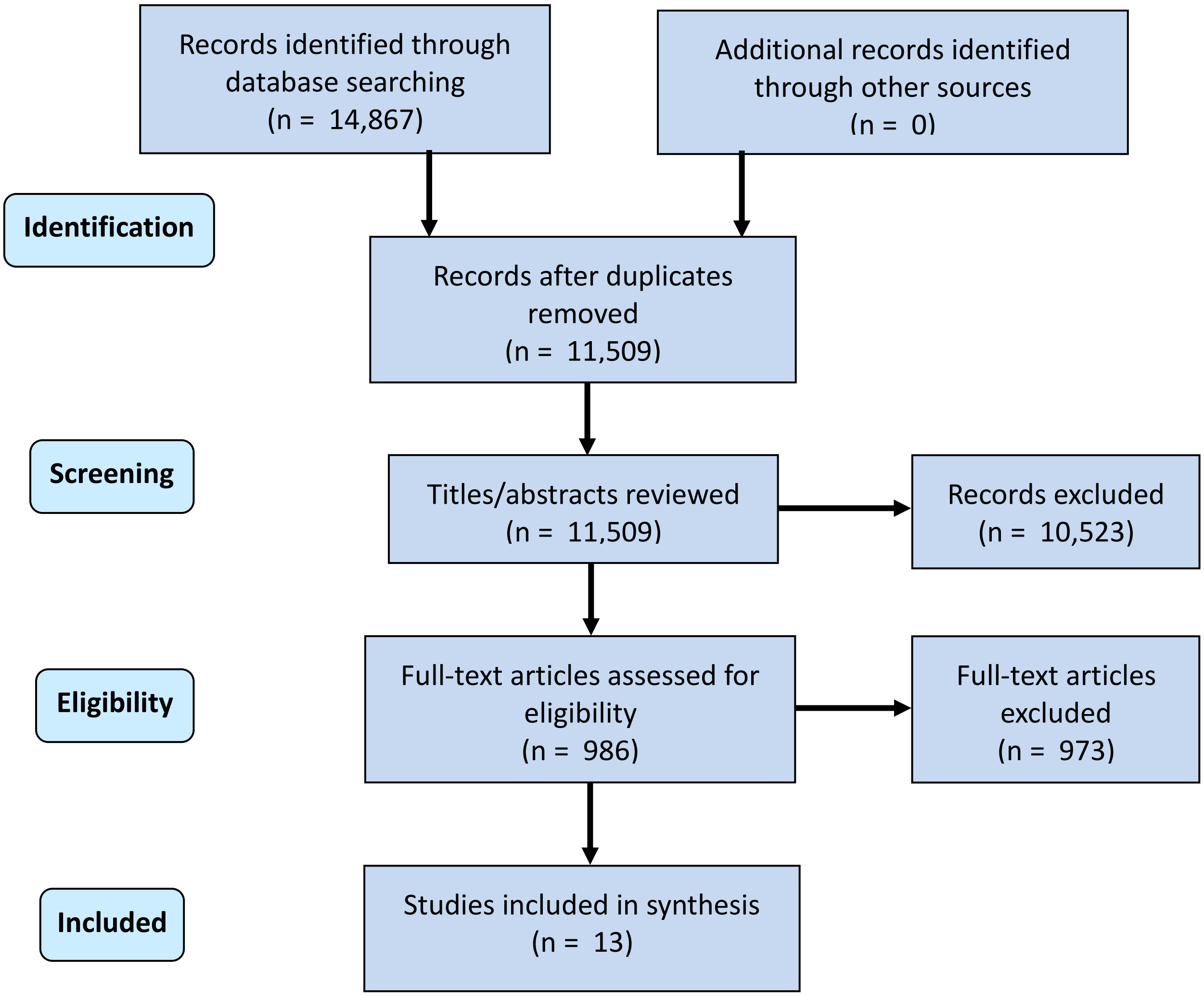

Figure 6: Flow diagram of studies included after each level of screening

3.3.3 Main Findings from Included Studies

Table 4 shows the primary objective and the main conclusions of each of the 13 studies that met the inclusion criteria. In many cases the study looked solely at BECs and walking; however, some studies looked at other behavioural influences, such as perceptions of the environment or psychosocial factors, and some studies looked at outcomes in addition to walking, such as all types of physical activity. While the overall objective and/or conclusion listed in Table 4 may imply that the study did not specify *built environment* characteristics of neighbourhoods or walking for transportation or recreation, at least one of the effect estimates must have looked at this association for the study to be included in the review. However, in some cases this was not their primary objective.

Table 4: Main objectives and conclusions of included studies

Author/Year	**Primary Objective**	**Main Conclusions**
Carlson et al. 2012 [83]	Explore interactions among individual, interpersonal, and environmental correlates of physical activity in a large sample of community-dwelling older adults.	Results support synergistic interactions between the built environment and psychosocial factors in explaining physical activity levels among older adults.
McConville et al. 2011 [84]	Analyze how accessibility, intensity, and diversity of nonresidential land uses are related to walking for transportation.	Accessibility and intensity of certain land uses, as well as land use diversity, are positively associated with walking for transportation.
Mumford et al. 2011 [85]	Test hypothesis that relocation to a dense, walkable residential environment promotes physical activity and pedestrian-oriented travel.	Adults increase their levels of walking for transportation and recreation, increase public transit use, and decrease automobile travel after moving to a dense, mixed-use neighbourhood.
Duncan et al. 2010 [86]	Examine magnitude of association between adults' walking for transport and four measures of land use mix (LUM) at the census collection district (CCD) level. Also, examine magnitude of association between each LUM measure and residents' perceptions of the corresponding local environment attributes.	Refined LUM measures (but not original measures) are significantly associated with frequency of walking for transport. Area-corrected LUM measures had significant associations with duration of walking for transport. All LUM measures had significant associations with perceived proximity to destinations, but refined measures had stronger associations than original.

Sallis et al. 2009 [87]	Investigate how living in high vs. low walkability neighbourhoods relates to biological, behavioural, social, and mental health outcomes; examine whether these relationships are similar in high vs. low income neighbourhoods.	Living in walkable neighbourhoods is associated with higher physical activity levels and lower levels of overweight and obesity, but not with other outcomes. High and low income groups benefit similarly from living in high walkability neighbourhoods.
Coleman et al. 2008 [88]	Examine how dog ownership, participant characteristics, and neighborhood walkability interacted to explain objectively monitored physical activity levels and weight status.	Dog walking is associated with higher levels of physical activity and lower levels of obesity, and appears to be a mechanism for residents of high walkable neighbourhoods to be active.
Rodriguez et al. 2008 [89]	Examine associations between neighbourhood environment attributes that are modifiable in the short term and walking for transport and overall walking.	Difficulty parking and perceived access to transit are the only modifiable neighbourhood characteristics associated with walking.
Cerin et al. 2007 [90]	Examine associations with objective and perceived measures of access to destinations.	Measures of access to destinations are associated with transport walking, with workplace proximity as the most significant contributor to transport walking. These associations depend on sociodemographic factors and types of destinations.
Lee et al. 2007 [44]	Examine validity of proposed conceptual frameworks. Test associations among physical activity, population characteristics, and the social and physical environment. Examine how levels of physical activity vary among different health risk and economic groups, and how their levels of support differ in their neighbourhoods.	The social environment is more strongly associated with recreational physical activity, while the physical environment is more strongly associated with transportation physical activity. Lower income populations live in more walkable areas and are more active for transportation than higher income populations. People with more health risks are less active. Further study of subpopulations is needed.

Oakes et al. 2007 [91]	Test basic hypotheses about the relationship between density, street connectivity, and walking behaviour.	Associations between density and street connectivity and walking and physical activity are modest to non-existent, if not contrary to hypotheses.
Owen et al. 2007 [92]	Examine relationships among objectively determined neighborhood walkability attributes and adults' walking.	Neighbourhood walkability attributes are associated with walking for transport, but not walking for recreation. Walkability accounted for a modest but statistically significant proportion of the variation in walking.
Saelens et al. 2003 [41]	Assess reliability and validity of self-report measures of neighbourhood environmental variables. Compare physical activity and weight status among residents of neighbourhoods characterized as having high or low walkability.	The study supports the reliability and validity of self-report neighbourhood subscales. The neighbourhood environment is associated with physical activity and the prevalence of overweight.
Giles-Corti et al. 2002 [93]	Examine socioeconomic status (SES) differences in patterns of physical activity and access to a supportive physical environment.	Supportive physical environments (particularly perceived access to sidewalks and attractiveness) are associated with walking and vigorous physical activity. Respondents in low SES areas have superior access to many facilities, but are less likely to use them than respondents in high SES areas.

The main conclusions reported by the included studies appear to offer fairly consistent evidence of associations between several types of BECs and walking, particularly walking for transportation. The one exception is Oakes et al.'s study, which states that "contrary to prior research, the authors conclude that the effects of density and block size on total walking and physical activity are modest to non-existent, if not contrapositive to hypotheses" [91]. Considering that research articles tend to focus on positive results over null results [94], a deeper investigation into the specific study characteristics and effect estimates is needed.

3.3.4 Characteristics of Included Studies

In addition to each study's main conclusions, I extracted data on a variety of study characteristics using the data extraction form shown in Appendix D. Tables 5 and 6 show the following data extracted from each study: first author, year of publication, study location(s), study design, survey used and delivery method, sample size, mean age (with standard deviation) of study participants, proportion of male participants, relevant subgroups of participants (if any), the relevant BEC exposures and their comparators, the walking outcomes and how they were measured (minutes per week, frequency, or yes/no), the types of effect estimates (B, OR, etc.), the point estimates, confidence intervals, p-values, and the covariates adjusted for. The studies by McConville et al. and Carlson et al. stated that they measured a number of relevant BECs and walking associations, but some of these were not reported in the published articles. I contacted the lead authors of both studies to request these additional data. Both authors responded with the requested data and these data are included in Tables 5 and 6. In addition to the data shown in Tables 5 and 6, I also extracted data on each study's primary objective, dates of data collection, methods used to control confounding at both the design and analysis stage, sources of study and/or author funding, additional baseline characteristics such as BMI and education level, participant eligibility criteria, methods used to measure BEC exposures, whether walking was measured objectively or subjectively, and statistical methods used for data analyses.

Table 5: Evidence summary of included studies examining walking for transportation

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
Carlson (2012) [83]	King County WA (Seattle) & Baltimore/ Washington, US	CS (SNQLS); CHAMPS; Mailed	718; 74.4 (6.3) years (all > 65); 46.9% male	0 VS. >=1 parks and/or private recreation facilities within 500m buffer from home	Walking for transport (mins/wk)	B=9.12; 95% CI [-4.18, 22.42]; p=0.178	Age, Ethnicity, Months at address, Car ownership
				High VS. low walkability[i] 500m from home	Walking for transport (mins/wk)	B=21.52; 95% CI [14.91, 28.14]; p<0.001	
				High VS. low walkability[i] 500m from home (high social support only)	Walking for transport (mins/wk)	B=35.75; 95% CI [25.79, 45.70]; p<0.001	
				High VS. low walkability[i] 500m from home (low social support only)	Walking for transport (mins/wk)	B=17.91; 95% CI [10.31, 25.51]; P<0.001	
				High VS. low walkability[i] 500m from home (high self-efficacy only)	Walking for transport (mins/wk)	B=38.40; 95% CI [28.66, 48.14]; P<0.001	
				High VS. low walkability[i] 500m from home (low self-efficacy only)	Walking for transport (mins/wk)	B=11.43; 95% CI [4.64, 18.22; P=0.001	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
Carlson (2012) [83]	King County WA (Seattle) & Baltimore/ Washington DC, US	CS (SNQLS); CHAMPS; Mailed	718; 74.4 (6.3) years (all > 65); 46.9% male	High VS. low walkability[i] 500m from home (high barriers only)	Walking for transport (mins/wk)	B=17.00; 95% CI [7.84, 26.17]; P<0.001	Age, Ethnicity, Months at address, Car ownership
				High VS. low walkability[i] 500m from home (low barriers only)	Walking for transport (mins/wk)	B=37.74; 95% CI [28.69, 46.79]; p<0.001	
McConville (2011) [84]	Montgomery County MD (DC suburb), US	CS; IPAQ-LF; Phone & door-to-door interviews	260; Median (IQR) 51 (19-90) years; 33.8% male	Distance to closest bank (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=0.75; 95% CI [0.18, 3.22]	Age, Sex, Education level, Residential population density (people/acre), Sidewalk density (feet/acre), Neighborhood type (urban, suburban, exurban)
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.15; 95% CI [0.02, 0.97]	
				Distance to closest fast-food restaurant (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=0.30; 95% CI [0.22, 0.42]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.49; 95% CI [0.08, 2.98]	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
McConville (2011) [84]	Montgomery County MD (DC suburb), US	CS; IPAQ-LF; Phone & door-to-door interviews	260; Median (IQR) 51 (19-90) years; 33.8% male	Distance to closest restaurant (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=0.36; 95% CI [0.19, 0.69]	Age, Sex, Education level, Residential population density (people/acre), Sidewalk density (feet/acre), Neighborhood type (urban, suburban, exurban)
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.28; 95% CI [0.04, 2.18]	
				Distance to closest grocery store (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=0.38; 95% CI [0.26, 0.54]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.27; 95% CI [0.07, 1.06]	
				# grocery stores ½ mile from home	Walking for transport <150 mins/wk VS. no walking	OR=1.71; 95% CI [1.55, 1.88]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=1.69; 95% CI [1.05, 2.71]	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
McConville (2011) [84]	Montgomery County MD (DC suburb), US	CS; IPAQ-LF; Phone & door-to-door interviews	260; Median (IQR) 51 (19-90) years; 33.8% male	# grocery stores 1/4 mile from home	Walking for transport <150 mins/wk VS. no walking	OR=5.42; 95% CI [1.73, 17.01]	Age, Sex, Education level, Residential population density (people/acre), Sidewalk density (feet/acre), Neighborhood type (urban, suburban, exurban)
					Walking for transport >= 150 mins/wk VS. no walking	OR=5.13; 95% CI [1.40, 18.79]	
				# offices ½ mile from home	Walking for transport <150 mins/wk VS. no walking	OR=1.14; 95% CI [1.08, 1.20]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=1.14; 95% CI [1.06, 1.23]	
				# offices 1/4 mile from home	Walking for transport <150 mins/wk VS. no walking	OR=1.71; 95% CI [1.18, 2.47]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=1.56; 95% CI [1.06, 2.29]	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
McConville (2011) [84]	Montgomery County MD (DC suburb), US	CS; IPAQ-LF; Phone & door-to-door interviews	260; Median (IQR) 51 (19-90) years; 33.8% male	# retail stores ½ mile from home	Walking for transport <150 mins/wk VS. no walking	OR=1.05; 95% CI [1.03, 1.06]	Age, Sex, Education level, Residential population density (people/acre), Sidewalk density (feet/acre), Neighborhood type (urban, suburban, exurban)
					Walking for transport >= 150 mins/wk VS. no walking	OR=1.06; 95% CI [1.03, 1.08]	
				# retail stores 1/4 mile from home	Walking for transport <150 mins/wk VS. no walking	OR=1.27; 95% CI [1.02, 1.59]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=1.23; 95% CI [0.94, 1.63]	
				Distance to closest rail/metro station (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=0.91; 95% CI [0.85, 0.97]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.90; 95% CI [0.82, 0.99]	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
McConville (2011) [84]	Montgomery County MD (DC suburb), US	CS; IPAQ-LF; Phone & door-to-door interviews	260; Median (IQR) 51 (19-90) years; 33.8% male	Distance to closest bus stop (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=0.44; 95% CI [0.14, 1.38]	Age, Sex, Education level, Residential population density (people/acre), Sidewalk density (feet/acre), Neighborhood type (urban, suburban, exurban)
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.01; 95%CI [0.001, 0.11]	
				# bus stops ½ mile from home	Walking for transport <150 mins/wk VS. no walking	OR=1.05; 95% CI [1.01, 1.08]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=1.06; 95% CI [1.00, 1.11]	
				# bus stops 1/4 mile from home	Walking for transport <150 mins/wk VS. no walking	OR= 1.00; 95% CI [0.96, 1.04]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=1.16; 95% CI [1.12, 1.20]	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
McConville (2011) [84]	Montgomery County MD (DC suburb), US	CS; IPAQ-LF; Phone & door-to-door interviews	260; Median (IQR) 51 (19-90) years; 33.8% male	Distance to closest recreational facility (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=0.48; 95% CI [0.33, 0.69]	Age, Sex, Education level, Residential population density (people/acre), Sidewalk density (feet/acre), Neighborhood type (urban, suburban, exurban)
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.27; 95% CI [0.05, 1.43]	
				Distance to closest sports facility (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=0.49; 95% CI [0.33, 0.72]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.47; 95% CI [0.20, 1.06]	
				Distance to 'physical activity use' (parks, playgrounds, athletic properties) (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=0.29; 95% CI [0.07, 1.24]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.11; 95%CI [0.05, 0.25]	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
McConville (2011) [84]	Montgomery County MD (DC suburb), US	CS; IPAQ-LF; Phone & door-to-door interviews	260; Median (IQR) 51 (19-90) years; 33.8% male	# parks ½ mile from home	Walking for transport <150 mins/wk VS. no walking	OR=0.99; 95% CI [0.85, 1.15]	Age, Sex, Education level, Residential population density (people/acre), Sidewalk density (feet/acre), Neighborhood type (urban, suburban, exurban)
					Walking for transport >= 150 mins/wk VS. no walking	OR=1.08; 95% CI [0.95, 1.23]	
				# parks 1/4 mile from home	Walking for transport <150 mins/wk VS. no walking	OR=0.88; 95% CI [0.64, 1.21]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=1.00; 95% CI [0.88, 1.14]	
				# ‘physical activity use’ ½ mile from home	Walking for transport <150 mins/wk VS. no walking	OR= 0.98; 95% CI [0.85, 1.14]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=1.09; 95% CI [0.96, 1.23]	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
McConville (2011) [84]	Montgomery County MD (DC suburb), US	CS; IPAQ-LF; Phone & door-to-door interviews	260; Median (IQR) 51 (19-90) years; 33.8% male	# 'physical activity use' 1/4 mile home	Walking for transport <150 mins/wk VS. no walking	OR=0.86; 95% CI [0.64, 1.15]	Age, Sex, Education level, Residential population density (people/acre), Sidewalk density (feet/acre), Neighborhood type (urban, suburban, exurban)
					Walking for transport >= 150 mins/wk VS. no walking	OR=1.00; 95% CI [0.89, 1.13]	
				Distance to 'social use' (religious & cultural areas, playgrounds, athletic properties) (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=0.51; 95% CI [0.30, 0.87]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.19; 95% CI [0.11, 0.35]	
				# land use types ½ mile from home	Walking for transport <150 mins/wk VS. no walking	OR=1.39; 95% CI [1.20, 1.59]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=1.53; 95% CI [1.21, 1.92]	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	**Effect Estimates** (Estimate; CI; p-value)	Covariates Adjusted For
McConville (2011) [84]	Montgomery County MD (DC suburb), US	CS; IPAQ-LF; Phone & door-to-door interviews	260; Median (IQR) 51 (19-90) years; 33.8% male	# land use types 1/4 mile from home	Walking for transport <150 mins/wk VS. no walking	OR=1.46; 95% CI [1.35, 1.57]	Age, Sex, Education level, Residential population density (people/acre), Sidewalk density (feet/acre), Neighborhood type (urban, suburban, exurban)
					Walking for transport >= 150 mins/wk VS. no walking	OR=1.69; 95% CI [1.30, 2.20]	
				Distance to library (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=1.05; 95% CI [0.47, 2.35]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.6; 95% CI [0.26, 1.40]	
				Distance to 'night use' (restaurants, bars, theaters, sports arenas) (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=0.36; 95% CI [0.13, 1.05]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.31; 95% CI [0.05, 2.05]	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
McConville (2011) [84]	Montgomery County MD (DC suburb), US	CS; IPAQ-LF; Phone & door-to-door interviews	260; Median (IQR) 51 (19-90) years; 33.8% male	Distance to office (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=0.36; 95% CI [0.12, 1.10]	Age, Sex, Education level, Residential population density (people/acre), Sidewalk density (feet/acre), Neighborhood type (urban, suburban, exurban)
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.19; 95% CI [0.03, 1.42]	
				Distance to park (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=0.32; 95% CI [0.07, 1.43]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.14; 95% CI [0.01, 2.54]	
				Distance to retail store (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=0.34; 95% CI [0.11, 1.11]	
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.23; 95% CI [0.03, 1.89]	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
McConville (2011) [84]	Montgomery County MD (DC suburb), US	CS; IPAQ-LF; Phone & door-to-door interviews	260; Median (IQR) 51 (19-90) years; 33.8% male	Distance to school (one mile increase in distance)	Walking for transport <150 mins/wk VS. no walking	OR=1.27; 95% CI [0.56, 2.88]	Age, Sex, Education level, Residential population density (people/acre), Sidewalk density (feet/acre), Neighborhood type (urban, suburban, exurban)
					Walking for transport >= 150 mins/wk VS. no walking	OR=0.92; 95% CI [0.12, 6.95]	
Mumford (2011) [85]	Atlanta, US	CS (planned as B/A); Survey designed for study (most questions came from NEWS and IPAQ); Completed on site;	101; 64% <= 34 years; 33% male	New mixed-use development[ii] (pre VS. post-move)	Walking for transport (responded "yes")	*44 pre-move VS. 84 post-move; p<0.0001	None/not applicable
					Walking for transport (days/wk)	*2.76 pre-move VS. 4.52 post-move; p<0.0001	
					Walking for transport (mins/wk)	*46.1 pre-move VS. 85.5 post-move; p<0.0001	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
Duncan (2010) [86]	Adelaide, AUS	CS (PLACE); IPAQ; Mailed	2506; 44.3 (12.3) years; 36.0% male	Original LUM score[iii] (one decile increase in score)	Walking for transport in previous 7 days (mins/day)	B <0.01; 95% CI [-0.61, 0.61]; p=NS	Age, Sex, Income level, Education level, Employment status, Presence of children in household, Number of adults in household, CCD-level median weekly household income
					Walking for transport in previous 7 days (mins/day)	*B=-0.28; 95% CI [-0.84, 0.29]; p=NS	
				Area-corrected (corrected for size of CCDs) LUM score[iii] (one decile increase in score)	Walking for transport in previous 7 days (mins/day)	B=1.06; 95% CI [0.33, 1.78]; p<0.01	
					Walking for transport in previous 7 days (mins/day)	*B=0.78; 95% CI [0.17, 1.39]; p<0.05	
				Revised LUM score[iv] (one decile increase in score)	Walking for transport in previous 7 days (mins/day)	B=0.28; 95% CI [-0.29, 0.85]; p=NS	
					Walking for transport in previous 7 days (mins/day)	*B=0.14; 95% CI [-0.42, 0.69]; p=NS	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
Duncan (2010) [86]	Adelaide, AUS	CS (PLACE); IPAQ; Mailed	2506; 44.3 (12.3) years; 36.0% male	Area-corrected (corrected for size of CCDs) revised LUM score[iv] (one decile increase in score)	Walking for transport in previous 7 days (mins/day)	B=0.75; 95% CI [0.22, 1.28]; p<0.01	Age, Sex, Income level, Education level, Employment status, Presence of children in household, Number of adults in household, CCD-level median weekly household income
					Walking for transport in previous 7 days (sessions/wk)	*B=0.60; 95% CI [0.07,1.13]; P<0.05	
				Original LUM score[iii] (one decile increase in score)	Walking for transport in previous 7 days (sessions/wk)	B=0.01; 95% CI [-0.01, 0.02]; p=NS	
					Walking for transport in previous 7 days (sessions/wk)	*B=0.01; 95% CI [-0.01, 0.02]; p=NS	
				Area-corrected (corrected for size of CCDs) LUM score[iii] (one decile increase in score)	Walking for transport in previous 7 days (sessions/wk)	B=0.04; 95% CI [0.03, 0.05]; p<0.001	
					Walking for transport in previous 7 days (sessions/wk)	*B=0.05; 95% CI [0.03, 0.06]; p<0.001	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
Duncan (2010) [86]	Adelaide, AUS	CS (PLACE); IPAQ; Mailed	2506; 44.3 (12.3) years; 36.0% male	Revised LUM score[iv] (one decile increase in score)	Walking for transport in previous 7 days (sessions/wk)	B=0.02; 95% CI [0.01, 0.04]; p<0.01	Age, Sex, Income level, Education level, Employment status, Presence of children in household, Number of adults in household, CCD-level median weekly household income
					Walking for transport in previous 7 days (sessions/wk)	*B=0.03; 95% CI [0.01, 0.04]; p<0.001	
				Area-corrected (corrected for size of CCDs) revised LUM score[iv] (one decile increase in score)	Walking for transport in previous 7 days (sessions/wk)	B=0.04; 95% CI [0.03, 0.05]; p<0.001	
					Walking for transport in previous 7 days (sessions/wk)	*B=0.04; 95% CI [0.03, 0.06]; p<0.001	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
Sallis (2009) [87]	King County WA (Seattle) & Baltimore/ Washington, US	CS (NQLS); IPAQ; Mail, online, or phone interview	2199; 45.1 (11.0) years; 51.8% male	High VS. low walkability[ib]	Walking for transport (antilog mins/wk)	Mean high VS. mean low = 44.3 VS. 12.8; p<0.0001	Age, Sex, Ethnicity, Marital status, Education level, Number of people in household, Number of motor vehicles/adults in household, Time (to account for repeated measures), Neighborhood clustering, Site, Length of time at current address
				High VS. low walkability[ib] (High income only)	Differential between high VS. low walkability neighbourhoods (mins/wk)	Differential; 5.1 mins; p=NR (but states that significantly higher in high walkability)	
				High VS. low walkability[ib] (Low income only)	Differential between high VS. low walkability neighbourhoods (mins/wk)	Differential; 2.3 mins; p=NR (but states that significantly higher in high walkability)	
				High VS. low walkability[ib] (Reasons for choosing neighbourhood added to model)	Significance of previously identified associations	Walkability main effect remained significant p<0.0001; Interaction with income no longer significant: p=0.027 before, p=0.11 after addition of variable	All covariates listed above, plus Reasons for choosing neighbourhood

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
Rodriguez (2008) [89]	Minneapolis-St. Paul & Montgomery County MD (DC suburb), US	CS (Survey data merged from Minneapolis-St. Paul study and Montgomery County, MD study) IPAQ-LF; NR	887; 47.5 (13.65) years; NR	Distance to nearest transit stop (100 foot increase in distance)	Transport walking time (none, <150 mins/wk, >= 150 mins/wk)	OR=1.00; 95% CI [0.99, 1.00]	Age, Sex, Ethnicity, Income level, Population density, Self-reported access to destinations, Study site (MD or MN)
				Bus stop density (each additional stop within 400m radius of home)	Transport walking time (none, <150 mins/wk, >= 150 mins/wk)	OR=0.82; 95% CI [0.31, 2.21]	
				Sidewalk density (each increase in 100 feet of sidewalks within 400m radius of home)	Transport walking time (none, <150 mins/wk, >= 150 mins/wk)	OR=1.01; 95% CI [0.99, 1.03]	
Cerin (2007) [90]	Adelaide, AUS	CS (PLACE); IPAQ; Mailed	2369; 44.5 (12.3) years; 35.8% male	LUM score[iii] (one unit increase in score)	Walking for transport (mins/wk)	B=30; 95% CI [-165, 224]; p=0.765;	Sociodemographic covariates (not specified)
				(LUM score[iii])^2 (one unit increase in score)	Walking for transport (mins/wk)	B=-63; 95% CI [-318, 192]; p=0.639	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
Cerin (2007) [90]	Adelaide, AUS	CS (PLACE); IPAQ; Mailed	2369; 44.5 (12.3) years; 35.8% male	Difference between Commercial/Industrial and Recreational groupings of CCDs	Walking for transport (mins/wk)	Difference; 39.6; 95% CI [0.4, 78.9]; p=0.048	Sociodemographic covariates (not specified)
				Difference between Recreational and Residential groupings of CCDs	Walking for transport (mins/wk)	No significant differences	
Lee (2007) [44]	Seattle, US	CS (Walkable and Bikable Communities project); Survey from Walkable and Bikable Communities project; Phone	438; NR; NR	Mean net residential density within 1-km buffer (area-based density)	Walking for transport in a usual week (sessions/wk)	*NR; +ve association; p<0.01	None/not applicable
				Number of residential units in the household parcel (parcel-based density)	Walking for transport in a usual week (sessions/wk)	*NR; +ve association; p<0.01	
				Distance to closest restaurant	Walking for transport in a usual week (sessions/wk)	*NR; +ve association; p<0.01	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
Lee (2007) [44]	Seattle, US	CS (Walkable and Bikable Communities project); Survey from Walkable and Bikable Communities project; Phone	438; NR; NR	Distance to closest bank	Walking for transport in a usual week (sessions/wk)	*NR; +ve association; p<0.01	None/not applicable
				Distance to closest grocery store	Walking for transport in a usual week (sessions/wk)	*NR; +ve association; p<0.01	
				Total length of sidewalks within 1-km buffer	Walking for transport in a usual week (sessions/wk)	*NR; +ve association; p<0.01	
				Mean slope within 1-km buffer (hills)	Walking for transport in a usual week (sessions/wk)	*NR; -ve association; p<0.01	
				Total number of street trees within 1-km buffer	Walking for transport in a usual week (sessions/wk)	*NR; +ve association; p<0.01	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
Oakes (2007) [91]	Minneapolis-St. Paul, US	CS (Twin Cities Walking Study); IPAQ-LF; NR;	716; 47.01 (13.73) years; 35.19% male	High population density VS. low population density	Metabolic equivalent (MET)[v] quintile	OR=1.992; 95% CI [1.296, 3.060]	Age, Sex, Ethnicity, Overall health, Education level, Marital status, Home ownership, Home tenure
				Large blocks VS. small blocks	Metabolic equivalent (MET)[v] quintile	OR=0.948; 95% CI [0.600, 1.497]	
Owen (2007) [92]	Adelaide, AUS	CS (PLACE); IPAQ-LF; Mailed	2650; 14.6% 20-29, 32.7% 30-44, 50.8% 45-65 years; 35.6% male	Walkability index[ic] (4th quartile VS. 1st quartile of index)	Walking for transport (mins/wk)	B=1.2; (0.8 SE); p=0.129	Age, Sex, Income level, Education level, Children in household, CCD-level SES
					Walking for transport (sessions/wk)	B=0.02; (0.01 SE); p<0.001	
				Walkability index[ic] (Reasons for choosing neighbourhood added to model) (4th quartile VS. 1st quartile of index)	Walking for transport (mins/wk)	B=0.7; (0.8 SE); p=0.406	All covariates listed above, plus Reasons for choosing neighbourhood
					Walking for transport (sessions/wk)	B=0.01; (0.00 SE); p<0.001	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
Saelens (2003) [41]	San Diego, US	CS; New survey developed for study; Mailed	106; Mean 47.9 years; 46.7% male	High walkability VS. low walkability[vi]	% of residents walking for errands	B=1.04 ; (0.50 SE); p=0.01	Age, Education level
					% of residents walking for errands	*85.2% VS. 59.6%; p=0.003	None/not applicable
					Walking to or from work or school (mins/wk)	*0.0 VS. 0.0; NS	
					Walking to or from bus/transit stop (mins/wk)	*0.0 VS. 0.0; NS	
					Walking for errands outside home (mins/wk)	*30.0 VS. 15.0; p<0.05	
Giles-Corti (2002) [93]	Perth, AUS	CS; "Modified items from other Australian surveys"; NR;	1773; Range 18-59 years; 32.2% male	Public open space access: Poorer access VS. top quartile of access	Any walking for transport in previous 2 weeks	OR=1.35; 95% CI [1.05, 1.73]; p=0.020	Age, Sex, Number of children <18 in household, Education level, Household income, Work outside home
				Beach access: Poorer access VS. top quartile of access	Any walking for transport in previous 2 weeks	OR=0.62; 95% CI [0.48, 0.81]; p: 0.000	

CS = Cross Sectional, B/A = Before & After, NR = Not Reported, NS = Not Significant, OR = Odds Ratio, SE = Standard Error, SD = Standard Deviation, IQR = Interquartile Range, NQLS = Neighborhood Quality of Life Study, SNQLS = Senior Neighborhood Quality of Life Study, PLACE = Physical Activity in Localities and Community Environments (based on NQLS), CHAMPS = Community Healthy Activities Model Program for Seniors, IPAQ-LF = International Physical Activity Questionnaire – Long Form, NEWS = Neighborhood Environment Walkability Scale, CCD = Census Collection District, LUM = Land Use Mix, SES = SocioEconomic Status

*Indicates unadjusted effect estimates
†Mean (SD) unless otherwise indicated
[i, ib, ic] Walkability index based on residential density, retail floor area ratio, intersection density, land use mix
[ii]Mix of residential (single-family, condo, loft, apt.), office (medical, dental, financial), retail (shops, restaurants, grocery, large retail); two parks; free shuttles to transit bike lanes; sidewalks
[iii]Original LUM score (index measuring heterogeneity of residential, commercial, industrial/institutional, recreational, and other land uses)
[iv]Revised LUM score (index measuring heterogeneity of residential, commercial, industrial/institutional land uses [excl. recreational & other])
[v]MET: measure of energy expended/oxygen consumed during specified activity per specified unit time
[vi]High VS. low walkability (mix of single & multiple family homes, non-residential land use, gridlike streets, short block lengths) VS. (mainly single-family homes, mostly residential land use, longer block lengths, mix of gridlike & curvilinear streets, more cul-de-sacs)

Table 6: Evidence summary of included studies examining recreational walking

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
Carlson (2012) [83]	King County WA (Seattle) & Baltimore/ Washington, US	CS; SNQLS (mailed)	718; 74.4 (6.3) years; 46.9% male	0 VS. >=1 parks and/or private recreation facilities within 500m buffer from home	Walking for leisure (mins/wk)	B=-8.09; 95% CI [-29.72, 13.53]; p=0.463	Ethnicity, Months at address
				High VS. low walkability[i], based on index for 500 metre buffer around home	Walking for leisure (mins/wk)	B=12.52; 95% CI [2.03, 23.02]; p=0.019	
Mumford (2011) [85]	Atlanta, US	CS (planned as B/A); Survey designed for study (most questions came from NEWS and IPAQ); Completed on site;	101; 64% <= 34 years; 33% male	New mixed-use development[ii] "pre VS. post-move"	Walking for recreation (responded "yes")	*46 pre-move VS. 54 post-move; NS at p>0.10	None/not applicable
					Walking for recreation (days/wk)	*2.09 pre-move VS. 2.96 post-move; p<0.02	
					Walking for recreation (mins/wk)	*98.5 pre-move VS. 105.9 post-move; NS at p<0.10	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
Sallis (2009) [87]	King County WA (Seattle) & Baltimore/ Washington, US	CS (NQLS); IPAQ; Mail, online, or phone interview	2199; 45.1 (11.0) years; 51.8% male	High VS. low walkability[ib]	Leisure walking (antilog mins/wk)	Mean high VS. mean low = 18.5 VS. 14.2; p=0.012	Age, Sex, Ethnicity, Marital status, Education level, Number of people in household, Number of motor vehicles/adults in household, Time (to account for repeated measures), Neighborhood clustering, Site, Length of time at current address
				High VS. low walkability[ib] ("Reasons for moving here" added to model)	Significance of previously identified associations	Walkability main effect no longer significant: p=0.012 before, p=0.36 after; (NS for interaction with income to begin with p=0.54)	
Coleman (2008) [88]	Seattle & Baltimore, US	CS (NQLS); Not specified; Mailed	612; Mean 46 years; 55% male	High VS. low walkability[ic]	Dog owner/walker VS. dog-owner/non-walker	*47% of walkers lived in high walkability VS. 32% of non-walkers; p<=0.002	None/not applicable

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
Oakes (2007) [91]	Minneapolis-St. Paul, US	CS (Twin Cities Walking Study); IPAQ-LF; NR;	716; 47.01 (13.73) years; 35.19% male	High population density VS. low population density	Metabolic equivalent (MET)[v] quintile	OR=0.896; 95% CI [0.667, 1.204]	Age, Sex, Ethnicity, Overall health, Education level, Marital status, Home ownership, Home tenure
				Large blocks VS. small blocks	Metabolic equivalent (MET)[v] quintile	OR=1.403; 95% CI [0.962, 2.046]	
Owen (2007) [92]	Adelaide, AUS	CS (PLACE); IPAQ-LF; Mailed	2650; 14.6% 20-29, 32.7% 30-44, 50.8% 45-65 years; 35.6% male	Walkability index[ic] (4th quartile VS. 1st quartile of index)	Walking for recreation (mins/wk)	NR; NS; NR	NR, but assume same as walking for transport
					Walking for recreation (mins/wk)	NR; NS; NR	
					Walking for recreation (sessions/wk)	NR; NS; NR	
					Walking for recreation (sessions/wk)	NR; NS; NR	

1st Author & Year	Location	Design; Survey; Delivery;	Sample; †Age; Sex	BECs	Walking	Effect Estimates (Estimate; CI; p-value)	Covariates Adjusted For
Saelens (2003) [41]	San Diego, US	CS; New survey developed for study; Mailed	106; Mean 47.9 years; 46.7% male	High walkability VS. low-walkability[vi]	% of residents walking during breaks at work or school	B; NR; NS	Age, Education level
					% of residents walking during breaks at work or school	*50% VS. 25%; p=0.008	None/not applicable
					Walking during breaks at work or school (mins/wk)	*2.5 VS. 0.0; p<0.01	
					Walking for exercise (mins/wk)	*30.0 VS. 20.0; NS	
Giles-Corti (2002) [93]	Perth, AUS	CS; "Modified items from other Australian surveys"; NR;	1773; Range 18-59 years; 32.2% male	Beach access: Poorer access VS. top quartile of access	Any walking for recreation in previous 2 weeks	OR=1.49; 95% CI [1.14, 1.93]; p=0.003	Age, Sex, Number of children <18 in household, Education level, Household income, Work outside home

CS = Cross Sectional, B/A = Before & After, NR = Not Reported, NS = Not Significant, OR = Odds Ratio, SE = Standard Error, SD = Standard Deviation, IQR = Interquartile Range, NQLS = Neighborhood Quality of Life Study, SNQLS = Senior Neighborhood Quality of Life Study, PLACE = Physical Activity in Localities and Community Environments (based on NQLS), CHAMPS = Community Healthy Activities Model Program for Seniors, IPAQ-LF = International Physical Activity Questionnaire – Long Form, NEWS = Neighborhood Environment Walkability Scale, CCD = Census Collection District, LUM = Land Use Mix, SES = SocioEconomic Status

*Indicates unadjusted effect estimates
†Mean (SD) unless otherwise indicated
[i, ib, ic] Walkability index based on residential density, retail floor area ratio, intersection density, land use mix
[ii]Mix of residential (single-family, condo, loft, apt.), office (medical, dental, financial), retail (shops, restaurants, grocery, large retail); two parks; free shuttles to transit bike lanes; sidewalks
[iii]Original LUM score (index measuring heterogeneity of residential, commercial, industrial/institutional, recreational, and other land uses)
[iv]Revised LUM score (index measuring heterogeneity of residential, commercial, industrial/institutional land uses [excl. recreational & other])
[v]MET: measure of energy expended/oxygen consumed during specified activity per specified unit time
[vi]High VS. low walkability (mix of single & multiple family homes, non-residential land use, gridlike streets, short block lengths) VS. (mainly single-family homes, mostly residential land use, longer block lengths, mix of gridlike & curvilinear streets, more cul-de-sacs)

The study characteristics shown in Tables 5 and 6 are important to report in order to assess generalizability and comparability between studies. Study location is a characteristic of especial importance in the review, as the exposure of interest is intrinsically dependent on the study location. As discussed in section 3.2.1, Eligibility Criteria, I attempted to attain a certain degree of homogeneity in the urban built form across study locations by restricting to studies conducted in one of four countries: Australia, Canada, New Zealand, and the United States. Of the 13 included studies, four were conducted in Australia, nine in the United States, and none in Canada or New Zealand. Among the nine U.S. studies, participants resided in one of five urban areas. One single-centre study was conducted in each of the following urban areas: Seattle, San Diego, Minneapolis/St. Paul, Atlanta, and the Baltimore/Washington DC area. One two-centre study included participants from Minneapolis and the Wahsington DC area, and three additional two-centre studies each included participants from Seattle and the Washington DC area. Among the four Australian studies, all were single-centre and three of these were conducted in Adelaide, while one was conducted in Perth. Population density, shown for the studies' urban areas in Table 7, is a common indicator of urban form [95]. The overall density of these urban areas is very low when compared to cities worldwide; however, with the exception of Atlanta, densities are relatively high in comparison to other Australian or American cities [72,96-98]. As intended, study locations are relatively homogeneous with respect to population density, a demonstrated indicator of built form.

Table 7: Urban areas of residence for study participants

Country	**Urban Area**	**Population**	**Population Density (people/km^2)**
United States	Washington, DC	4,586,770	1,400
	Atlanta, GA	4,515,419	700
	Seattle, WA	3,059,393	1,200
	San Diego, CA	2,956,746	1,600
	Minneapolis/St. Paul, MN	2,650,890	1,000
	Baltimore, MD	2,203,663	1,200
Australia	Perth, WA	1,670,953	1,100
	Adelaide, SA	1,103,979	1,300

[96,99,100]

While I attempted to restrict included studies to areas with a similar built form, I placed no restrictions on urban area population. Nonetheless, included studies were relatively homogeneous with respect to urban area populations as well. Table 7 shows that urban area populations of study participants' cities of residence range from approximately 1 to 4.5 million. All are large, regional centres in their respective countries. Small and midsize urban areas are notably absent from studies on the built environment, which indicates a gap in research applicable to smaller towns and cities.

Another source of homogeneity between the included studies is from the study designs. All of the included studies used cross-sectional study designs. One study that looked at participants' walking behaviours before and after moving to a new pedestrian-friendly neighbourhood (Mumford et al.) was initially planned as a before and after study; however, due to financial constraints tied to the 2008 housing crisis in the United States, the study was revised into a cross-sectional survey. Questions asking respondents to recall pre-move behaviours substituted for the separate pre-move survey that had been originally planned. The other 12 studies were planned and executed as cross-sectional studies. Moreover, six of these were based on the same or similar studies. Two studies used the Neighbourhood Quality of Life Study (NQLS), one used the Senior NQLS, and three studies used the Physical Activity in Localities and Community Environments study which was based on the NQLS [101-104]. Additional similarities between studies were due to the surveys used to measure the walking outcomes. Of the 13 included studies, seven used the International Physical Activity Questionnaire to assess walking (Tables 5 and 6) [105]. The eligibility criteria did not specify how walking had to be measured. Nonetheless, the same survey was used in the majority of studies. There appears to be a fair amount of homogeneity across study designs in the included studies.

The 13 included studies had 138 separate effect estimates that met the eligibility criteria (Tables 5 and 6). However, due to significant overlap between estimates within some of the studies, only 64 of these estimates represented completely unique measures of association between BECs and walking. If there were multiple measures of the same (or very similar) exposure – outcome association in the same population in the same study (i.e., estimates that were too similar to other estimates within the same study), these additional estimates were highlighted in grey in Tables 5 and 6. As an example, Carlson's study compared the effect of high vs. low walkability on walking for transport in the overall study population as well as within three pairs of subgroups, for a total of seven effect estimates. As each of these estimates measured an association between the same measure of walkability and walking for transport in the same population, counting all of them in a synthesis of the results would result in double-counting estimates. Therefore, I only included the effect estimates for the high and low social support subgroups in the synthesis of results, so these were not highlighted in Tables 5 and 6, while the remaining effect estimates were highlighted in grey to indicate that they were not counted.

For an estimate to be shaded grey and not counted, the study, population, exposure, and outcome all had to be the same (or very similar) as another estimate. Even if only one of these four components was different, the estimate was considered unique and was counted. Hence, the same population could have been counted more than once if there were unique exposure – outcome estimates within that population. This would have been problematic if I had done a meta-analysis, as the pooled estimate in a meta-analysis is based on the assumption that the pooled sample size comprises unique individuals. However, the quantitative analysis method was vote counting, which does not hold the same assumptions as a meta-analysis.

In cases with overlapping effect estimates, I made the selection as systematic as possible. To do this, I used the decision rules outlined in Table 8 to determine which estimates would be counted. In general, I selected the effect estimates that provided the most information. Selection of the estimate providing "more information" was more clear-cut for some of these rules than for others; however, in every case a decision had to be made, and I applied the same criteria to each study to make the estimate selection as systematic as possible. To check whether alterations in some of these decision rules affected the conclusions, I performed several post-hoc sensitivity analyses with one or more of these rules changed. The results of these sensitivity analyses are reported in section 3.3.8, Sensitivity Analyses.

Table 8: Decision rules applied in each study

Author Year	**Selected Estimate(s)**	**Unselected Estimate(s)**	**Decision Rule/Rationale**
Carlson et al. 2012 [83]	High vs. low walkability and walking for transport in: 1) high social support subgroup 2) low social support subgroup	High vs. low walkability and walking for transport in: 1) overall study population 2) high self-efficacy subgroup 3) low self-efficacy subgroup 4) high barriers subgroup 5) low barriers subgroup	Social support interacted with walkability, so subgroups provide more info. Self-efficacy subgroups arbitrarily chosen because choosing other subgroups gives the same result, as all estimates were significant.
McConville et al. 2011 [84]	1) All distance based exposures and walking for transport < 150 minutes/week 2) ½ mile buffer based exposures and walking for transport < 150 mins/week	1) All outcomes of walking for transport ≥ 150 mins/week 2) ¼ mile buffer based exposures	More participants are likely to meet the outcome of < 150 minutes/week than ≥ 150 minutes/week. More BECs are captured in a ½ mile buffer than a ¼ mile buffer. *sensitivity analyses done
Mumford et al. 2011 [85]	All outcomes measured in mins/week	All outcomes measured in: 1) days/week 2) yes/no response	Time-based outcomes give more info. than frequency or yes/no.
Duncan et al. 2010 [86]	1) Adjusted, area-corrected land-use mix score and walking measured in mins/day 2) Adjusted, area-corrected and revised land-use mix score and walking measured in mins/day	1) All unadjusted estimates 2) All outcomes measured in sessions/week 3) Adjusted, original land-use mix score and walking measured in sessions/week 4) Adjusted, revised land-use mix score and walking measured in sessions/week	Adjusting estimates is important due to high probability of confounding. Time based outcomes give more info. than frequency. Area-corrected exposures give more info. *Both original and revised scores included because they are categorized into separate BEC constructs
Sallis et al. 2009 [87]	High vs. low walkability with both walking for transport and recreation outcome, with “reasons for moving here” added to model	1) High vs. low walkability with both walking for transport and recreation outcome, without “reasons for moving here” in model 2) High vs. low walkability with walking for transport outcome in: A) High income subgroup B) Low income subgroup	“Reasons for moving here” is an important covariate that should be added. Adding this covariate made the interaction between walkability and income no longer significant, so the overall effect is reported.

Coleman et al. 2008 [88]	Only one relevant association, which was used	None	N/A
Rodriguez et al. 2008 [89]	All relevant associations used	None	N/A
Cerin et al. 2007 [90]	Following exposures and walking for transport: 1) Land-use mix score (not squared) 2) Difference between commercial and industrial 3) Difference between recreational and residential	Land-use mix score squared and walking for transport	Squared land-use mix score arbitrarily chosen because unsquared score gives the same result, as both estimates were not significant.
Lee et al. 2007 [44]	1) Area-based density and walking for transport 2) All other relevant associations except parcel-based density	Parcel-based density and walking for transport	Parcel-based density is a more granular measure than area-based density (both gave same result)
Oakes et al. 2007 [91]	All relevant associations used	None	N/A
Owen et al. 2007 [92]	Walkability index and walking for transportation and recreation in mins/week, with neighbourhood self-selection added to models	1) All frameworks without neighbourhood self-selection 2) All outcomes reported in sessions/week	Neighbourhood self-selection is an important covariate that should be added. Time-based outcomes give more info. than frequency.
Saelens et al. 2003 [41]	1) Adjusted high vs. low walkability and percent of residents walking for both errands and during breaks at work or school 2) All outcomes measured in mins/week (unadjusted)	1) Unadjusted high vs. low walkability and percent of residents walking for both errands and during breaks at work or school	Adjusting estimates is important due to high probability of confounding.
Giles-Corti et al. 2002 [93]	All relevant estimates used	None	N/A

Keeping in mind the preferences in selecting walking outcomes (time spent walking > frequency of walking > walking vs. no walking), most of the 64 included effect estimates measured walking in units of time (typically in minutes/week). 45 of the included estimates measured time spent walking, while seven measured frequency of walking, six measured whether or not the respondent walked, four measured metabolic equivalents (METS) (see Glossary for definition), and two measured whether the significance of previous associations changed (Figure 7). Unlike measurement of the walking outcome, no preference was given to the type of measure of association between BECs and walking when selecting the 64 estimates. 33 estimates used odds ratios (ORs), 11 used beta coefficients (B), 10 used other measures of association, and 10 did not report the type of association measure used (Figure 8).

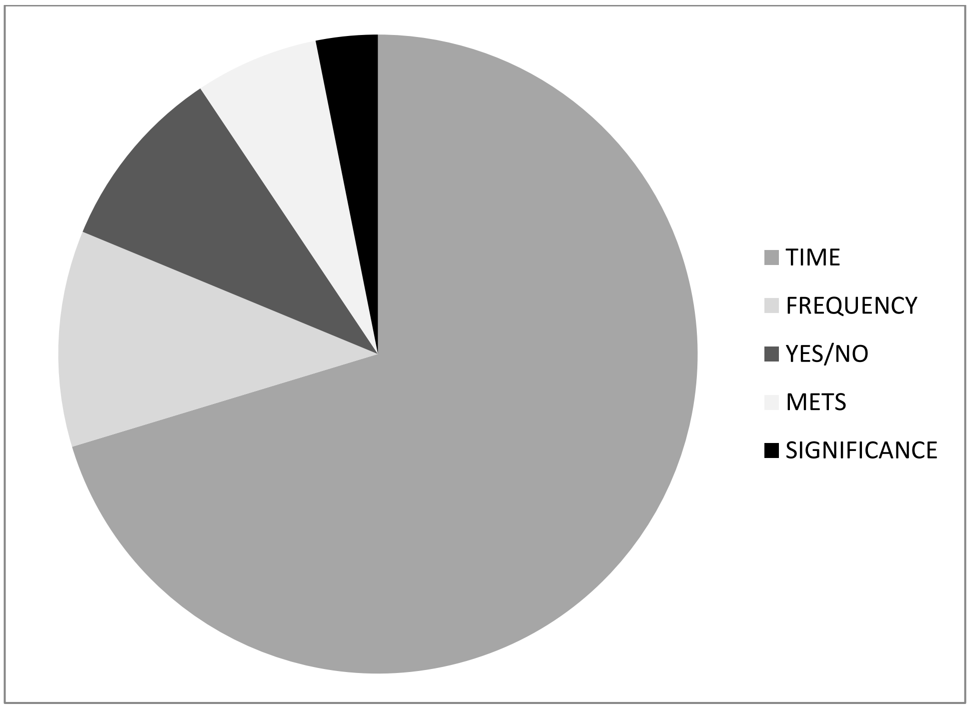

Figure 7: Measures of walking used in 64 included effect estimates
(METS = metabolic equivalents)

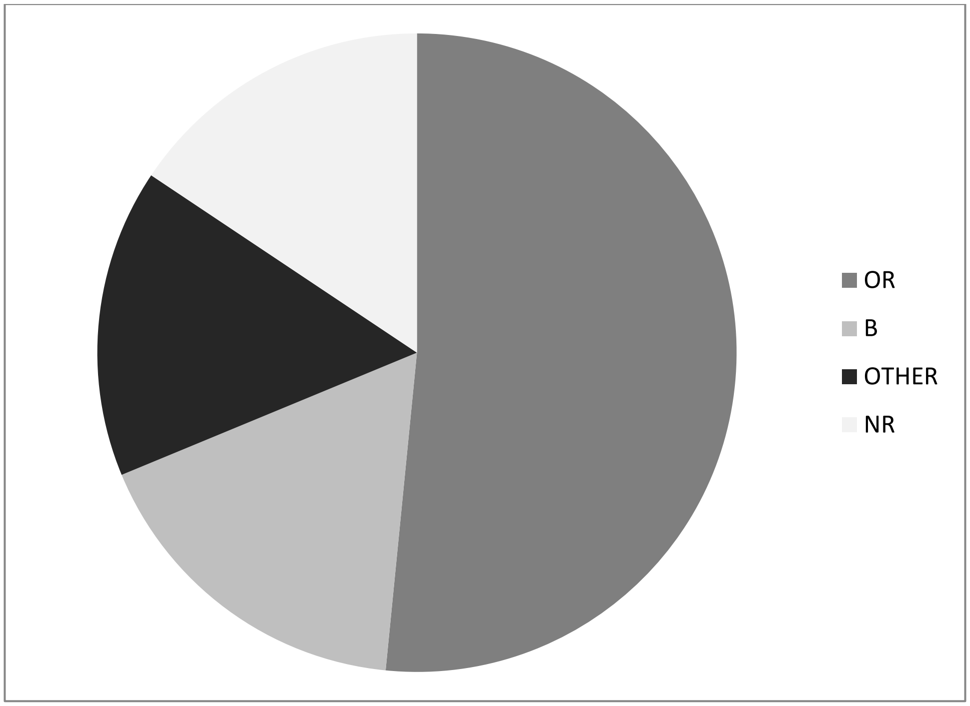

Figure 8: Measures of association used in 64 included effect estimates
(OR = odds ratio, B = beta coefficient, NR = not reported)

The fact that the majority of studies used odds ratios indicates that most studies compared proportions of individuals achieving a certain threshold of walking. For instance, many studies dichotomized a time measurement by comparing the proportion of people who achieved at least 150 minutes per week of walking to the proportion that did not (see Tables 5 and 6 for specific studies). While most included studies used a dichotomous outcome to calculate ORs, the study by Oakes et al. split measurements of METS (see Glossary) into quintiles and calculated odds ratios using ordinal logistic regression [91].

3.3.5 Methodological Quality of Included Studies

I used the Downs and Black tool to assess methodological quality in each of the included studies [76]. Table 9 shows the score I gave each study overall and in each of the five domains included in Downs and Black's checklist (the question on power in fifth domain was adapted as described in section 3.2.5 Methodological Quality Assessment). The total scores ranged from 14 to 20, out of a possible total of 27. Given the narrow range of scores among the included studies, no subgroup or sensitivity analyses were done based on methodological quality score. This is consistent with recommendations in the Cochrane Handbook for Systematic Reviews [73].

While I did not incorporate results from the Downs and Black checklist into any quantitative analyses, I used them to frame the following narrative summary of the studies' methodological quality. Scores in the reporting quality domain were moderate to excellent, ranging from 6/10 to a perfect 10/10 (Table 9). Scores in the external validity domain ranged from 1/3 to a perfect 3/3. Interestingly, all included articles received a score of five in the internal validity – bias domain, likely because they share the same cross-sectional study design. Scores in the selection bias domain were uniformly low, with the highest score a 3/6. Again, this is likely due to the cross-sectional study designs which are limited in their ability to control for selection biases due to a lack of randomization of the study groups. Finally, all studies received a 0 in the power domain because none of them reported a sample size or power calculation. The Downs and Black scores give a quick indication of some of the shared methodological issues in the BECs and walking literature, many of which I elaborate on in section 3.4.3, Strengths and Limitations of Included Studies.

Table 9: Downs and Black methodological quality scores for included studies: total score and score in each domain

Author, Year	Reporting (/10)	External Validity (/3)	Internal Validity – Bias (/7)	Internal Validity – Selection Bias (/6)	Power (/1)	Total Score (/27)
Sallis et al, 2009 [87]	10	2	5	3	0	20
Owen et al, 2007 [92]	9	2	5	3	0	19
Saelens et al, 2003 [41]	9	3	5	2	0	19
Carlson et al, 2012 [83]	9	1	5	3	0	18
Duncan et al, 2010 [86]	7	3	5	3	0	18
Oakes et al, 2007 [91]	8	3	5	2	0	18
McConville et al, 2011 [84]	8	1	5	3	0	17
Coleman et al, 2008 [88]	9	1	5	2	0	17
Giles-Corti et al, 2002 [93]	8	1	5	3	0	17
Rodriguez et al, 2008 [89]	6	2	5	3	0	16
Lee et al, 2007 [44]	7	2	5	2	0	16
Cerin et al, 2007 [90]	8	2	5	1	0	16
Mumford et al, 2011 [85]	7	0	5	2	0	14

3.3.6 Analysis and Synthesis of Study Findings

The quantitative synthesis method was vote counting, as described in section 3.2.6, Analysis. Prior to this synthesis, it became apparent that I would need to include a new BEC construct in the conceptual framework to capture the effect estimates that used an exposure measure combining two or more existing BEC constructs. Such combined measures included walkability indices, where components fitting into the 'utilitarian destinations' construct such as dwelling density and land use mix were combined with components fitting into the 'routes' construct such as intersection density. These walkability indices provided a single measure where the individual components could not be separated out. I therefore added the 'combined BECs' construct in the revised framework (Figure 9).

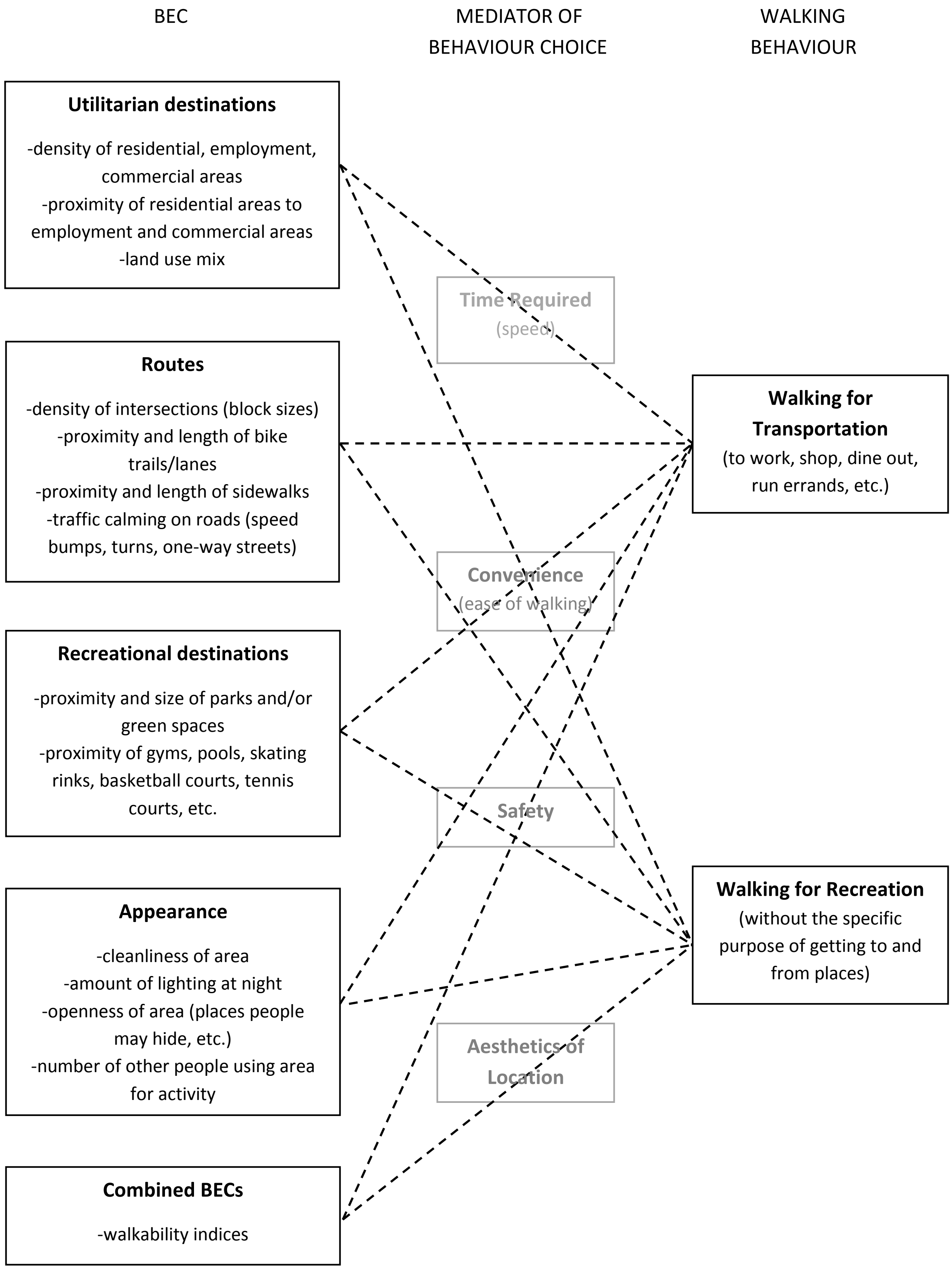

Figure 9: Revised conceptual framework of BECs and walking

Vote counting is a very limited quantitative synthesis method because it only considers the statistical significance of each effect estimate. It does not give any indication of the magnitude of effect, sample size, or variability of the estimates. As the heterogeneity between studies precluded a quantitative synthesis that included magnitude of effect, I summarized the range of odds ratios and beta coefficients in each of the conceptual framework's 10 hypothesized relationships (Table 10). I should point out that the ranges of odds ratios may include odds ratios comparing different outcome measures. Outcome measures may be a yes or no response to having walked during a period of time, whether participants met a time threshold such as 150 minutes of walking per week, or a measurement of METS during a period of time. On the other hand, the beta coefficient ranges in Table 10 only include the outcome of minutes per week spent walking. If an estimate could not be converted to minutes per week, I did not include the estimate in Table 10.

Table 10: Ranges of odds ratios and beta coefficients by conceptual framework construct

Walking Construct	**BEC Construct**	**Odds Ratio Range [95% Confidence Interval]**	**Change in Walking (mins/week)**
Walking for Transportation	Utilitarian Destinations	0.30 [0.22, 0.42] – 1.99 [1.30, 3.06]	*5.25 [0.22, 1.28]
	Routes	0.44 [0.14, 1.38] – 1.05 [1.01, 1.08]	None
	Recreational Areas	0.29 [0.07, 1.24] – 1.35 [1.05, 1.73]	*9.12 [-4.18, 22.42]
	Appearance	None	None
	Combined	0.36 [0.13, 1.05] – 1.39 [1.20, 1.59]	0.70 [-0.87, 2.27]
Walking for Recreation	Utilitarian Destinations	*0.90 [0.67, 1.20]	None
	Routes	*1.40 [0.96, 2.05]	None
	Recreational Areas	*1.49 [1.14, 1.93]	*-8.09 [-29.72, 13.53]
	Appearance	None	None
	Combined	None	*12.52 [2.03, 23.02]

*Only one odds ratio or beta coefficient in this category

Tables 11 and 12 show the number of statistically significant estimates compared with the total number of estimates categorized along each line in the conceptual framework, for walking for transportation and walking for recreation respectively. The tables also show these proportions as the percentage of estimates in each category that were statistically significant at $p<0.05$. Lastly, the tables show p-values for the exact chi square goodness of fit tests, which were also set to $p<0.05$. Hence, the p-values show whether the proportion of statistically significant estimates in each category was statistically significant. I used two-tailed p-values, as the direction of association could have been positive or negative for each of the BECs, although none of the included estimates showed statistically significant associations in the direction opposite to the hypothesized association. For a two-tailed p-value to be statistically significant at $p<0.05$ in an exact chi square goodness of fit test, the total number of estimates must be more than five. If the total number of estimates in a category was five or less I simply reported the p-value as not applicable (NA), as it would have been impossible to have a two-tailed p-value that was significant at $p<0.05$.

Table 11: Proportions of statistically significant effect estimates examining walking for transportation

BEC Construct from conceptual framework	**# Signif. Est./ # Total Est.**	**% Signif. Estimates**	**p-value for goodness of fit test**
Utilitarian destinations	12/17	70.6%	p=0.14
Routes	4/9	44.4%	p=1.0
Recreational destinations	4/9	44.4%	p=1.0
Appearance	1/1	100%	NA
Combined Constructs	9/16	56.3%	p=0.80

NA = not applicable due to < 6 estimates

Table 12: Proportions of statistically significant effect estimates examining walking for recreation

BEC Construct from conceptual framework	# Signif. Est./ # Total Est.	% Signif. Estimates	p-value for goodness of fit test
Utilitarian destinations	0/1	0%	NA
Routes	0/1	0%	NA
Recreational destinations	1/2	50%	NA
Appearance	0/0	N/A	NA
Combined Constructs	3/8	37.5%	p=0.73

NA = not applicable due to < 6 estimates

Tables 11 and 12 show that none of the conceptual framework's hypothesized associations between BEC constructs and walking constructs had a statistically significant majority of statistically significant associations. A statistically significant majority of null results was not observed in any of the relationships either. I planned to use solid lines in the revised framework to represent relationships that had a statistically significant majority of statistically significant associations in the same direction; however, as I identified none, I left all lines dashed in the revised framework (Figure 9). The revised framework shows that none of the hypothesized relationships between BECs and walking were supported by evidence from the systematic review.

For most of the hypothesized relationships, the goodness of fit tests were not (or could not have been) statistically significant because such a small number of studies were categorized into the relationship. This was especially true for relationships that involved the 'walking for recreation' construct. Four of the five lines connecting to 'walking for recreation' did not have enough studies included to conduct a goodness of fit test. On the other hand, among the estimates categorized along the lines connecting to 'walking for transport', only the 'appearance' BEC construct lacked the six or more studies required to observe a significant majority. It can therefore be said with certainty that there was limited evidence on the associations that fit into the following BEC and walking constructs: 'appearance' – 'walking for transportation', 'utilitarian destinations' – 'walking for recreation', 'routes' – 'walking for recreation', 'recreational destinations' – 'walking for recreation', and 'appearance' – 'walking for recreation'.

Evidence on BECs and walking associations categorized along the remaining lines in the conceptual framework was mixed, with some estimates showing statistically significant associations and others not; although evidence in some of these categories was somewhat limited as well. Only eight studies were categorized into the 'combined constructs' – 'walking for recreation' relationship (Table 12) and only nine were categorized into the 'routes' – 'walking for transportation' and 'recreational destinations' – 'walking for transportation' relationships (Table 12). It seems that the 'utilitarian destinations' – 'walking for transportation' and the 'combined constructs' – 'walking for transportation' relationships have been the most popular foci of BECs and walking research, with 17 and 16 effect estimates categorized into each relationship respectively. Nonetheless, evidence supporting associations within these two categories remained equivocal, with some estimates showing significant associations and others not.

I made a post-hoc decision to use the conceptual framework to display the number of estimates categorized into each relationship. Figure 10 depicts the conceptual framework with the width of each line set to a thickness representing the number of estimates categorized into that construct. For instance, the line connecting the 'utilitarian destinations' and 'walking for transportation' constructs is set to a 17 point thickness because 17 estimates were categorized into the BEC and walking relationship represented by that line. At a quick glance, Figure 10 provides a visualization of the degree to which each of the conceptual framework's relationships has been studied.

Figure 10 also gives a snap shot of where there may be research gaps. It shows that the review included very few effect estimates where walking for recreation was an outcome. In fact, no studies that examined a relationship between 'appearance' and 'walking for recreation' were identified in the review, despite the logical feasibility of such a relationship. Therefore, adapting the conceptual framework to show the number of estimates categorized along each line may help researchers identify research gaps and prioritize future research.

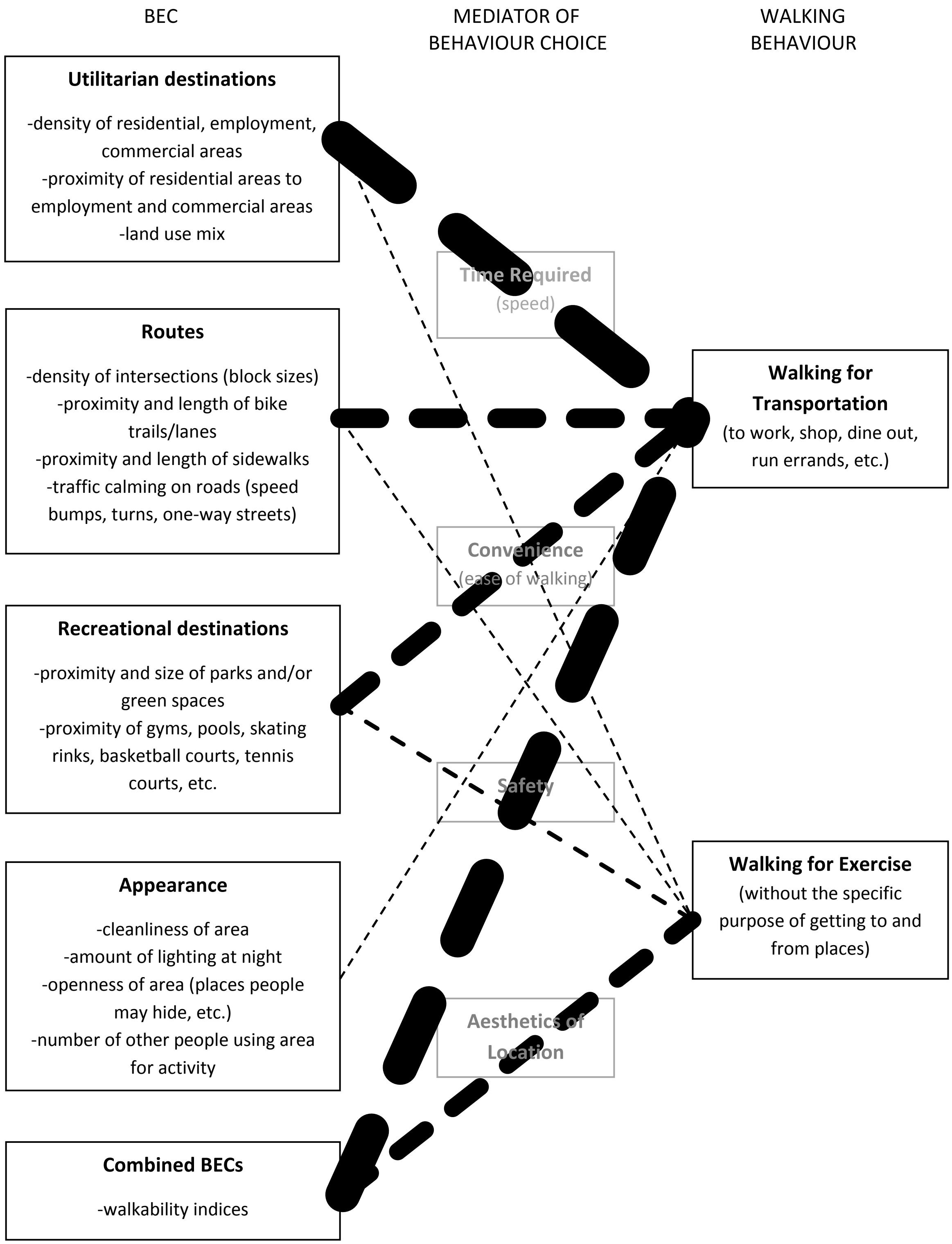

Figure 10: Conceptual framework of BECs and walking – line thickness corresponds to number of studies categorized into each relationship

3.3.7 Subgroup Analyses

In addition to the overall results described above, I conducted several subgroup analyses to investigate the robustness of the results. Subgroup analyses are useful for detecting effect modification; that is, whether the BEC and walking association is different at various levels of another covariate. In the protocol I planned subgroup analyses based on geographic location, income, and body mass index (BMI). I also stated that subgroup analyses would depend on whether enough studies were included to make such analyses worthwhile. Only two included studies reported BMIs for their respondents, so I did not conduct a subgroup analysis based on BMI. I did, however, conduct subgroup analyses based on the country in which the study was conducted and another based on income.

Subgroup analyses by country were only done for the American studies due to the small number of Australian studies included in the review. Proportions of statistically significant estimates for the Australian subgroups are not displayed because none of the BECs and walking categories had more than the five estimates required for a goodness of fit test. Table 13 shows the following for the subgroup of studies that took place in the United States: the proportions of effect estimates in each BEC – 'walking for transportation' category that were statistically significant at $p<0.05$, as well as the p-values for the goodness of fit test (also at $p<0.05$). Likewise, Table 14 shows the same thing for BEC – 'walking for recreation' categories in the subgroup of studies that took place in the United States. For both walking for transportation and walking for recreation, the conclusions remained the same. None of the relationships had a statistically significant goodness of fit test. Again, too few studies fit into the following BEC and walking constructs to conduct the test: 'appearance' – 'walking for transportation', 'utilitarian destinations' – 'walking for recreation', 'routes' – 'walking for recreation', 'recreational destinations' – 'walking for recreation', and 'appearance' – 'walking for recreation'. The remaining categories included mixed and somewhat limited evidence. Therefore, subgroup analyses based on study country did not alter the overall results.

Table 13: Proportions of statistically significant effect estimates examining walking for transportation - American studies only

BEC Construct from conceptual framework	**# Signif. Est./ # Total Est.**	**% Signif. Estimates**	**p-value for goodness of fit test**
Utilitarian destinations	11/16	68.8%	p=0.21
Routes	4/9	44.4%	p=1.0
Recreational destinations	2/7	28.6%	p=0.45
Appearance	1/1	100%	NA
Combined Constructs	7/11	63.6%	p=0.55

NA = not applicable due to < 6 estimates

Table 14: Proportions of statistically significant effect estimates examining walking for recreation - American studies only

BEC Construct from conceptual framework	**# Signif. Est./ # Total Est.**	**% Signif. Estimates**	**p-value for goodness of fit test**
Utilitarian destinations	0/1	0%	NA
Routes	0/1	0%	NA
Recreational destinations	0/1	0%	NA
Appearance	0/0	N/A	NA
Combined Constructs	3/7	42.9%	p=1.0

NA = not applicable due to < 6 estimates

As with the subgroup of Australian studies, too few studies were in the high income subgroup to allow for subgroup analysis. Only three studies included estimates for high income participants: the studies by Mumford et al., Coleman et al., and Sallis et al. (high-income subgroup only). Eight studies included estimates for participants of 'low to middle income' (see Glossary for definition): these were by Duncan et al., Oakes et al., Carlson et al., Giles-Corti et al., Cerin et al., Owen et al., Saelens et al. and Sallis et al. (low-income subgroup only). The remaining studies, by McConville et al., Rodriguez et al., and Lee, did not report income information in such a way that walking behaviours of high and average subgroups could be ascertained.

Table 15 shows the proportions of effect estimates in each BEC – 'walking for transportation' category that were statistically significant at $p<0.05$, as well as the p-values for the goodness of fit test at $p<0.05$, in the subgroup of effect estimates in the low to middle income subgroup. None of the BEC – 'walking for recreation' categories had over five estimates in the low to middle income subgroup, so these are not shown. As with the location-based analysis, subgroup analysis based on income did not change any of the conclusions. The only category in the low to middle income subgroup with over five estimates was the 'combined constructs' – 'walking for transportation' category, and again the evidence was mixed, with some statistically significant estimates and some not, but no statistically significant majority of either.

Table 15: Proportions of statistically significant effect estimates examining walking for transportation – Low to middle income (< $60,000/year) only

BEC Construct from conceptual framework	# Signif. Est./ # Total Est.	% Signif. Estimates	p-value for goodness of fit test
Utilitarian destinations	2/2	100%	NA
Routes	0/1	0%	NA
Recreational destinations	2/3	66.6%	NA
Appearance	0/0	N/A	NA
Combined Constructs	3/9	33.3%	p=0.51

NA = not applicable due to < 6 estimates

3.3.8 Sensitivity Analyses

In addition to the subgroup analyses, I conducted several sensitivity analyses to investigate whether selecting different estimates from groups of overlapping estimates altered the results. In cases where studies reported the same or very similar BECs and walking associations in the same population, I used the decision rules described in Table 8 to select which of these duplicate estimates to include in the quantitative analysis. Some of these decision rules are fairly straightforward, so I did not conduct sensitivity analyses on these. For instance, if both unadjusted and adjusted estimates were provided, I used the adjusted estimates (e.g.,[41,86]). There are undoubtedly numerous confounders of relationships between BECs and walking, so adjusted estimates are more informative and methodologically sound. Likewise, in some studies the following outcome measures were reported for a specified time period: time spent walking, frequency of walking, and/or yes/no responses to having walked (e.g.,[85,86]). I gave preference in the following order: time > frequency > ever having walked. The amount of time spent walking gives more information than frequency and yes/no responses, which do not account for differing amounts of time spent walking. In addition, one study provided estimates using measures of land-use mix that were corrected for geographic area, as well as those that were not corrected [86]. The area-corrected measures were selected because these measures adjusted for variation in size between Census Collection Districts (CCDs), which were the geographic unit of analysis in this study. If CCDs are not area-corrected, it is possible for a large CCD and a small CCD to have the same land-use mix score, yet the large CCD may have much longer walking distances between land uses and therefore a different effect on walking. As these types of estimates clearly provide more accurate information, I decided that sensitivity analyses based on adjusted vs. unadjusted analysis, time vs. frequency vs. yes/no to walking, and area-corrected vs. uncorrected measures were not necessary.

I also decided that more accurate information was provided in every case where estimates were adjusted for a greater number of covariates. This is despite the fact that the inclusion of more covariates is not always ideal, particularly when sample sizes are small [106,107]. In both studies that provided adjusted estimates as well as estimates adjusted for additional covariates, the additional covariates attempted to measure neighbourhood self-selection (e.g.,[87,92]). Neighbourhood self-selection may have a major confounding effect on the BEC and walking association and is therefore a very important covariate to consider, so I selected estimates that included neighbourhood self-selection over estimates that did not. This was the only variable added in both cases where estimates adjusted for varying numbers of covariates were provided, so I did not perform a sensitivity analysis based on number of covariates adjusted for.

There is one final situation where I did not perform a sensitivity analysis comparing selected estimates with their unselected counterparts. Here, selecting the counterparts gave the exact same result as the selected estimates (e.g.,[44,83,90]). While it was more difficult to justify why the chosen estimate was selected in these three studies, selecting the alternatives did not change the conclusions of the quantitative synthesis, as the conclusions were based on whether the estimates were statistically significant at p<0.05 rather than the magnitude of effect. In each of these cases, the significance of the alternative estimates was the same as that of the estimates chosen, so sensitivity analyses would not have changed the results.

After ruling out the need for sensitivity analysis on the estimates included in the studies cited above, there was only one remaining study that provided overlapping estimates: the study by McConville et al [84]. McConville et al.'s study provided two types of overlapping estimates and in both cases the type of estimate that provided more accurate information was not completely straightforward. First of all, two walking outcomes were given for each BEC and walking association: walking < 150 minutes/week and walking ≥ 150 minutes/week. I chose walking < 150 minutes/week because I assumed that more people would achieve this outcome. However, there is no guarantee of this assumption and even if there was, this particular outcome does not inherently provide more accurate estimates. Secondly, for the buffer-based estimates two buffer distances were used: a ½ mile buffer and a ¼ mile buffer. I chose the ½ mile buffer because more BECs would be captured in a larger buffer. Again, this is not inherently more accurate. Therefore, I conducted three sensitivity analyses to examine whether selecting different estimates changed the results and conclusions.

The three sensitivity analyses were: 1) Including estimates that used the outcome of walking ≥ 150 minutes/week instead of walking < 150 minutes/week, 2) including estimates that measured BECs within a ¼ mile buffer instead of a ½ mile buffer, and 3) including estimates that used both the walking ≥ 150 minutes/week outcome and the ¼ mile buffer to measure BECs. The proportions of statistically significant estimates (at p<0.05) in each BEC and walking for transportation category, as well as the p-values for the goodness of fit tests, are shown in Tables 16 – 18. McConville's study did not look at walking for recreation, so these outcomes were not included in the sensitivity analyses. Tables 16 – 18 show that the results do not change for any of the relationships between BECs and walking in any of the sensitivity analyses. As before, each relationship did not have a statistically significant majority (or minority) of results showing statistical significance. These analyses show that the conclusions would not have changed if I had chosen alternative estimates in cases of overlapping estimates where the most appropriate estimate is not obvious.

Table 16: Proportions of statistically significant effect estimates examining walking for transportation – Outcomes of walking >= 150 min/wk used instead of < 150 min/wk in McConville's study

BEC Construct from conceptual framework	**# Signif. Est./ # Total Est.**	**% Signif. Estimates**	**p-value for goodness of fit test**
Utilitarian destinations	10/17	58.8%	p=0.63
Routes	5/9	55.6%	p=1.0
Recreational destinations	3/9	33.3%	p=0.51
Appearance	1/1	100%	NA
Combined Constructs	9/16	56.3%	p=0.80

NA = not applicable due to < 6 estimates

Table 17: Proportions of statistically significant effect estimates examining walking for transportation – Outcomes based on ¼ mile buffer used instead of ½ mile buffer in McConville's study

BEC Construct from conceptual framework	**# Signif. Est./ # Total Est.**	**% Signif. Estimates**	**p-value for goodness of fit test**
Utilitarian destinations	12/17	70.6%	p=0.14
Routes	3/9	33.3%	p=0.51
Recreational destinations	4/9	44.4%	p=1.0
Appearance	1/1	100%	NA
Combined Constructs	9/16	56.3%	p=0.80

NA = not applicable due to < 6 estimates

Table 18: Proportions of statistically significant effect estimates examining walking for transportation – Outcomes of walking >= 150 min/wk and ¼ mile buffer used instead of < 150 min/wk and ½ mile buffer in McConville's study

BEC Construct from conceptual framework	**# Signif. Est./ # Total Est.**	**% Signif. Estimates**	**p-value for goodness of fit test**
Utilitarian destinations	9/17	52.9%	p=1.0
Routes	5/9	55.6%	p=1.0
Recreational destinations	3/9	33.3%	p=0.51
Appearance	1/1	100%	NA
Combined Constructs	8/16	50.0%	p=1.00

NA = not applicable due to < 6 estimates

3.4 Discussion

3.4.1 Main Conclusions

According to data from the studies included in the systematic review, there is no conclusive evidence of associations between BECs and walking in any of the conceptual framework's 10 relationship categories. In most categories the lack of evidence is due to the limited number of estimates that fit into the category. However, even in categories with 16 or 17 effect estimates, the evidence is mixed and no clear majority of studies supports an association or lack thereof. The main conclusion that can be drawn from the systematic review is that more evidence is needed to draw conclusions about the hypothesized relationships between BECs and walking. The quantitative synthesis of results shows that the quantity of studies is too low in most of the conceptual framework's categories to draw conclusions. This synthesis does not, however, account for variability in the included studies' sample size, magnitude of effect, population, methodology, or methodological quality. These factors must also be considered when weighing the evidence and are therefore discussed below.

3.4.2 Strengths and Limitations of Systematic Review

It is important to note that the vote counting method used for quantitative synthesis does not allow for the same conclusions as a meta-analysis. A meta-analysis typically pools study results into an overall summary estimate that is a more valid and more precise effect estimate than those given by the individual studies; this pooled estimate is a more accurate estimation of the true effect. The goal of the synthesis I used, on the other hand, was to help assess the level of scientific evidence on relationships between BECs and walking in each of 10 categories and to identify priority areas for future study. Hence, conclusions can be drawn about where research is lacking, but cannot be made about the true associations between BECs and walking.

Vote counting does not account for magnitude of effect, differences in precision, or statistical heterogeneity between studies, as a meta-analysis would have. Instead, this method is based solely on whether the individual study results are statistically significant. Pooled results from the vote counting method should be interpreted cautiously, as relying too heavily on an arbitrary cut point used to determine statistical significance can result in misinterpretation of data [108,109]. For instance, important results may be disregarded if they are slightly over the threshold of statistical significance, and equivocal results may be emphasized too strongly if they are slightly under that threshold [108]. As vote counting does not account for sample size, null results from underpowered studies may lead to the conclusion that there is no evidence of association, when in fact, these null results may have been due to type II error [110]. As vote counting does not account for magnitude of effect, no conclusions can be drawn about the clinical significance of identified associations. Another limitation of the quantitative synthesis is that the exact chi square goodness of fit test used to assess the statistical significance of the proportion of statistically significant estimates did not account for the clustering that resulted from multiple estimates coming from the same studies. However, failing to account for clustering usually inflates test statistics, resulting in artificially small p-values and increased risk of type I error [82]. As none of the p-values were statistically significant, this limitation is unlikely to affect conclusions. Due to the limitations of these quantitative synthesis methods, I only used the results to identify where research may be lacking. However, in section 3.4.3, Strengths and Limitations of Included Studies, I provide a narrative synthesis of the included studies that does consider precision and methodological quality within the included studies.

There are also some limitations to the review's literature search that need to be reported. The literature search retrieved studies published between January 1, 2000 and March 2, 2012. As mentioned previously, very few studies on BECs and walking were published before 2000, so the earlier date limit is unlikely to affect the conclusions. However, the built environment's potential association with physical activity is a rapidly developing area of study [27], so it is possible that studies have been published since March 2, 2012 that would have been included in the review if the search were done later. Results from such studies would increase the number of estimates in some of the conceptual framework's categories and could potentially provide enough evidence to change the conclusions about the research that is needed. This limitation provides the impetus for updating the systematic review.

Another limitation of the search strategy is that it did not include a systematic search for grey literature. The search was limited to the following databases: MEDLINE, EMBASE, PsycINFO, and TRID. While I did not explicitly search for grey literature, I also did not exclude studies based on publication status. As there was a large amount of grey literature retrieved by the TRID database, I believe that the risk of publication bias was minimal. Furthermore, publication bias is typically away from the null hypothesis. That is, studies showing positive results are more likely to be published [111]. Given that I did not identify a statistically significant majority of significant results in any of the BEC – walking categories, it is unlikely that publication bias would have affected the conclusions.

There are also strengths to the search, including its high sensitivity. I checked the search results to see if all of the articles I picked up during the initial scoping for relevant studies were also retrieved by the final systematic review search strategy. All of these articles were picked up in the search, with the exception of one that was not indexed in the database I used for this verification. I also did not limit the search by study design or language to avoid missing relevant studies, which further increased sensitivity.

In addition to the search's strengths and limitations, there are strengths and limitations in the screening methodology that I should point out. A limitation is that I only included studies that were reported in English. This was due to resource restrictions, English being the only language understood by the lead reviewer. There is a risk of language bias in excluding studies based on language, as it has been shown that authors are more likely to publish positive results in an English-language journal [112]. As mentioned previously, however, I did not identify significant numbers of positive results in any of the categories, so language bias is also unlikely to have influenced the conclusions.

On the other hand, there are strengths to the screening methods as well. For one, I did not use study design labels to exclude studies. Instead, I used the reported study design characteristics such as the study group comparison methods. This allowed me to avoid inconsistencies in the terminology used to label study designs. I therefore avoided erroneously excluding relevant study designs that were incorrectly labeled.

One aspect of the screening strategy that likely had a major effect on the results is the fact that I excluded studies that did not report the following three characteristics on the study population: 1) mobility status, 2) age, and 3) residence in an urban/suburban or rural area. To be included in the systematic review, study populations for relevant estimates had to be able-bodied adults living in urban areas. However, many studies did not report all three of these characteristics. Mobility status, in particular, was frequently not reported, and 57 studies were excluded because they did not report mobility status. Contacting each of these authors to see if they had this information was beyond the scope of this project. If I had not excluded studies for failing to report these three population criteria I may have ended up with different results. Nonetheless, as discussed in section 3.2, Methods, these characteristics must be known and reported if BEC and walking associations are to be valid and comparable.

Lastly, there are a number of limitations with the methodological quality assessment. I used Downs and Black's tool that is intended for both experimental and observational study designs [76]. Despite this tool's broad applicability, it does not appear to consider cross-sectional study designs. For instance, question 17 asks "In trials and cohort studies, do the analyses adjust for different lengths of follow-up of patients, or in case-control studies, is the time period between the intervention and outcome the same for cases and controls? Where follow-up was the same for all study patients the answer should be yes. If different lengths of follow-up were adjusted for by, for example, survival analysis the answer should be yes. Studies where differences in follow-up are ignored should be answered no." Additionally, question 26 asks "Were losses of patients to follow-up taken into account? If the numbers of patients lost to follow-up are not reported, the question should be answered as unable to determine. If the proportion lost to follow-up was too small to affect the main findings, the question should be answered yes." The answer to both questions for cross-sectional studies would always be 'yes' because participants are examined at the same time they are recruited and therefore cannot be lost to follow-up. The result is that cross-sectional studies tend to score higher than more 'bias resistant' study designs such as cohort studies. All of the included studies are cross-sectional, so this would not have impacted comparisons based on score. However, I still observed a narrow range in quality scores among the included studies, indicating that the Downs and Black tool may not adequately differentiate between high and low quality studies of the same study design. The validity of the Downs and Black tool, including an assessment of how well it evaluates cross-sectional studies, should be explored further in future studies.

3.4.3 Strengths and Limitations of Included Studies

In the preceding section I discussed some limitations of the systematic review methodology. The present section examines a number of major limitations of the individual studies. The first limitation I discuss primarily concerns studies that were not included after the third level of screening. Level three screening excluded 57 studies that did not report on one of the following population characteristics: mobility, age, or urban/suburban vs. rural residence. More studies were excluded due to poor reporting than were eventually included, indicating that failure to report on these important characteristics is the norm. These excluded studies might have contributed valuable information to the systematic review, but were excluded because these types of characteristics must be reported if valid comparisons are to be made between studies. The following example illustrates why it is imperative to report such population features. If a study population includes a significant number of people who have mobility limitations, the walking outcomes are likely going to be much lower than if the study population is entirely able-bodied. Not only is an important confounder of the exposure of interest not reported in such a study, but the study population is not directly comparable with other studies that may not have included people with mobility problems. Results from multiple studies must be compared and synthesized if the knowledge they generate is to be translated into real-world changes to policy and practice. Poor reporting of studies inhibits the ability to synthesize and translate the knowledge they generate.

The omission of these key population characteristics is an example of the very widespread problem of poor reporting in research [113-116]. If the 57 studies excluded for this reason had simply reported these characteristics they would have been much more useful and therefore less wasteful. Poor reporting that leads to wasted research resources has been identified as a common problem [113-116]. While it can be difficult to anticipate information sought by future knowledge syntheses that may use a primary study, characteristics such as age, urban residence, and mobility status are central to research on BECs and walking and should always be reported in these studies. The effort to report key characteristics such as these is minimal, yet the increased utility that results from improved reporting makes research much more cost-effective.

In addition to the limitations of studies I excluded, there are a number of limitations concerning the 13 studies included in the systematic review. First of all, there is the risk of information bias that is common to all studies that measure outcomes by self-reported means such as surveys. All 13 of the studies assessed walking using self-report and were therefore prone to information biases such as recall bias. It has been demonstrated that people tend to overestimate the amount of physical activity they engage in [117,118]. Biases such as these can be avoided by measuring walking outcomes objectively; although, objective measures are generally more resource-intensive.

Another limitation common to all included studies is due to their study design. All 13 studies used cross-sectional designs and it is not possible to determine temporality from a cross-sectional study. Temporality is one of Bradford Hill's criteria for determining causality and is arguably the most important [119]. Therefore, it cannot be determined whether BECs made people walk more or whether people who walk more chose neighbourhoods with BECs that are conducive to walking. If neighbourhood self-selection occurs in a study, any observed association between the neighbourhood and walking does not necessarily indicate that the neighbourhood features are influencing walking at all. Intuitively, it makes sense that failing to account for neighbourhood self-selection would bias estimates away from the null, as it seems more likely that people who prefer walking would choose neighbourhoods more conducive to walking and the higher walking behaviour observed in this group would not be the sole result of the built environment. However, results from studies on the impact of residential self-selection on the relationship between neighbourhood walkability and walking have been mixed. Some have shown that accounting for self-selection attenuates the association, some have shown minimal effects, and one has shown a strengthening of the association [27,120]. In any case, to avoid this limitation, well-designed longitudinal studies are the most effective approach. However, such studies are typically more expensive and time-consuming, hence the tendency to conduct cross-sectional studies.

Despite their inability to account for temporality, accounting for neighbourhood self-selection is still useful and informative in cross-sectional studies. Three of the 13 cross-sectional studies included in our review attempted to do this by controlling or adjusting for self-selection [85,87,92]. Mumford et al. accounted for self-selection by using the study participants as their own controls. Therefore, other biases notwithstanding, increases in walking behaviour were due to the change in BECs rather than differences in walking preferences between the study groups. Sallis et al. and Owen et al. each accounted for self-selection by asking participants about reasons they moved to their neighbourhoods of residence. Sallis et al.'s study asked respondents about the importance of "desire for nearby shops and services", "ease of walking", and "closeness to recreational facilities" in choosing their neighbourhood. Owen et al. asked respondents about the importance of "closeness to job/school, PT, shops/services", and "ease of walking". These two studies then coded these responses into a variable that was included in regression models to adjust for self-selection.

Assuming these variables adequately accounted for self-selection, this confounder was controlled for in their models of BECs and walking behaviour.

Another limitation specific to neighbourhood-based studies is due to the varying amounts of time people spend in their neighbourhoods of residence. If people spend more time in their home neighbourhoods, they have more opportunities to engage in walking in their neighbourhood; if only walking in their neighbourhoods of residence is measured, they will appear to walk more than people who spend less time in their home neighbourhoods. However, people may do a lot of walking in their workplace or other neighbourhoods and none of this walking would be captured. All 13 included studies measured home neighbourhood walking only. Failure of these studies to account for walking in areas outside respondents' neighbourhoods of residence may bias results toward or away from the null. If people who walk more in their neighbourhood of residence also walk more in non-residential neighbourhoods, estimates that fail to account for this would be biased toward the null. However, if the reverse is true this would bias estimates away from the null. Both possibilities are feasible. Future studies should therefore attempt to measure all walking, not just walking in respondents' neighbourhoods of residence.

Low statistical power is another common study limitation. A study lacks power if the sample size is too small to detect an effect. Previous studies have described various BECs as having a modest but important effect and/or accounting for a modest proportion of variation in walking behaviour [41,44,46,92,121-123]. A modest individual-level effect can still have important population-level benefits if a large enough segment of the population achieves these effects. If the effect of BECs on walking behaviour is, in fact, small but important, a high degree of power from a large sample size would be required to detect these effects.

The numerous and interconnected determinants of walking are another reason a large sample size is needed. For complex health behaviours such as walking, it is important to analyze how effects vary according to determinants other than the exposure of interest. The high number of potential confounders and effect modifiers of complex relationships require statistical models that can account for numerous covariates. Logistic regression and proportional hazards models, both common in epidemiological research, should generally have at least 10 outcome events for each predictor variable included in the model [124]. As a larger sample size leads to more outcome events, a larger sample will allow many variables to be included in models so that potential interactions can be assessed. Subgroup analyses are another method of identifying interactions between variables that influence walking. Again, large sample sizes provide the necessary power for subgroup analyses to detect an effect [125]. The extensive analyses of effect modification are necessary because relationships between BECs and walking likely differ between age, socioeconomic, and geographical subgroups [26,69].

Another limitation common to all included studies is that they were all conducted in one or two large cities in Australia or the United States (Table 7). The result is that the geographical variability within each study was confined to the variation existing within one or two cities. Recent systematic reviews have suggested that the high number of non-significant relationships in existing studies may be due to the limited geographic variability in these studies [27,126]. Again, as studies included in my review showed many null results, achieving a high degree of geographic variability within studies should be another research priority.

Restricted external validity is another limitation that resulted from restriction to one or two large and prominent Australian or American cities. The generalizability of findings outside of the cities that were studied is questionable, and in smaller cities it is almost certainly very low. In small towns, for example, residents may tend to drive more and walk less, regardless of the BECs in their residential neighbourhoods. While I restricted the inclusion criteria to only four countries, I placed no restrictions on city size. This indicates a severe lack of research on BECs and walking in smaller centres, pointing to a large gap in research conducted in towns and small cities.

I have identified a number of common limitations in the BEC and walking research that preclude formation of conclusions about relationships between BECs and walking. Ideally, future studies would avoid all of these limitations. However, as discussed in Chapter 4, this can be costly and is not always feasible, so certain limitations should be prioritized. In Chapter 4 I provide suggestions on how future studies can investigate BECs and walking associations while avoiding certain high-priority limitations that arise in much of the scientific literature on this topic.

CHAPTER 4: Recommendations for Future Research

4.1 Rationale: Overcome Study Limitations

The third thesis objective is to propose a plan for appropriate future studies of relationships between BECs and walking. The conceptual framework structured potential BEC and walking associations into feasible relationships between various constructs (Figure 9). The systematic review identified many limitations in the existing body of evidence. The plan for future research focuses on the hypothesized associations displayed in the revised conceptual framework, while attempting to overcome many of the limitations in the existing research.

4.2 Comparison of Potential Study Designs

Determination of the most appropriate study design is possibly the most fundamental decision to be made about a future study on BECs and walking associations. I have outlined the limitations inherent in cross-sectional study designs and identified the eventual requirement of more rigorous longitudinal designs. However, the choice of study design must consider more than methodological rigour, as feasibility, resource requirements, and the current state of evidence ought to inform this decision as well. Below, I discuss some pros and cons of several study designs before deciding upon a cross-sectional design as the final recommendation.

4.2.1 Randomized Controlled Trials

If methodological rigour is the only consideration, RCTs are the best option because randomizing participants to their study groups virtually eliminates the potential for selection bias. However, a study randomizing people to live in different neighbourhoods would be prohibitively expensive, pose major participant recruitment challenges, and be potentially unethical. An alternative to a traditional RCT is a cluster randomized trial that would randomize whole neighbourhoods instead of individuals. Neighbourhoods would be randomly assigned to receive a BEC intervention or no intervention. While a cluster randomized trial may be more feasible than a traditional RCT, there would still be a tremendous resource requirement for most of the BECs examined in the studies included in the systematic review. For instance, increasing a neighbourhood's building density or altering its street network for the purpose of an investigation would require a considerable amount of time and money.

4.2.2 Quasi-experimental Studies

A quasi-experimental study, such as an interrupted time series analysis or a controlled before and after study, is the design option closest to an RCT that may still be feasible. Such a study could involve a partnership between researchers and condominium developers, municipal employees such as urban planners, and civil or transportation engineers. In a controlled before and after study, the investigators would assist these partners in designing two new condominium neighbourhoods: a highly walkable neighbourhood for the intervention group and a less walkable neighbourhood for the control group. The groups would not be assigned randomly; instead, they would be formed according to who purchases the pre-sale condominiums in each neighbourhood. In Canada, the majority of a condominium development's units are sold before construction begins [127]. This provides an opportunity to use pre-construction condominium buyers (and end-users) as the sampling frame for a before and after study. The people who are recruited and consent to the study would have their walking behaviours measured before and after they move to their new neighbourhood. BECs would also be measured in the pre-move and post-move neighbourhoods. This would allow for differences in walking behaviour in pre-move and post-move neighbourhoods to be assessed and compared in both the intervention group and the control group. The generalizability of such a study would be limited, however, due to the fact that all respondents have the means to purchase a new home and are choosing to live in a condominium; hence they are in a higher socioeconomic category and are choosing a multi-family dwelling type.

A separate before and after study could assess BECs and walking associations in a lower socioeconomic population. Instead of working with market-rate condominiums, the researchers could partner with the redevelopment of a municipally-managed social housing complex. A number of large social housing developments built in the middle of the twentieth century are undergoing complete demolition and rebuild over the next few years [128]. The initial design of these communities was characterized by disconnected street networks and a lack of amenities, so the re-designs are intended to provide a more connected street network, improved access to amenities such as grocery stores and banks, improved access to recreational facilities, and improved appearance [128]. All of these planned changes happen to be BECs that are of interest in this thesis. Examples of neighbourhood redevelopments in the municipality of Toronto include the Regent Park and Alexandra Park redevelopments, which are currently in progress, and the Lawrence Heights redevelopment, which is planned for the near future [128]. During the tear-down and rebuild of these communities, residents are temporarily relocated to other municipally-owned housing units before they are moved back to their newly-built homes. Unfortunately, while residents of these housing developments are consulted throughout the relocation process, ultimately they are not given a choice about their temporary relocation. If there is an upside to the lack of control these residents have over their neighbourhood's redevelopment, it's that it provides an opportunity to evaluate the impact of neighbourhood changes on walking in a population that is not specifically choosing their neighbourhood of residence. A partnership with this type of project could provide an opportunity for a before and after study in a lower socioeconomic group with little to no risk of confounding from neighbourhood self-selection.

4.2.3 Prospective Cohort Studies

The two aforementioned quasi-experimental studies could be planned as cohort studies instead. Cohort studies would require a less intense partnership with condominium developers and municipal staff, which would likely mean fewer approvals required and would increase study feasibility. Opportunities for cohort studies also exist in new, large-scale neighbourhood developments, some of which are planned to be walkable and mixed-use. There are two examples of new developments that are attempting a more walkable design in the suburban municipalities of Markham and Vaughan, which are suburbs of Toronto [129,130]. A cohort study that recruits condominium pre-sale buyers and evaluates their walking behaviour before and after their move to the new neighbourhood would provide valuable insights into many relationships between BECs and walking.

Study designs that involve a partnership with a new or redeveloped neighbourhood may provide the best opportunity to look for causal relationships between BECs and walking; however, the external validity of such studies may not be ideal. As described, the study population would be limited to households with an income high enough to purchase a new home or low enough to be eligible for government-assisted housing. This leaves out the large segment of the population that lies between these income groups and must rent their homes, as well as higher income populations who choose to rent for a variety of reasons. Such studies are also confined to cities that are undergoing large-scale residential development and redevelopment projects, which are typically cities with large and growing populations. Towns and cities with smaller and more stable populations would likely require a different approach.

Another type of cohort study can overcome these issues of generalizability. The assessment of transportation and recreational walking behaviours could be incorporated into a long-term cohort study such as the Framingham Heart Study [131]. If participants are followed up for a time period long enough for many participants to change residential locations, the BECs in the new neighbourhoods can be compared to those in the old neighbourhoods and changes in walking outcomes can be investigated. The Nurses' Health Study and the Nurses' Health Study II are longitudinal studies that include questions on physical activity and walking behaviour [132]. However, questions addressing walking in the Nurses' Health Studies do not differentiate between walking for transportation and walking for recreation, which is problematic for reasons mentioned in section 2.6, Proposed Conceptual Framework. Furthermore, the study samples are restricted to female Nurses who were between 25 and 55 years old at the beginning of the study, which greatly limits the generalizability of study findings. It may also be difficult to account for strong confounders like changing age and lifestyle of participants throughout the study. For instance, participants' walking behaviours likely change as they get older and when they start families, and this may be difficult to account for. Although, the main issue with such a study is feasibility, due to the huge length of follow-up time required for the BECs to change in a large enough segment of the study population.

4.2.4 Cross-sectional Studies

A major advantage longitudinal studies have over cross-sectional studies is their ability to establish temporality in the relationships between BECs and walking. Temporality is an important criterion in Bradford Hill's considerations of causality [119]. Nonetheless, cross-sectional studies maintain certain advantages over longitudinal studies. For one, cross-sectional studies are better able to obtain the large sample sizes that are needed to control for many confounders in logistic regression models, and allow for adequately-powered subgroup analyses. It is also easier for cross-sectional studies to cover large geographical areas and include a variety of community sizes.

The impetus to fund more resource-intensive longitudinal studies can come from preliminary evidence generated by cross-sectional studies. According to the results of the systematic review, this preliminary evidence does not presently exist. This may be due to methodological flaws such as those identified in the review's included studies. Although, one would expect that certain flaws, such as failing to account for neighbourhood self-selection, would bias the results away from null hypotheses, and the review did not find that study results tended away from the null. Given the lack of evidence from existing research, I suggest that future studies address the limitations that may have biased previous study results toward null hypotheses. Specifically, future studies should focus on achieving the large sample sizes and population variability required to investigate confounding and effect modification by many covariates. If such studies show the expected associations, this may provide the incentive to conduct more rigorous longitudinal studies on these associations; however, if they fail to show the expected associations, it may be harder to justify the resource requirements of more rigorous study designs.

My recommendation, therefore, is a cross-sectional study that attempts to address the methodological flaws of the studies identified in the systematic review. While a cross-sectional study is not able to establish temporality, it would be much less time-consuming and resource-intensive than the various longitudinal study designs. Indeed, it has been observed by McCormack and Shiell that while cross-sectional studies cannot establish causation, they contribute to a better understanding of the plausibility, consistency, coherence, and specificity of relationships between

BECs and physical activity [70]. The inconsistent results of studies included in the systematic review indicate that the consistency, coherence, and specificity of relationships between BECs and walking has not yet been established. Research evidence is seriously lacking on most of the conceptual framework's relationships between BEC and walking, and is inconclusive and/or lacking in the remaining relationships. I therefore feel that, given the current state of the evidence, well-designed cross-sectional studies that overcome certain flaws of previous studies are still justified. If such cross-sectional studies show positive BEC and walking associations, longitudinal study designs such as quasi-experimental or cohort studies will be warranted.

4.3 Suggestions on Design and Methodology

A future cross-sectional study should overcome many of the limitations of previous studies if it is going to add to the evidence base. Small sample sizes are a common limitation that may be one reason many studies did not identify statistically significant effects [46,92,126,133]. A lack of geographic variability is even more common in the existing literature, and this may also lead to null results [27,126]. Considering that I did not identify a significant majority of significant associations in any of the conceptual framework's categories, the next step in research should be etiologically-focused studies with large sample sizes and a geographically diverse population. I therefore propose the following plan for a potential future study.

4.3.1 Population Data

Obtaining a large sample size would be very resource intensive if a study planned to do primary data collection. Given that one of the main reasons I am suggesting a cross-sectional study is the smaller resource requirement, I suggest secondary data analysis instead of primary data collection. Therefore, existing large population data sources that measure respondents' health behaviours must be identified. The Canadian Community Health Survey (CCHS), administered by Statistics Canada on an ongoing basis, assesses the health, health care use, and health determinants of Canadians [134]. Each cycle, released every two years, has a sample size of approximately 120,000 that represents approximately 98% of the Canadian population aged 12 and over [135,136]. Separate cycles of the CCHS can also be combined together, providing an even larger sample size [137]. The CCHS also includes many of the individual-level covariates likely to influence relationships between BECs and walking, such as age, sex, income, and education level. The CCHS can, therefore, be used to control for many covariates while maintaining enough power to detect a small BEC effect.

Use of the CCHS addresses another set of limitations of previous research; that is, the limitations that arise from studying only one or two large cities. The systematic review showed that previous studies have largely been confined to one or two large metropolitan centres. The CCHS's sampling strategy allows this survey to represent all residents of Canada over the age of 12, with the exception of people living on Aboriginal Reserves, Crown Lands, institutions, and certain remote regions (as well as full-time Canadian Forces members) [134]. People living in towns and cities of all sizes are included, as are rural residents. Including populations in a variety of geographical regions allows study results to be generalized beyond residents of large urban centres.

The diverse geographical coverage of the CCHS also increases the geographic variability *within* the study population. Another limitation that arises from previous studies confined to one or two cities is that the range of neighbourhoods is restricted to those that exist within one or two cities. Indeed, some studies have suggested that such limited study areas may not have included enough variability in BEC exposure to detect an effect [27,126,133,138]. The vast coverage of the CCHS allows researchers to examine a number of geographical and other subgroups. Furthermore, the large sample size allows these subgroup analyses to be adequately powered to detect an association. Subgroup analysis can provide insight into variables that interact with associations between BECs and walking. Therefore, in addition to the improved power and generalizability, use of the CCHS provides many more opportunities for comparisons within the study population.

4.3.2 Exposure Data

The CCHS is a national-level survey that covers almost all regions of Canada; therefore, a BEC measure that can also cover all regions of Canada is needed. As evidenced in the systematic review, BECs were assessed using a variety of different methods, most of which were specifically designed for the studies in which they were used. In fact, the heterogeneous methods used to assess BEC exposures have been identified as a major limitation in synthesizing literature on this topic [27,46,70]. I suggest the Street Smart Walk Score® metric (hereafter referred to as Walk Score®) as a BEC measure that addresses this need [139]. Walk Score® values can be calculated for almost any set of latitude/longitude coordinates in Canada, the United States, and Australia [139]. Use of Walk Score® values in assessing BECs in walkability research has been previously validated [140,141]. In fact, Walk Score® values have been used in two recent studies looking at BECs and physical activity [142,143]. Walk Score® values, therefore, are a method of BEC measurement that is uniform across the country, which is necessary for a national-level analysis. The Walk Score® metric also provides the opportunity for additional studies to use an accessible, standardized method of assessing BEC characteristics. Not only can this improve the comparability of measured BECs and walking associations across studies, but Walk Score® values may also reduce resource requirements as they are readily available and do not require time-consuming measurement and computation by study researchers.

Walk Score® is a commercial organization that uses geospatial data from Google, Localeze, Open Street Map, Education.com, and various transit agencies to calculate a unique Walk Score® value for any latitude/longitude coordinate [139]. These data sources are used to determine distances from a specific location to amenities in the following nine categories: grocery stores, restaurants/bars, shopping locations, coffee shops, banks, parks, schools, book stores, and entertainment destinations. The Walk Score® algorithm weights each category according to its relative importance to neighbourhood walkability. In some categories, such as restaurants/bars, having multiple options within walking distance is important. The Walk Score® algorithm therefore counts multiple amenities within these categories, with a lower weight assigned to amenities that are further away to account for the diminishing contribution of additional amenities in the same category. Table 19 shows the weights assigned to each amenity category, with multiple numbers in a category if multiple amenities are counted.

Table 19: Weights of amenity categories according to order and proximity in the Walk Score® metric

Amenity category	**Weights**						
	Closest	**2nd closest**	**3rd closest**	**4th closest**	**5th closest**	**6th – 8th closest**	**9th – 10th closest**
Grocery stores	3						
Restaurant/bar	0.75	0.45	0.25	0.25	0.225	0.225	0.2
Shops (other)	0.5	0.45	0.4	0.35	0.3		
Coffee shops	1.25	0.75					
Entertainment	1						
Banks	1						
Book stores	1						
Schools	1						
Parks	1						

The scores shown in Table 19 are the maximum score a location can receive for each amenity. The percentage of a maximum score assigned to a location is calculated using a distance decay function. Amenities within 0.25 miles (0.40 km) of a location receive close to a full score. The proportion of a full score received then drops off at a constant rate until 1.0 miles (1.61 km) from the location. Between 1.0 miles (1.61 km) and 1.5 miles (2.41km) this proportion tapers off, and after 1.5 miles (2.41km) amenities no longer count toward the final Walk Score® value [139]. The distance-weighted scores for each amenity are summed and these scores are penalized according to the surrounding street network, as shown in Table 20.

Table 20: Walk Score® value reductions according to intersection density and average block length

Percent penalty	**Intersection density**	**Average block length (metres)**
None	Over 200	Under 120
1%	150-200	120-150
2%	120-150	150-165
3%	90-120	165-180
4%	60-90	180-195
5%	Under 60	Over 195

A look at the method used to derive Walk Score® values shows that they fit the definition of BECs and cover several of the BEC constructs. Amenity categories such as grocery stores, restaurants, bars, shops, and banks comprise many components of the 'utilitarian destinations' construct in the conceptual framework. Walk Score® values also incorporate components of the 'recreational destinations' construct (parks) and 'routes' construct (intersection density and average block length). Considering that Walk Score® values can be calculated for almost all areas of Canada, it makes sense to use this as a BEC exposure measure in a national-level study.

4.3.3 Outcome Data

In addition to the sociodemographic data described previously, the CCHS includes the following outcome data: walking to work or school and walking for exercise. These two outcomes comprise the outcome constructs in the conceptual framework (Figure 9). However, CCHS data are self-reported and therefore do not overcome the limitations that arise from subjective outcome measures. Statistics Canada administers another national health survey, the Canadian Health Measures Survey (CHMS), that includes objective measurements of physical activity [144,145].

However, these objective measures are done using an accelerometer and do not differentiate between walking and other types of step-based physical activity. This may be of use in a study looking at all types of physical activity together, but does not work for the focus on walking. The CHMS also uses a much smaller sample size than the CCHS and therefore does not provide the same advantages of allowing for inclusion of many covariates while maintaining a very high level of power, or allowing adequately-powered subgroup analyses. Despite the limitations that result from subjectively-measured outcomes, the CCHS is still the best option for the suggested study.

4.3.4 Data Acquisition and Merging

Walk Score® values are freely available through the Walk Score® website; however, the Walk Score® developers can be contacted to obtain Walk Score® values for latitude/longitude coordinates in a table or other format conducive to epidemiological analysis [139]. Disaggregated scores can also be obtained that give separate scores for each Walk Score® component (grocery stores, restaurants/bars, shopping locations, coffee shops, banks, parks, schools, book stores, and entertainment destinations). CCHS data are available through Statistics Canada's Research Data Centre program to successful applicants [146]. CCHS data include respondent's postal codes, which can be joined to the Walk Score® values of latitude longitude coordinates using the Postal Code Conversion File [147]. These datasets can be merged using statistical software such as SAS [148]

4.3.5 Statistical Analysis

After merging Walk Score® values with CCHS responses, associations between walkability and walking can be investigated using regression analyses that control for the relevant covariates included in the CCHS. Walk Score® values will be joined to postal codes and are therefore an area-level variable, while the CCHS data are at the individual level, so the analyses must account for clustering that occurs at the postal code area level. Respondents are said to be clustered because people sharing the same postal code are more similar to each other than they are to the broader population sample. This means that the assumption of independence required for traditional linear and logistic regression modeling is violated. Multi-level regression modeling can account for clustering by including Level 1 (individual level) and Level 2 (area level) variables [149]. Multi-level modeling can be performed in SAS using PROC MIXED for continuous outcomes or PROC GLIMMIX for dichotomous outcomes [148]. Generalized estimating equations are another modeling option that can account for clustering. These can also be performed in SAS using PROC GENMOD with GEE [148,150].

In addition to analyzing the overall CCHS population, the regression analyses described above can be performed in a number of subgroups. The large sample size and range of variables in the CCHS allow for important sources of population variability to be analyzed in well-powered subgroup analyses. Key examples include subgroups based on age, socioeconomic status, or city size, as these variables are likely to modify the association between BECs and walking. Such analyses can examine whether estimated associations differ according to age group, socioeconomic category, or size of urban area, thereby providing valuable information on how the association between BECs and walking may vary.

4.4 Limitations of Suggested Study Plan

I have discussed the advantages of using a large sample size; however, caution must be exercised when interpreting statistically significant results from very large samples. The high degree of statistical power can cause very slight associations to show statistical significance. Often, such slight associations are not clinically meaningful. It is, therefore, important to evaluate the magnitude of the association in the context of what is useful, as well as the reliability of the estimate of association between multiple studies.

Our suggested study overcomes some, but not all of the limitations of previous cross-sectional studies. The outcomes in the suggested study are still subjectively measured, leading to various types of information bias such as recall bias and overestimating walking behaviour. Residential self-selection is also not accounted for, as the CCHS does not include questions that ask about reasons for moving to a neighbourhood. Nonetheless, I feel that the advantages gained from using a large geographically diverse study sample to assess walking, as well as an exposure measure that can be applied across the country, outweigh the limitations. This is apparent when considering the evidence in the systematic review. The review did not show evidence of associations in any of the model's BEC and walking categories. It has been suggested that this is due to inconsistent methods used to measure BECs, small sample sizes, and a lack of geographic variability [27,46,70,126,133]. The suggested study addresses all three of these issues.

CHAPTER 5: Summary

5.1 Overall Conclusions

The ultimate goal of research into relationships between BECs and walking is to learn whether making certain changes to the built environment will result in people increasing their levels of walking and other physical activities, which would lead to reduced risk of chronic diseases such as heart disease and type II diabetes. In order to achieve this goal, a causal association between BECs and walking must be identified. This causal association can only be identified through rigorous longitudinal studies such as quasi-experimental studies; however, such studies are generally very resource-intensive. Given the competing demand for the limited resources dedicated to research, longitudinal studies of relationships between BECs and walking must be justifiable. These studies can be justified by identifying which relationships are conceivable, as well as examining evidence from less resource-intensive cross-sectional studies. I identified gaps in both of these areas, providing the impetus for the thesis project.

We identified conceivable relationships between BECs and walking by formulating a conceptual framework. In doing so, I achieved the first thesis objective of improving conceptualization of relationships between BECs and walking. Using the conceptual framework, I then examined the existing evidence in the scientific literature with the systematic review, thereby achieving objective two. All of the studies included in the systematic review were cross-sectional, so I analyzed them according to the conceptual framework in search of some preliminary evidence that might be used to justify more resource-intensive study designs. However, I did not identify evidence of BECs and walking associations in any of the hypothesized relationships between BECs and walking. Therefore, to achieve objective three I proposed a plan for an additional cross-sectional study that would overcome previous studies' limitations due to small sample sizes and restricted geographies.

5.2 Next Steps

Based on the evidence identified in the systematic review, it seems premature to cite the health impacts of BECs on walking when making policy recommendations or changes. It appears that more research is required. There may be other reasons to recommend changes to BECs, such as the possibility of reduced vehicle emissions or roadway injuries; these were not covered in this study. However, according to recent research, evidence of the impact BECs have on walking behaviour is still lacking. Nonetheless, public policies are increasingly citing the benefits that certain BECs can have on walking, overall physical activity, and health [33-37]. Therefore, further research on the relationships between BECs and walking is needed to determine whether these health claims are substantiated.

The next step, therefore, is to conduct additional research into BECs and walking associations, taking the suggestions from this thesis into account. If future research identifies statistically significant associations, this will increase the justifiability of conducting more resource-intensive research. This is particularly true if future studies address the limitations that have been cited as a potential cause of null results in previous studies. Such limitations include small sample sizes, broadly-defined walking outcomes, and inconsistently measured BEC exposures [27,46,70,133]. The proposed study plan addresses these three limitations. Therefore, if the suggested study plan does not identify statistically significant associations between BECs and walking it will be hard to attribute this to the aforementioned limitations. Of course, results such as these should not be interpreted as evidence that BECs are not associated with walking, as absence of evidence is not evidence of absence. Nonetheless, such results will have implications for future research. In the competitive environment of research funding applications, evidence demonstrating the potential of proposed research is critical.

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Appendix A: Search strategy

exp environment design/ or exp city planning/
population density/ or residence characteristics/ or exp housing/
transportation/
environment/ or cities/
urbanization/
neighbo?rhood.ti,ab.
(park or parks).ti,ab.
sidewalk$.ti,ab.
(trail or trails or path or paths).ti,ab.
((population or urban or residen$ or hous* or building) adj3 densit$).ti,ab.
traffic.ti,ab.
(mixed adj1 use$).ti,ab.
(land adj1 use$).ti,ab.
(communit$ adj4 (neighbo?rhood$ or environment$ or urban$ or suburb$ or city or cities or metro$ or municipal$)).ti,ab.
(communit$ adj4 (densit$ or buil$ or physical or structur$ or hous$ or residen$ or layout$ or plan$ or form$ or design)).ti,ab.
((determinants or correlates or barriers) adj3 walk$).ti,ab.
(built adj1 form).ti,ab.
(road$ or street$).ti,ab.
(environment$ adj4 (neighbo?rhood$ or communit$ or urban$ or suburb$ or city or cities or metro$ or municipal$)).ti,ab.
(environment$ adj4 (densit$ or buil$ or physical or structur$ or hous$ or residen$ or layout$ or plan$ or form$ or design)).ti,ab.
(urban$ or suburb$).ti,ab.
hous$.ti,ab.
(car or cars or automobile$).ti,ab.
walkab$.ti,ab.
sprawl$.ti,ab.
pedestrian$.ti,ab.
streetscape.ti,ab.
or/1-27
recreation/ or sports/
exercise/ or movement/ or locomotion/ or exp walking/
sedentary lifestyle/ or physical fitness/
walk$.ti,ab.
exercis$.ti,ab.
commut$.ti,ab.
(jog or jogs or jogging or jogged).ti,ab.
(stroll$ or hik$).ti,ab.
(physical$ adj2 activ$).ti,ab.
or/29-37
suburban population/ or urban population/
(humans/ or adult/) and (environment/ or residence characteristics/ or environment design/ or city planning/ or population density/ or housing/ or cities/ or transportation/ or public facilities/)
39 or 40
28 and 38 and 41
limit 42 to humans
limit 43 to "all adult (19 plus years)"
limit 43 to ("all infant (birth to 23 months)" or "all child (0 to 18 years)")
45 not 44
43 not 46
limit 47 to yr="2000 -Current"

Appendix B: PRESS checklist

PRESS Checklist

ESS worksheet

1. Translation: Is the search question translated well into search

concepts?

_ Adequate

_ Needs revision Provide an explanation or example

2. Operators: Are there any mistakes in the use of Boolean or

proximity operators?

_ Adequate

_ Needs revision Provide an explanation or example

3. Subject headings: Are any important subject headings missing or have any

irrelevant ones been included?

_ Adequate

Needs revision Provide an explanation or example

4. Natural language: Are any natural language terms or spelling variants missing, or

have any irrelevant ones been included? Is

truncation used optimally?

_ Adequate

_ Needs revision Provide an explanation or example

___

___

5. Spelling & syntax: Does the search strategy have any spelling mistakes, system syntax errors, or wrong line numbers?

_ Adequate

_ Needs revision Provide an explanation or example

___

___

6. Limits: Do any of the limits used seem unwarranted or are any potentially helpful limits missing?

_ Adequate

_ Needs revision Provide an explanation or example

___

___

7. Adapted for db: Has the search strategy been adapted for each database to be searched?

_ Adequate

_ Needs revision Provide an explanation or example

___

___

From: Sampson M, McGowan J, Lefebvre C, Moher D, Grimshaw J. PRESS: Peer Review of Electronic Search Strategies. Ottawa: Canadian Agency for Drugs and Technologies in Health; 2008.

Appendix C: Level One, Two, and Three Screening Forms

Level 1 – Title and Absract Screening

Definitions

Physical Characteristics of Neighbhourhoods (PCONs): tangible components of neighbourhoods including both built structures and natural settings.
(e.g., population density; building density; street layout; block sizes; speed bumps; cleanliness; lighting; proximity of workplaces, retail, parks, recreational facilities, sidewalks, bike lanes, and public transit to residences; etc.)

1. Is the study in English?

Yes

No

Unclear

Clear Response

2. Does the study *possibly* evaluate physical characteristics of neighbourhoods (PCONs) and time spent or frequency of walking?

Yes

No

Unclear

Clear Response

3. Does the study compare two or more groups with different exposures or outcomes, or two or more time periods with different exposures or outcomes? *(exclude uncontrolled trials, case-series, case studies, case reports, narrative reviews, commentaries, editorials, etc.)*

Yes

No

Unclear

Clear Response

Submit Form and go to or Skip to Next

Level 2 – Full Text Screening

Does the article contain a logic model of physical environment - physical activity relationships?

Yes

Does the logic model focus on PCON - walking associations?

Yes

No

PCON - walking within broader framework

No PCON construct

PA construct, but walking not specified

No walking or PA construct

Clear Response

No/no full text

Clear Response

4. Is the full text available?

Yes

No

Clear Response

5. Does the study evaluate physical components of neighbourhoods (PCONs*) and walking behaviour?

Yes

No

Unclear

Clear Response

The following questions concern the study population

6. Was the study conducted in Australia, Canada, New Zealand, or the United States?

Yes

No

7. Was the study conducted in Western Europe*?

Yes

No

Unclear

Clear Response

Unclear

Clear Response

8. Does at least one of the comparisons evaluate <u>able-bodied</u> people exclusively? (exclude if people with physical disabilites, vision problems, or other conditions affecting mobility are included in *every* comparison)

Yes

No

Unclear

Clear Response

9. Does at least one of the comparisons evaluate able-bodied adults aged 18 and up exclusively? (exclude if children under 18 are included in *every* comparison)

- Yes
- No
- Unclear

Clear Response

10. Does at least one of the comparisons evaluate able-bodied adults residing in urban areas* exclusively? (exclude if rural residents are included in *every* comparison)

- Yes
- No
- Unclear

Clear Response

The following questions concern the exposure(s) and the outcome(s)

11. Is *objectively measured exposure** to PCONs evaluated separately in at least one comparison? (exclude if perceived / self-reported exposures included in *every*comparison)

- Yes
- No
- Unclear

Clear Response

12. Is a separate estimate caculated for *walking for transportation** OR *walking for exercise/leisure**, whether objectively measured or self-reported?

- Yes
- No
- Unclear

Clear Response

Optional

Should the study be excluded for another reason?

- Yes (state reason)

Definitions*

PCON (Physical Characteristic Of Neighbourhood): A component of a neighbourhood that relates to the built form or natural setting. Eg, park, recreational facility, trail, bike lane, retail density, building density, population density, land-use mix.

Western Europe: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom

Urban area: An area with a population of at least 1000 and a population density of at least 400 people/km2 (as defined by Statistics Canada). Generally includes all cities, suburbs and towns. Exclude if area described as rural, countryside, etc.

Objectively measured exposure: PCONs measured using GIS or other mapping software, neighbourhood audits, or other objective means. Perceived PCONs and study participants' recall of PCONs are *not* objectively measured.

Walking for transportation: Moving on two feet with at least one foot on the ground at all times with the purpose of reaching a destination.

Walking for exercise/leisure: Moving on two feet with at least one foot on the ground at all times with the intention of improving or maintaining phyiscal fitness. Include dog walking here.

Level 3 – final full-text screening

What is the study design?

- Systematic Review
- Primary comparative study (RCT, cohort, case-control, before/after, cross-sectional etc.)
- Study with no comparison group (narrative, case reports, etc)

Clear Response

Does at least one of the comparisons evaluate able-bodied people exclusively? (exclude if people with physical disabilites, vision problems, or other conditions affecting mobility are included in every comparison)

- Yes
- No
- Not reported

Clear Response

Does at least one of the comparisons evaluate able-bodied adults aged 18 and up exclusively? (exclude if children under 18 are included in every comparison)

- Yes
- No
- Not reported

Clear Response

Does at least one of the comparisons evaluate able-bodied adults residing in urban areas* exclusively? (exclude if rural residents are included in every comparison)

- Yes
- No
- Not reported

Clear Response

The study should be excluded for another reason

- Yes. Specify: ______

Submit Form and go to ______ or Skip to Next

Appendix D: Data Extraction Form

Data Extraction

1) Indicate "NR" if information not reported
2) Indicate "N/A" if information not applicable
3) Complete separate forms for each relevant subgroup
4) If a checkbox/radio button is ticked that has a comment box, the COMMENT BOX MUST BE WRITTEN IN

I. Study Characteristics

Another article(s) included in the review reports on the same study (data analyzed may be different):

- ○ Yes. Specify (RefID, author, year) [ ]
- ○ No/can't tell

The following information concerns...

- ○ Total study population
- ○ Subgroup of study population. Define subgroup: [ ]

First author (LAST NAME, FIRST NAME):

[ ]

Year of publication (YYYY):

[ ]

Primary study objective:

Location of study participants (check country, type: PROVINCE/STATE, COUNTY, CITY)

- ☐ Australia
- ☐ Canada
- ☐ New Zealand
- ☐ United States

Data collection start / end dates (YYYY-MM-DD):

Start date: End date:

Study design (if mixed-methods, check multiple). Specify participant recruitment sites, population data sources, or survey methods:
**based on extractor's assessment or label used in study?*

- ☐ CHECK IF MULTICENTRE. SPECIFY NUMBER OF SITES:
- ☐ Randomized controlled trial
- ☐ Non-randomized trial (trial with improper/no randomization)
- ☐ Controlled before & after study
- ☐ Prospective cohort study
- ☐ Retrospective cohort study
- ☐ Historical cohort study
- ☐ Nested case-control study
- ☐ Case-control study
- ☐ Cross-sectional survey

- [ ] Before & after study (no control group)
- [ ] Other
- [ ] Can't tell

Comparison method (if mixed-methods, check multiple):

- [ ] 2 or more groups with different exposures
- [ ] 2 or more groups with different outcomes
- [ ] 1 group over 2 or more different time periods
- [ ] Other
- [ ] Can't tell or n/a

Group allocation method (if mixed-methods, check multiple). Provide details:

- [ ] Investigators randomly allocated participants
- [ ] Investigators allocated participants, but inadequate or no randomization
- [ ] Allocation based on participant's location
- [ ] Participants chose their own exposure
- [ ] Clinicians chose exposure for participants
- [ ] Other
- [ ] Can't tell or n/a

Method(s) to control confounding at study design stage:

- [ ] Random allocation to study groups
- [ ] Division of study population into subgroups. Specify subgroups:
- [ ] Restriction of study population to subset of affected population: Specify:
- [ ] Matching study groups on certain characteristics: Specify characteristics:

- Other. Specify:
- None
- Can't tell or n/a

Source(s) of study and/or author funding:

- Government (eg, NIH, CIHR). Specify:
- University, public or private (eg, U. of Ottawa). Specify:
- Non-government, not-for-profit organization (eg, Bill & Melinda Gates Foundation). Specify:
- Private, for-profit organization (eg, Pfizer, Merck). Specify:
- Other. Specify:
- Not reported

II. Population

Sample size (###):

Baseline characteristics (Specify proportions or averages (with SD) for total population and EACH STUDY GROUP):

TOTAL	GROUP 1	GROUP 2	GROUP 3	GROUP 4
*Age	*Age	*Age	*Age	*Age
*All over 65	*All over65	*All over65	*All over65	*All over65
*Sex	*Sex	*Sex	*Sex	*Sex
*BMI	*BMI	*BMI	*BMI	*BMI
Ethnicity	Ethnicity	Ethnicity	Ethnicity	Ethnicity

Mobility/Phys health	Mobility/Phys health	Mobility/Phys health	Mobility/Phys health	Mobility/Phys health
Other biol/Demogr	Other biol/Demogr	Other biol/Demogr	Other biol/Demogr	Other biol/Demogr
Immigration	Immigration	Immigration	Immigration	Immigration
*Income level	*Income level	*Income level	*Income level	*Income level
Education level	Education level	Education level	Education level	Education level
Employment status	Employment status	Employment status	Employment status	Employment status
Other socioecon	Other socioecon	Other socioecon	Other socioecon	Other socioecon
Percep/Knowledge	Percep/Knowledge	Percep/Knowledge	Percep/Knowledge	Percep/Knowledge
Atti/Valu/Pref/Motiv	Atti/Valu/Pref/Motiv	Atti/Valu/Pref/Motiv	Atti/Valu/Pref/Motiv	Atti/Valu/Pref/Motiv
Self-efficacy/esteem	Self-efficacy/esteem	Self-efficacy/esteem	Self-efficacy/esteem	Self-efficacy/esteem
Soc support/Interper	Soc support/Interper	Soc support/Interper	Soc support/Interper	Soc support/Interper
Other psychosocial	Other psychosocial	Other psychosocial	Other psychosocial	Other psychosocial
Incentives	Incentives	Incentives	Incentives	Incentives
Regulations	Regulations	Regulations	Regulations	Regulations
Other policy change	Other policy change	Other policy change	Other policy change	Other policy change
Dog ownership				

CAR OWNERSHIP	Dog ownership	Dog ownership	Dog ownership	Dog ownership
WEATHER/ CLIMATE	Car ownership	Car ownership	Car ownership	Car ownership
Other	Weather/Climate	Weather/Climate	Weather/Climate	Weather/Climate
Other	Other	Other	Other	Other
Other	Other	Other	Other	Other
	Other	Other	Other	Other

Participant inclusion criteria:

Participant exclusion criteria:

Walking for TRANSPORTATION

III. Exposures, comparators, outcomes

Specify how the PCONs were measured (if multiple methods used, specify which PCONs measured in text box beside each method):

- ☐ GIS / mapping. Specify software: [ ]
- ☐ Audit (trained observers recording info. on PCONs). Specify observers: [ ]
- ☐ Secondary data source (eg, census). Specify source: [ ]
- ☐ Other. Specify: [ ]
- ☐ Can't tell or n/a

UNADJUSTED effect estimates:

(If comparator given, type "exposure vs. comparator" in Exposure(s): text box. Otherwise, just type "exposure") ***ENTER REFID BEFORE EACH EXPOSURE***

Specify exposures in each category:	Outcomes for each exposure:	Type of measure; estimate; confidence interval:
☐ BUILDINGS...................... Exposure(s): [ ]	☐ Outcome(s): [ ]	☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]
☐ ROUTES.......................... Exposure(s): [ ]	☐ Outcome(s): [ ]	☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]
☐ RECREATIONAL AREAS Exposure(s): [ ]	☐ Outcome(s): [ ]	☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]
☐ APPEARANCE................. Exposure(s): [ ]	☐ Outcome(s): [ ]	☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]
☐ MULTIPLE....................... Exposure(s): [ ]	☐ Outcome(s): [ ]	☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]
☐ OTHER............................ Exposure(s): [ ]	☐ Outcome(s): [ ]	☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]

☐ Additional exposures in one or more categories checked above

Specify exposures in each category:	Outcomes for each exposure:	Type of measure; estimate; confidence interval:
☐ BUILDINGS...................... Exposure(s): [ ]	☐ Outcome(s): [ ]	☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]

ROUTES........................... Exposure(s): | Outcome(s): | (eg, OR; #.##; 95% CI [#.##, #.##]):

RECREATIONAL AREAS Exposure(s): | Outcome(s): | (eg, OR; #.##; 95% CI [#.##, #.##]):

APPEARANCE................. Exposure(s): | Outcome(s): | (eg, OR; #.##; 95% CI [#.##, #.##]):

MULTIPLE........................ Exposure(s): | Outcome(s): | (eg, OR; #.##; 95% CI [#.##, #.##]):

OTHER............................ Exposure(s): | Outcome(s): | (eg, OR; #.##; 95% CI [#.##, #.##]):

Additional exposures in one or more categories checked above

ADJUSTED effect estimates:

(If comparator given, type "exposure vs. comparator" in Exposure(s): text box. Otherwise, just type "exposure") ***ENTER REFID BEFORE EACH EXPOSURE***

Specify exposures in each category:	Outcomes for each exposure:	Type of measure; estimate; confidence interval:
BUILDINGS...................... Exposure(s):	Outcome(s):	(eg, OR; #.##; 95% CI [#.##, #.##]):
ROUTES........................... Exposure(s):	Outcome(s):	(eg, OR; #.##; 95% CI [#.##, #.##]):
RECREATIONAL AREAS Exposure(s):	Outcome(s):	(eg, OR; #.##; 95% CI [#.##, #.##]):
APPEARANCE................. Exposure(s):	Outcome(s):	(eg, OR; #.##; 95% CI [#.##, #.##]):
MULTIPLE........................ Exposure(s):	Outcome(s):	(eg, OR; #.##; 95% CI [#.##, #.##]):
OTHER............................ Exposure(s):	Outcome(s):	

☐ (eg, OR; #.##; 95% CI [#.##, #.##]):

☐ Additional exposures in one or more categories checked above

Specify how walking for transportation was measured:

☐ Objectively (eg, accelerometer). Specify:

☐ Subjectively (eg, self-report). Specify:

☐ Can't tell or n/a

IV. Analysis, adjustment for confounding

Covariates adjusted for:

☐ Age

☐ *Sex

☐ *BMI

☐ Ethnicity

☐ Mobility / Physical health

☐ Other biological / Demographic

☐ Immigrantion

☐ *Income level

☐ Education level

- [ ] Employment status
- [ ] Other socioeconomic
- [ ] Perceptions / Knowledge
- [ ] Attitudes / Values / Preferences / Motivation
- [ ] Self-efficacy / Self-esteem
- [ ] Social support / Interpersonal influences
- [ ] Other psychosocial
- [ ] Incentives
- [ ] Regulations
- [ ] Other policy change
- [ ] Dog ownership
- [ ] CAR OWNERSHIP
- [ ] WEATHER / CLIMATE
- [ ] Other
- [ ] Other
- [ ] Other
- [ ] None/not applicable

Data analysis method(s):

- [ ] Multiple logistic regression
- [ ] Multiple linear regression
- [ ] Generalized linear regression
- [ ] Log-binomial regression

- [ ] Modified Poisson regression
- [ ] Cox proportional hazards model
- [ ] ANOVA or ANCOVA
- [ ] Chi-square
- [ ] T-test or Student's T-test
- [ ] Other
- [ ] Can't tell or n/a

Method(s) to adjust for confounding at data analysis stage:

- [ ] Inclusion in regression model
- [ ] Stratification
- [ ] Restriction
- [ ] Other

Did study attempt to control for neighbourhood self-selection?

- ( ) Yes. Describe how:
- ( ) No

Clear Response

Did study attempt to control for varying amounts of time spent in neighbourhood of residence?

- ( ) Yes. Describe how:
- ( ) No

Clear Response

Walking for EXERCISE/LEISURE

III. Exposures, comparators, outcomes

Specify how the PCONs were measured (if multiple methods used, specify which PCONs measured in text box beside each method):

- ☐ GIS / mapping. Specify software: [ ]
- ☐ Audit (trained observers recording info. on PCONs). Specify observers: [ ]
- ☐ Secondary data source (eg, census). Specify source: [ ]
- ☐ Other. Specify: [ ]
- ☐ Can't tell or n/a

UNADJUSTED effect estimates:

(If comparator given, type "exposure vs. comparator" in Exposure(s): text box. Otherwise, just type "exposure") ***ENTER REFID BEFORE EACH EXPOSURE***

Specify exposures in each category:	Outcomes for each exposure:	Type of measure; estimate; confidence interval:
☐ BUILDINGS...................... Exposure(s): [ ]	☐ Outcome(s): [ ]	☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]
☐ ROUTES.......................... Exposure(s): [ ]	☐ Outcome(s): [ ]	☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]
☐ RECREATIONAL AREAS Exposure(s): [ ]	☐ Outcome(s): [ ]	☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]
☐ APPEARANCE................. Exposure(s): [ ]	☐ Outcome(s): [ ]	☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]
☐ MULTIPLE........................ Exposure(s): [ ]	☐ Outcome(s): [ ]	☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]
☐ OTHER............................ Exposure(s): [ ]	☐ Outcome(s): [ ]	☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]

☐ Additional exposures in one or more categories checked above

ADJUSTED effect estimates:
(If comparator given, type "exposure vs. comparator" in Exposure(s): text box. Otherwise, just type "exposure") ***ENTER REFID BEFORE EACH EXPOSURE***

Specify exposures in each category:

- ☐ BUILDINGS...................... Exposure(s): [ ]
- ☐ ROUTES........................... Exposure(s): [ ]
- ☐ RECREATIONAL AREAS Exposure(s): [ ]
- ☐ APPEARANCE................. Exposure(s): [ ]
- ☐ MULTIPLE........................ Exposure(s): [ ]
- ☐ OTHER............................ Exposure(s): [ ]

Outcomes for each exposure:

- ☐ Outcome(s): [ ]
- ☐ Outcome(s): [ ]
- ☐ Outcome(s): [ ]
- ☐ Outcome(s): [ ]
- ☐ Outcome(s): [ ]
- ☐ Outcome(s): [ ]

Type of measure; estimate; confidence interval:

- ☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]
- ☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]
- ☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]
- ☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]
- ☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]
- ☐ (eg, OR; #.##; 95% CI [#.##, #.##]): [ ]

☐ Additional exposures in one or more categories checked above

Specify how walking for exercise/leisure was measured:

- ☐ Objectively (eg, accelerometer). Specify: [ ]
- ☐ Subjectively (eg, self-report). Specify: [ ]
- ☐ Can't tell or n/a

IV. Analysis, adjustment for confounding

Covariates adjusted for:

- [ ] Age
- [ ] *Sex
- [ ] *BMI
- [ ] Ethnicity
- [ ] Mobility / Physical health
- [ ] Other biological / Demographic ______
- [ ] Immigrantion
- [ ] *Income level
- [ ] Education level
- [ ] Employment status
- [ ] Other socioeconomic ______
- [ ] Perceptions / Knowledge
- [ ] Attitudes / Values / Preferences / Motivation
- [ ] Self-efficacy / Self-esteem
- [ ] Social support / Interpersonal influences
- [ ] Other psychosocial ______
- [ ] Incentives
- [ ] Regulations

- [ ] Other policy change
- [ ] Dog ownership
- [ ] CAR OWNERSHIP
- [ ] WEATHER / CLIMATE
- [ ] Other
- [ ] Other
- [ ] Other
- [ ] None/not applicable

Data analysis method(s):

- [ ] Multiple logistic regression
- [ ] Multiple linear regression
- [ ] Generalized linear regression
- [ ] Log-binomial regression
- [ ] Modified Poisson regression
- [ ] Cox proportional hazards model
- [ ] ANOVA or ANCOVA
- [ ] Chi-square
- [ ] T-test or Student's T-test
- [ ] Other
- [ ] Can't tell or n/a

Method(s) to adjust for confounding at data analysis stage:

- [ ] Inclusion in regression model

☐ Stratification

☐ Restriction

☐ Other

Did study attempt to control for neighbourhood self-selection?

○ Yes. Describe how:

○ No

Clear Response

Did study attempt to control for varying amounts of time spent in neighbourhood of residence?

○ Yes. Describe how:

○ No

Clear Response

Submit Form and go to or Skip to Next

Appendix E: Studies Excluded During Full-Text Screening

Level 2 Exclusions

No.	Bibliography
1	Anonymous. Increasing activity can be a walk in the park. Every little bit helps; fun and convenience are key factors.. Harv.Heart Lett.. 2012.
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