GENDER AND AGE DIFFERENCES IN RECREATIONAL AND TRANSPORT WALKING: THE CONTRIBUTION OF THE NEIGHBOURHOOD SOCIAL AND BUILT ENVIRONMENTS

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Statement of Authorship and Sources

This thesis contains no material that has been extracted in whole or in part from a thesis that I have submitted towards the award of any other degree or diploma in any other tertiary institution.

No other person's work has been used without due acknowledgment in the main text of the thesis.

All research procedures reported in the thesis received the approval of the relevant Ethics/Safety Committees (where required).

I would like to acknowledge the co-operation from my research team who have mentored and supported me through this candidature. However, this research program was undertaken for my PhD and remains my own intellectual property.

As is the nature of research, several authors contributed in part to publications included in this thesis; however, the actual research undertaken and the preparation of manuscripts for publication were solely my own work (except where duly acknowledged). My contribution, and the contributions of additional co-authors to each of the papers included in this thesis, is outlined in detail in Appendix A.

All other work included in this thesis that is not part of a published paper, or one that has been accepted for publication, is entirely my own work, except where duly acknowledged.

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"It has long been recognized that getting an education is effective for bettering oneself and one's chances in the world. But a degree and an education are not necessarily synonymous. A vigorous culture capable of making corrective, stabilizing changes depends heavily on its educated people, and especially upon their critical capacities and depth of understanding." — Jane Jacobs, Dark Age Ahead [1]

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List of Abbreviations

Acronym	Definition
AAS	Active Australia Survey
ABS	Australian Bureau of Statistics
AHS	Australian Health Survey
ALGA	Australian Local Government Association
ALSWH	Australian Longitudinal Study on Women's Health
CCDs	Census Collection Districts
CIs	95% Confidence Intervals
CrIs	95% Credible Intervals
GIS	Geographic Information Systems
GPS	Global Positioning Satellite
HABITAT	How Areas in Brisbane Influence HealTh and AcTivity study
IPEN study	International Physical Activity and the Environment Network (IPEN) Adult Study
IPAQ	International Physical Activity Questionnaire
IRSD	Index of Relative Socio-economic Disadvantage
NHF	National Heart Foundation of Australia
NEWS	Neighbourhood Environment Walkability Scale questionnaire
NCDs	Non-Communicable Diseases
MET	Metabolic Equivalent of Task
OR	Odds Ratio
PA	Physical Activity
PIA	Planning Institute Australia
SEP	Socio-Economic Position
WfR	Walking for Recreation
WfT	Walking for Transport
WHO	World Health Organization

Abstract

Populations are growing and ageing globally, and they concentrate in urban centres, placing greater pressure on city infrastructure and resources. The burden of non-communicable diseases partly reflects the increasing inactivity trends in populations, possibly from living in environments primarily designed for private motor vehicle transportation rather than active transportation.

Walking as regular physical activity (PA) is an important behaviour to facilitate active living in ageing communities. Compared to men and younger adults, women and older adults are less physically active, and favour walking rather than more vigorous PA. Research underpinned by social-ecological frameworks indicates that certain social and built neighbourhood features influence the walking patterns of residents. Therefore, the identification of specific environmental features that facilitate walking in populations, particularly in those demographic groups predisposed to inactivity, can inform the social and physical planning or retrofitting of urban forms that might potentially reduce the gender and age disparities in overall PA participation.

Multilevel neighbourhood-based studies to date mostly reported the average neighbourhood effects of gender and age differences in recreational and transport walking, implicitly assuming that neighbourhood environments influence the walking patterns of men and women, and younger and older persons, similarly. However, this might not be a true reflection of what is actually happening. Through three multilevel cross-sectional studies underpinned by a social-ecological framework, this thesis explored the contribution of the neighbourhood built and social environments to explaining gender and age differences in recreational and transport walking. The thesis contains seven chapters outlined below.

Chapter 1 provides an overview of the context, purpose and structure of this thesis, including a conceptual framework underpinning three studies within this thesis. This chapter highlights the important role that neighbourhood designs have in facilitating walking, and notes the benefits of using a social-ecological framework to inform multilevel interventions (targeted both at individuals and communities) which have the maximum potential to increase population walking levels.

Chapter 2 presents the historical perspective of the influence of neighbourhoods on health behaviours such as walking, as well as an overview of the relevant policy and research frameworks supporting the investigation of the environmental correlates and determinants of recreational and transport walking. This chapter also presents an overview on the health benefits, recommendations and measurement of PA, with a focus on walking patterns, noting that it usually occurs within neighbourhoods, and that recreational walking has different environmental correlates than transport walking. Furthermore, the literature indicates that walking patterns vary by gender and age, and these differences are discussed within a social-ecological framework. A critical appraisal of the social and physical neighbourhood features influencing walking is also presented. Finally, this review provides a summary of the literature gaps which informed the research questions addressed within this thesis.

Chapter 3 describes the methodology in two parts: the first part describes the sampling design, selection methods and data collection instruments of the How Areas in Brisbane Influence healTh And acTivity (HABITAT) survey, the multilevel study underpinned by a social-ecological framework used in this thesis; the second part provides more specific information on relevant measures as well as the analytic and statistical modelling strategies undertaken to address the research questions.

Chapter 4 presents Study 1, which examined whether gender and age differences in walking for recreation (WfR) and walking for transport (WfT) were similar or different across neighbourhoods. This study used Wave 2 of HABITAT (collected in 2009), involving a sample of 7,866 residents aged 42-68 years living within 200 Brisbane neighbourhoods. On average, women were significantly more likely to engage in WfR at moderate and high levels and no gender differences in WfT were observed. Older adults were significantly less likely to walk for transport and more likely to walk for recreation at high levels. More interestingly, the relationships between gender and walking, and age and walking, were not the same in all neighbourhoods (i.e. the Brisbane average concealed important information), suggesting that neighbourhood-level factors influenced the walking patterns of men and women, and younger and older adults, differently. The subsequent two studies focused on identifying these neighbourhood-level factors.

Chapter 5 presents Study 2, which investigated the contribution of the neighbourhood social environment (assessed through neighbourhood-level perceptions of social cohesion, incivilities, and safety from crime) to explaining the gender differences in WfR observed across neighbourhoods in Study 1. Study 2 used Wave 2 of HABITAT (collected in 2009), involving a sample of 7,866 residents aged 42-67 years living within 200 Brisbane neighbourhoods. On average, women were more likely than men to walk for recreation prior to adjustment for covariates. Gender differences in WfR varied significantly across neighbourhoods (as previously established in Study 1), and the magnitude of the between-neighbourhood variation for women was twice that of men, suggesting that women are more sensitive to their neighbourhood environments in regards to WfR. However, the social environment did not explain neighbourhood differences in the gender-WfR relationship, nor did it explain the observed between-neighbourhood variation in WfR for men or women. This is most likely due to the noted limited variation in social environments across Brisbane neighbourhoods, an urban setting where structural differences between neighbourhoods might not be as extreme as in other cities.

Chapter 6 presents Study 3, which investigated the contribution of the neighbourhood built environment (objectively assessed through neighbourhood-level measures of residential density, street connectivity and land-use mix) to explaining the age differences in WfT observed across neighbourhoods in Study 1. Study 3 used Wave 1 of HABITAT, (collected in 2007) involving a sample of 11,035 residents aged 40-65 years living within 200 neighbourhoods. On average, older adults were less likely to walk for transport. Age differences in WfT varied significantly across neighbourhoods (as previously established in Study 1), and the magnitude of the between-neighbourhood variation for older groups was twice that of the youngest group, suggesting that older adults are more sensitive to their neighbourhood environment than their younger counterparts. The built environment played a limited role in explaining neighbourhood differences in the age-WfT relationship. Residential density and street connectivity (but not land use mix) partially explained the observed between-neighbourhood variation in WfT for across age groups.

Finally, Chapter 7 provides the discussion and conclusions of this research program. Collectively, the three studies comprising this thesis confirmed that the walking patterns of men and women, and younger and older persons are differently shaped and circumscribed by different neighbourhood environments. In particular, women and older adults seemed more sensitive to their environments than their counterparts, suggesting that they might require more supportive environments to walk. While Brisbane's social environment did not contribute to explaining gender differences in WfR across neighbourhoods, the age differences in WfT across neighbourhoods were partly attributed to the contextual effects of residential density and street connectivity. Thus, in designing neighbourhoods that facilitate active living and ageing communities, governments should consider denser and more connected urban forms which would produce more equitable increases in WfT across age groups.

This body of evidence contributes to the literature investigating the important role that the neighbourhood design has in facilitating the healthy lifestyle of residents who are regularly exposed to it. More specifically, the findings from this thesis favour the ongoing multilevel analyses of demographic heterogeneity around the neighbourhood averages –rather than *mean centric approach*– as they more realistically reflect the impact of neighbourhood exposures on the walking patterns of different demographic groups. As cities vary widely in their social and built environments, such research –especially when undertaken in urban settings characterised by larger variation in their environments– is relevant for informing ecological interventions which facilitate walking opportunities everywhere for all demographic groups, particularly those predisposed to inactivity, resulting in sustainable public health, socioeconomic and environmental gains for the overall population.

Chapter 1: Introduction and overview

This chapter describes the background, context and purpose of this thesis, including its scope and significance, and provides an outline of the chapters within this thesis.

1.1 BACKGROUND

The proportion of older adults is forecasted to increase considerably worldwide over the next few decades, reflecting the extended life expectancy as well as decreases in fertility [2]. As the baby boomer generation approaches retirement age [3], challenges and opportunities arise for the wellbeing of populations [4]. Older adults offer a valuable socioeconomic, cultural and intergenerational resource, particularly when in optimal health and wellbeing. However, if they suffer from non-communicable diseases (NCDs), have multiple coexisting and inter-related conditions manifested in physical and cognitive declines, their mobility and overall quality of life will be negatively impacted, placing a significant health and socioeconomic burden on society [3].

Although life expectancy in older age is increasing in most countries, the quality of these additional years remains unclear [3]. Individuals become less active as they age [5], particularly women, who are consistently less active than men [6-8]. Physical inactivity refers to a regular insufficient activity level below the present physical activity recommendations [9] and is a key public health concern since populations are becoming increasingly inactive; it is estimated that 31% of adults worldwide are physically inactive, particularly women and older adults [8]. Physical inactivity is a risk factor contributing to the global burden of NCDs and represents 9% of premature mortality [9] as well as the fourth leading cause of death worldwide [10].

Epidemiological research indicates that physical activity (PA) is an important modifiable behaviour, and its promotion across the life-span is a cost-effective strategy to prevent and/or postpone NCDs, maintain independence and improve the quality of life, particularly in older populations [11-13]. The World Health Organization (WHO) has published several policy frameworks calling for urgent action in the form of multilevel strategies (i.e. structural, behavioural or psychological) to reverse the increasing inactivity trends in populations, particularly in those demographic groups predisposed to inactivity. These frameworks include the *Global action plan for the prevention and control of non-communicable diseases 2013-2020* [14], *Global health and ageing* [2], *Ageing and Health: A*

Framework for Action [15], *Global age-friendly cities: a guide* [16], *Women, Ageing and Health: A Framework for Action*[15], *World report on ageing and health* [4], and the *Active Ageing. A policy framework* [17].

Such frameworks include the concepts of *active living* and *active ageing*, implying lifestyles characterised by regular participation in physical and social activities through active transportation and recreation opportunities which enhance the quality of life throughout the lifespan and into older age [17-19]. Overall declines in PA levels disguise the fact that not every individual is necessarily becoming inactive as they age. While physical and cognitive functions might decline naturally with age, many older adults remain healthy and productive [20], making them an important group in the investigation of predictors of active ageing [21]. Neighbourhood design can facilitate active lifestyle choices, which, in turn, can potentially postpone functional decline and compress morbidity (illness and/or disability) into a shorter period later in life [20,22].

Research reveals that women and older adults experience more individual and environmental barriers to PA participation compared to men and younger adults [3,23,24]. As interventions targeting individual behavioural change have had limited short-term success [25-27], the focus has shifted to modifying the environments in which people live, work and play to facilitate active and healthy lifestyles as a complementary strategy. Multilevel interventions directed at both individuals and communities have a potential long-lasting, broad reach, making them the most effective in increasing and maintaining population PA levels [19].

Good urban design can support women as well as older adults to remain physically and socially active in their communities and age in place by improving their health and wellbeing, increasing their mobility, independence and social interactions through walking [16,28]. Therefore, a comprehensive public health strategy should consider improving the physical and social environments within which people live as a way of reducing gender and age disparities in PA participation [3].

The nature and type of preferred PA varies with gender and age. Walking is the most common type of PA practiced by older adults [29], and seems to be preferred by women [30], whereas men and young adults are more likely to participate in vigorous-intensity PA [8]. Regular walking has been shown to reduce and/or postpone morbidity and mortality from NCDs [31,32].

Therefore, the identification and implementation of cost-effective and sustainable multilevel strategies that increase population levels of walking (particularly in demographic groups predisposed to inactivity) offers an ideal opportunity to reduce the gender and age disparities in overall PA participation to promote and prolong the optimal health and quality of life of communities into old age [33] and to decrease NCDs-related morbidity and mortality as well as associated health care costs [12]. Identifying the key design elements of active living and ageing communities is thus a research priority within the overall efforts to reverse the increasing inactivity trends in populations.

Emerging evidence using social-ecological frameworks indicate that the factors influencing walking operate at multiple levels (individual, environmental and political) [19]. As walking is typically undertaken within the local neighbourhood [34], social and built environment features might either facilitate or inhibit the residents' walking patterns [35]. Evidence indicates that the social and built environment correlates of WfR (which is typically planned and discretionary) differ from those of WfT (which is mostly incidental) [19,26], suggesting that these walking domains should be investigated separately. Designing neighbourhoods that encourage both recreational and transport walking in residents presents an opportunity for promoting active living and ageing communities.

1.2 CONTEXT

Urban and transport planners currently face the challenge of rapidly accommodating population increases in a sustainable manner (e.g. reducing carbon emissions and traffic congestion), through two approaches: reducing the residential density of developments on the urban fringe, and increasing the residential density of developments in the inner city. Unless these approaches are informed by evidence, they can potentially produce negative population health outcomes.

Cities vary widely in their socioeconomic, cultural and physical characteristics[36]. Therefore, urban research informing multilevel interventions to increase walking levels should be context-specific. Australia is a high income country with well-established welfare provisions [36], and Australian cities have been mainly designed for vehicular transportation (with separation of land uses), to the detriment of more active forms of transportation such as walking, cycling or public transport [28,37]. Emerging research from the public health, and the urban and transport planning literature indicates that these urban forms are contributing to overall Australian population declines in PA [5,38-41]. Therefore, the planning or retrofitting of environments in which people live is potentially a wide-reach, long-term and sustainable approach to reversing inactivity trends in communities [42].

Research framework

This thesis is underpinned by a social-ecological research framework, which acknowledges not only the influence of factors associated with individuals, but also those concerning the environment in which they live and function (social and organisational influences). More specifically, some neighbourhood environments might promote walking, while others might discourage it through actual and perceived social and physical neighbourhood barriers, which might have a stronger influence on the walking patterns of vulnerable groups [43]. The social-ecological framework also supports behaviour specific domains (WfR and WfT) which show stronger associations with respective environmental exposures [44].

Research underpinned by social-ecological frameworks is operationalised through multilevel data collection and the corresponding application of mutilevel investigations, which enable the comprehensive and simultaneous analyses of individual and area-level influences on walking. By facilitating the assessment of environmental differences in influencing walking patterns, accounting for both individual-level and neighbourhood-level covariates, the social-ecological framework is consistent with the social determinants of health [45].

More relevant to this thesis, the social-ecological framework does not assume that the same environment has the same impact on all individuals [46]. This is directly applicable to the study of demographic groups predisposed to inactivity such as women (whose walking patterns seem more influenced by their social environment [35,47]) as well as older adults (whose walking patterns seem more sensitive to their built environments [48] due to natural declines in their physical and cognitive functions [49]).

However, the role of environmental factors within current social-ecological models of walking remains unclear [50], particularly in demographic groups predisposed to inactivity. There is a need for high-quality empirical evidence supporting environment-behaviour associations, given the emerging interest from public policy and practice in the role of environmental attributes in determining walking patterns as part of the broader efforts to reverse inactivity trends in populations [51].

1.3 PURPOSE

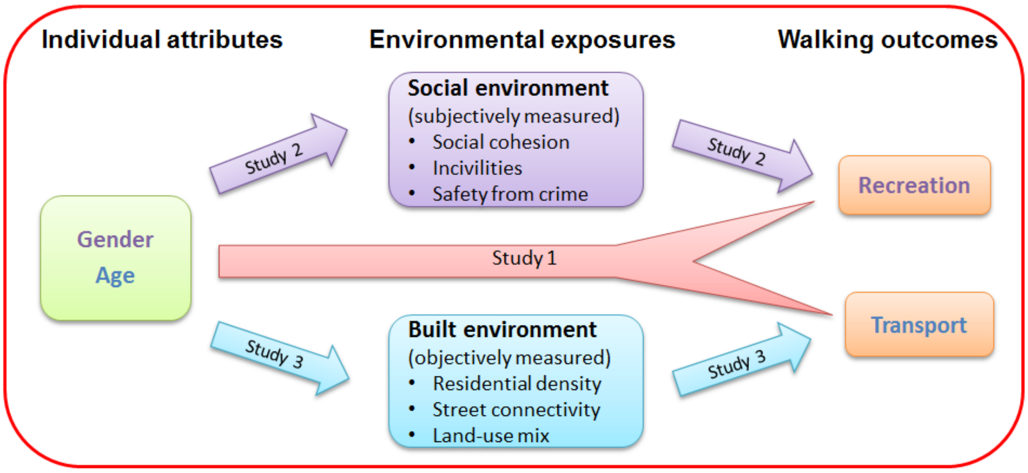
Previous multilevel research indicates different patterns of walking activity depending on gender and age. Compared to men and younger adults, women and older adults walk less for transport [52-58] and more for recreation [35,47,59-61]. Women and older adults are also likely to experience more individual and environmental (perceived and objective) barriers to walking [3,23,24,43]. To date, neighbourhood studies have mostly reported the average neighbourhood effects in the gender and age differences in WfR and WfT, overlooking the possibility that these relationships differ depending on the neighbourhood context. There is little evidence about how the social and built environment of neighbourhoods differentially influences the walking of men and women, and younger and older adults. This evidence could inform the environmental interventions likely to have the highest impact in increasing the walking levels in all demographic groups in all neighbourhoods.

Research questions

While there are indications that men and women, and younger and older adults interact with their neighbourhood environments in different ways in regards to walking patterns, multilevel neighbourhood-based studies to date have commonly reported the neighbourhood average effects of gender and age differences in walking, implicitly assuming that the same neighbourhood environment influences the walking of men and women, and younger and older persons, similarly. This thesis was designed to sensitise the investigation of the relative contribution of the neighbourhood social and built environments to the walking patterns by gender and age, in order to predict the environmental conditions under which all demographic groups walk more for transport and recreation. Such evidence is aimed at informing a more efficient use of the limited resources available for interventions through equity promoting policies that address gender and age disparities in overall PA through walking, ultimately promoting active living and ageing communities.

A diagram depicting the structured studies was developed based on a comprehensive literature review (presented in Chapter 2) to guide the research questions within this thesis (Figure 1.1). This diagram presents three studies increasing in complexity to assess whether gender and age differences in WfR and WfT vary across neighbourhoods, as well as the relative contribution of the neighbourhood's social and built environments to explaining these differences.

Figure 1.1: Diagram depicting the structured studies within this thesis



Study 1, titled *Gender and age differences in walking for transport and recreation: are the relationships the same in all neighbourhoods?,* assessed whether the average gender and age effects on WfR and WfT were similar or different across neighbourhoods. If these average effects do not apply to everyone everywhere, it would suggest that neighbourhood-level factors differentially influenced the walking patterns of men and women, and younger and older adults. In other words, men and women, and younger and older adults might experience –and engage with– their local environments in distinct ways in regards to walking patterns [62]. Identifying these neighbourhood-level factors would, therefore, be a priority for subsequent investigations in order to inform equitable ecological interventions to encourage walking in all demographic groups everywhere.

In regards to Study 2, the literature indicates that the social environment is more likely to be associated with WfR, particularly in women [62]. Several studies have identified gender as a potential modifier between the social environment and WfR, with stronger effects observed in women [35,47], suggesting that more social environment support might be required to encourage women to walk for recreation. Therefore, it is plausible that the social environment might partly explain the gender differences in WfR observed in Study 1 across neighbourhoods, with favourable social environments generating minimal or no gender differences in WfR, whereas larger gender disparities in WfR might be observed in socially fractured neighbourhoods, with men more likely to have a higher crime threshold for WfR. Study 2, titled *Do differences in social environments explain gender differences in recreational walking across neighbourhoods?,* explored the contribution of the social environment (conceptualised through neighbourhood-level perceptions of social cohesion, incivilities, and crime) to explaining: (1) neighbourhood differences in the gender-WfR relationship, and (2) between-neighbourhood variation in WfR for men or women.

In regards to Study 3, built environment features are more likely to be associated with WfT [63], especially among the elderly [64,65]. Several studies identified age as a potential moderator in the relationship between the built environment and WfT [64,65], suggesting that more supportive built environments might be required to encourage older adults to walk for transport. Therefore, it is plausible that the built environment might partly explain the age differences in WfT observed across neighbourhoods in Study 1, with pedestrian-friendly neighbourhoods (characterised by greater residential density, street connectivity and land-use mix) generating smaller age differences in WfT because such physical features are more conducive to walking for everyone, whereas unfavourable built environments might produce larger age disparities in WfT, accelerating older adults' physical function decline as a result of engaging in less WfT. Study 3, titled *Do differences in built environments explain age differences in transport walking across neighbourhoods?*, explored the contribution of the built environment (objectively measured through residential density, street connectivity and land-use mix) to explaining: (1) neighbourhood differences in the age-WfT relationship, and (2) between-neighbourhood variation in WfT for younger and older adults.

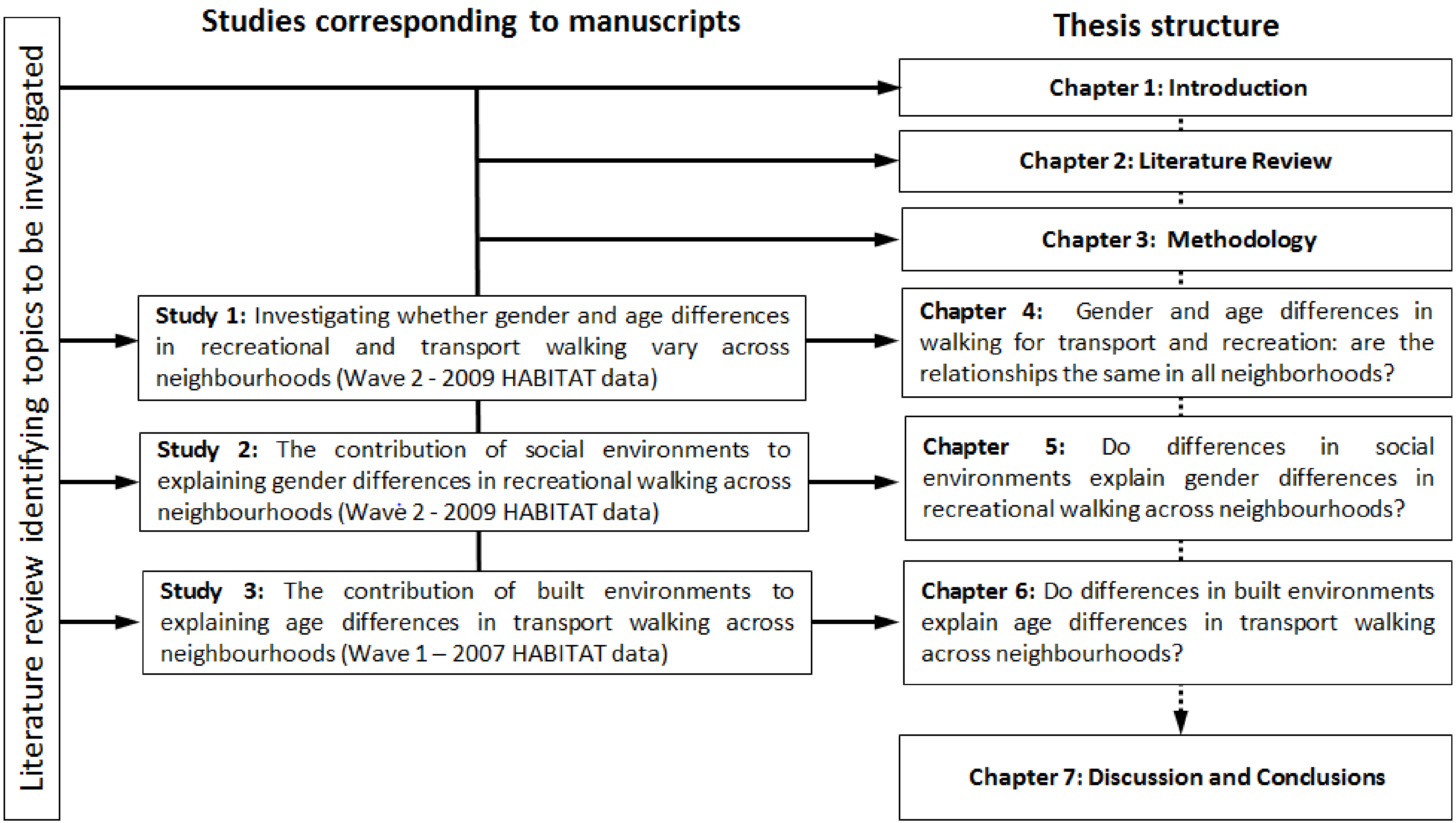
The literature review that follows was scoped to reflect the current state of research relevant to these specific study questions. Furthermore, certain individual factors such as self-efficacy as well as additional health behaviours, intermediate markers and health outcomes were deemed out of the scope of this thesis.

1.4 THESIS STRUCTURE AND OUTPUTS

Thesis outline

This thesis produced three manuscripts corresponding to three studies within the conceptual framework presented in Figure 1.2 as well as several international conference papers outlined under the research portfolio (Appendix A). Study 1 (Chapter 4) has been published in *Preventive Medicine Reports* (a peer reviewed open access journal). Study 2 (Chapter 5) is to be submitted, while Study 3 (Chapter 6) has been accepted for publication by the *Journal of Transport & Health*.

Figure 1.2: Thesis structure incorporating three studies



Practical implications of this thesis

This thesis is part of the broader efforts conducted by the National Health and Medical Research Council (NHMRC) Centre of Research Excellence (CRE) in Healthy, Liveable Communities. This CRE established a research agenda focused on: (1) identifying the most cost-effective environmental interventions (types and 'dose') required to create healthy, liveable and equitable communities; and (2) facilitating research translation into urban planning policy and practice.

This thesis was designed not only to address a gap in the literature, but also to have community and policy relevance. This work responds to calls from international, national, regional and local policy frameworks [2,4,15-18,66,67] to inform gender and age-responsive multilevel strategies to increase PA levels in populations. The body of evidence provided by the three studies undertaken within this thesis can potentially inform the following stakeholders:

- Fellow researchers in replicating this gender and age sensitised research in other urban settings;
- Advocacy groups such as the National Heart Foundation of Australia and the Cancer Council Australia, which will support the translation of this research into practice, in line with their overarching objective of reducing the incidence of NCDs in Australia;
- Urban planners in designing more walkable neighbourhoods by prioritising cost-effective environmental interventions that promote walking in all demographic groups everywhere as a safe, affordable and sustainable recreation and transport alternative to traffic congestion;
- Health practitioners, by facilitating the tailoring of specific activity recommendations, taking into account the gender and age as well as the residential address of the client; and
- Demographic groups predisposed to inactivity (women and older adults) in either selecting a residence or community more conducive to active transportation and recreation; or in actively requesting the retrofitting of their living environments to facilitate their active living and ageing in place.

1.5 SUMMARY

In the last decade, efforts to reverse the rising inactivity trends in populations have shifted their focus from targeting individual behavioural change to creating neighbourhoods that promote the active lifestyle of their residents through planned and incidental PA. Certain demographic groups predisposed to physical inactivity (women and older adults) seem to experience more individual and environmental barriers to PA participation and favour walking over more vigorous PA.

Social-ecological frameworks consider individuals' interactions with their physical and socioeconomic habitats, incorporating environmental and policy variables likely to influence walking patterns. Emerging evidence from social-ecological frameworks indicates that the context in which people live influences their walking patterns; walking often occurs within the neighbourhood for either transport or recreation, and the environmental correlates of WfR (which is usually planned) are different from those of WfT (which is mainly incidental). Therefore, the design of neighbourhoods that facilitates walking in all demographic groups presents a contextual opportunity for promoting active living and ageing communities.

Multilevel neighbourhood-based studies to date have mostly reported average neighbourhood effects of gender and age differences in walking patterns, implicitly assuming men and women, and younger and older adults are influenced in the same way in their walking patterns by the same neighbourhood environment. However, women and older adults are likely to be more sensitive to their neighbourhood environments in regards to walking. It is therefore, plausible that neighbourhoods with better social and built environments may generate smaller gender and age differences in walking because they are more conducive to walking for everyone, whereas socially fractured neighbourhoods with poor walking infrastructure may produce larger gender and age differences in walking.

This thesis utilised data from the How Areas in Brisbane Influence HealTh and AcTivity (HABITAT) Survey to generate evidence that can potentially inform neighbourhood interventions that increase walking in all demographic groups everywhere. More specifically, this thesis:

1) describes the average neighbourhood effects of the gender/age differences in WfR/WfT;
2) assesses whether these average effects varied across neighbourhoods;
3) examines between-neighbourhood variation for men and women in regards to WfR, and for different age groups in regards to WfT;

4) investigates the relative contribution of the social environment to explaining: (a) neighbourhood differences in the gender-WfR relationship; and (b) between-neighbourhood variation in WfR for men and women.

5) investigates the relative contribution of the built environment to explaining: (a) neighbourhood differences in the age-WfT relationship; and (b) between-neighbourhood variation in WfT for different age groups.

The following chapter reviews the literature regarding the gender and age differences in recreation and transport walking as well as the contribution of the neighbourhood social and built environments to these individual-level relationships.

Chapter 2: Literature Review

This chapter provides an historical background of the influence that neighbourhoods have on health behaviours and outcomes, noting that social-ecological frameworks of research are the most appropriate for investigating the contextual correlates of walking patterns. It also provides an overview of PA and related health benefits, focussing on walking, which mainly occurs within neighbourhoods for either transportation or recreation. This is followed by a literature review of gender and age differences in recreational and transport walking as well as the relative contribution of the neighbourhood social and built environments to these relationships. This review notes that over the past decade, researchers have mainly reported the average neighbourhood effects of gender and age differences in walking patterns. These average effects assume that all neighbourhoods have the same effect on the walking of all demographic groups, overlooking the possibility that these gender and age differences in walking patterns might vary depending on the neighbourhood context. This review informed a set of innovative research questions addressed by this thesis.

2.1 NEIGHBOURHOODS AND HEALTH

2.1.1 Historical perspective

> *"Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. The enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being, without distinction of race, religion, political belief, economic or social condition".*
>
> — Art. 1 of the Constitution of the World Health Organization WHO [68]
>
> *"All through organized history, if you wanted prosperity you had to have cities. Cities are places that attract new people with new ideas".*
>
> —Jane Jacobs, Dark Age Ahead [1].

What are neighbourhoods? Although scholars are yet to agree on a definition for *neighbourhood*, it broadly refers to the geographically defined public space surrounding an individual's home. This public space is shared by a group of individuals forming a residential community within a larger urban area [69]. Neighbourhoods provide the practical efficiencies of shared community spaces and resources, and enable opportunities for social interactions [70].

Evidence indicates that the spatial planning of human settlements has a profound effect on the health of populations [70]. Early settlements played an essential role in supporting life, and were strategically located near food and water sources. They also had a centralised public space for trade and social interactions around which individuals would choose to live, often within convenient walking distance. These public spaces were accessible through well-connected, grid-like streets providing several pedestrian routes to destinations, and instigated socioeconomic developments in pre-industrial cities by attracting new residents through opportunities for trade, employment and education [69].

As urban centres increased in residential density, so did the level of investment required for their functioning. The city fringe kept expanding, reflecting population and economic growth. The industrial revolution introduced technological developments (such as motor vehicles) in urban centres, reducing the amount of physical work required to perform many activities of daily living [8]. Rapid changes in motorised transportation led to modern urban planning forms [39,70].

While many pre-industrial urban centres maintained features of the original walkable design, new residential developments sprawled in the periphery. These post-industrial urban developments were designed mainly for vehicular transportation (characterised by low residential density, less connected streets with monotonous uniform houses, with separation of land uses), and are often poorly serviced in regards to public transport and other amenities, making walking impractical due to long distances [70]. These urban forms, common in many Australian and American cities, promote unhealthy car-dependent lifestyles to the detriment of active forms of travel (such as walking, cycling or public transport) as well as unsustainable development [28,37]. They have also created a contextual disadvantage based on the location of residence; the value of residential property in modern cities typically reflects the distance from the urban centre (or Central Business District), displacing low income earners further away from well-serviced areas into less desirable neighbourhoods, creating clusters of disadvantaged residents within particular neighbourhoods [69,71,72].

Over the past decade, researchers have confirmed that neighbourhoods influence the health and wellbeing of residents through structural, socioeconomic and compositional characteristics. In particular, the daily conditions in which people live significantly influence their health outcomes through facilitating or inhibiting safe opportunities for healthy behaviours and lifestyles, such as regular walking [71].

Ultimately, urban disparities in walking patterns (which might reflect neighbourhood-level disadvantage) are detrimental to all city inhabitants, as non-friendly pedestrian environments generate unsustainable development, noise and traffic pollution and congestion and, in the worst cases, crime and social unrest [73]. Public health researchers have an important role in producing evidence which: (1) enables communities to have increased control over their health outcomes by advocating for better neighbourhood environments [74]; and (2) informs urban and transport planning policies, infrastructure, and services that facilitate walking in all demographic groups everywhere, targeting the effective integration of health and urban planning [70]. Considering these overarching aims, as well as the fact that vulnerable demographic groups such as women and older adults are predisposed to inactivity [8], and often face more individual and environmental barriers (perceived and objective) to PA –particularly for walking– than men and younger adults [3,23,24,43], this thesis investigated the contribution of social and built environments to gender and age differences in walking patterns across neighbourhoods.

2.1.2 Policy frameworks for environmental correlates of walking

This section provides an overview of the relevant policy frameworks at several tiers of government (international, national, regional and local levels) calling for urgent action to reverse the increasing inactivity trends in populations. These frameworks emphasise the influence that neighbourhood environments have in facilitating active living and ageing communities through providing opportunities for healthy lifestyles such as regular walking. This thesis addresses such calls by generating gender and age sensitive research to inform environmental interventions which can effectively increase the walking patterns of all demographic groups everywhere.

Active living incorporates PA as part of everyday activities, including opportunities for active transportation and recreation, which are affordable and sustainable solutions to traffic congestion [18,19]. As emerging evidence indicates that social and biological factors from early life onwards affect later health, active living should reflect a life-course approach through incorporating active ageing [21]. *Active ageing* is defined by the World Health Organization as "*the process of optimising opportunities for health, participation and security, in order to enhance quality of life and wellbeing as people age*" [17] and can greatly facilitate *ageing in place*, rather than transferring to aged care facilities [75].

While physical and cognitive function declines naturally with age, many older adults (often defined as 65 years and over for research purposes, corresponding to the qualifying state pension age in most countries [76]), remain healthy, independent and productive [20], contributing to their communities with their experience and service [77]. This is an important group in investigating the predictors of active ageing [21]. Healthy lifestyle choices facilitate active living and ageing, postponing functional declines and preventing or delaying chronic diseases and disabilities (i.e. compressing morbidity into a shorter period later in life) [20,22,74].

A prerequisite of successful ageing in place involves the design of residential settings which facilitate independence in performing the *activities of daily living*[78]. In a practical sense, active ageing policies and programs should encourage age-friendly environments and services that are inclusive and accessible to older adults [74].

Promoting active lifestyle choices at the population level across the life-span is a cost-effective strategy to prevent disease, maintain independence and improve quality of life of communities [11]. It is estimated that a 10% reduction in population-level physical inactivity would result in a conservative saving of AUD $258 million, with 37% of savings arising from the health sector [12]. Epidemiologic research indicates that walking is an important modifiable behaviour and its promotion across the life-span is a cost-effective strategy to prevent and/or postpone the onset of illness/disability related to NCDs, maintain independence and improve quality of life in populations [11-13].

The active living and ageing concepts guide the recommendations provided within several of the World Health Organization's (WHO) frameworks, including the *Global action plan for the prevention and control of non-communicable diseases 2013-2020* [14], *Global health and ageing* [2], *Ageing and Health: A Framework for Action* [15], *Global age-friendly cities: a guide* [16], *Women, Ageing and Health: A Framework for Action*[15], *World report on ageing and health* [4], and the *Active Ageing. A policy framework* [17]. In particular, the WHO's *Global age-friendly cities: a guide* [16] promotes communities where older adults are valued, respected and actively engaged through preventing age-related barriers to walking and community participation. However, there is limited evidence about the modifiable social and built environmental factors (policies, services and structures) which characterise age-friendly communities [74].

At the national level, the *Blueprint for an active Australia* [18] proposes a multi-sectorial approach to increasing population activity levels through recommendations for urgent action in thirteen areas, four of which are relevant to this thesis (namely, older people, built environments, active travel and active recreation). In particular, there is an increased interest from the health, transportation, and urban planning sectors in transport walking and its potential contributions to environmental and personal health [61]. The Australian guide to designing places for healthy living, *Healthy Spaces and Places* [38], notes that well-designed urban planning should encourage active recreation and transport choices which promote social inclusiveness and safe communities. Furthermore, the national transport plan for a productive and active Australia, *Moving Australia 2030* [66], notes that urban design should facilitate incidental daily PA through active transport options that are easy, safe and attractive, setting a target for active and public transport to account for over 30% of all passenger trips in Australian capital cities by 2030.

At the regional level concerning this thesis, the *South East Queensland Regional Plan 2009-2031* [79] notes that "*best practice planning and design of the built environment encourages physical activity and healthy lifestyle choices, provides a sense of community safety and assists in preventing crime*". At the local level, a strategic outcome within the *Brisbane City Plan* [67] is that "*Brisbane's healthy and safe communities are ensured through development which is designed to minimise environmental risks, contribute to crime prevention and promote active travel and recreation*". Furthermore, the aims of *Brisbane Vision 2031* [80] include the promotion of *active, healthy communities* through environmental design practices (such as an integrated transport system) which facilitate the adoption of efficient, safe and sustainable recreational and travel choices by residents, such as walking.

Although such plans provide a broad strategic direction for urban development and transport planning, specific evidence on the influence of built environments for connecting communities through safe social interactions and its subsequent effects on walking patterns is limited, particularly for demographic groups predisposed to inactivity [81]. Research on environmental factors affecting walking among Brisbane residents could guide the successful achievement of these planned outcomes by informing a more efficient use of the limited resources available for interventions in urban infrastructure to effectively encourage active living and ageing.

The next section describes the theoretical research frameworks of research underpinning the investigation of correlates and determinants of PA behaviours, and walking in particular.

2.1.3 Research frameworks of physical activity

Active living and ageing research has attempted to identify the associated factors (barriers and facilitators) of walking in order to inform cost-effective interventions that increase overall PA population levels. The following section provides an overview of the relevant research frameworks underpinning the investigation of such factors at different levels of understanding and analysis, from the micro to the macro-scale perspectives, noting their relevance to this thesis.

Socio-cognitive framework

Early active living and ageing research was guided by socio-cognitive theories which assumed that healthy lifestyle choices, such as regular walking, are conscious and deliberate, originating from an individual's attitudes, intentions, self-efficacy, and other cognitive mediators of behavioural change [82,83]. Accordingly, early research into correlates (reflecting cross-sectional associations) and determinants (reflecting longitudinal relationships indicating causality) of PA focused on individual-level factors, revealing that gender, age, health status, motivation and self-efficacy are associated with PA [5].

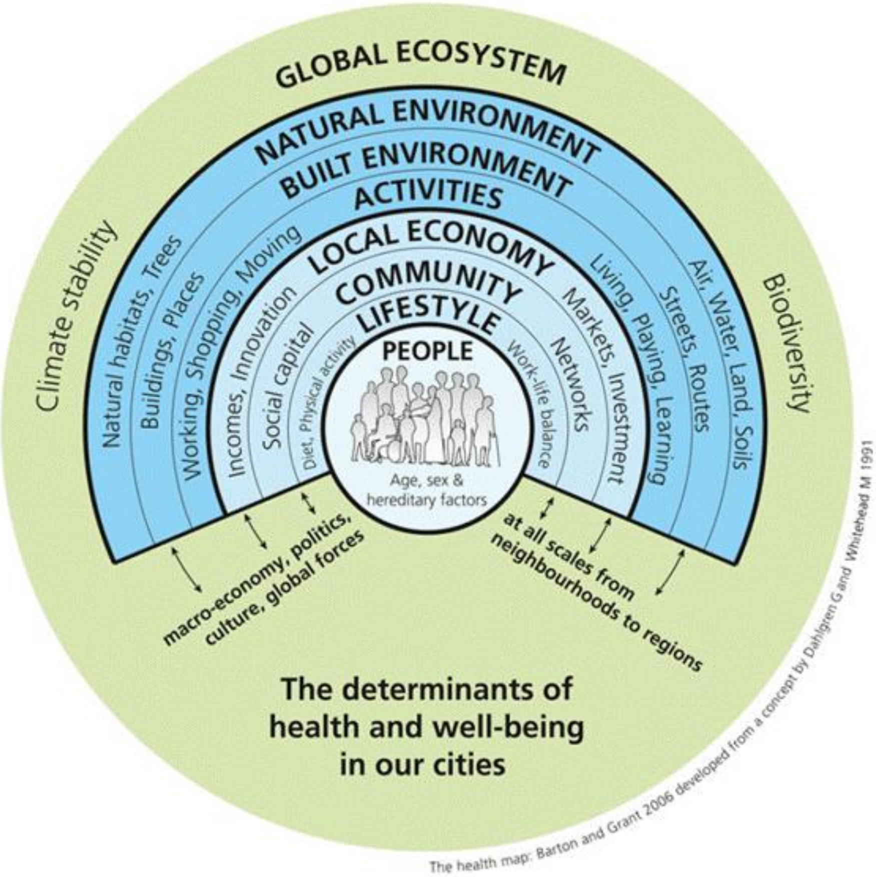
Consistent with these findings, earlier interventions aimed at increasing PA levels focused on individual behavioural change through population campaigns promoting daily activity (mainly through walking) which have been used for over 20 years in Australia with limited reach and short-term results [25-27]; Australians responded to the 1996 concept of moderate-intensity exercise with modest short-term increases in walking [27]. The limited success of individual behavioural change interventions led to the development of more sophisticated theoretical research frameworks.

Social-ecological framework

Social-ecological frameworks built on socio-cognitive theories by considering the way in which socioeconomic and environmental influences shape individual behaviours. In regards to this thesis, walking might be strongly inhibited by the environmental context in which it takes place, through actual and/or perceived physical and social neighbourhood barriers [43], which might override an individual’s motivation and intentions to be physically active. By enabling the simultaneous assessment of the individual-level differences in walking patterns as well as the environmental, social and structural differences between neighbourhoods [83,84], social-ecological frameworks reflect a more sophisticated and realistic representation of the influences on walking, and remain consistent with the social determinants of health [45,71].

Figure 2.1 depicts the complexity of the multiple levels of influence on the health of individuals living within the ecosystem on which they ultimately depend. These cultural, social, political, economic and environmental influences are determinants of health that shape and are shaped by spatial urban planning [70]. Predetermined inherited characteristics (gender, age and genetics) are placed at the core, while the additional spheres around it represent the individual-level and environmental-level influences. Most of these influences are modifiable, and interactions among levels can be multidirectional as well as cumulative in influencing health behaviours [85]. For instance, a new road changes the pattern of human activity in the form of travel behaviour and destinations. Activity, in turn, impacts the local natural environment (through air pollution), the global ecosystem (greenhouse emissions), the efficiency of the local economy, and residents’ lifestyle choices (the likelihood of walking or driving). Lifestyle changes might, in turn, impact the pattern of social networks [85].

Figure 2.1: Determinants of health and wellbeing in urban centres



Reproduced with permission from: Barton H, Grant M. 2013. Urban planning for healthy cities. Journal of Urban Health 90:129-141. Original figure was published as Barton H, Grant M. 2006. A health map for the local human habitat. The Journal for the Royal Society for the Promotion of Health 126:252-253. It was refined from Dahlgren G, Whitehead M (1991). “The main determinants of health” model, version accessible in: Dahlgren G, Whitehead M. 2006. European strategies for tackling social inequities in health: Levelling up part 2. Copenhagen: World Health Organization.

More relevant to this thesis, social-ecological frameworks do not assume that the same environment influences the walking patterns of all demographic groups in the same way [46]. This is directly applicable to the investigations of demographic groups predisposed to inactivity such as women and older adults, who might be more vulnerable to actual and perceived environmental influences compared to men and younger adults [43] due to their physical limitations (such as feeling unsafe and physically vulnerable when walking at night through a dark, deserted street) and/or as a result of functional and cognitive declines [49].

Social-ecological frameworks are operationalised through multilevel data collection methods (e.g. residents living within neighbourhoods), and require a complementary multilevel analytical approach to assess the independent or combined effects of a range of influences on a particular behaviour [86-88], such as walking.

Operationalising the social-ecological framework

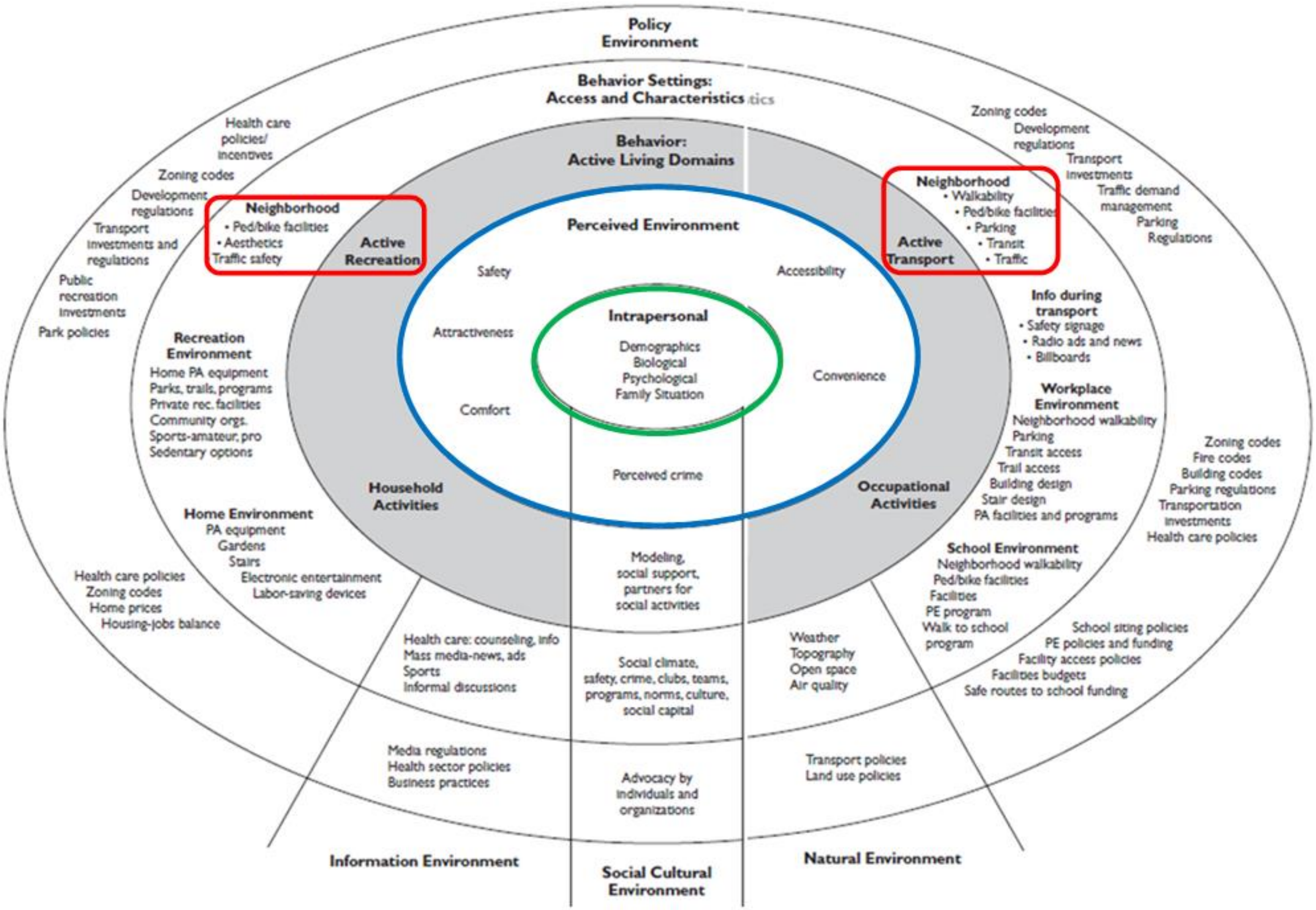
Social-ecological evidence is consistent with WHO's strategy of health in all policies and at all levels of government (local, city and regional), promoting equity in health, community participation and inter-sectoral cooperation [89], with the synergistic co-benefits of environmental sustainability, social justice and economic development [70].

Multilevel interventions targeted at both the individual and community levels are likely to have a broad and long-lasting reach in increasing and maintaining walking levels, [19] supporting the overarching aim of promoting active living and ageing communities. In a practical sense, campaigns focusing on modifying individual behaviours should be complemented with environmental interventions (such as improving the designs of neighbourhoods, transportation systems, and amenities) informed by social-ecological evidence [5,19,39,90-92].

The identification of physical and social environmental barriers to walking can support the achievement of the objectives stated within the earlier mentioned policy frameworks by making walking an easy and incidental choice rooted in life's daily activities for all demographic groups [19], regardless of their gender and age. The effects of such environmental interventions are likely to be large, effective, and long-lasting, and have the potential to reduce gender and age disparities in overall PA participation, as well as benefit the walking of other vulnerable demographic groups, such as children and disabled populations.

Active living and ageing research underpinned by social-ecological frameworks notes that different environmental correlates are associated with specific PA behaviors [61]. For instance, while the neighbourhood environment might influence both WfR and WfT, the latter shows stronger correlations with certain built environmental features [76,93,94], while WfR has been more related to the social environment [35,95]. Sallis and colleagues [19] developed a social-ecological framework to guide the investigation of facilitators and barriers to active living through environmental correlates specific to PA domains [5]. While the conceptualisation process is ongoing, partial progress has been made in measuring the impact of factors at every level of influence [19]. The focus of this research is on the active recreation and active transportation domains, highlighted in colour in Figure 2.2.

Figure 2.2: Social-ecological model: four domains of active living



Reproduced with permission from Sallis J, Cervero RB, Ascher W, Henderson KA, Kraft MK, Kerr J. 2006. An ecological approach to creating active living communities. Annu Rev Public Health 27:297-322.

2.2 PHYSICAL ACTIVITY AND WALKING

This section provides an overview of PA and related health benefits, with a focus on walking as the main outcome investigated in this thesis. An understanding of how walking is being measured facilitates the critical appraisal of studies examining the individual factors and environmental correlates and determinants associated with walking.

2.2.1 Physical activity: definition

PA refers to any bodily movement produced by the contraction of skeletal muscle, increasing its energy expenditure [96] (such as walking), which can be measured in kilocalories [97]. PA is categorised through its type (e.g., walking, cycling and swimming) and frequency (e.g., daily, weekly). The PA intensity (light, moderate, vigorous or moderate-to-vigorous physical activity) is estimated through Metabolic Equivalent of Task (MET), a physiological measure representing the energy cost of activities, with 1 MET[1] being the energy expended at rest[98]. PA is further categorised by domain, namely recreational, transport, occupational or domestic activity, as shown in Figure 2.2 [5].

2.2.2 The burden of physical inactivity

Physical inactivity refers to a regular insufficient activity level below the present physical activity recommendations detailed in Table 2.1 and remains a global health burden [9]. Research estimates that 31% of adults worldwide are physically inactive [8]. Physical inactivity is a risk factor contributing to the global burden of NCDs and mortality, representing 9% of premature mortality (over 5 million deaths) [9], and the fourth leading cause of death worldwide [10]. The worldwide ageing profile calls for improvements in the quality of life of older adults. PA surveillance has become a priority of public health in order to inform effective NCDs prevention programmes [8]. While international efforts to increase the PA of youth and adult populations have been documented, older adults have attracted less research interest, resulting in limited data on their PA patterns and adherence to PA guidelines [33].

The demographic distribution of the burden of physical inactivity

Sex is often described as a biological construct while gender is considered as a sociological construct [99]. However, for the purpose of this thesis, gender comprises the

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[1] The relative intensity of a given absolute rate of working is age dependent: the maximal aerobic power is at most 8 MET at 65 years, dropping to 5–6 MET at 85 years. Thus, the activities undertaken by a senior over a typical day can be divided into the following intensity categories: low (<3 MET); moderate (3–6 MET); and high (>6 MET) (Aoyagi et al., 2010).

interaction between biological and socio-environmental factors that influence health behaviour. There are biological reasons (in terms of biological structure, function and psychosocial development) for which women are less active than men [100]. However, individual characteristics such as gender and age are predetermined attributes nested within wider determinants of health, arising from social, environmental and economic conditions [73]. Gender and age disparities in PA participation are consistently observed across countries [8]. Reviews reveal that individuals become less active as they age [5], specially women, who are consistently less active than men across the life-span [6-8,100], particularly in leisure-time PA, measured both objectively and subjectively [33], although variation has been found across geographical settings [5,6,33,101,102].

Men and young adults consistently surpass women and older adults in frequency, duration and intensity of total PA. Results from the 2011-12 Australian Health Survey revealed sharp declines in the proportion of older adults meeting the recommended PA levels of 150 minutes per week, from 38% of 65–74 year olds to 25% of those aged 75 years and over [103]. This decline was also observed in the Australian Longitudinal Study on Women's Health (ALSWH), with 43% of women aged 70–75 years meeting PA guidelines (excluding domestic activities), compared with 25% at 82–87 years [104]. In Central Queensland, longitudinal analyses of the Active Australia Survey (AAS) data (N≥1,200 yearly), revealed that less than half (46.5%) of the population met the Australian PA recommendations, and this was particularly true for women and older people [105].

A decline in PA with age is consistently found in the literature, although is not well understood [106]. However, there seem to be critical periods of decline during the life-span, and this decline seems to vary by gender, type and intensity of the activity. Animal studies documented the age-related decline in many species, which suggest biological reasons [106].

Older women are often the most physically inactive of all demographic groups. A US study [107] noted the difference in self-reported levels of PA between men and women by age group was small at 18–29 years, moderate at 65–74 years and very large at over 75 years, suggesting that the gender gap in PA widens as people age. These findings were confirmed by objectively assessed PA data in several studies. Accelerometer data from British seniors [108] showed step-count declines with increasing age, with men achieving 754 more daily steps than women. Furthermore, 12-month pedometer and accelerometer data from a convenience sample of older Japanese [109] indicated that year-averaged daily step count was significantly greater in men than in women (1,700 more steps per day), and in the 65-74 year olds compared to the 75-83 year olds (2,000 more steps per day).

This evidence indicates the need for gender and age sensitised multilevel research that informs multilevel interventions that address the consistent disparities in overall PA participation among demographic groups.

2.2.3 Physical activity: health benefits

Epidemiologic research indicates that PA is an important modifiable behaviour in older adults for preventing and/or delaying morbidity and mortality from NCDs, including cardiovascular diseases, diabetes and certain cancers [110,111]. PA also improves physical function [11,112] and life expectancy [111].

Regular PA has been shown to prevent disability, [11] slow down physical function declines, [11,22,112] and protect against cognitive decline [113]. Evidence indicates that there is a dose-response relationship of PA, with greater benefits derived from increased frequency, intensity and duration of PA [110]. Vigorous PA shows the largest positive effects on overall health in preventing functional decline [112] and all-cause mortality regardless of gender and age [114]. Moving from a physically inactive state to regular moderate PA (such as walking) has also been shown to significantly reduce/postpone morbidity and all-cause mortality, [11,115-117], particularly among women [118]. These health benefits are also seen among individuals who became physically active comparatively later in life [119]. Furthermore, regular PA has been associated with a decrease in falls in older adults and greater functional capacity, which is associated with the capacity to live in the community and remain independent [120]. Therefore, public health and other socioeconomic gains arise from promoting planned or incidental PA as part of daily life [120].

2.2.4 Physical activity: recommendations

The *Global recommendations on physical activity for health* advises adults to be as physically active as their abilities and conditions allow them to, noting that increasing the duration and intensity of physical activities has additional health benefits [91]. Different combinations of moderate and vigorous intensity PA can be undertaken to meet these guidelines [121], which are summarised in Table 2.1. The *Australian physical activity guidelines* [122] reflect the global recommendations, leaving the choice of activity patterns at the discretion of individuals, based on their general health condition and age as follows:

- Adults aged 18-64 years should engage in either 150-300 minutes of moderate PA, or 75-150 minutes of vigorous PA, or an equivalent combination of both weekly, with additional muscle strengthening activities on at least 2 days per week.

- Adults aged 65 years and over should engage on at least 30 minutes of moderate intensity PA on most, preferably all, days.

Table 2.1: Global recommendations on physical activity for health

Age group	Global Recommendations on Physical Activity for Health [a]
Adults 18-64 years	• Adults aged 18-64 should do at least 150 minutes of moderate-intensity aerobic PA throughout the week, or do at least 75 minutes of vigorous-intensity aerobic PA throughout the week, or an equivalent combination of moderate- and vigorous-intensity activity. • Aerobic activity should be performed in bouts of at least 10 minutes duration. • For additional health benefits, adults should increase their moderate-intensity aerobic PA to 300 minutes per week, or engage in 150 minutes of vigorous-intensity aerobic PA per week, or an equivalent combination of moderate- and vigorous-intensity activity. • Muscle-strengthening activities should be performed involving major muscle groups on 2 or more days a week.
Adults 65 + years	• Adults aged 65 years and above should do at least 150 minutes of moderate-intensity aerobic PA throughout the week, or do at least 75 minutes of vigorous-intensity aerobic PA throughout the week, or an equivalent combination of moderate- and vigorous intensity activity. • Aerobic activity should be performed in bouts of at least 10 minutes duration. • For additional health benefits, adults aged 65 years and above should increase their moderate intensity aerobic PA to 300 minutes per week, or engage in 150 minutes of vigorous intensity aerobic PA per week, or an equivalent combination of moderate-and vigorous-intensity activity. • Adults of this age group with poor mobility should perform physical activity to enhance balance and prevent falls on 3 or more days per week. • Muscle-strengthening activities should be performed involving major muscle groups, on 2 or more days a week. • When adults of this age group cannot do the recommended amounts of PA due to health conditions, they should be as physically active as their abilities and conditions allow.

[a] Reproduced from: World Health Organization. 2010a. *Global recommendations on physical activity for health*.

2.2.5 Physical activity: measurement

This section provides an overview of the measurement of PA, of which walking is a key component. An understanding of the validity and reliability of the most commonly-used instruments measuring PA, and walking in particular, facilitates the critical appraisal of the relevant literature that follows.

The monitoring of population PA levels enables the assessment of progress over time towards meeting the PA recommendations outlined previously, and can inform the planning, implementation and evaluation of PA related interventions. While there are several methods to monitor population PA levels (e.g. direct observation, accelerometers, etc.), the most cost-effective is through representative self-reported surveys.

While physical inactivity is an international concern, the use of diverse PA measures in earlier research prevented international comparisons [123]. The International Physical Activity Questionnaire (IPAQ) was developed in the 1990s to monitor self-reported PA and facilitate international comparisons. Although the IPAQ instrument is not used in the analyses undertaken within this thesis, results from investigations using IPAQ are commonly reported, therefore this overview facilitates the critical appraisal of the relevant literature that follows. The IPAQ was evaluated in 12 countries, and has good reliability and validity compared with accelerometer measures [123] for monitoring population levels of PA among adults aged 18-65 years in diverse geographical settings. The development of IPAQ led to the Global Physical Activity Questionnaire (GPAQ), which enabled the national and international monitoring of PA levels.

The most commonly used tool to assess compliance with the PA recommendations in Australia is the Active Australia Survey (AAS), which collects data on the duration, frequency and intensity of PA types (such as walking or cycling) across different domains (including transport and recreation) in the previous week [105]. Previous AAS research has established its reliability [124] and validity against accelerometer measures [125], and thus, was recommended for Australian population-based research [126].

2.2.6 Walking as physical activity

Regular walking contributes to daily energy expenditure [96]. Since this thesis focuses on walking as the main behavioural outcome, this section discusses how walking is being measured in the literature, presents the walking recommendations for several demographic groups, and discusses the purposes for walking.

Activity recommendations highlight the importance of accumulated activity of moderate intensity [127]. Walking is a low-risk, moderate intensity activity, is practically and financially accessible for most demographic groups, and promotes social interactions [128]. Since it is relatively easy to incorporate into daily routines, walking is an essential component of strategies to promote PA in populations. Regular walking has been shown to reduce and/or postpone morbidity and mortality from NCDs [31,32]. Therefore, the active living and ageing literature has identified walking as the PA type most amenable to change in adults [129], particularly in the least active socio-demographic groups [130].

Several methodological issues arise when measuring walking patterns in populations. While self-reporting is the most common and cost-efficient method for capturing walking [93], it has limited accuracy, particularly in older adults, who might have difficulties with recalling the time spent walking for different purposes [109] and may be inclined to provide socially desirable answers, overestimating their walking levels [131]. A qualitative study noted that physically inactive seniors misperceived themselves as being active [24]. Furthermore, older adults might combine WfT with WfR within the same trip, and therefore, the differentiation between purpose of walking may be less clear in this demographic group [132].

On the other hand, objective measures (e.g. step-counting devices such as accelerometers and pedometers), which might assess walking more accurately in older adults [133], lack the contextual aspects of walking, such as its purpose and location [134]. Furthermore, PA monitors are placed on the hip, focusing on lower body activities, which excludes extra effort of upper body activities, such as walking uphill or carrying loads [33]. For instance, the activPAL activity monitor is a small lightweight device utilising accelerometer-derived information that assesses 24-hour PA patterns and has been validated in adults to estimate the time spent resting, standing, and stepping [135]. Ideally, however, walking is best assessed through a combined approach of objective and self-reported measures, although these studies are rare, due to the significant resources required to collect these data.

In operationalising the recommended PA guidelines through walking, 30 minutes of moderate-intensity PA in adults is equivalent to a brisk walk that accelerates the heart rate, or 3000-4000 steps at a minimum pace of 100 steps per minute, accumulated in at least 10 minutes sessions [121,136]. However, these steps should be taken additionally to some minimal level of PA below which individuals might be categorised as inactive [136].

While a recent review noted the limited existing evidence to inform a moderate intensity walking pace in healthy older adults for health benefits, an estimate of at least 3000 daily steps at a pace of 100 steps per minute has been derived as the equivalent to 30 mins of daily PA using the adults' threshold [137]. However, a linear dose-response relationship indicates that the more steps taken, the better for health. Physical health is better in older adults who spend at least 20 min/day of moderate intensity walking and a further >60 min of light activity per day [111]. Including all activities, it is recommended that healthy older adults take an equivalent of 7,000-10,000 steps/day [137].

Table 2.2 presents the estimated step ranges for different demographic groups. Healthy older adults average 2,000-9,000 steps/day, while those with disabilities/chronic diseases average 1,200-8,800 steps/day [137]. Most researchers interpret meeting the Global PA guidelines as walking for 150 mins or more per week, although variation exists across studies and in older adults as well as in approaches to measurement, which presents methodological challenges to metadata analyses [33].

Walking for 2-4 hrs weekly is achievable target for healthy individuals and communities, and can be integrated into daily activities as recreation or transport, making it a key PA type to target multilevel interventions [138]. Adult participation in walking is influenced by a combination of personal, socioeconomic and environmental factors [102], and the correlates of recreational walking are different to the those of transport walking [26]. Therefore, these two walking domains should be analysed separately [19].

Table 2.2: Recommended step range for different demographic groups

Description [a]	**Healthy adults (20-65 years)**	**Older adults (>65years)**	**Special populations** [b]
≥30 mins of daily PA [c]	3000–4000 steps	≥3000 steps [d]	_
Pace	≥100 steps/min	≥100 steps/min	_
Total daily steps	**Steps/day**	**Steps/day**	**Steps/day**
Highly active	12,500	_	_
Active	10,000–12,499	7,000-10,000	6,500-8,500 [e]
Somewhat active	7,500–9,999	_	_
Low active	5,000–7,499	_	_
Sedentary	<5,000	_	_

[a] Adapted from: "How many steps/day are enough?" by Tudor-Locke et al. [137,139], *Sports Medicine*, 34(1), 1-8.

[b] Includes individuals living with disability or chronic illnesses

[c] Adult public health guidelines "*promote ≥30 mins of moderate-intensity daily PA. This translates to 3000–4000 steps if they are: at least moderate in intensity (at a pace of ≥100 steps/min); accumulated in at least 10 mins sessions; and taken additionally to some minimal level of PA below which individuals might be classified as sedentary*" [136].

[d] While there is limited evidence to inform moderate intensity pace in older adults, multiplying the adult pace of ≥100 steps/min at the lowest intensity (3 METs) by the recommended 30 minutes of daily activity produces a guiding estimate of 3,000 steps [137].

[e] Estimate based on a single accelerometer study of patients in a cardiac rehabilitation program [137].

Walking for recreation

Walking for recreation (WfR) or leisure is a voluntary activity undertaken with the purpose of exercising or enjoying the scenery [19]. Recreational walking is the most common form of leisure-time PA in adults [140] and seniors [141]. Since it is usually undertaken outdoors, WfR is likely to be influenced by environmental attributes such as communitarian recreation areas (spaces) and facilities (places). Public open spaces provide opportunities for WfR at low or no cost, and should be inclusive and conducive of participation for all demographic groups [19]. Recreational walking is a component of active living and ageing, and is linked to sociocultural and safety-related factors. Therefore, investigation of correlates of WfR should incorporate constructs such as social cohesion and safety from crime [19].

Walking for transport

Walking for transport (WfT) is undertaken for the purpose of reaching a destination, such as work, shops or public transit [18]. Transport-related walking is mostly of an incidental nature, and it might be the only choice for individuals of low socio-economic position (SEP) who might not have access to other forms of transport [19]. Active transportation in the form of WfT has health benefits in preventing morbidity and mortality [11,115-118,142], and can increase PA levels in populations in an incidental and sustainable manner [143-145]. Environments that facilitate WfT have synergistic co-benefits across portfolios (such as health, transport, community and environment, through reduced traffic noise, pollution and congestion [144]), all of which support sustainable development [39].

Reviews from the transportation literature [40,41] conclude that the environment provides opportunities for individuals to engage in walking within their neighbourhoods, and these relationships seem to exist across different population subsets [146]. Since lack of time has been reported as a major barrier to PA [102], active incidental travel is a strategic way of incorporating walking into daily routines [18].

Context of walking

"If you plan cities for cars and traffic, you get cars and traffic. If you plan for people and places, you get people and places."

—Fred Kent, Project for Public Spaces

Walking generally occurs in public places, such as neighbourhoods, for transportation or recreational purposes [19] and different environmental correlates are associated with each walking purpose [61]. Fewer Australians meet the current PA guidelines (150 mins or more of weekly walking at moderate or brisk pace [91]) through WfT alone compared to WfR [61], and since WfT has stronger association with built environment features [65,94,147,148], modifying built environments to facilitate incidental WfT is a practical way to help Australians achieve the current PA guidelines.

The public health and the urban and transport literature indicate a link between an individual's health and wellbeing and the design and structure of urban living spaces [5,40,41]. Australian cities are mainly designed for vehicular transportation with separation of land uses, to the detriment of more active forms of transportation such as walking, cycling or public transport [28,37]. These urban forms are likely contributors to the declining PA levels of Australians [38]. Moreover, location of residence does not always reflect an individual's preference for active travel [149]. Transport has been identified as a determinant of health contributing to inequities in health behaviours and outcomes within –and between– cities, since the benefits of vehicular transportation are less accessible to low socioecomic populations whose only choice might be walking [39].

Walkability is defined as the extent to which a neighbourhood facilitates active living through walking from home to nearby destinations [55], and involves specific urban design forms. The walkability of urban neighbourhoods is a key element in designing active liveable communities [150]. *New Urbanism* is a movement promoting walkable neighbourhoods, scaled to pedestrians (400m radius/five minute walk), characterised by diversity of land-use, and greater residential density and street connectivity, as well as a well-defined high quality public space [151]. The degree to which neighbourhood features facilitate the active recreation and transportation of all demographic groups is reflected in the demographic diversity of its users (including vulnerable populations such as children, women, older adults and people with disabilities), as well as the quality of social interactions, and the desirability to live in it [152].

Living in walkable environments encourages active travel by providing opportunities that incorporate walking into daily activities [45] and it has been associated with increased walking and lower prevalence of overweight and obesity [149,153]. Walkable neighbourhoods also promote sustainable social, economic and environmental development by discouraging driving [154,155].

The approach of decreasing the reliance on private motorised transport by facilitating active transport [156] has been recommended to governments as a means of improving health outcomes, [157] while simultaneously addressing additional public concerns such as climate change, air pollutant emissions, fossil fuel dependency, traffic congestion and transport cost-effectiveness, otherwise termed as ‘co- benefits’ [158].

2.2.7 Summary of relevance to this thesis

The benefits of physical activity are well-established. However, populations are becoming increasingly inactive worldwide, and inactivity is responsible for a large burden of NCDs in the form of morbidity and mortality, with related socioeconomic costs. Promoting active living and ageing across the life-span is a cost-effective strategy to prevent disease, maintain independence in older age and improve the quality of life in populations. Recent active living and ageing research is underpinned by social-ecological frameworks incorporating more determinants at higher levels of influence in recognition of the complex relationship between individuals and their environmental context.

Overall PA levels (frequency, intensity and duration) are consistently lower among women and older adults, who seem to prefer walking over vigorous activities. For these populations predisposed to inactivity, walking is a low to moderate intensity exercise that can be easily integrated into daily routines. However, these demographic groups have attracted less research interest with resultant limited data on how environments can facilitate and maintain their walking patterns. Collectively, this information indicates a practical need for gender and age sensitised multilevel research that informs multilevel interventions to increase walking as a way of reducing the observed demographic disparities in overall PA participation.

This thesis responds to urgent calls for action at different government levels to reverse the increasing inactivity trends in populations by focusing on walking, because it is the most common PA type practiced by adults, particularly women and older adults. Since it usually takes place within neighbourhoods, for either transport or recreation, the design of neighbourhood features that facilitate walking presents an opportunity for promoting the active lifestyle of its residents, potentially improving their functional capacity and preventing or postponing morbidity and mortality from NCDs. Evidence from social-ecological frameworks indicates that the environmental correlates of WfR differ from those of WfT [19,26], and thus these two purposes for walking should be measured and analysed separately.

2.3 INDIVIDUAL PREDETERMINED ATTRIBUTES ASSOCIATED WITH WALKING

The following section provides a review of how walking patterns vary by gender and age to better understand the contribution of the neighbourhood social and built environment to these patterns. As previously mentioned, there are biological reasons for which women are less active than men [100], and the nature and type of preferred PA varies by gender and age: while higher proportions of vigorous PA have been observed in men and younger adults [8], walking as a low to moderate intensity activity remains the most prevalent form of PA in women [30] and older adults [29], who are predisposed to inactivity. Walking was the most common form of self-reported exercise in US seniors [159], although only 9.3% of men and 1.4% of women achieved adequate levels of walking for health benefits. Therefore, targeting sustainable increases in WfR and WfT for women and older adults has the potential to address the gender and age disparities in overall PA participation [8]. The following section describes how WfR and WfT are patterned by gender and age.

2.3.1 Gender and walking

Walking contributes more towards meeting the current PA guidelines in women than in men [61]. Previous research indicates that walking varies by gender; several multilevel studies using the IPAQ revealed that women were less likely to walk for transport compared to men in Australia [55], Sweden [52] and the US [53,54]. On the other hand, single-level studies of Australian [61] and Taiwanese adults [60], and multilevel studies of adults conducted in the US [47] and the Netherlands [59], observed that on average, women walked more for recreation than men. Only one multilevel study of Swedish adults noted that women walked less for recreation compared to men [52], reflecting perhaps cultural differences. Women in the US walked for recreation for shorter times and distances per session than men, although no gender differences were found in frequency of walking [159]. Perhaps women walk more for recreation because they spend more time in their neighbourhood, as they engage less in full-time employment [160]. Furthermore, women typically have more concerns about personal safety [7], especially at night [161], which is likely to influence their WfR [162]. In contrast, safety from crime seems to have either no impact [163] or an inverse effect [59] on men's WfR. This evidence suggests opportunities for gender-sensitised social environment interventions that address the gender disparity in overall PA participation [164] by facilitating WfR.

2.3.2 Age and walking

Previous research across geographical settings indicates that older adults walk less for transport [53,56-58,165] and more for recreation [35], compared to their younger counterparts, possibly reflecting retirement age activities [166]. Longitudinal analyses of older adults suggest that the time around retirement is a critical life-stage for promoting active ageing through walking, thereby decreasing sedentary behaviour. While PA generally declines with age, studies in Canada and Finland observed an increase in PA at retirement age (60-65 years) prior to a sharp decline in activity levels [127]. Post-retirement increases in leisure-time PA (about 2 hours per week of mainly walking) were observed in French adults [167]. In Australians adults, there were post-retirement decreases in passive and active transport, combined with increases in time spent watching television [168]. A longitudinal multilevel study of Australian adults [58] observed overall reductions in WfT as people aged, but the declines were steeper among those with low income and those who were retired. This body of evidence suggests that active transport within the work context in pre-retirement is not being replaced with active transport in other contexts (e.g. walking to the shops) in post-retirement [168]. Given that shopping is the most common reason for older adults leaving their homes [169], this body of evidence suggests a contextual opportunity for interventions around retirement age that increase and maintain incidental WfT.

2.3.3 Gender and age within the social-ecological framework of physical activity

Physical activity levels arise from the complex interaction among biological, environmental, and behavioural characteristics. However, factors associated with physical inactivity in women and older adults are currently poorly understood [33,170]. Research reveals that women and older adults are more likely to experience more individual and environmental barriers (perceived and objective) to PA and walking, compared to men and younger adults [3,23,24].

Apart from the biological reasons for which women are less active than men[100], the observed demographic differences in overall PA, and walking in particular, are likely to be determined by a gender effect across the life-span linked to individual-level inequalities in education, occupation, income, personal autonomy and entertainment [23], and environmental disadvantages are likely to exacerbate these inequalities. It has also been suggested that women might lack the social support required to adopt and sustain regular PA, and they might even be exposed to social messages indicating that PA is not a priority [23]. A multilevel study of Australian women revealed educational variation, with the less educated group being less likely to participate in both WfR and WfT. A combination of personal, social and environmental factors contributed to explaining lower levels of WfR among women with low education [171].

A complex range of social environment factors influences women's PA, particularly leisure-time PA, including social support networks and cultural gender role expectations within life transitions [23]. Traditional gender roles influence the type of PA men and women engage with; women perform more caregiving and domestic activities compared to men [23,62,172] and are often the primary carers of children, elders and disabled relatives, adding physical and psychological burdens to their lives [120,173]. Family, household and caregiving responsibilities present a key barrier for the discretionary time spent on PA (i.e. leisure-time PA) [23]. Evidence from the ALSWH indicates that adoption of women's traditional roles involving family relationships (such as moving to a live-in relationship, getting married, and becoming a mother) are strongly associated with decreases in PA levels [174]. In particular, having a child for the first time led to decreased PA levels over a 4-year follow-up period [174,175]. In a cross-sectional study [140], Irish men were twice as active in work and recreation-related activities, while women were three times more active in performing domestic tasks. These traditional gender roles strongly influenced the types and levels of regular PA engagement well into later life; a longitudinal study of British seniors [176] revealed that women had higher levels of indoor productive (domestic) activity while men had higher levels of outdoor activity. This body of evidence suggests that higher levels of social support might be required to encourage women to walk for recreation.

Both women –who commonly engage in part-time work [160]– and older adults, are more likely to be low income earners. This might make them particularly vulnerable to housing affordability issues, and might drive them to live in less desirable and connected neighbourhoods, restricting their mobility and neighbourhood life [29], which in turn, might affect their opportunities for social interactions [70]. Australian cities are becoming increasingly segregated by age and socioeconomic position (SEP), with unemployment rising and skill levels decreasing as distances increase from the city centre, resulting in a concentration of poverty and social disadvantage [72]. In 2011, 65% of Australians aged 65 years and over lived in major urban areas [177]. In the previous decade, there was a noticeable migration of this demographic group from the inner and middle city areas towards the outer areas [72], which tend to be less resourced in services and infrastructure, such as public transport [29]. Low-income groups are more likely to experience crime and disorder in their neighbourhoods, although WfT might be their only transport alternative, despite being more fearful [39,165,178].

2.3.4 Summary of relevance to this thesis

Previous multilevel research noted that different walking patterns vary depending on gender and age; compared to men and younger adults, women and older adults walk less for transport and more for recreation, and are likely to experience more individual and environmental barriers to walking. Women typically have more concerns about personal safety especially at night, which is likely to influence their WfR, while men's WfR does not seem affected by personal safety. This evidence suggests opportunities for environmental interventions to reduce the gender disparity in overall PA participation through WfR. On the other hand, longitudinal studies of walking patterns around retirement note abrupt drops in WfT and an increase in WfR in both men and women (possibly reflecting retirement age activities) prior to a sharp decline in total walking levels. The combination of these findings indicates a contextual opportunity for intervention around retirement age to increase and maintain WfT.

2.4 NEIGHBOURHOOD FEATURES ASSOCIATED WITH WALKING

> *"Whenever and wherever societies have flourished and prospered rather than stagnated and decayed, creative and workable cities have been at the core of the phenomenon. Decaying cities, declining economies, and mounting social troubles travel together. The combination is not coincidental."*
>
> — Jane Jacobs, The death and life of great American cities [179].

> *"A city that outdistances man's [women] walking powers is a trap for a man [women]."*
>
> — Toynbee AJ. A study of history. Vol 2: Oxford University Press; 1947.[180].

> *"A developed country is not a place where the poor have cars. It's where the rich use public transportation."*
>
> — Gustavo Petro, former Mayor of Bogotá, Colombia.

Understanding what it is about neighbourhoods that influences the walking patterns of its residents requires their characterisation into the social and physical features that might either facilitate or inhibit walking. This section presents a critical review of the literature on the contribution of the neighbourhood social and built environment features to gender and age differences in walking patterns.

Conceptualisation of neighbourhoods

The critical appraisal of neighbourhood influences on walking patterns requires an understanding of how the neighbourhood is conceptualised. Due to the absence of an agreed criteria for what constitutes a *neighbourhood* for research purposes, most literature has utilised administratively defined geographic boundaries [69,181]. In Australia, researchers have used Census Collection Districts (CCDs) [182], although recent developments enabled the study of smaller geographical areas, such as mesh blocks, which refers to the smallest geographical area defined by the Australian Bureau of Statistics [183]. Other ways of operationalising neighbourhoods include circular or network buffers within a 1600, 800 or 400m radius from a resident's home [93], while a 10-20 mins walk from home is the most frequently reported perceived neighbourhood definition[181]. It is important to note that different neighbourhood boundaries might have more or less relevance depending on the type of PA (transport vs recreational walking) and the demographic groups examined [184,185]. For instance, older adults might have a slower walking pace, and thus, the environment nearby their home might be more relevant for walking [43]. Studies investigating the relationship between urban design and walking revealed that the geographical scale chosen for measuring the environmental characteristics of neighbourhoods affects the strength of associations with walking patterns [186], suggesting that an increased correspondence between the environmental measure, the behaviour of interest and the setting in which the behaviour takes place is likely to produce stronger associations [44].

Measurement of neighbourhood features

Through exploring the features of environmentally diverse neighbourhoods (i.e. the qualitative and quantitative differences between residential areas), researchers can identify environmental barriers and facilitators of walking in populations. Neighbourhood features have been broadly categorised into social and built environment characteristics [69]. The quality of social environments is commonly assessed through proxy measures of individual perceptions (e.g. safety from crime, collected through surveys) aggregated at the neighbourhood level, while built environments have been characterised through perceptions and objective measures (e.g. perceived amount of destinations vs actual count of destinations).

Valid, reliable and standardised survey instruments are required to conceptualise neighbourhood environments and compare results across studies, populations and urban settings. The Neighbourhood Environment Walkability Scale (NEWS) is a valid and reliable instrument measuring the perceived social and built attributes believed to influence walking patterns [187] and the most commonly used questionnaire of its type internationally [181]. The NEWS is being used by several landmark studies, such as the International Physical Activity and the Environment Network (IPEN) Study, investigating the PA patterns of more than 13,000 adults from 12 countries for the purpose of informing evidence-based international and country-specific PA policies and interventions [188].

Studies investigating the degree to which perceived measures of neighbourhood features (collected through surveys of residents) overlap with objective environmental measures captured through Geographical Information Systems (GIS), revealed a mismatch of both perceptions and objective measures in regards to their impact on walking patterns [69,189], with environmental perceptions showing stronger associations with walking [148,181,189,190].

Features of the social and built neighbourhood environment are likely to influence the frequency, duration and intensity of walking patterns [191], and the perceived and objective correlates of WfR are different from those of WfT [43,49,192,193].

While results from the IPEN study suggest some consistency in the environmental associations with walking across cities [95], other multi-country studies suggest that environmental associations with walking might be site specific, imposing potential challenges for environmental recommendations [35]. However, countries, cities and neighbourhoods vary in their cultural and structural characteristics [36], and local governments shape neighbourhood environments through the planning, implementation, and delivery of services, infrastructure, and policies [45]. This evidence suggests that environmental interventions might be most effective in facilitating walking patterns when they are context specific.

Broader environmental associations with walking by demographic groups

This section provides a rationale for further scoping the literature review. Human-scale or micro-scale spatial features characterising pedestrian environments, (such as aesthetics, sidewalks, curbs, footpaths and recreational facilities) revealed stronger associations with leisure-time PA and WfR than with WfT [95,194-196]. High-quality micro-urban design features, such as public community spaces, facilitate walking and increase the likelihood of social interactions [150,197-200]. Consistent patterns across urban settings reveal stronger social environment associations with WfR for women, suggesting that they might be more sensitive to the social environment of neighbourhoods in regards to walking [164], particularly WfR [35,60]. Women typically have more concerns about personal safety [7], especially at night [161], which is likely to influence their WfR [162]. This evidence suggests a contextual opportunity for the identification of particular social environment interventions that promote active living while addressing the gender disparity in overall PA participation through planned increases in WfR [164].

On the other hand, the macro-scale spatial features of neighbourhoods (measured both subjectively and objectively) such as street and transportation networks and land development patterns, have been more frequently associated with transport-related PA and WfT in adults [76,93,147,201,202] compared with other types of PA [65,94,147,148], with some studies reporting null associations with WfR [93,186]. Built environment features are more likely to be associated with WfT in the elderly [76,203], who walk less for transport, on average, compared to their younger counterparts [53,56-58,165], suggesting that more supportive built environments might be required to facilitate the WfT of older adults. This evidence suggests a contextual opportunity for the identification of built environment interventions around retirement age that promote active ageing while addressing the age disparity in overall PA participation through incidental increases in WfT.

Based on this evidence, the review that follows reflects two distinct scopes: (1) the contribution of the social environment to gender differences in recreational walking; and (2) the contribution of the built environment to age differences in transport walking.

2.4.1 The social environment, gender and recreational walking

> *"The sum of such casual public contact at a local level –most of it fortuitous, most of it associated with errands, all of it metered by the person concerned and not thrust upon him (her) by anyone– is a feeling for the pubic identity of people, a web of public respect and trust, and a resource in time of personal or neighbourhood need."*
>
> —Jane Jacobs, The death and life of great American cities [179].

This section reviews the literature on the contribution of the neighbourhood social environment to gender differences in WfR. The social environment comprises residential features related to the social interactions among its residents, which are important in promoting healthy cohesive communities [204]. Social environment features are related to the liveability indicators which make a community desirable to live in [205]. Liveability indicators, in turn, align with the social determinants of health currently examined within social-ecological frameworks to inform healthy urban design and policy [45].

Measuring the social environment

The quality of social environments is usually assessed through proxy measures of individually perceived neighbourhood features, collected via surveys and aggregated at the neighbourhood-level, deriving average social characteristics of neighbourhoods [206]. These proxy measures range in sensitivity for capturing a neighbourhood's favourable (such as social capital/social cohesion or safety from crime) and unfavourable social features (such as neighbourhood physical disorder).

However, it is important to note that social environments can vary widely within –and between– cities, reflecting socioeconomic and structural developments. Likewise, self-reported perceptions of the same social environment (commonly captured through Likert scales) can also vary widely across individuals, reflecting demographic and cultural differences as well as walking preferences (referred to as scale perception bias), which could lead to inaccurate assumptions [207] and produce inconsistent results across geographical settings [181].

Research indicates that the social environment of neighbourhoods can significantly influence the walking patterns of residents [102,208]. The social environment can be conceptualised through neighbourhood-level perceptions of social cohesion, aesthetics/incivilities, and safety from crime, which tend to reflect area-level disadvantage [181]. Disadvantaged neighbourhoods, typically characterised by extreme levels of poverty, ethnic segregation and high urban crime rates like Chicago [209], have been shown to influence levels of exercise and WfR, with stronger effects seen in women, [210,211] indicating that women might be more sensitive to their neighbourhood social environment. Several multilevel studies have observed that gender is a potential modifier of the relationship between the social environment and WfR, with stronger environmental effects observed in women [35,47]. These findings suggest that more supportive social environments might be required, (particularly in disadvantaged neighbourhoods), to facilitate the WfR of women.

Social cohesion, gender and recreational walking

"The trust of a city street is formed over time from many, many little public sidewalk contacts... Most of it is ostensibly trivial but the sum is not trivial at all."

— Jane Jacobs, The death and life of great American cities [179]

"*Growth is inevitable and desirable, but destruction of community character is not. The question is not whether your part of the world is going to change. The question is how*."

—Edward T. McMahon, The Conservation Fund, Loudon 2001 Master Plan Steering Committee.

Social capital originates from those social relationships which facilitate the attainment of common specific goals [212]. Social cohesion is a measure of neighbourhood social capital, [213] and reflects the inclination of individuals within a community to collaborate with each other [214], which may be shared by other residents, referred to as neighbourhood cohesiveness [215]. A highly cohesive neighbourhood is one "*where residents, on average, report feeling a strong sense of community, report engaging in frequent acts of neighbouring, and are highly attracted to live in, and remain residents of the neighbourhood"* [215]. Research indicates that this sense of community makes residents feel safer, and is associated with better health outcomes [204,213,216]. A meta-analysis found a strong positive relationship between social capital, and self-reported health and mortality [212]. High-quality micro-urban design features facilitate walking and increase the likelihood of social interactions, contributing to social capital and community cohesion [150,197-200].

While a multilevel cross-sectional study found null associations between social cohesion and PA [206], other studies revealed positive associations between PA/walking and neighbourhood social cohesion/social capital[211,217-221]. Higher levels of recreational PA were observed among Canadian adults who rated their neighbourhoods more positively in regards to social connectedness [221]. However, the mechanism explaining the direct positive effects of social cohesion/social capital on PA remains unclear. Residents of neighbourhoods with high neighbourhood-level social capital reported being more physically active, [191] indicating that cohesive neighbourhoods might share health-related behaviours such as walking, [222] which might partly explain the effect of neighbourhood social capital on health. Trusting neighbours increased the likelihood of being active among US adults [223]. On the other hand, neighbourhoods might also produce social capital as consequence of residents being active and regular users of public spaces [191]. Individuals with less social contacts were more likely to report good health if they lived in high social capital neighbourhoods, suggesting that living in a highly connected neighbourhood might be an important protective factor for the health of its residents, particularly in unconnected individuals [224].

Despite inconsistent definitions and measurements of social cohesion/social capital across studies [212], there are indications that the health effects of neighbourhood social capital differ by gender, with stronger effects seen in women. A qualitative study of older Australian women noted social capital as an important factor in the way that neighbourhoods potentially influence their health, by maintaining their independence and social connections with their community [75]. Positive associations between social capital and self-rated health were found among women, but not among men in several studies [62,225], and a higher incidence of functional disability was found among older women with lower perceptions of social capital compared to men [226]. A multilevel study in Chicago noted that both social capital and neighbourhood disadvantage were significant correlates of PA, with stronger negative effects of neighbourhood deprivation (overriding household income) and low social capital observed in women [211], suggesting that women are more sensitive to their neighbourhood social environment in regards to overall PA.

Recreational walking has been positively associated with favourable social environments (characterised by interpersonal trust, norms of reciprocity and social cohesion) in Australian women; those reporting higher social participation had greater odds of WfR, and WfR in their neighbourhood (96% and 51% respectively) [217]. Nevertheless, the cross-sectional nature of this research limits conclusions about causality.

In conclusion, high neighbourhood social cohesion is likely to be facilitated by high quality micro-scale urban design features such as safe open public spaces. There are indications that social cohesion has a stronger effect in women's health and health behaviours, particularly in WfR, compared to men.

Perceptions of aesthetic/incivilities, gender and recreational walking

While perceptions of aesthetics and incivilities measure two difference constructs, these are related. Environmental aesthetics refers to the visually appealing features of an environment, which can be natural or man-made [187], while incivilities capture the perceived neighbourhood physical disorder, typically assessed through the presence of vandalism/graffiti/rubbish or litter [206]; and/or disturbance/noise/antisocial behaviour by neighbours or youngsters [227].

Favourable neighbourhood aesthetics show strong associations with leisure-time PA and WfR [95,194-196], whilst less perceived incivilities has previously been associated with increased PA levels in older Australians [206].

Analyses from the IPEN study revealed curvilinear associations of aesthetics with WfR, although these associations were not consistent across countries [95]. Another multi-country study using NEWS and IPAQ noted that gender was a significant moderator in the curvilinear relationship of WfR with aesthetics, with women showing stronger and different shaped associations than men [35].

Safety from crime, gender and recreational walking

"This is something everyone knows: A well-used city street is apt to be a safe street. A deserted city street is apt to be unsafe."

—Jane Jacobs, The death and life of great American cities [179].

In environmental studies, safety from crime is commonly measured through individual perceptions of crime and safety aggregated at the neighbourhood level. Large international studies using standardised data collecting tools (NEWS and IPAQ) from environmentally diverse cities across geographical locations reveal some discrepancies. The IPEN study observed that perceived safety from crime was linearly associated with WfR (decision to walk, frequency and duration) across twelve countries [95], which seems to indicate that similar environmental attributes are associated with WfR internationally. However, findings from another multi-country study noted between-sites variation in perception of safety from crime, which was predictive of less WfR in Belgium and the US, and more WfR in Australia [35].

The mostly cross-sectional evidence linking perceived safety from crime with walking is inconsistent; some cross-sectional studies find a positive association of perceived safety from crime with adults' PA [206], self-reported walking [163,181,228], and WfR [171,229], including a meta-analysis [181], while others find no statistically significant association [194,230], as does a meta-analysis [146]. These inconsistent findings could be partly attributed to the use of Likert scales (commonly used to capture perceptions of safety from crime), which are subject to perception bias (reflecting demographic, interpersonal and cross-cultural preferences), leading to inaccurate assumptions [207].

However, these associations seem more consistent in vulnerable populations perceiving themselves to be physically vulnerable to crime (such as women and older adults) [39], suggesting that these demographic groups are more sensitive to their environments in regards to WfR. Gender was a significant moderator in the linear relationships of WfR with perceived safety from crime in a multi-country study, with women showing stronger associations than men [35].

There are marked gender differences in perceptions of neighbourhood safety; women typically have more concerns about personal safety [7], especially at night [161], which is likely to influence their walking [162]. Adult Canadian women were more likely to state that crime made it unsafe to walk, [231] while older Australian women were less likely to report feeling safe to walk [208]. Women in the US were more likely to walk for exercise if they perceived their neighbourhood as being safe [232]. British women who reported feeling unsafe to walk in their neighbourhood during the day were 47% less likely to report at least 15 mins of weekly walking than women who felt safer. In contrast, neighbourhood safety seems to have either no impact [163] or an inverse effect [47,59] on men's WfR.

Residing in a neighbourhood perceived as unsafe at night is a likely barrier to women's regular walking, particularly for those women living in disadvantaged neighbourhoods. Adult women were more likely than men to perceive their neighbourhood as unsafe to walk at night [233]. Additionally, US women reporting feeling unsafe at night took significantly fewer steps per day (4,302 versus 5,178) [232].

It is likely that social cohesion is a mediator between perception of safety from crime and walking. For instance, integration into social networks may protect residents from the negative effects of high perception of crime [234]. High perception of crime might also restrict an individual's ability to develop social connections, increasing social isolation [235].

In conclusion, women seem more affected by perceptions of safety from crime than men, and that influences their walking patterns, particularly WfR and at night time.

Summary of relevance to this thesis

Previous research has focused on analysing and reporting the average neighbourhood effects of gender differences in WfR, implicitly assuming that neighbourhoods affect the WfR of men and women similarly. Although there are indications that the social environment might differentially impact the WfR of women compared to men, and women might require more supportive social environments to walk for recreation, no study was found that investigated whether these average effects vary across neighbourhoods.

This body of evidence indicates an opportunity to assess whether neighbourhood environments have a similar or different influence on the WfR of men and women, with an emphasis on identifying specific social environment features that could explain these gender differences in WfR across neighbourhoods. Such research could inform social environment interventions that promote WfR everywhere for everyone, particularly women, who are predisposed to inactivity, ultimately addressing the gender disparity in overall PA participation.

2.4.2 The built environment, age and transport walking

> *"Automobiles are often conveniently tagged as the villains responsible for the ills of cities and the disappointments and futilities of city planning. But the destructive effect of automobiles are much less a cause than a symptom of our incompetence at city building".*
>
> — Jane Jacobs, The death and life of great American cities [179].

This section reviews the literature on the contribution of the neighbourhood environment to age differences in WfT. Active living and ageing research can inform the planning or retrofitting of current pedestrian infrastructure to increase incidental WfT in populations [26]. The built environment comprises the neighbourhood's physical features which are either natural (i.e. topography or climate) or man-made (i.e. streets and destinations). Research on the impact of the neighbourhood built environment on the WfT of residents has been guided by social-ecological frameworks [236].

The development of macro-scale spatial features of neighbourhoods (i.e. street and transportation networks and land development patterns) is typically guided by regional and city planning guidelines. Both objective and perceived macro-scale features have consistently been associated with transport-related PA and WfT in adults [65,94,147,148] and older adults [76].

Measuring the built environment

Built environments can be measured through objective or perceived neighbourhood level variables (e.g. count of destinations vs perceived amount of destinations aggregated at the neighbourhood level). However, while some studies of adults noted that both the objectively and subjectively measured built environment follows the same direction in facilitating or hindering walking [55,134], other studies describe a mismatch between objective and subjective environmental appraisals, more common among older adults, with environmental perceptions showing stronger associations with walking [148,201,237]. However, the understanding of the underlying reasons for such misperceptions is limited [238]. A study of Canadian adults suggest that the objectively measured built environment might moderate associations between built environment perceptions and WfT within the neighbourhood [239].

The most common method for the objective characterisation of the built environment is through application of Geographical Information Systems (GIS) software, enabling the overlaying of built environment measures on survey data [93]. Most studies investigating the influences of the built environment on walking focus on three main components which characterises pedestrian friendly or walkable neighbourhoods. These are: residential density (residential units per area of residential use); street connectivity (count of grid-like pattern of streets); and land-use mix. Adult [93] and senior [76,203] residents living in communities with greater density and connectivity, and a more diverse land-use consistently report higher rates of WfT than low-density, poorly connected, and single land-use neighbourhoods [41].

Emerging research uses a combination of these built environmental characteristics, measured through walkability indexes [93], usually incorporating residential density, street connectivity and land use mix. Walkable built environments (objectively and subjectively measured) have been found in cross-sectional and longitudinal studies to be positively associated with walking, physical activity and some health outcomes [240-245].

Furthermore, the geographical scale chosen for measuring the objective built environment influences the strength of associations with WfT, with a 15 mins walk from home being the most predictive of walking, and the weakest at the CCD scale [186].

Built environment, older adults and transport walking

Environmental ageing theories suggest that, as individuals age and their mobility, physical and cognitive functioning and social contacts decline, they might become more dependent on their neighbourhood's services and amenities, [49] increasing their sensitivity to the environment [236]. Thus, a poorly designed community is likely to limit mobility and independence in older adults. Several qualitative studies indicate that a decrease in walking in older age is a complex mix of psychosocial factors, neighbourhood factors and functional limitation [24,166,192]. Thus, it is important to further investigate these associations through both qualitative and quantitative methods.

A recent systematic review and meta-analysis of the impact of the neighbourhood built environment in older adults [76] concluded that self-reported WfT was positively associated with objective and perceived built environment characteristics, including residential density, street connectivity and land-use mix, among other less commonly explored pedestrian-friendly features. A few studies have explored the role of age as a moderator in the relationship between the perceived built environment and WfT [64,65,246], with two investigations observing that neighbourhoods with mixed land use may delay the decline in WfT across time [64,65], indicating that more supportive built environments might be required to encourage older adults to walk for transport [247].

Residential density, age and transport walking

"The presence of great numbers of people gathered together in cities should not only be frankly accepted as a physical fact... they should also be enjoyed as an asset and their presence celebrated"

—Jane Jacobs, The death and life of great American cities [179].

Residential density refers to the number of dwellings per area of residential use. Evidence consistently indicates that residents of communities characterised by higher density walk more for transport than those living in low-density, poorly connected neighbourhoods [41]. Living in a high density neighbourhood was associated with increased WfT in US adults [54]. In older adults, a recent systematic review and meta-analysis of the influence of built environments [76] concluded that WfT was positively associated with both objective and perceived residential density. Perception of greater residential density was associated with walking for daily errands/walking for commuting in older Japanese [194].

Street connectivity, age and transport walking

"Streets and their sidewalks —the main public places of a city— are its most vital organs."

"...frequent streets and short blocks are valuable because of the fabric of intricate cross-use that they permit among the users of a city neighbourhood."

— Jane Jacobs, The death and life of great American cities [179].

Greater connectivity, measured through counts of street intersections, provides additional choices to reach specific destinations as well as a shorter route between origin and destination. A review of longitudinal studies [193] concluded that greater street connectivity is a determinant of transport-related PA, while other reviews [5,41,193] suggest it is a consistent correlate of WfT. Street connectivity has been positively associated with WfT in Australian adults [195]. In older adults, a recent systematic review and meta-analysis of the influence of built environments [76] concluded that WfT was positively associated with both objective and perceived street connectivity.

Land-use mix/destinations, age and transport walking

"Intricate minglings of different uses in cities are not a form of chaos. On the contrary, they represent a complex and highly developed form of order."

—Jane Jacobs, The death and life of great American cities [179].

"The segregation of land uses undermines the potential for integrated neighbourhoods, thriving local facilities and local social capital."

— Urban planning for healthy cities [70].

Land-use mix is usually derived as a balance of land-use codes (e.g. retail, office, social service, recreation and residential) representing an even distribution of types of land-use. Varying the combination of land uses in the land-use mix calculation has shown to impact the strength of relationships with different types and amounts of walking [248].

A review summarising the findings from the transportation and urban design literature on factors related to WfT [41] concluded that residents from neighbourhoods with more diversity of land uses consistently reported higher rates of WfT than single land-use neighbourhoods. In older adults, a recent systematic review and meta-analysis of the influence of built environments [76] concluded that WfT was positively associated with both objective and perceived land-use mix. High perception of land-use mix was also associated with walking for daily errands/walking for commuting in older Japanese [194].

Two studies observed that neighbourhoods with mixed land-use may delay the decline in WfT in older adults across time [64,65], suggesting that more land-use mix might be required to encourage older adults to walk for transport [247].

Furthermore, the quantity (and possible the quality) of destinations near home also seems to influence WfT. Having destinations within walking distance from home was the strongest correlate of transportation activity for both perceived and objective land-use measures in US adults [189]. Perception of proximity to non-residential destinations such as shops and recreational facilities was associated with WfT in US seniors [65]. In Dutch adults aged 50-70 years, the odds of never walking to the shops or work was significantly higher for residents of neighbourhoods with a decreased proximity to shops [249]. Built environment characteristics supporting more efficient walking and places to walk, were associated with increased WfT in US seniors [250]. The evidence indicating that the presence of destinations is important for WfT is, therefore, very relevant to older adults, particularly since shopping seems their most common reason for leaving their home [169].

Walkability indices

"Get walkability right and so much of the rest will follow"

—Jeff Speck, Walkable City, 2012

Walkability refers to a neighbourhood's capacity to support active living and ageing through the pedestrian friendly design of urban spaces so that residents can walk from home to nearby destinations [251]. Reflecting on the idea that the key elements through which built environments are measured (namely, residential density, street connectivity and land-use mix) are likely to have a combined effect on walking, particularly on WfT, researchers have collated these elements into a single walkability index measure providing an indication of how friendly a neighbourhood is for pedestrians [52], which can be subjectively or objectively measured [187].

A walkability index developed by US researchers [252] has been adapted for use in Australia using a Geographic Information System (GIS) which measures density, street connectivity, slope and hilliness, residential/retail mix and green space [253]. Methods of defining, weighting and scoring these elements of walkability are currently being developed. Cross sectional travel survey data of US adults showed that walking was consistently higher in adults living in objectively measured walkable neighbourhoods with the highest density, connectivity and the greatest mix of land uses [254]. Several recent reviews noted a strong positive relationship between WfT and neighbourhood walkability in adults [5,41,94], including a review of longitudinal studies [193].

Open-source objective measures of neighbourhood built environments that supports walking and access to transportation include Walk Score®, Transit Score® and Street-smart Walk Score®. The Walk Score, a published website originally developed for property market purposes, is increasingly becoming a reliable, valid, convenient and inexpensive option for estimating the number of nearby walkable destinations and amenities in active living research [255,256].

Objectively measured walkability has been strongly associated with WfT. Researchers using Walk Score observed the benefits of having nearby destinations; Australian adults living in more walkable areas were more likely to walk for transport for 30 min per day [257]. A strong independent positive association between weekly frequency of WfT and the objectively derived neighbourhood walkability index was noted in Australian adults, independent of neighbourhood self-selection [55]. A US study across regions and time [258] observed that senior residents of objectively measured more walkable neighbourhoods reported 22-40 more minutes per week of active transport compared to those in less walkable neighbourhoods, irrespective of neighbourhood income. Interestingly, reported active transport levels were similar for the most mobility-impaired adults living in walkable neighbourhoods and the less mobility-impaired adults living in less walkable neighbourhoods [258], suggesting that favourable environments can compensate for individual barriers to walking.

Perceptions of walkability have also been associated with WfT and showed a stronger relationship than objective measures. High perceived neighbourhood walkability was associated with 41.5 more minutes per week of WfT in Swedish adults, compared with 35 more minutes for objective neighbourhood walkability, suggesting the importance of measuring both [148].

Some cross-sectional studies have observed a mismatch between objective and perceived walkability, more commonly among older adults, with perceptions having stronger effects on walking [148,201,237]. Australian adults who lived in a neighbourhood with low street connectivity or land-mix use, but perceived it as being more connected or with more mixed use, were more likely to walk locally for transport. However, no evidence of this relationship was observed for WfR [201], suggesting that WfR might be more influenced by social environment factors. Australian adults living in more walkable neighbourhoods (characterised by land-mix use and dwelling/retail density), who perceived it as low had a significant decline in WfR over four years, compared with those with matched perceptions [237]. This suggests that interventions should not only create pedestrian-friendly environments but also target residents' perceptions.

Findings from a cross-sectional study of adults from Australia, Belgium and the US [57] using NEWS observed a non-linear positive association between perceived walkability (composed of perceived residential density, land use mix access, proximity of destinations and aesthetics) and self-reported WfT, and this association was gender (stronger in women) and country specific (strongest in Seattle, weakest in Adelaide and in Ghent, the association weakened at higher levels of walkability).

Summary of relevance to this thesis

Previous research has focused on analysing and reporting the average neighbourhood effects of age differences in WfT. Although there are indications that the built environment might differentially impact the WfT of older adults compared to younger adults, and older adults might require more supportive built environments to walk for transport, no study to date has investigated the possibility that the same neighbourhood environment has a differential impact on the WfT of younger and older adults.

This body of evidence suggests an opportunity to assess whether neighbourhood environments have a similar or different influence on the WfT of younger and older adults, with an emphasis on identifying the specific built environment features that could explain these age differences in WfT across neighbourhoods. Such research could inform built environment interventions that promote WfT everywhere for everyone, particularly older adults, who are predisposed to inactivity, ultimately addressing the age disparity in overall PA participation.

2.5 OVERALL CONCLUSIONS AND RESEACH QUESTIONS

Research indicates that regular PA is important in preventing chronic diseases, disabilities and functional decline in older age, as well as related health care costs to society. However, people become less active as they age, particularly women, who are consistently less active than their male counterparts throughout the life-span, possibly reflecting traditional gender roles as well as cumulative inequalities in parenting, occupation and income across the life-course. Governments around the world are facing the challenge of maintaining populations active as they age by implementing interventions that reverse the increasing inactivity trends.

Walking is the most prevalent and preferred type of PA in women and older adults, and it usually takes place within neighbourhoods, for either transport or recreation. Active living and ageing research was initially underpinned by theoretical approaches to understanding individual behaviours within socio-cognitive frameworks, and have evolved to include environmental influences within social-ecological frameworks, representing a more holistic and realistic reflection of influences on health behaviours. The social-ecological framework incorporates a range of individual, social and built environment factors which act in combination to motivate, support and provide opportunities for walking. Social-ecological frameworks are operationalised through multilevel research, which can inform a comprehensive public health strategy that would have the greatest long-term impact in shifting behaviours, namely increasing walking patterns in populations.

Emerging evidence from social-ecological frameworks indicates that the context in which people live influences their walking patterns, and the environmental correlates of WfR (which is usually planned) are different from those of WfT (which is mainly incidental). Therefore, these walking domains should be measured and analysed separately. Furthermore, the identification of neighbourhood features that encourage walking, particularly in those predisposed to inactivity, presents an opportunity for contextual interventions which promote active living and ageing communities and address gender and age disparities in overall PA participation.

Over the past twenty years, active living and ageing researchers have reported the average neighbourhood effects of gender and age differences in walking patterns, observing that women and older adults walk less for transport and more for recreation than their counterparts. By reporting only the average effects, these studies overlook the possibility that these gender and age differences in walking patterns might vary depending on the neighbourhood context. Emerging research indicates marked gender and age differences in the experience of –and engagement with– local environments regarding walking patterns, with women and older adults facing more individual and environmental barriers (perceived and objective) to walking, which possibly makes them more sensitive to their environments.

It is then plausible that neighbourhoods with favourable walking environments might generate minimal or no gender or age differences in walking, because they are more conducive to walking for everyone, whereas large gender and age disparities in walking might be observed in socially fractured neighbourhoods with poor walking infrastructure. However, evidence about how the social and built environment of a neighbourhood differentially influences the walking of men and women, and younger and older adults, is very limited. The investigation of the contextual factors that explain gender and age differences in walking patterns across neighbourhoods enables the contextual tailoring of interventions that increase walking everywhere for everyone, particularly for those demographic groups predisposed to inactivity, informing a more efficient use of limited resources available for interventions.

There are clear gender differences in perceptions of the social neighbourhood environment. Women seem more responsive to social cohesion and have more concerns about personal safety, especially at night, which is likely to influence their WfR. In contrast, neighbourhood safety seems to have either no impact or an inverse effect on men's WfR. While women seem to walk more for recreation on average compared to men, it is not clear whether this average neighbourhood effect applies to every specific neighbourhood. The combined evidence suggests that more supportive social environments might be required to encourage women to walk for recreation. Therefore, an opportunity exists for the identification of social environment interventions that promote active living through WfR while addressing the gender disparity in overall PA participation.

Objective and perceived greater density, street connectivity and land-use mix (which characterises pedestrian-friendly neighbourhoods), are consistent correlates of WfT in adults, particularly in older adults, who walk less for transport on average, compared to their younger counterparts. However, it is not yet clear whether this average applies to every neighbourhood. The combined evidence suggests that more supportive built environments might be required to encourage older adults to walk for transport, and provides a contextual opportunity for the identification of built environment interventions around retirement age that promote incidental WfT while addressing the age disparity in overall PA participation.

This comprehensive literature review supports further research underpinned by a social-ecological framework to inform neighbourhood interventions that increase walking patterns in all demographic groups everywhere. This thesis was developed to address the identified literature gap through a set of innovative research questions corresponding to the following three investigations increasing in complexity. These studies were designed to:

1. Assess whether gender and age differences in recreational and transport walking vary significantly across neighbourhoods (Study 1, titled *Gender and age differences in walking for transport and recreation: are the relationships the same in all neighbourhoods?*);
2. Investigate the contribution of the social environment to explaining gender differences in WfR across neighbourhoods (Study 2, titled *Do differences in social environments explain gender differences in recreational walking across neighbourhoods?*); and
3. Investigate the contribution of built environments to explaining age differences in WfT across neighbourhoods (Study 3, titled *Do differences in built environments explain age differences in transport walking across neighbourhoods?*).

These questions were addressed by using data from a relevant multilevel survey and applying the corresponding statistical multilevel analyses, the details of which are further described in the following methodology chapter. The evidence produced can inform neighbourhood interventions that increase walking everywhere for everyone, supporting active living and ageing communities that address the gender and age disparities in overall PA participation, making them more healthy, liveable and equitable.

Chapter 3: Methodology and Design

This chapter describes the methodology undertaken within this thesis. Part one describes the sampling design, selection methods and data collection instruments used by How Areas in Brisbane Influence HealTh and AcTivity (HABITAT), the multilevel study underpinned by the social-ecological framework used in this thesis. Part two presents the methodology undertaken by the Candidate, including more specific information on relevant measures as well as the analytic and statistical modelling strategy undertaken to address the innovative research questions arising from the literature review.

3.1 METHODOLOGY FOR DATA COLLECTION: THE HABITAT STUDY

This section describes the data source used by this thesis, including its design, sampling and data collection. HABITAT is a longitudinal (2007–2016) population-based study of physical activity (PA) change in adults aged 40–65 years at baseline, which enables the investigation of correlates and determinants of PA.

3.1.1 Background and context

Brisbane is the third largest city (after Sydney and Melbourne) in Australia; a high income country with well-established welfare provisions [36]. Brisbane has a medium density urban environment, with a population of 1.2 million in 2015 [259], characterised by low crime rates and managed by a single City Council [260] that shapes neighbourhood environments through the planning, implementation, and delivery of services, infrastructure, and policies [45]. Brisbane's urban environment is currently under pressure to accommodate population increases (1.4% growth from 2014 to 2015) [259] from internal migration of residents attracted by employment in the expanding tourist industry and the lower cost of living compared to other Australian cities [261].

In Central Queensland, results from the Active Australia Survey (AAS) indicated that from 2002 to 2008, less than half (46.5%) of the population met the Australian PA recommendations, and this was particularly true for women and older people [105]. Men surpassed women in frequency, duration and intensity of overall PA, and higher proportions of younger people met the guidelines compared to older people. Walking was the most frequently reported PA, representing about 60% of total PA. While men and young people reported more moderate and vigorous PA, women and older adults reported more walking [105].

These findings indicate an opportunity for environmental interventions that address the gender and age disparities in overall PA [105] through increases in walking.

HABITAT is a longitudinal multilevel study designed to examine the ways that mid to older adults adopt, maintain and cease PA (including recreational and transport walking) in Brisbane. Since it incorporates a range of multilevel correlates and determinants of PA within a social-ecological framework, it enables the simultaneous investigation of the relative contribution of individual and environmental influences (barriers and facilitators) on recreational and transport walking.

For these reasons, HABITAT is ideally placed to address the research questions posited by this thesis, which investigates the environmental factors that promote active living and ageing communities. HABITAT involved a cohort of 11,035 Brisbane residents aged 40-65 years at baseline (2007), nested within 200 Brisbane neighbourhoods [87]. This thesis used HABITAT data collected in 2007 (Wave 1) and 2009 (Wave 2) from two components: a population-based observational study and a neighbourhood Geographic Information System (GIS) study. The following sections describe these components in detail.

3.1.2 The population-based observational study: sampling design and selection methods

HABITAT used a longitudinal two-stage probability sampling design to randomly select neighbourhoods (Stage 1) and then randomly select residents (Stage 2) living within those neighbourhoods, as explained below. The HABITAT Study received ethical clearance from the Queensland University of Technology Human Research Ethics Committee (Ref. No. 3967H & 1300000161) (Appendix B).

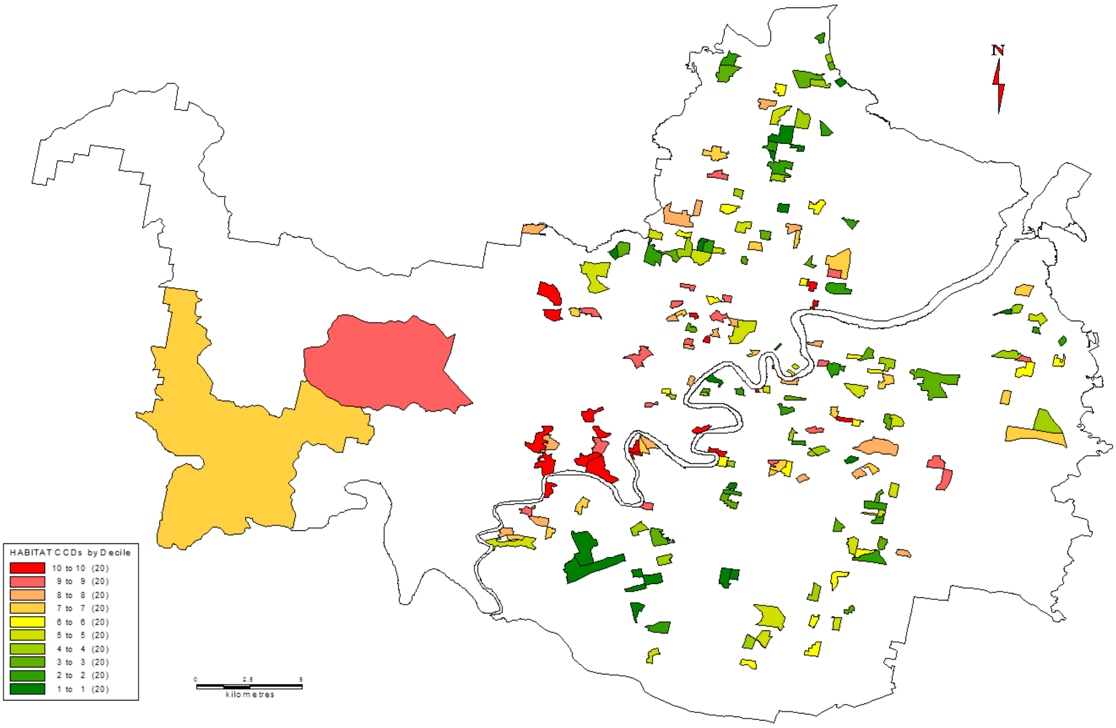
Random selection of neighbourhoods (Stage 1)

The primary area-level unit-of-analysis for the HABITAT Study is the Census Collection District (CCD). When Wave 1 of data were collected in 2007, CCDs were the smallest administrative units used by the Australian Bureau of Statistics (ABS) to collect census data. In urban centres such as Brisbane, an average of 200 private dwellings is contained within each CCD, which is considered relatively homogeneous in regards to socioeconomic features. Since the CCD area is likely to have significance for their residents [58], the terms CCD and 'neighbourhood' are used interchangeably in this thesis.

In Stage 1 of the sampling, 1,625 CCDs in Brisbane were ranked into deciles using the ABS' Index of Relative Socioeconomic Disadvantage (IRSD) and 20 CCDs were randomly selected from each decile, producing a stratified sample of 200 CCDs or 'neighbourhoods' [262]. Each of the 200 CCDs was assigned an IRSD score reflecting the area's overall level of disadvantage measured on the basis of 17 variables that capture a wide range of socioeconomic attributes, including education, occupation, income, unemployment, household structure, and household tenure among others [182].

The geographical scope of HABITAT is presented in Figure 3.1, with the dark green coloured areas depicting the 20 most disadvantaged neighbourhoods, while the red areas represent the 20 most advantaged neighbourhoods.

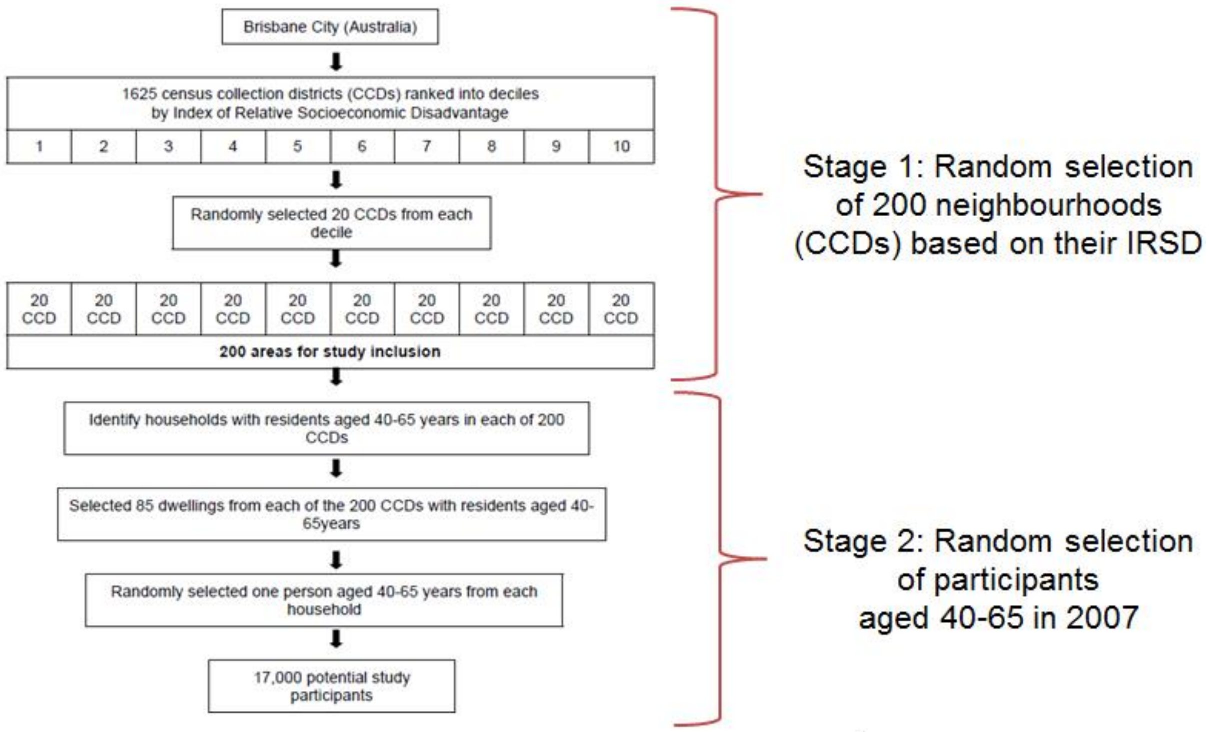
Figure 3.1: HABITAT sampled neighbourhoods within Brisbane



Random selection of participants (Stage 2)

Stage 2 of the sampling involved the selection of residents based on demographic characteristics from each pre-selected neighbourhood. The Australian Electoral Commission's electoral roll data were used to identify all households in each of the selected 200 CCDs that had at least one person aged 40-65 years in March 2007 (in Australia voting is compulsory for all persons aged 18 years and over). Using a systematic probability without replacement proportional-to-size sampling method, an average of 85 households, each containing at least one individual aged 40-65 years, was sampled from each CCD. Finally, a randomly selection of potential participants was undertaken among those aged 40-65 from each of 17,000 households (85 x 200) [87]. An overview of the two-stage HABITAT sampling procedure is presented in Figure 3.2.

Figure 3.2: Overview of sampling procedure for the HABITAT Study [2]



3.1.3 Data collection

Mailed survey

A structured self-administered questionnaire was mailed to selected participants every two years from May 2007 up to 2013, then a three year gap to 2016. A mail-survey method developed by Dillman [263] was undertaken, whereby advertisements about HABITAT were published in newspapers a month prior to the mailing of the baseline questionnaires in 2007. Potential participants receive a personalised letter in May of each data collection year advising them of the upcoming questionnaire in the week that followed, noting the relevance of participating, along with a pre-addressed and pre-paid reply envelope for its return. A postcard was mailed to the whole sample a week later thanking individuals who returned their survey, and reminding others to return it. Personalised reminder letters and replacement questionnaires were sent to all non-respondents seven weeks post-initial mail-out.

The questionnaire included items assessing sociodemographic characteristics, the type and duration of physical activity in the previous week (WfR, WfT, moderate and vigorous activity, cycling for transport, recreational activities), sedentary behaviour, perceptions of neighbourhood features (social cohesion, incivilities, safety from crime), social support,

[2] Adapted with permission from: 87. Burton NW, Haynes M, Wilson LA, et al. HABITAT: A longitudinal multilevel study of physical activity change in mid-aged adults. *BMC Public Health.* 2009;9:76.

activity-related cognitions (attitudes, efficacy, barriers, motivation) and overall health status [87]. An overview of HABITAT data by collection year is presented in Table 3.1 located at the end of this chapter.

Clinical sub-study

HABITAT also includes a clinical sub-study conducted in 2014 using global positioning satellite (GPS) capabilities and Actigraph GT3X+ accelerometers, which provided an objective assessment of timing, distance and use of different types of mobility. This thesis used HABITAT data collected at baseline (2007) and at Wave 2 (2009), which do not match the accelerometer data collected in 2014. Therefore, the accelerometer data was not incorporated in the analyses for this thesis.

Response rates

After excluding out-of-scope respondents (i.e. those deceased, not residing at the address or unable to participate for health-related reasons) the response rate was 68.4% in 2007 (11,035 valid responses from 16,127 eligible and contactable respondents) and 72.6% (7,866/10,837) in 2009. The baseline HABITAT sample (2007) was broadly representative of the targeted population, although those living in disadvantaged areas, blue-collar employees, and those who did not attain a post-school educational qualification were slightly underrepresented [262].

3.1.4 The Neighbourhood Geographic Information Systems study

A detailed objectively-measured area-level database was compiled for each of the HABITAT neighbourhoods or CCDs using a MapInfo Geographic Information Systems (GIS) from a range of sources, including the Brisbane City Council, National Resources and Water, Energex (electricity supplier), Queensland Transport, the Bureau of Meteorology, online databases (such as the white pages telephone directory) and environmental assessments [87]. Data comprised an extensive array of objectively measured features, from which residential density, street connectivity and land-use mix were derived. The GIS software enabled the overlaying of these physical environment measures on survey data, as undertaken in similar studies [93].

3.2 METHODOLOGY USED IN THIS THESIS

This section outlines detailed information on measures relevant to this thesis as well as the analytic and statistical modelling strategy undertaken to address the research questions posited by this thesis. A literature review (presented in Chapter 2) concluded that multilevel neighbourhood-based studies to date have mainly reported the average neighbourhood effects of gender and age differences in walking patterns, overlooking the possibility that these individual-level relationships vary across neighbourhoods.

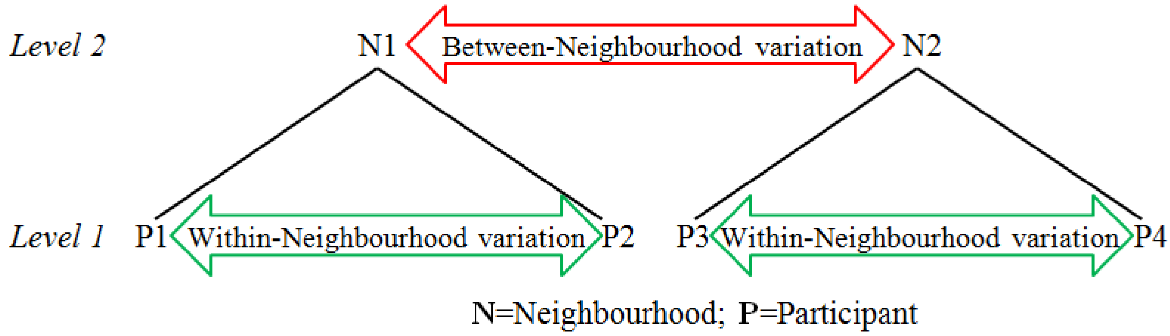
Three quantitative multilevel cross-sectional analyses of data from the HABITAT Study (underpinned by a social-ecological framework) were undertaken increasing in complexity, corresponding to the following three investigations:

1. *Gender and age differences in walking for transport and recreation: are the relationships the same in all neighbourhoods?*
2. *Do differences in social environments explain gender differences in recreational walking across neighbourhoods?*
3. *Do differences in built environments explain age differences in transport walking across neighbourhoods?*

The demonstration of a contextual effect requires a multilevel study design in which individuals are nested within different geographical and social contexts, in this case, neighbourhoods, and HABITAT provided the ideal dataset to assess the research questions posited by this thesis.

HABITAT's stratified sampling structure resulted in a hierarchical data structure (Figure 3.3) enabling multilevel statistical modelling to explore within –and between– neighbourhood variation in ecological exposures. This thesis focuses on the investigation of variability of environmental exposures across neighbourhoods after adjusting for individual-level compositional variables. Studies 1-3 comprised cross-sectional multilevel analyses of participants (at level 1) nested within neighbourhoods (at level 2). Study 1 assessed whether relationships between gender and walking, and age and walking, varied across neighbourhoods; Study 2 investigated the relative contribution of the social environment to explaining the gender differences in WfR observed across neighbourhoods; and Study 3 investigated the relative contribution of the built environment to explaining the age differences in WfT observed across neighbourhoods.

Figure 3.3: HABITAT hierarchical data structure



Study 1 and 2 used data from the 2009 HABITAT collection (Wave 2), comprising 7,866 residents aged 42-68 years (72.6% response rate), because both studies had WfR as a main outcome, which was not collected at baseline. For Study 3 investigating WfT, the 2007 HABITAT collection (Wave 1) was utilised providing a larger sample of 11,035 residents aged 40-65 years (68.4% response rate) [262].

3.2.1 Variables used in this thesis

Table 3.2 (presented at the end of this Chapter) provides detailed information on the measures used in this thesis, as well as their treatment for analytical purposes. The following section provides a justification for the relevant variables used in this thesis.

Outcome variables: walking for recreation and walking for transport

The outcome variables for this thesis were self-reported minutes of WfR (Study 1 and 2) and WfT (Study 1 and 3) in the previous week, as collected by HABITAT and outlined below.

- *Walking for Recreation (WfR):* recreational walking was measured using a single question asking participants to report the total time (converted to minutes) spent walking for recreation, leisure or exercise in the previous week. This question was a HABITAT specific question based on the one used in the Active Australia Survey which asked 'What do you estimate was the total time that you spent walking in this way in the last week?', which has demonstrated reliability [124] and validity against accelerometer measures [125], and has been recommended for Australian population-based research [126].
- *Walking for Transport (WfT):* transport walking was measured using a single question that asked participants to report the total time (converted to minutes) spent WfT (i.e. travelling to and from work, to do errands, or to go from place to place) in the

previous week. Respondents were instructed to exclude any time walking for exercise or recreation when answering this question.

The WfR and WfT variables were positively-skewed and included outlier values, which were top-coded to 840 minutes as recommended [264], equivalent to a maximum of two hours of walking per day. Several analytical approaches were explored to model the outcome variable, each considered with its inherent advantages and disadvantages. The exploratory analyses of the WfR and WfT variables in the 2007 and 2009 analytic samples (presented in Table 3.3 at the end of this Chapter, with 28% of the Study 2 sample reporting 0 mins of WfR in the previous week, while 65% of the Study 3 sample reported 0 mins of WfT) favoured their final treatment as categorical variables, revealing several discrete groups in each of the study samples considered:

- In Study 1, minutes of WfR and WfT were categorised into: none (0 mins – reference group); low (1-59 mins); moderate (60-149 mins); and high (150 mins+). Multinomial models can be fitted as ordered or unordered. While the multinomial walking outcome might have been more appropriately analysed as an ordered variable (which assumes an order between the categories more vs less minutes of walking) rather than no inherent ordering (e.g. religious belief), the ordered multinomial logit model can only handle explanatory variables which are attributes of choices and becomes problematic when explanatory variables are attributes of individuals. Therefore, the unordered multinomial logit model, which can handle explanatory variables which are attributes of either individuals or choices [265], was chosen for Study 1.
- In Study 2, minutes of WfR were categorised into none (0 mins – reference group) and any (1-840 mins).
- In Study 3, minutes of WfT were categorised into none (0 mins – reference group) and any (1-840 mins).

A multinomial outcome with four walking categories was modelled in Study 1. Consistent with Study 1, the outcome variable was modelled using three and four walking categories, but caused issues with model convergence due to small cell sizes in Studies 2 and 3, which incorporated more sophisticated statistical analyses and predictors than Study 1. Since the results did not seem to change the final interpretation of the statistical models, it was decided that a more parsimonious approach (a binomial walking outcome) would better fit the models in Studies 2 and 3 to progress these investigations.

Level 1 attributes: gender and age

The main attributes for analyses were gender and age as described below. The reference categories for these variables were selected so that the odds ratios were, as often as possible, greater than 1.

- *Gender:* male (reference group) and female. Gender was used as the main predictor in Study 1 & 2; and as a covariate in Study 3.
- *Age:* participants were asked for their date of birth, from which a year of age was derived for the data collection year. Age was considered as a:
    - main predictor in Study 1, categorised as: 42-46 (reference group); 47-51; 52-56; 57-61 and 62-68 years;
    - continuous covariate in Study 2, ranging from 42-67 years; and
    - main predictor in Study 3, categorised as: 40-48 (reference group); 49-57; and 58-65 years.

Level 2 exposures: neighbourhood social environment

The social environment was conceptualised through measures of individual perceptions of social cohesion, incivilities, and safety from crime aggregated to the neighbourhood (or CCD) level. These area-level exposures are the most commonly used social environment factors in neighbourhood-based research assessing WfR [5,76,95,181]. Further details on these variables, which were cleaned and prepared for the analyses by the Candidate, are presented in Table 3.2 at the end of this Chapter.

- *Perception of social cohesion:* participants were asked to respond to eight Likert-type items, ranging from strongly disagree to strongly agree, which measured perceptions of neighbourliness, trust in neighbours, shared values, and friendships and relationships with neighbours. The items closely reflect those used by the Buckner Social Cohesion Scale [215], an individual-level variable assessed by an 18-item instrument with acceptable reliability [266] (for comparability purposes, the Buckner Social Cohesion Scale has been reproduced in Table 3.2). The items were submitted to a Principal Components Analysis (PCA) with Varimax rotation and combined to form a weighted linear scale (Cronbach's alpha = 0.85).
- *Perception of incivilities:* this was assessed using two Likert-type items that asked participants about the presence of litter or rubbish, and graffiti in the neighbourhood. The items have acceptable reliability [267] and the resultant PCA scale had a Cronbach's alpha 0.63.

- *Perceptions of safety from crime:* participants responded to six Likert-type items that asked about the level of crime in the neighbourhood, whether the neighbourhood was a safe place for adults to walk during the day and at night, and if children were safe in the neighbourhood. The items were adapted for the Australian population from the Neighbourhood Environment Walkability Scale [268], which has acceptable reliability [187,267]. The PCA scale created from these items had a Cronbach's alpha of 0.80.

For analytic purposes, as the focus of this study was on whether different social environments (i.e. an ecologic exposure) influenced gender differences in WfR across neighbourhoods, neighbourhood-level perceptions of social cohesion, crime and safety, and incivilities were derived using a mean scaled score for each of the 200 neighbourhoods.

An Empirical Bayes Exchangeable (EBE) estimation method was applied to the neighbourhood social environment exposures in the analyses. This method is based on the independence assumption where random effects are regarded as exchangeable (i.e. assumes neighbourhoods to be exchangeable in borrowing strength). This estimation method is superior to a mean aggregated score previously used in studies of the social environment [217-220] (such as the Ordinary Least Squares (OLS) estimator, which relies solely on the information from each neighbourhood in estimating that neighbourhood's latent variable [269]), as it produces a mean neighbourhood social environment score that not only accounts for the number of participants per neighbourhood, but also the variability of the exposure within and between neighbourhoods [269]. Spatial dependence was not considered due to the sparsity of neighbourhoods included in the study throughout the Brisbane area.

Calculation of the EBE estimate involved four steps [269] reported in an earlier HABITAT study co-authored by the Candidate [270] as follows:

1. creating a mean score of the exposure for each neighbourhood ($\bar{Y}_{.j}$);
2. using an ANOVA model of the exposure, fitted using maximum likelihood to obtain estimates of the between –and within– neighbourhood variance. This was then used to obtain an estimate of the reliability of the exposure estimate $\hat{\lambda}_{Ej}$ for each neighbourhood, using Equation 1, where $\hat{\tau}_E$ is the between-neighbourhood variance, $\hat{\sigma}_e^2$ the within-neighbourhood variance, and n_j the number of informants within the neighbourhood;
3. estimating the exposure intercept $\hat{\gamma}_E$; and
4. calculating the EBE estimate using Equation 2

Equation 1:

$$\hat{\lambda}_{Ej} = \frac{\hat{\tau}_E}{(\hat{\tau}_E + \frac{\hat{\sigma}_e^2}{n_j})}$$

Equation 2:

$$\hat{\beta}_{EBEj} = \hat{\gamma}_E + \hat{\lambda}_{Ej}(\bar{Y}_{.j-}\hat{\gamma}_E)$$

A previously used approach considering social environment exposures as continuous measures in the statistical analyses [271] was replicated to ensure comparability between studies as recommended [181]. Therefore, the average effects can be interpreted as the likelihood of WfR for every 1 standard deviation (SD) unit increase in social environment. The social environment measures were correlated (Pearson correlation r=0.44-0.76, p<0.001) within the 200 HABITAT neighbourhoods, thus each measure was modelled separately.

Level 2 exposures: objectively measured built environment

The built environment of neighbourhoods was conceptualised through contextual variables derived from data provided by the Brisbane City Council (the local government responsible for the geographical area covered by the HABITAT Study) and MapInfo StreetPro [272] using the Geographical Information Systems (GIS) software, which enabled the overlaying of physical environment measures on survey data [93].

Area-level exposures (residential density, street connectivity and land-use mix) are the most commonly used built environment factors in neighbourhood studies assessing WfT [5,76,95,181]. As recommended to ensure comparability between studies [181,273], continuous spatial measures of the built environment were developed by the former HABITAT data manager for each of the 200 HABITAT neighbourhoods, or CCDs, using ArcMap [274] and prepared and analysed by the Candidate. Further details about these variables are presented in Table 3.2 at the end of this Chapter.

- *Residential density* was estimated by calculating the number of dwellings per hectare of residential land within the CCD in which the participant resided at the time of data collection. For ease of interpretability, the residential density was divided by 5, such that the coefficient could be interpreted as the likelihood of WfT for a 5 dwelling increase. Following transformation, the density across the 200 CCDs ranged from 0.04 to 28.85, with a mean of 3.87 (SD 3.05).
- *Street connectivity* was measured through a count of the number of four-way or more intersections within each of the CCDs. The number of four-way intersections across the 200 CCDs ranged from 0 to 12, with a mean of 2.5 (SD 2.3).

- *Land-use mix* was derived as the balance of five land-use codes (retail, office, social service, recreation and residential) that quantified the proportion of land area within a CCD using an entropy equation described previously elsewhere [253]. This entropy score ranged from 0 to 1, with 0 representing complete homogeneity of land use within the CCD, and 1 indicating an even distribution of the five types of land use. For ease of interpretability, the land-use mix variable was multiplied by 10, so that the coefficient could be interpreted as a 10% increase in land-use mix. Following transformation, entropy scores ranged from 0.91 to 7.96 across the 200 CCDs, with a mean of 3.46 (SD 1.49).

Further details about the environmental exposures as well as the corresponding collection instruments are presented in Table 3.2 at the end of this Chapter.

As mentioned in Chapter 2, in many studies, the built environment features used in this thesis (density, land use mix, and street connectivity) are combined into a single measure of walkability or walkability index. It should be noted that a walkability index combining residential density, street connectivity and land-use mix was developed by the Candidate and analysed as an environmental explanatory variable in Study 3. However, this walkability measure had limited explanatory potential compared with the individual measures of residential density, street connectivity and land-use mix, perhaps due to the direction of association being in opposite direction for land-use mix. Therefore, it was decided to only report the results of each environmental measure independently assessed.

Covariates

Covariates considered in these investigations were identified from the literature review (in Chapter 2), and are further described below as well as in Table 3.2.

- Study 1 did not include any covariates, as the intention was to assess whether the gender and age differences in WfR and WfT varied across neighbourhoods.
- Covariates for Study 2 included age, socioeconomic position, residential self-selection, and neighbourhood disadvantage.
- Covariates for Study 3 included gender, socioeconomic position, residential self-selection, and neighbourhood disadvantage.

Socio-economic position comprised education, occupation and income in categories as described in detail in Table 3.2 at the end of this Chapter.

Residential self-selection: self-selection into neighbourhoods is likely to produce an overestimation of the impact of environmental features on walking patterns [93]. Adjustment for residential self-selection (which is rare among cross-sectional neighbourhood studies [93,181]), ensures more reliable estimates of the influence of environmental exposures on walking patterns by accounting for individual-level bias (a regular recreational walker might select a residence which facilitates their WfR), and controlled –to a certain extent– for reverse causation [54,69,93,181]. HABITAT collected residential attitudes at each wave, which enabled the adjustment of residential self-selection in the analyses. Participants were asked to respond on a five-item Likert scale in 2007, ranging from ‘not at all important’ to ‘very important’ on a number of statements regarding ‘How important were the following reasons in your decision to move to your current suburb?’ Principal components analysis (PCA) with Varimax rotation identified three factors whose items had loadings of 0.50 or above, as recommended (Matsunaga 2015), subsequently described as:

1. ‘destinations’ (three items, composed of ‘ease of walking to places’; ‘closeness to public transport’ and ‘wanted to live close to shops’; Cronbach’s alpha: Study 2 and 3 = 0.80);
2. ‘nature’ (three items, composed of ‘near to green-space or bushland’; ‘closeness to open space (e.g. parks)’ and ‘closeness to recreation facilities’; Cronbach’s alpha: Study 2 and 3 = 0.78): and
3. ‘family’ (two items, composed of ‘closeness to schools’ and ‘closeness to childcare’; Cronbach’s alpha: Study 2= 0.61; Study 3=0.62). The Cronbach’s alpha for family’ differed between studies as they reflected different analytic samples collected at different waves.

Neighbourhood disadvantage: each of the 200 HABITAT neighbourhoods was assigned a socioeconomic score using the Australian Bureau of Statistics’ Index of Relative Socioeconomic Disadvantage (IRSD) calculated using 2001 census data derived by the ABS using Principal Components Analysis [182]. The Index reflects each area’s overall level of disadvantage based on 17 socioeconomic attributes, including education, occupation, income, unemployment, and household tenure. For each time period of interest, the calculated IRSD value from the regression trend line was generated, and weighted according to its proximity to the nearest ABS census. The average of the calculated IRSDs for each point was derived for the HABITAT neighbourhoods in which they occurred. The IRSD scores from the HABITAT neighbourhoods were then quantised as percentiles, relative to all of Brisbane [87] ranging from 1-100, with lower scores denoting more disadvantaged neighbourhoods.

Handling of missing records

The samples included 11,035 participants aged 40-65 years in 2007 (Study 3) and 7,866 participants aged 42-68 years in 2009 (Study 1 and 2) living within 200 neighbourhoods in Brisbane, Australia.

Although participants who moved from their original neighbourhood at baseline (2007) to another address in 2009 (movers) would have provide useful insights, they were excluded from the analyses in Study 1 and 2. The baseline HABITAT data had an average of 85 individuals per neighbourhood or CCD [87]. In Wave 2, most movers changed their place of residence to a CCD where only they resided from the HABITAT sample, or outside the HABITAT catchment area (which meant that no environmental exposures would have been available for them). Furthermore, including movers in the data analyses would have caused additional problems with models converging due to the small cell size per neighbourhood. Therefore, movers, as well as those who were a different respondent from baseline, were excluded from the analytical samples.

Those records missing for the outcome variables in Study 1 accounted for 3.7% for the WfT sample and 2.8% for the WfR sample of the remaining eligible participants. Those records missing for education, residential self-selection and outcome variables accounted for 6.9% of the remaining eligible participants in Study 2; and 6.2% in Study 3.

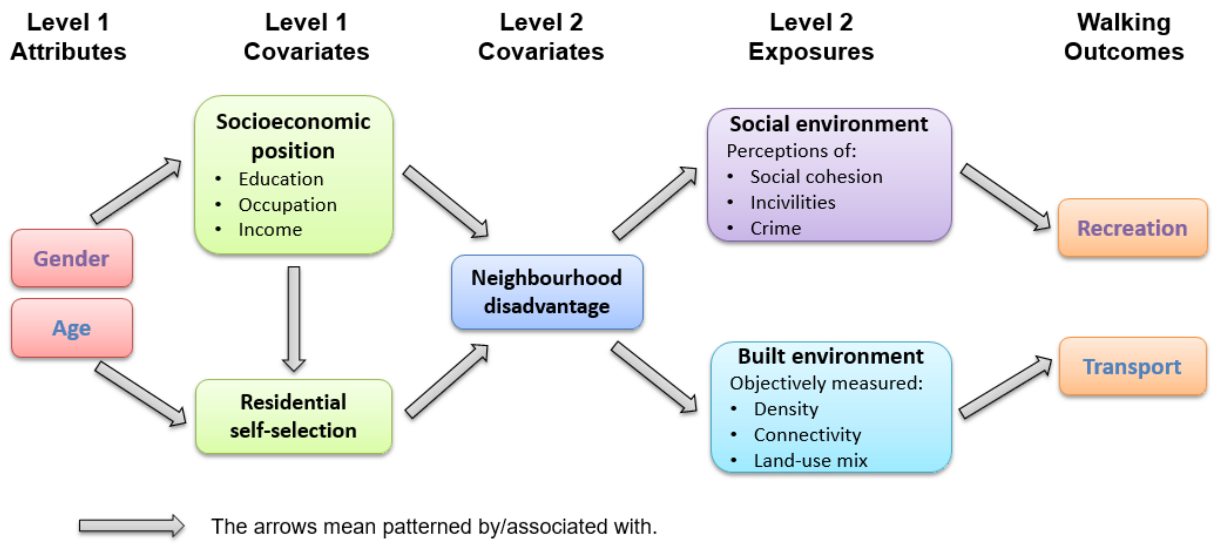
A listwise deletion (where an entire record is excluded from analysis if any single value is missing) was applied to missing records –rather than applying multiple imputation methods– based on the following rationale:

- the missing data approached the recommended 5% threshold for imputation [275];
- sensitivity analyses revealed that the first wave of HABITAT was broadly representative of the targeted population [262];
- efficiency gains offered by applying imputation methods (which add another layer of measurement error to the data) are often minor in large samples [276]; and
- the analytic samples (7,004 for WfT and 7,069 for WfR within 200 CCDs in Study 1; 6,643 in Study 2 and 10,350 in Study 3) remained large enough to address the research questions.

3.2.2 Analytic strategy

Social-ecological frameworks use corresponding multilevel data collection methods (e.g. residents nested within neighbourhoods) which require a complementary multilevel analytical approach. The analytic strategy was informed by a literature review (Chapter 2) postulating relationships between gender, age, the neighbourhood social and built environments and walking patterns (WfR and WfT), adjusted for potential covariates: socioeconomic position (education, occupation and income), residential self-selection and neighbourhood disadvantage. These relationships, depicted in Figure 3.4 within their corresponding level and treatment, informed the analytical steps undertaken to address the research questions.

Figure 3.4: Analytical framework for this thesis



The research questions outlined in Section 3.2 were tested by applying the corresponding analytical steps outlined in Table 3.4 at the end of this Chapter.

3.2.3 Statistical modelling strategy

Multilevel data are complemented by multilevel statistical modelling enabling the simultaneous analyses of individual and contextual-level factors, which facilitates the investigation of several types of relationships (e.g. within-neighbourhood and between-neighbourhood variation) to assess the independent or combined effects of potential correlates on walking patterns [86-88]. The multilevel nature of the HABITAT Study enabled the fitting of multilevel statistical models that investigated how contextual factors (social and built environment exposures) impact on individual-level relationships (gender and WfR, and age and WfT). The separate specification of individual and neighbourhood characteristics enabled the contextual variables to explain gender and age differences in walking patterns across neighbourhoods, after adjustment of individual-level compositional variables.

The multilevel analytical approach is consistent with the social-ecological framework underpinning the HABITAT Study [87] and added predictive power, description and precision to the understanding of neighbourhood effects [86]. Table 3.4 (presented at the end of this Chapter) summarises the three investigations undertaken within this thesis.

HABITAT data were prepared in Stata v.14.1 [277]. To determine the strength and pattern of the relationship between each of the neighbourhood exposures and walking patterns, multilevel analyses in the form of separate two-level Markov chain Monte Carlo (MCMC) multinomial (Studies 1) and binomial (Study 2 and 3) logit models were run in *MLwiN* v.2.36 [278], which is the software of choice for multilevel modelling due to its fast computations [279].

The development of MCMC methods enabled Bayesian models to be fitted, making it possible to compute large hierarchical models that require integrations over hundreds of unknown parameters, where prior distributions for the model parameters are specified. By default, *MLwiN* sets diffuse priors which can be used to approximate maximum likelihood estimation. *MLwiN* enables a multilevel Bayesian analysis using MCMC based on a combination of Gibbs sampling and Metropolis-Hastings sampling [280], both examples of MCMC sampling.

In contrast, quasi-likelihood approximations such as those implemented in Iterative Generalised Least Squares (IGLS) may produce estimates biased towards zero in certain circumstances, particularly when data are sparse [281]. Furthermore, bootstrapping (a statistical method that relies on random sampling with replacement which increases accuracy to sample estimates) was considered. However, unless the underlying distribution is not heavy tailed, bootstrapping on the sample mean when the underlying population lacks a finite variance will stop the bootstrap distribution from converging to the same limit as the sample mean, making confidence intervals on the basis of a MCMC simulation of the bootstrap misleading [282].

Taking all this into consideration, in Study 1, a two-level random intercept MCMC multinomial logit models (first-order marginal quasi-likelihood base estimates, burn-in=500, chain=50,000) were fitted to determine the average neighbourhood effects in the relationship between gender, age and the combined gender/age variable and levels of WfT and WfR.

However, model convergence became an issue with three and four categories for the outcome variable in Study 2 and 3, (which incorporated more sophisticated statistical analyses and predictors than Study 1) due to small cell size. Since the interpretation of the model was the same, and previous research noted that even small amounts of WfT, (which supports the use of a 1-840 mins category) might contribute to meeting the recommended levels of PA [283], (currently endorsing at least 150 mins of moderate intensity PA per week [91]), it was decided that a more parsimonious approach (a binomial walking outcome) would better fit the models in Studies 2 and 3 to progress these investigations. Therefore, WfR (Study 2) and WfT (Study 3) were analysed as binomial dependent variables using multilevel logistic regression through two-level random intercept Markov chain Monte Carlo (MCMC) binomial logit models (first-order marginal quasi-likelihood base estimates; burn-in=500, chain=50,000). For each of the models, odds ratios (ORs) with 95% credible intervals (CrIs) were calculated to estimate whether the environmental exposures were associated with WfR (in Studies 1 and 2) and WfT (in Studies 1 and 3).

HABITAT's hierarchical data (Figure 3.3) was subjected to cross-sectional multilevel modelling with fixed effects and random coefficients to address the research questions for Studies 1, 2 and 3. These models estimated the environmental conditions under which women and men, and older and younger adults walked more for recreation and transport [87,284].

A detailed description of the three investigations, including the analytic and statistical stages, is provided in Table 3.4 and the statistical modelling strategy and corresponding formulas used to address the research questions in each of the three studies included in this thesis is provided in Table 3.5 (both tables are presented at the end of this Chapter). The chapters that follow provide the manuscripts for Study 1, 2 and 3.

Table 3.1: Overview of HABITAT data by year of collection

Domain	Multilevel measures	2007	2009	2011	2013	2014	2016-17
HABITAT Waves	Number of participants by year of data collection Response rate by year of data collection The response rate at baseline (2007) was 68.4% (11,035 surveys from 16,127 eligible and contactable respondents); 72.4% in 2009 (7,866/10,837); 67.3% in 2011 (6,900/10,252); and 67.1% (6,520/9,716) in 2013, and 57.2% (5,188/9,069) in 2016.	11,035 68.4%	7,866 72.6%	6,900 63.3%	6,520 67.1%	767	5,188 57.2%
Individual level	*Individual-level psychological, social and environmental factors are measured using scale-scores derived by summing across the relevant questionnaire items (reversing negatively worded items)*	√	√	√	√		√
Socio-demographic factors	- Individual characteristics (age, gender, ethnicity, country of birth) - Socioeconomic composition (educational qualifications, employment status, occupation group, housing type, household composition, living arrangements, pregnancy, children living in care, household income) - Socioeconomic position (occupation and hours worked, occupation at 25 years, father's and mother's occupation, socioeconomic position in childhood and early childhood, household income) - Residential history (length of time at current address, location of previous residence, motivations in moving, place of residence at age 10 & 25 years)	√	√	√	√		√
Social factors	- Relationships with significant others (friends, family, neighbours) - Levels of encouragement, companionship and support - Social correlates and determinants of PA (frequency of: PA with social network, recreational activities, social barriers to PA)	√	√	√	√		√
Psychological factors	- Attitudes to activity (intentions, beliefs, efficacy, motivations, barriers) - Perceived barriers to PA (work/family commitments, disinterest)	√	√	√	√		√
Area level							
Self-reported data	Neighbourhood quality; social capital (see below); surroundings; streets and footpaths; crime and safety (see below); driving time and walking distance to suburb facilities and services; and length of residence and reasons for moving to the suburbs	√	√	√	√		√
Social influence measures	Perception of neighbourhood: - Social cohesion scale (supports, connection & interactions) adapted from Buchner[215]; social isolation; life events experienced	√	√	√	√		√
Crime & safety measures	**Neighbourhood perception** - personal safety - safety of public places: traffic, surroundings, streets and footpaths, dog walking **Objective measure** Brisbane police-recorded crime data, provided by the Queensland Police Service (QPS), has been incorporated into HABITAT from 2005 to date, including location, time, date, type of crime (against person, property or family violence)	√	√	√	√		√
Objectively measured data	Area level measures based on counts and distance, using Euclidean (or circular) and network buffers and street buffers. - Index of relative socioeconomic disadvantage (IRCD) - Physical neighbourhood features, including: street connectivity; residential density; hilliness; land use mix; street lighting; length of off-road bike paths; and distance by road from each respondents' home to the closest shop, park and public transport	√	√	√	√	√	

Domain	Multilevel measures	2007	2009	2011	2013	2014	2016-17
Behaviours	*Physical Activity domain*						
Self-reported data	**Utilitarian PA (HABITAT questions)** - Walking for transport; cycling for transport **Total walking time** In the last week, how many times have you walked continuously, for at least 10 minutes, for recreation, exercise, or to get to or from places? What do you estimate was the total time you spent walking in this way in the last week? **Recreational PA, (modelled to Active Australia Survey instrument)** - Participation in specific types of recreational activities; use of recreational facilities Participants are asked to indicate the frequency of doing each of 15 types of recreational PA (e.g., exercise class, tennis, swimming) in the last 12 months (never, once every six months, once a month, once every two weeks, once a week, more than once a week). **Occupational PA** Questions about PA in main job, including frequency of standing, walking and heavy labour or physically demanding work, as well as workplace exercise facilities **Domestic PA (collected through Active Australia Survey instrument)** Questions about the number of times and total time spent doing vigorous gardening and household activity in the previous week. Items from the AAS will be used to assess frequency and time spent in walking, moderate and vigorous activity. **Sedentary behaviour, adapted from the Australian Longitudinal Study on Women's Health instrument** - Sedentary behaviour (sitting time in leisure, occupational sitting) Sitting time items ask participants to indicate how much time (hours and minutes) they spend sitting, on a usual week day and on a usual weekend day in each of the following situations: traveling to and from places, watching television (including DVDs and games), using the computer at home, and at leisure (e.g., hobbies, reading). A separate item asks employed respondents how much time is spent sitting while at work on a usual day.	√	√	√	√		√
Objectively measured PA	Actigraph GT3X+ accelerometers					√	√
Health Outcomes	*Physical function*						
Self-reported data	Using Physical Functioning Scale (PF-10)				√		√
Objectively measured data	Senior Fitness Test (SFT)					√	√

Table 3.2: HABITAT variables relevant to this thesis

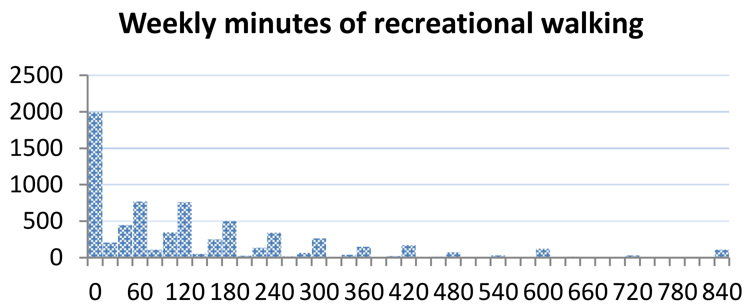
Variable	Instrument	Description	Treatment, justification & metrics
Outcome variables	*Walking behaviours*		**Categorisation/scale**
Walking for recreation (WfR)	This question was a HABITAT specific question based on the one used in the Active Australia Survey (AAS) which asked 'What do you estimate was the total time that you spent walking in this way in the last week?'. The next questions are about any physical activities that you may have done in the LAST WEEK: In the LAST WEEK, how many times have you walked continuously, for at least 10 minutes, for recreation, exercise, or to get to or from places? What do you estimate was the total time that you spent walking in this way in the LAST WEEK?	Self-reported total spent walking for recreation in the previous week (mins)	Outlier values top-coded to 840 minutes, as recommended [264], equivalent to a maximum of 2 hours of walking per day. Study 1 categories: none (0 mins, ref); low (1-59 mins); moderate (60-149 mins); and high (150 mins+). Study 2 categories: none (0 mins – reference group); any (1-840 mins).
Walking for transport (WfT)	The next question is about walking for transport. Transport includes things like travel to and from work, to do errands, or to go from place to place. When answering these questions please do not count walking for exercise or recreation. What do you estimate was the total time that you spent walking for transport in the LAST WEEK?	Self-reported total time spent walking for transport in the previous week (mins)	Outlier values top-coded to 840 minutes, as recommended [264], equivalent to a maximum of 2 hours of walking per day. Study 1 categories: none (0 mins, ref); low (1-59 mins); moderate (60-149 mins); and high (150 mins+). Study 3 categories: none (0 mins – reference group); any (1-840 mins), because the group reporting 0 mins represented 65% of the sample.
Level 1 attributes	*Demographic factors (individual-level)*		
Self-reported predetermined demographic attributes (gender and age)	*Explored in Study 1: Gender and age differences in walking for transport and recreation: are the relationships the same in all neighbourhoods?*	*See below*	*Used in Study 2 only (2009 HABITATA data).* *1. Multilevel logistic regression models estimated the average neighbourhood effects of the gender and age differences in WfR and WfT; and* *2. Random coefficients for gender and age tested whether the average effects of the gender and age differences in WfR and WfT varied across neighbourhoods.*
Gender	Are you: Male/Female (please tick one)	Self-reported gender: 1 male; 2 female	Male (reference group). Main predictor in Study 1 & 2; Control in Study 3
Age	What is your date of birth (e.g. 23/5/1951)? Age was derived from the date of birth provided by the participant.	Self-reported DoB	Main predictor in Study 1 categories: 42-46 (ref); 47-51; 52-56; 57-61 and 62-68 years Control in Study 2: continuous, ranging from 42 to 67 years (mean 53.7 years, SD 7.0). Main predictor in Study 3 categories: 40-48 (ref); 49-57; and 58-65 years

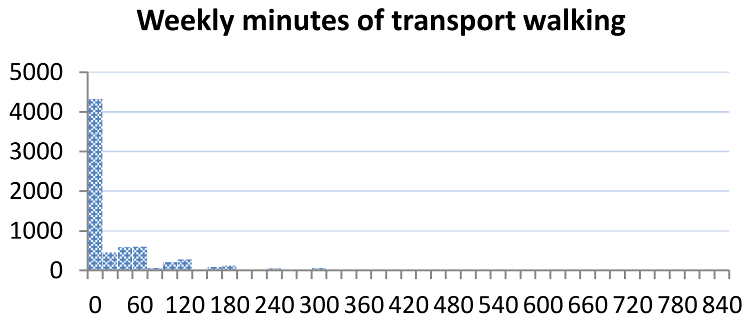
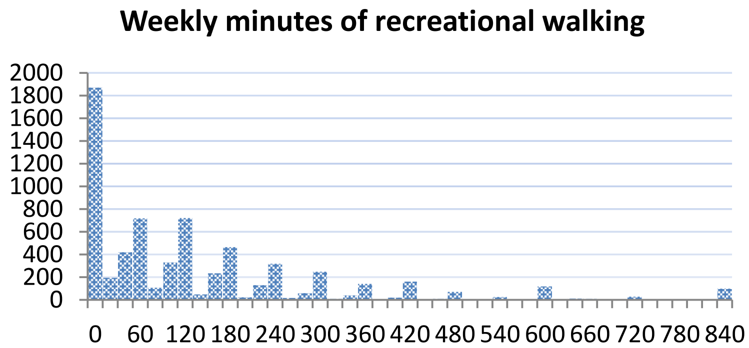
Variable	Instrument	Description	Treatment, justification & metrics
Level 2 exposures	*Neighbourhood-level factors*		
Neighbourhood social factors	*Explored in Study 2: Do differences in social environments explain gender differences in recreational walking across neighbourhoods?*	*Self-reported 5 point Likert scale, from (1) 'strongly disagree' to (5) 'strongly agree'.*	*Used in Study 2 only (2009 HABITATA data).* *1. The items were submitted to a Principal Components Analysis (PCA) with Varimax rotation and combined to form a weighted linear scale;* *2. Neighbourhood-level measures of social cohesion, safety from crime, and incivilities were derived for each of the 200 HABITAT neighbourhoods;* *3. Empirical Bayes Exchangeable (EBE) was applied to produce more reliable estimates of the neighbourhood social environment; and* *4. Continuous forms of the social environment exposures were considered in the statistical models, as recommended [181,271].*
Perception of neighbourhood social cohesion	The following items closely reflect those used in the Buckner Social Cohesion Scale [215], with acceptable reliability [266]. The following statements are about your suburb and the people living around you. How much do you agree or disagree with each statement? I have a lot in common with many people in my suburb; If I no longer lived here, hardly anyone around here would notice; I am good friends with many people in my suburb; I generally trust my neighbours to look out for my property; I have little to do with most people in my suburb; Most of the time, people in my suburb try to be helpful; Generally speaking, people in my suburb can be trusted; Most of the time, people in my suburb just look out for themselves.	Self-reported 5 point Likert scale of 8 items	The resultant PCA scale had an internal reliability Cronbach's alpha = 0.85. For comparability purposes, the individually assessed 18-item instrument Buckner Social Cohesion Scale [215] has been reproduced below **Table II.** Corrected Item – Total Scale Correlation Coefficients for Items Constituting the Neighborhood Cohesion In Item — 37-item scale 1. Overall, I am very attracted to living in this neighborhood. .79 2. I feel like I belong to this neighborhood. .84 3. I visit with my neighbors in their homes. .68 4. The friendships and associations I have with other people in my neighborhood mean a lot to me. .79 5. Given the opportunity, I would like to move out of this neighborhood. .72 6. If the people in my neighborhood were planning something I'd think of it as something "we" were doing rather than "they" were doing. .70 7. If I needed advice about something I could go to someone in my neighborhood. .71 8. I think I agree with most people in my neighborhood about what is important in life. .57 9. I believe my neighbors would help me in an emergency. .63 10. I feel loyal to the people in my neighborhood. .83 11. I borrow things and exchange favors with my neighbors. .65 12. I would be willing to work together with others on something to improve my neighborhood. .60 13. I plan to remain a resident of this neighborhood for a number of years. .75 14. I like to think of myself as similar to the people who live in this neighborhood. .65 15. I rarely have neighbors over to my house to visit. .66 16. A feeling of fellowship runs deep between me and other people in this neighborhood. .84 17. I regularly stop and talk with people in my neighborhood. .65 18. Living in this neighborhood gives me a sense of community. .87 [a]Response alternatives for all items are (1) *strongly agree*, (2) *agree*, (3) *neither agree/nor disagree*, (4) *disagree*, (5) *strongly a* for Item 5 and Item 15 which are negatively keyed, all other items require recoding before means are computed (e.g., 1 = 2; 5 = 1). After recoding the sense of community/cohesion variable is equal to the mean of all 18 items. Items 1, 5, and 13 written to measure attraction-to-neighborhood; items 3, 7, 11, 15, and 17 to measure neighboring; and items 2, 4, 6, 8, 10, 18 to measure psychological sense of community.
Perception of neighbourhood incivilities	This was assessed using two items that asked participants about the presence of litter, rubbish, and graffiti in the neighbourhood. The items have acceptable reliability [267]. The following statements are about your suburb's surroundings. How much do you agree or disagree with each statement? Please tick the box that best applies to your suburb: My suburb is generally free from litter or rubbish: My suburb is generally free from graffiti. The items have demonstrated acceptable reliability [267].	Self-reported 5 point Likert scale of 2 items	The resultant PCA scale had an internal reliability Cronbach's alpha = 0.63.

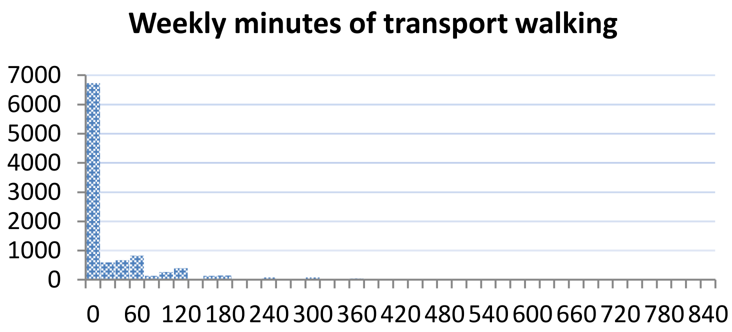
Variable	Instrument	Description	Treatment, justification & metrics
Perception of neighbourhood safety from crime	The following items were adapted for the Australian population from the Neighbourhood Environment Walkability Scale (NEWS) questionnaire [268], which has acceptable reliability [187,267]. The following statements are about crime and safety in your suburb. How much do you agree or disagree with each statement? There is a lot of crime in my suburb; Children are safe walking around the suburb during the day; The crime in my suburb makes it unsafe to walk streets at night; Rowdy youth on streets or hanging around in parks in my suburb; The crime in my suburb makes it unsafe to walk streets during day time; I would feel safe walking home from bus stop/train station at night	Self-reported 5 point Likert scale of 6 items	The resultant PCA scale had an internal reliability Cronbach's alpha = 0.80.
Neighbourhood physical factors	*Explored in Study 3: Do differences in built environments explain age differences in transport walking across neighbourhoods? The neighbourhood-level data used to derive the built environment exposures were provided by the Brisbane City Council (the local government authority responsible for the jurisdiction covered by the HABITAT study) and MapInfo StreetPro [272]. Environmental variables are provided if the participant remains in Brisbane during that wave.*	*Objectively measured*	*As recommended to ensure comparability between studies [181,273], continuous spatial measures of the built environment were developed for each of the 200 HABITAT neighbourhoods using ArcMap [274], for overlaying on survey responses [93].*
Residential density	Residential density was measured by calculating the number of dwellings per hectare of residential land within the CCD in which the participant resided at the time of data collection.	Objectively measured	For ease of interpretability, the residential density was divided by 5, such that the coefficient is interpreted as the likelihood of doing any minutes of WfT for a 5 dwelling difference. The density across the 200 CCDs ranged from 0.04 to 28.85, with a mean of 3.87 (SD 3.05)
Street intersections	Greater connectivity suggests additional choices along the way and often a more direct route between origin and destination. Street connectivity was measured as a count of the number of four-way or more intersections within each of the HABITAT's CCDs.	Objectively measured	The number of 4-way intersections across the 200 CCDs ranged from 0 to 12, with a mean of 2.5 (SD 2.3).
Land-use mix	Land use mix was derived as the balance of five land-use codes (retail, office, social service, recreation and residential) that quantified the proportion of land area within a CCD using an entropy equation described previously [253]. This entropy score ranged from 0 to 1, with 0 representing complete homogeneity of land use within the CCD, and 1 representing an even distribution of the five types of land use.	Objectively measured	For ease of interpretability, the land use mix variable was multiplied by 10 so that the coefficient is interpreted as a 10% change in land-use mix. Across the 200 CCDs, entropy scores ranged from 0.91 to 7.96 with a mean of 3.46 (SD 1.49).
Covariates	***The following controls were used in Study 2 and 3***		
Education	What is the highest educational qualification you have completed? Tick ONE only. Year 9 or less 1; Year 10 (Junior/4th form) 2; Year 11 (Senior/5th form) 3; Year 12 (Senior/6th form) 4; Certificate (trade or business) 5; Diploma or Associate Degree 6; Bachelor Degree (Pass or Honours) 7; Graduate Diploma or Graduate Certificate 8; Postgraduate degree (Master degree or Doctorate) 9; Other (please describe)	Self-reported	For analyses, education was re-categorised into: (1) bachelor degree or higher (including postgraduate diploma, master's degree, or doctorate); (2) diploma (associate or undergraduate); (3) vocational (trade or business certificate or apprenticeship); (4) no post-school qualifications.

Variable	Instrument	Description	Treatment, justification & metrics
Occupation	Participants who were employed at the time of completing the survey were asked their job title. This information was subsequently classified using the Australian and New Zealand Standard Classification of Occupations (ANZSCO) [285] What is your current occupation? (If you have more than one job, we are interested in your main job.) Please give full title (for example: Childcare Aide, Maths Teacher, Pastry cook, Commercial Airline Pilot, Apprentice Toolmaker, etc.). For Public Servants, state official designation and occupation. For armed services personnel, state rank and occupation.	Self-reported	For analyses, occupation was re-categorised into: 1 "Manager/Professional" 2 "White collar" 3 "Blue collar" 4 "Home duties" 5 "Retired" 6 "Missing/nec" (1) managers/professionals (managers and administrators, professionals and paraprofessionals); (2) white-collar employees (clerks, salespersons and personal service workers); (3) blue-collar employees (tradespersons, plant and machine operators and drivers and other labourers and related workers); (4) not in the workforce (home duties and retired); and (5) Missing (not employed, students, permanently unable to work or category not classifiable).
Income	Participants were asked to estimate the total pre-tax annual household income using a single question comprising 13 income categories. Please add up the amount of BEFORE -TAX income received by ALL members of your household, and tick the box that comes closest to this number. Please indicate income either per year, per fortnight, or per week.	Self-reported	For analyses, income was re-categorised into: (1) >AU$130,000; (2) AU$129,999 – 72,800; (3) AU$72,799 – 52,000; (4) AU$51,999 – 26,000; (5) <AU$25,999; and (6) Missing/Not classified (i.e. left the income question blank, ticked 'Don't know' or 'Don't want to answer this').
Residential self-selection	Justification for inclusion in Study 2 and 3: adjustment for residential self-selection (which is rare among cross-sectional neighbourhood studies [93,181]), ensures more reliable estimates of the influence of environmental exposures on WfR by accounting for individual-level bias (a regular recreational walker might select a residence which facilitates their WfR), and controlling to a certain extent for reverse causation [54,69,93,181]. To assess residential attitudes, participants were asked to respond to five Likert-type items at baseline (data collected in 2007), ranging from 'not at all important' to 'very important' on a number of statements regarding "How important were the following reasons for choosing your current address?". The items have been shown to have acceptable test-retest reliability [267].	Self-reported 5 point Likert scale, ranging from (1) 'not at all important' to (5) 'very important'.	Principal components analysis (PCA) with Varimax rotation identified three factors whose items had loadings of 0.50 or above, as recommended [286], subsequently described as: (1) 'destinations' (three items, composed of 'ease of walking to places'; 'closeness to public transport' and 'wanted to live close to shops'; Cronbach's alpha: Study 2 and 3 = 0.80). (2) 'nature' (three items, composed of 'near to green-space or bushland' and 'closeness to open space (e.g. parks)'; Cronbach's alpha: Study 2 and 3 = 0.78); and (3) 'family' (two items, composed of 'closeness to schools' and 'closeness to childcare'; Cronbach's alpha: Study 2= 0.61; Study 3=0.62). The Cronbach's alpha differed between studies as they reflect different analytic samples collected in distinct waves.
Neighbourhood socioeconomic disadvantage	Each of the 200 HABITAT neighbourhoods was assigned a socioeconomic score using the Australian Bureau of Statistics' Index of Relative Socioeconomic Disadvantage (IRSD) [182]. The Index reflects each area's overall level of disadvantage based on 17 socioeconomic attributes, including education, occupation, income, unemployment, and household tenure.	Objectively measured	The derived socioeconomic scores from the HABITAT neighbourhoods were then quantised as percentiles, relative to all of Brisbane [87] ranging from 1-100 with lower scores denoting more highly disadvantaged neighbourhoods. Study 2 mean= 56.8; SD 28.0; Study 3 mean= 57.2; SD 28.1.

Table 3.3: Outcome variables: description and categories

<table>
<tr><th>Data source</th><th>Outcomes</th><th>Metrics</th><th>Frequency distribution of the outcome variable</th><th>Categories for analyses</th></tr>
<tr>
<td>Study 1: Wave 2 (2009) of HABITAT (response rate 72.6%; retention rate 71.3%)
Sample: 7,866 residents nested within 200 neighbourhoods</td>
<td>Minutes of Walking for Transport (WfT) and Walking for Recreation (WfR)</td>
<td>Range 0-840
WfR
Mean 135.0
SD 169.3
28.2% of the sample reported 0 mins of WfR
WfT
Mean 35.7
SD 85.4
61.8% of the sample reported 0 mins of WfT</td>
<td>


</td>
<td>Minutes of WfR & WfT categorised into none (0 mins); low (1-59 mins); moderate (60-149 mins); and high (150 mins+)
<table>
<tr><th></th><th>WfR</th><th></th><th>WfT</th><th></th></tr>
<tr><th>Categories</th><th>Freq.</th><th>%</th><th>Freq.</th><th>%</th></tr>
<tr><td>0mins</td><td>1,993</td><td>28.2</td><td>4,327</td><td>61.8</td></tr>
<tr><td>1-59mins</td><td>727</td><td>10.3</td><td>1,130</td><td>16.1</td></tr>
<tr><td>60-149mins</td><td>1,964</td><td>27.8</td><td>1,088</td><td>15.5</td></tr>
<tr><td>150+mins</td><td>2,385</td><td>33.7</td><td>459</td><td>6.6</td></tr>
<tr><td>Total</td><td>7,069</td><td>100.0</td><td>7,004</td><td>100.0</td></tr>
</table></td>
</tr>
<tr>
<td>Study 2: Wave 2 (2009) of HABITAT (response rate 72.6%)
Sample: 7,866 residents nested within 200 neighbourhoods</td>
<td>Minutes of Walking for Recreation (WfR)</td>
<td>Range 0-840
Mean 134.8
SD 168.6
28.2% of the sample reported 0 mins of WfR</td>
<td>
</td>
<td>Minutes of WfR categorised into none (0 mins ref) and any (1-840 mins)
<table>
<tr><th></th><th>WfR</th><th></th></tr>
<tr><th>Categories</th><th>Freq.</th><th>%</th></tr>
<tr><td>0 mins</td><td>1,870</td><td>28.15</td></tr>
<tr><td>1-840 mins</td><td>4,773</td><td>71.85</td></tr>
<tr><td>Total</td><td>6,643</td><td>100.0</td></tr>
</table></td>
</tr>
</table>

Data source	Outcomes	Metrics	Frequency distribution of the outcome variable	Categories for analyses
Study 3: Wave 1 (2007) of HABITAT (response rate 68.4%) *Sample:* 11,035 residents nested within 200 neighbourhoods	Minutes of Walking for Transport (WfT)	Range 0-840 Mean 34.9 SD 85.9 **65% of the sample reported 0 mins of WfT**		Minutes of WfT categorised into none (0 mins ref) and any (1-840 mins)

	WfT	
Categories	**Freq.**	**%**
0 mins	6,728	65.0
1-840 mins	3,622	35.0
Total	10,350	100.0

Table 3.4: Overview of studies within this thesis

Aims	Data source & sample	Outcome variable	Attributes and exposures	Statistical analyses
Study 1: Gender and age differences in walking for transport and recreation: are the relationships the same in all neighbourhoods?				Multilevel logistic regression
(1) describe the average neighbourhood effects of gender and age differences in WfR and WfT; (2) assess whether these average effects vary across neighbourhoods	Wave 2 (2009) of HABITAT (response rate 72.6%; retention rate 71.3%) *Sample:* 7,866 residents nested within 200 neighbourhoods	Minutes of Walking for Transport (WfT) and Walking for Recreation (WfR) categorised into none (0 mins ref); low (1-59 mins); moderate (60-149 mins); and high (150 mins+)	**Main attributes:** *Gender:* Men (ref)/Women *Age:* 42-46 (ref); 47-51; 52-56; 57-61 and 62-68 years	1) Average neighbourhood effects for gender and age; and 2) Random coefficients for gender and age and joined Wald test
Study 2: Do differences in social environments explain gender differences in recreational walking across neighbourhoods?				Multilevel logistic regression
(1) describe the gender-WfR relationship; (2) assess whether these average effects vary across neighbourhoods; (3) examine between-neighbourhood variation in the probability of WfR for men and women; and investigate the contribution of the social environment to explaining: (4) neighbourhood differences in the gender-WfR relationship; and (5) between-neighbourhood variation in WfR for men and women.	Wave 2 (2009) of HABITAT (response rate 72.6%) *Sample:* 7,866 residents nested within 200 neighbourhoods	Minutes of Walking for Recreation (WfR) categorised into none (0 mins ref) and any (1-840 mins)	**Attribute:** *Gender:* Men (ref)/Women **Social environment exposures:** continuous standardised neighbourhood-level perceptions of social cohesion, incivilities, and safety from crime **Controls:** age; socioeconomic position (education, occupation, income); residential self-selection; and neighbourhood disadvantage	1) Average effects for gender; 2) Random coefficients for gender and joined Wald test; 3) Area-level variance functions for men and women assessing reductions in: 4) Random coefficient post-inclusion of cross-level interactions; and 5) Variance functions for men and women, post-inclusion of social exposures as fixed effects.
Study 3: Do differences in built environments explain age differences in transport walking across neighbourhoods?				Multilevel logistic regression
(1) describe the age-WfT relationship; (2) assess whether these average effects vary across neighbourhoods; (3) examine between-neighbourhood variation in the probability of WfT for each age group; and investigate the contribution of the built environment to explaining: (4) neighbourhood differences in the age-WfT relationship; and (5) between-neighbourhood variation in WfT for each age group.	Wave 1 (2007) of HABITAT (response rate 68.4%) *Sample:* 11,035 residents nested within 200 neighbourhoods	Minutes of Walking for Transport (WfT) categorised into none (0 mins ref) and any (1-840 mins)	**Attribute:** *Age:* 40-48 (ref); 49-57; and 58-65 years **Built environment exposures:** objectively measured residential density, street connectivity and land-use mix **Controls:** gender; socioeconomic position; residential self-selection variables; and neighbourhood disadvantage	1) Average effects for gender; 2) Random coefficients for age and joined Wald test; 3) Area-level variance functions for each age group assessing reductions in: 4) Random coefficients post-inclusion of cross-level interactions; and 5) Variance functions for each age group, post-inclusion of built exposures as fixed effects.

Table 3.5: Description of the analytic and statistical modelling strategy used in each study

Study aims	Statistical analyses	Statistical formulas
Study 1: Gender and age differences in walking for transport and recreation: are the relationships the same in all neighbourhoods?		
1) describe the average neighbourhood effects of gender and age differences in WfR and WfT; and 2) assess whether these average effects vary across neighbourhoods	Multilevel multinomial (0 mins ref; 1-59 mins; 60-149 mins; and 150 mins+) modelling in 2 stages: **1) Average neighbourhood effects of gender/age differences in WfR/WfT** We fitted a random intercept model with gender/age as the primary attributes, comparing groups in terms of WfR/WfT (where the between-neighbourhood variance is a constant). Results were presented as odds ratios (ORs) with 95% Credible Intervals (CrIs). **2) Variation around the average effect (random coefficients for gender/age)** We incorporated random coefficients for gender/age at the neighbourhood level (in separated models) to allow its effect on levels of WfR/WfT to vary across neighbourhoods (where the variance across neighbourhoods is a function of gender/age). This analysis produces a level-2 random effect **u_{ij}**, (variation in these individual-level associations across neighbourhoods), which is what we were interested in testing. A joint Wald was conducted for the random coefficients to assess whether the effect of gender/age on WfR/WfT varied significantly across neighbourhoods,	**1) Average effects for gender/age** Random intercept model $\mathrm{WfR}_{ij}/\mathrm{WfT}_{ij} = \boldsymbol{\beta_{0j}} + \beta_1 \mathrm{gender}_{ij} + \beta_2 \mathrm{age}_{ij} + e_{ij} + \mathbf{u_{0j}}$ **2) Random coefficients for gender/age** Random coefficient model $\mathrm{WfR}_{ij}/\mathrm{WfT}_{ij} = \beta_{0j} + \boldsymbol{\beta_1 \mathrm{gender}_{ij}} + \beta_2 \mathrm{age}_{ij} + e_{ij} + u_{0j} + \mathbf{u_{1j}}$ $\mathrm{WfR}_{ij}/\mathrm{WfT}_{ij} = \beta_{0j} + \beta_1 \mathrm{gender}_{ij} + \boldsymbol{\beta_2 \mathrm{age}_{ij}} + e_{ij} + u_{0j} + \mathbf{u_{2j}}$ Wald test assessing the null hypothesis of no variation in levels of WfT/WfR across neighbourhood for the random coefficients [278]. *Nomenclature:* WfR_{ij}/WfT_{ij} = walking category for resident **i** in neighbourhood **j** β_{0j} = overall intercept (grand mean) β_{1j} = overall slope coefficient for gender (average change across all neighbourhoods) β_{2j} = overall slope coefficient for age (average change across all neighbourhoods) e_{ij} = level-1 random effect (within-neighbourhood variation) u_{0j} = level-2 random effect of the intercept (between-neighbourhood variation) **u_{ij} = level-2 random effect of the slope for gender (u_{1j}) or age (u_{2j}) (variation in the effect of gender/age on WfR/WfT across neighbourhoods)**

Study aims	Statistical analyses	Statistical formulas
Study 2: Do differences in social environments explain gender differences in recreational walking across neighbourhoods?		
(1) describe the gender-WfR relationship (2) assess whether these average effects vary across neighbourhoods (3) examine between-neighbourhood variation in the probability of WfR for men and women; and investigate the contribution of the social environment to explaining: (4) neighbourhood differences in the gender-WfR relationship; and (5) between-neighbourhood variation in WfR for men and women.	Multilevel binomial (0 mins-ref and 1-840 mins) logistic regression in stages, corresponding with the study aims: **1) Average neighbourhood effects of gender differences in WfR:** we fitted a random intercept model with gender as the primary attribute (where the between-neighbourhood variance is a constant), and adjusted for age. **2) Variation around the average effects (random coefficient for gender):** we then incorporated a *random coefficient* for gender at the neighbourhood-level to enable its effect on the odds of WfR to vary across neighbourhoods (where the variance across neighbourhoods is a function of gender). Further adjustment for education, occupation, household income, residential self-selection and neighbourhood disadvantage produced unbiased baseline estimates. A joint Wald test was conducted to examine whether the effect of gender on WfR varied significantly across neighbourhoods [278] **3) Between-neighbourhood variation in the probability of WfR for men and women:** We estimated the *neighbourhood-level variance functions* in the fully adjusted baseline model, which capture the extent to which the likelihood of WfR vary across neighbourhoods for men and women [287], providing an indication of the gender sensitivity to the neighbourhood environment in regards to WfR. **The contribution of the social environment to explaining:** ***4) neighbourhood differences in the gender-WfR relationship (cross-level interactions)*:** Following the *Best-practice recommendations for estimating cross-level interaction effects* [288], we then incorporated a *cross-level interaction* between gender at the individual-level and each of the social environment measures at the neighbourhood-level, and examined reductions from the baseline random coefficient for gender [289]; and ***5) between-neighbourhood variation in WfR for men and women (social exposures as fixed effects):*** Finally, the assessment of reductions in from the baseline neighbourhood-level variance functions in WfR for men and women post-inclusion of social environment measures as fixed effects tested whether differences in social environments explained between-neighbourhood variation for men and women.	**1) Average effects for gender (adjusting for age)** Random intercept model $\mathrm{WfR}_{ij} = \boldsymbol{\beta_{0j}} + \beta_1 \mathrm{gender}_{ij} + \beta_2 \mathrm{age}_{ij} + e_{ij} + \mathbf{u_{0j}}$ **2) Random coefficients for gender (adjusting for age)** Random coefficient model $\mathrm{WfR}_{ij} = \beta_{0j} + \boldsymbol{\beta_1 \mathrm{gender}_{ij}} + \beta_2 \mathrm{age}_{ij} + e_{ij} + u_{0j} + \mathbf{u_{1j}}$ $\mathrm{WfR2}_{ij} \sim \mathrm{Binomial}(\mathrm{cons}_{ij}, \pi_{ij})$ $\mathrm{logit}(\pi_{ij}) = \beta_{0j}\mathrm{cons} + \beta_{1j}\mathrm{Female}_{ij} + \beta_2 \mathrm{ageC}_{ij}$ $\beta_{0j} = \beta_0 + u_{0j}$ $\beta_{1j} = \beta_1 + u_{1j}$ $\begin{bmatrix} u_{0j} \\ u_{1j} \end{bmatrix} \sim \mathrm{N}(0,\ \Omega_u) \ : \ \Omega_u = \begin{bmatrix} \sigma^2_{u0} & \\ \sigma_{u01} & \sigma^2_{u1} \end{bmatrix}$ Wald test for the random coefficients assessing the null hypothesis of no variation across neighbourhoods in the odds of WfR [278] $(H_0\!: \sigma_{u01} = \sigma^2_{u1} = 0)$ **3) Neighbourhood-level variance functions** (where gender=x_1) $var(u_{0j} + u_{1j}\, x_{1ij}) = \sigma^2_{u0} + 2\sigma_{u01} x_{ij} + \sigma^2_{u1} x^2_{ij}$ σ^2_{u0} = variance in intercepts between neighbourhoods (it is also the level 2 variance when x_1=0); σ^2_{u1} = variance in slope at level 2; σ_{u01} = covariance between intercepts and slopes. We interpret them together. *Men variance* (the reference group x_1=0) in the odds of WfR was calculated using the following equations: $var(u_{0j} + u_{1j}\, x_{1ij}) = var(u_{0j}) = \sigma^2_{u0}$ *Women variance* (the comparison group x_1=1) $var(u_{0j} + u_{1j}\, x_{1ij}) = var(u_{0j} + u_{1j}) = \sigma^2_{u0} + 2\sigma_{u01} + \sigma^2_{u1}$ **4) Assessing reductions in random coefficients post-inclusion of cross-level interactions;** We then incorporated each social environment exposure, interacted it with gender, and the repeated step 2 to estimate the reduction in the random coefficient. **5) Assessing reductions in variance functions for men and women, post-inclusion of social exposures as fixed effects:** we then incorporated each social environment exposure and repeated step 3 to estimate the reduction in variances for men and women.

Study aims	Statistical analyses	Statistical formulas
Study 3: Do differences in built environments explain age differences in transport walking across neighbourhoods?		
(1) describe the age-WfT relationship (2) whether these average effects vary across neighbourhoods (3) examine between-neighbourhood variation in the probability of WfT for each age group; and investigate the contribution of the built environment to explaining: (4) neighbourhood differences in the age-WfT relationship; and (5) between-neighbourhood variation in WfT for each age group.	Multilevel binomial (0 mins-ref and 1-840 mins) logistic regression in stages, corresponding with the study aims: **1) Average neighbourhood effects of age differences in WfT:** we fitted a random intercept model with age as the primary attribute (where the between-neighbourhood variance is a constant), and adjusted for gender. **2) Variation around the average effects (random coefficient for age):** we then incorporated a *random coefficient* for age at the neighbourhood-level to enable its effect on the odds of WfT to vary across neighbourhoods (where the variance across neighbourhoods is a function of age). Further adjustment for education, occupation, household income, residential self-selection and neighbourhood disadvantage produced unbiased baseline estimates. A joint Wald test was conducted to examine whether the effect of age on WfT varied significantly across neighbourhoods [278] **3) Between-neighbourhood variation in the probability of WfT for each age group:** We estimated the *neighbourhood-level variance functions* in the fully adjusted baseline model, which capture the extent to which the likelihood of WfT vary across neighbourhoods for each age group [287], providing an indication of the age sensitivity to the neighbourhood environment in regards to WfT. **The contribution of the built environment to explaining:** ***4) neighbourhood differences in the age-WfT relationship (cross-level interactions)*:** Following the *Best-practice recommendations for estimating cross-level interaction effects* [288], we then incorporated a *cross-level interaction* between age at the individual-level and each of the built environment measures at the neighbourhood-level, and examined reductions from the baseline random coefficient for age [289]; and ***5) between-neighbourhood variation in WfT for each age group (built exposures as fixed effects):*** Finally, the assessment of reductions in from the baseline neighbourhood-level variance functions in WfT for each age group post-inclusion of built environment measures as fixed effects tested whether differences in built environments explained between-neighbourhood variation for men and women.	**1) Average effects for age (adjusting for gender)** Random intercept model $\mathrm{WfT}_{ij} = \boldsymbol{\beta_{0j}} + \beta_1 \mathrm{age}_{ij} + \beta_2 \mathrm{gender}_{ij} + e_{ij} + \boldsymbol{u_{0j}}$ **2) Random coefficients for each of the age categories (adjusting for gender)** Random coefficient model $\mathrm{WfT}_{ij} = \beta_{0j} + \boldsymbol{\beta_1 \mathrm{age}_{ij}} + \beta_2 \mathrm{gender}_{ij} + e_{ij} + u_{0j} + \boldsymbol{u_{1j}}$ $\mathrm{WfT2}_{ij} \sim \mathrm{Binomial}(\mathrm{cons}_{ij}, \pi_{ij})$ $\mathrm{logit}(\pi_{ij}) = \beta_{0j}\mathrm{cons} + \beta_{1j}\text{49-57}_{ij} + \beta_{2j}\text{58-65}_{ij} + \beta_3\mathrm{Female}_{ij}$ $\beta_{0j} = \beta_0 + u_{0j}$ $\beta_{1j} = \beta_1 + u_{1j}$ $\beta_{2j} = \beta_2 + u_{2j}$ $\begin{bmatrix} u_{0j} \\ u_{1j} \\ u_{2j} \end{bmatrix} \sim \mathrm{N}(0, \Omega_u) : \Omega_u = \begin{bmatrix} \sigma^2_{u0} & & \\ \sigma_{u01} & \sigma^2_{u1} & \\ \sigma_{u02} & \sigma_{u12} & \sigma^2_{u2} \end{bmatrix}$ Wald test for the random coefficients assessing the null hypothesis of no variation across neighbourhoods in the odds of WfT [278] $(H_0: \sigma_{u01} = \sigma^2_{u1} = \sigma_{u12} = 0)$ **3) Neighbourhood-level variance functions** (where age=x) $var(u_{0j} + u_{1j}\, x_{1ij}) = \sigma^2_{u0} + 2\sigma_{u01}x_{1ij} + \sigma^2_{u1}x^2_{1ij}$ σ^2_{u0} = variance in intercepts between neighbourhoods (it is also the level 2 variance when x =0); σ^2_{u1} = variance in slope at level 2; σ_{u01} = covariance between intercepts and slopes. We interpret them together. *40-48 years variance* (the reference group; x =0) for the likelihood of WfT was calculated using the following equation: $var(u_{0j} + u_{1j}\, x_{1ij}) = var(u_{0j}) = \sigma^2_{u0}$ *49-57 years variance* (comparison group 1; x=1) $var(u_{0j} + u_{1j}\, x_{1ij}) = var(u_{0j} + u_{1j}) = \sigma^2_{u0} + 2\sigma_{u01} + \sigma^2_{u1}$ *58-65 years variance* (comparison group 2; x=1): $var(u_{0j} + u_{1j}\, x_{1ij}) = var(u_{0j} + u_{1j}) = \sigma^2_{u02} + 2\sigma_{u12} + \sigma^2_{u2}$ **4) Assessing reductions in random coefficients post-inclusion of cross-level interactions;** We then incorporated each built environment exposure, interacted it with age, and the repeated step 2 to estimate the reduction in random coefficients. **5) Assessing reductions in variance functions for each age group, post-inclusion of social exposures as fixed effects:** we then incorporated each built environment exposure and repeated step 3 to estimate the reduction in variances for each age group.

Chapter 4: Gender and age differences in walking for transport and recreation: Are the relationships the same in all neighbourhoods?

Understanding the environmental contributors to walking patterns in demographic groups predisposed to inactivity can inform environmental interventions that increase walking everywhere for everyone. To date, multilevel studies have mostly reported the pooled (average) neighbourhood effects on walking, overlooking the possibility that the same neighbourhood environment has a differential influence on the walking patterns of men and women, and younger and older adults. This chapter presents Study 1 of this thesis, an ecological cross-sectional investigation that examined whether gender and age differences in walking for transport (WfT) and walking for recreation (WfR) were similar or different across neighbourhoods.

This paper has been published by an open access peer-review journal:

Ghani, F., Rachele, JN., Washington, S., Turrell, G. (2016). Gender and age differences in walking for transport and recreation: Are the relationships the same in all neighborhoods? *Preventive Medicine Reports* 4: 75-80.

4.1 ABSTRACT

Introduction: Walking as regular physical activity (PA) is central to healthy ageing, and environments influence walking. Multilevel neighbourhood-based studies that only report average (fixed-effect) walking differences for gender and age implicitly assume that neighbourhood environments influence the walking behaviour of men and women, and younger and older persons, similarly. This study tests this assumption by examining whether gender and age differences in walking for transport (WfT) and walking for recreation (WfR) are similar or different across neighbourhoods.

Methods: This paper used data from the HABITAT multilevel study, with 7,866 participants aged 42-68 years in 2009 living in 200 neighbourhoods in Brisbane, Australia. Respondents reported minutes spent WfT and WfR in the previous week, categorised as: none (0 mins), low (1-59 mins), moderate (60-149 mins) and high (150 mins+). Multilevel multinomial logistic models were used to estimate average differences in walking by gender and age, followed by random coefficients to examine neighbourhood variation in these individual-level relationships.

Results: On average, women were more likely to engage in WfR at moderate and high levels (no gender differences found in WfT); and older persons were less likely to do WfT and more likely to do high levels of WfR. These average (Brisbane-wide) relationships varied significantly across neighbourhoods.

Conclusion: Relationships between gender and walking, and age and walking, might not be the same in all neighbourhoods, (i.e. the Brisbane average conceals important information) suggesting that neighbourhood-level factors might differentially influence the walking behaviours of men and women and younger and older persons. Identifying these factors should be a priority for future research.

4.2 INTRODUCTION

Walking is an important health behaviour that can significantly reduce or postpone morbidity and mortality [31,32], particularly among women[118]. It is also the most popular form of physical activity (PA) among older populations [29,167]. Walking is typically undertaken within the local neighbourhood [34,290] for the purposes of transport or recreation [194]. Walking can be incorporated into daily routines at minimal cost, hence it is among the most modifiable form of PA among adult populations [129], resulting in public health and socioeconomic gains [128]. However, seniors walk less at levels that contribute to recommended PA guidelines, particularly older women [108].

During the last decade, there have been numerous neighbourhood-based multilevel studies of walking for transport and recreation that have included gender and age as part of their analyses [35,48,52,57,65,95,291-293]. Typically, these studies use gender and age as covariates or effect-modifiers, [35,57,95,293] and only occasionally as primary attributes of substantive interest. Findings from these studies show that on average, women are less likely to walk for transport [52-55] and recreation [52] than men, while seniors walk less for transport [53,56-58] and more for recreation [35].

Neighbourhood studies that report average differences in walking by gender and age make the implicit assumption that the walking behaviours of men and women and younger and older persons are similarly affected by the neighbourhood environment. However, average gender and age differences are produced by summing-over (i.e. pooling) neighbourhoods, effectively ignoring the possibility that the average relationship might not be observed in all areas. For example, in low crime neighbourhoods gender and age differences in walking for recreation might be minimal due to all demographic groups walking at high levels, whereas in high crime neighbourhoods these differences might be more pronounced, with young males more likely to have a higher crime threshold for walking. In short, average effects obfuscate between-neighbourhood variation in individual-level relationships, hence important information about how neighbourhoods influence walking behaviour is possibly omitted.

One approach to testing the assumption that individual-level associations are the same in all neighbourhoods is via the use of random coefficient models. These models allow the examination of whether relationships between gender and walking, and age and walking, are the same everywhere (reflecting the average effect) or whether the relationships vary across neighbourhoods [294]. This paper aims to advance current understanding of the contextual effects on walking by using random coefficient models to examine whether gender and age differences in walking for transport and walking for recreation are similar or different across neighbourhoods as a complementary approach to multilevel analyses where only average gender and age differences in walking are reported.

Based on previous evidence, we hypothesised that men would report more transport [53-55] and recreational [52] walking than women, while seniors would walk more for recreation[35] and less for transport [53,56-58]. Importantly, we expected these associations to vary significantly between neighbourhoods, thus challenging the implicit assumption that neighbourhood environments have a similar influence on the walking of all residents.

4.3 METHODS

Study design and data collection

This investigation uses data from the second wave (2009) of the How Areas in Brisbane Influence HealTh and AcTivity (HABITAT) multilevel study of mid-age adults living in Brisbane (Australia). HABITAT uses a social-ecological framework that allows for the exploration of the relative contributions of environmental, social, psychological and socio-demographic factors on walking. Details regarding HABITAT's sampling design have been published elsewhere [87]. Briefly, a multi-stage probability sampling design was used to select a stratified random sample (n=200) of Census Collection Districts (CCDs), with a random sample of people aged 40–65 years from each CCD subsequently selected. Eligible participants were mailed a survey; of the 16,127 in-scope participants, 11,035 valid responses (68.4%) were received at baseline (2007) and of the 10,849 in-scope participants in the second wave, 7,866 valid responses (72.5%) were received in 2009. The baseline sample was representative of the general Brisbane population [262]. The HABITAT Study received ethical clearance from the Queensland University of Technology Human Research Ethics Committee (Ref. no. 3967H & 1300000161).

Measures

Outcome variables

Walking for transport (WfT): a single question asked participants to report the total time (converted to minutes) spent WfT (i.e. travelling to and from work, to do errands, or to go from place to place) in the previous week. Walking for recreation (WfR): a single question asked participants to report the total time (converted to minutes) spent WfR, leisure or exercise in the previous week. These questions were closely modelled on the questions asked in the Active Australia Survey, which have demonstrated reliability [124] and validity against accelerometer measures [125] and have been recommended for Australian population-based research [126].

The distribution of the WfT and WfR variables were positively-skewed and included outlier values, which were top-coded to 840 minutes (i.e. equivalent to a maximum of two hours of walking per day) [264]. The quantitative measures of WfT and WfR (minutes per week) were categorised into: none (0 mins), low (1-59 mins), moderate (60-149 mins) and high (≥ 150 mins), as previously used in HABITAT investigations [165,295]. Those in the high category met the current international [91] and Australian PA guidelines [296], recommending at least 30 minutes of moderate intensity PA on most days of the week, through WfT alone or WfR alone.

Independent variables

Participants reported their gender and date of birth. A single-year age for each respondent was derived. Since an aim was to test for a dose-response relationship with age, participants were grouped into the following categories: 42-46; 47-51; 52-56; 57-61 and 62-68 years. A combined gender/age ten-category variable was also generated (with category 1 referring to men aged 42-46 and category 10 denoting women aged 62-68) to explore how particular gender-age subgroups differed in their walking behaviour.

Statistical analyses

Of the 7,866 participants who returned a valid questionnaire in 2009, the following were excluded from further analyses: 567 (7.2%) who relocated from their original neighbourhood at baseline (2007) to another address in 2009; 28 (0.4%) were a different participant from baseline with missing age; 267 participants (3.7%) did not indicate minutes spent WfT and 202 (2.8%) did not indicate minutes spent WfR. The resulting analytic sample comprised 7,004 participants for WfT and 7,069 for WfR (Table 4.1) nested within 200 CCDs. The non-respondents to the WfT question did not significantly differ from the respondents on the basis of age or gender; however, WfR non-respondents were significantly more likely to be female (OR 1.39; CI 1.04-1.87).

WfT and WfR were analysed in 2015 separately using multilevel multinomial regression models of participants within neighbourhoods, corresponding to HABITAT’s nested data structure. Data were prepared in Stata v.13 [277] and analysed in *MLwIN* v.2.30 [297]. Gender and age were the primary attributes of walking patterns in the statistical models, undertaken in two stages. First, we fitted two-level random intercept Markov chain Monte Carlo (MCMC) multinomial logit models (first-order marginal quasi-likelihood base estimates, burn-in=500, chain=50,000) to determine the average neighbourhood effects in the relationship between gender, age and the combined gender/age variable and levels of WfT and WfR. The reference categories for analysis were non-walkers (0 mins), men and the youngest age group (42-46 years). Results are presented as odds ratios (ORs) with 95% credible intervals (CrI). Second, we specified random coefficients (where the variance is calculated as a function of individual characteristics) in each of the random intercept models to test whether the fixed (*average*) effects of gender, age, and gender/age differences in WfT and WfR varied across neighbourhoods. We tested the statistical significance of the random coefficients using a Wald test to assess the null hypothesis of no neighbourhood variation in walking between men and women and younger and older persons.

4.4 RESULTS

A greater proportion of people walked for recreation than for transport in the previous week (72% compared to 38%, Table 4.1). The proportion of transport walkers was similar for men and women and tended to decrease with age. Similarly, no gender difference was observed in the proportion of recreational walkers, but this proportion was slightly lower for the mid-age cohorts. The rate of transport walking for the combined gender/age variable decreased with age and was generally lower for women compared to men, particularly for the oldest age groups. In contrast, the proportion of recreational walkers was higher for women in all age groups compared with men.

Table 4.1: Socio-demographic characteristics of the analytic sample, and proportion of transport and recreational walkers

	Total 2009 [a]		Walking for transport [b]		Walking for recreation [b]	
	N	% [c]	N	% who walked for transport [d]	N	% who walked for recreation [e]
			N	%[b]	N	%[c]
Total	7,866	100.0	7,004	38.2	7,069	71.8
Sex						
Males	3,358	42.7	2,991	39.3	3,036	69.6
Females	4,508	57.3	4,013	37.5	4,033	73.4
P-Value	--	--	--	0.126	--	0.000
Age [f]						
42-46	1,434	18.2	1,271	41.1	1,269	72.1
47-51	1,678	21.3	1,506	42.6	1,525	71.1
52-56	1,607	20.4	1,424	38.0	1,445	70.4
57-61	1,549	19.7	1,386	36.4	1,386	73.2
62-68	1,568	19.9	1,417	33.0	1,444	72.4
P-Value	--	--	--	0.000	--	0.507
Sex/age [f]						
Males						
42-46	686	8.7	605	41.8	609	68.6
47-51	743	9.4	670	43.3	680	70.0
52-56	680	8.6	594	35.5	612	67.8
57-61	620	7.9	567	39.3	565	71.2
62-68	609	7.7	555	35.5	570	70.7
Females						
42-46	748	9.5	666	40.5	660	75.3
47-51	935	11.9	836	42.0	845	72.1
52-56	927	11.8	830	39.8	833	72.3
57-61	929	11.8	819	34.4	821	74.5
62-68	959	12.2	862	31.3	874	73.5
P-Value	--	--	--	0.000	--	0.039

[a] This total includes movers

[b] The WfT and WfR databases were examined separately.

[c] Percent of the entire analytical sample (column percentages)

[d] Percent of the WfT analytical sample (row percentages)

[e] Percent of the WfR analytical sample (row percentages)

[f] Age was missing for 30 respondents who were excluded in further analyses, 2 of which were movers.

Walking for transport

There were no significant differences between men and women in their odds of WfT at low, moderate, or high levels (Table 4.2). However, the random coefficients – each of which was statistically significant – indicated that the association between gender and WfT, at all levels of walking, varied across neighbourhoods.

The association between age and WfT did not differ between those doing low amounts of walking (1-59 minutes per week) compared to those doing 0 minutes of walking (the reference category). Compared to the reference category (42-46 years), the odds of WfT at moderate levels (60-149 minutes/week) were significantly lower for those aged 52-56 years (20% lower), 57-61 (26% lower) and 62-68 years (45% lower). The odds of WfT at high levels (150 minutes or more per week) were significantly lower for respondents aged 62-68 years (36% lower). The random coefficients for each age group and level of WfT were statistically significant, indicating that relationships between age and transport walking varied across neighbourhoods, except for those aged 62-68 at high walking levels.

The association between the combined gender/age variable and WfT did not differ between those doing low amounts of walking (1-59 minutes per week) compared to men aged 42-46 years doing 0 minutes of walking (the reference category). However, compared to men aged 42-46 years, the odds of walking moderately for transport were significantly lower for men aged 62-68 years (40% lower), for women aged 57-61 years (36% lower), and for women aged 62-68 years (52% lower). A similar pattern was observed in the odds of walking at high levels; they were significantly lower for men aged 62-68 years (44% lower), and for women aged 57-61 (40% lower) and 62-68 (50% lower) years respectively. The random coefficients showed significant between-neighbourhood variation across most gender/age groups at the low and moderate walking levels for transport, except for men aged 57-61 years and women aged 47-51 and 52-56 years at low walking levels, and for men aged 57-61 years and women aged 57-61 years at moderate walking levels. No significant variation was observed at high levels of WfT in the gender/age groups.

Table 4.2: Average neighbourhood effects and between-neighbourhood variation of gender and age differences in transport walking

	Fixed-effects							Random coefficients (standard error)			
	None	Low		Moderate		High		None	Low	Moderate	High
	0 mins	1-59 mins		60-149 mins		150 mins+		0 mins	1-59 mins	60-149 mins	150 mins+
		OR	95% CrI	OR	95% CrI	OR	95% CrI				
Gender											
Males	--	1		1		1		--	--	--	--
Females	--	1.01	0.89,1.16	0.94	0.82,1.08	0.87	0.72,1.06	--	**0.153 (0.05)****	**0.173 (0.06)****	**0.269 (0.11)***
Age											
42-46	--	1		1		1		--	--	--	--
47-51	--	1.04	0.85,1.28	1.03	0.83,1.26	1.25	0.92,1.70	--	**0.236 (0.09)***	**0.231 (0.08)****	**0.256 (0.12)***
52-56	--	0.87	0.70,1.08	**0.80**	**0.64,0.98**	1.07	0.78,1.41	--	**0.310 (0.13)***	**0.213 (0.08)***	**0.276 (0.12)***
57-61	--	0.85	0.69,1.05	**0.74**	**0.60,0.92**	0.90	0.65,1.25	--	**0.247 (0.09)***	**0.296 (0.12)***	**0.380 (0.16)***
62-68	--	0.86	0.70,1.06	**0.55**	**0.43,0.69**	**0.64**	**0.46,0.91**	--	**0.194 (0.07)****	**0.295 (0.11)****	0.289 (0.13)
Gender/age											
Males											
42-46	--	1		1		1		--	--	--	--
47-51	--	1.18	0.86,1.62	0.91	0.66,1.24	1.19	0.79,1.82	--	**0.344 (0.16)***	**0.274 (0.12)***	0.443 (0.24)
52-56	--	0.77	0.55,1.09	0.74	0.54,1.02	0.64	0.39,1.02	--	**0.358 (0.15)***	**0.298 (0.13)***	0.377 (0.21)
57-61	--	0.89	0.64,1.24	0.82	0.59,1.13	0.95	0.61,1.49	--	0.305 (0.15)	0.392 (0.20)	0.440 (0.23)
62-68	--	1.01	0.72,1.39	**0.60**	**0.42,0.84**	**0.56**	**0.34,0.93**	--	**0.274 (0.12)***	**0.430 (0.19)***	0.452 (0.27)
Females											
42-46	--	1.10	0.80,1.51	0.92	0.67,1.25	0.68	0.43,1.10	--	**0.266 (0.11)***	**0.265 (0.11)***	0.425 (0.26)
47-51	--	1.04	0.77,1.41	1.04	0.78,1.40	0.91	0.60,1.37	--	0.373 (0.18)	**0.279 (0.12)***	0.348 (0.19)
52-56	--	1.03	0.76,1.40	0.78	0.58,1.05	1.08	0.73,1.62	--	0.503 (0.22)	**0.318 (0.13)***	0.322 (0.15)
57-61	--	0.90	0.67,1.23	**0.64**	**0.47,0.86**	**0.60**	**0.38,0.94**	--	**0.290 (0.12)***	0.350 (0.17)	0.439 (0.22)
62-68	--	0.85	0.63,1.15	**0.48**	**0.35,0.66**	**0.50**	**0.32,0.79**	--	**0.271 (0.10)***	**0.300 (0.12)***	0.401 (0.20)

Note: Boldface indicates significance (* $p<0.05$; ** $p<0.01$)

Walking for recreation

The odds of WfR in the previous week were significantly higher for women at the moderate (20% higher), and high levels (23% higher, Table 4.3) compared to those doing 0 minutes of walking (the reference category). There was significant between-neighbourhood variation in the association between gender and all levels of WfR.

Compared with the reference group (42-46 years), the odds of WfR at low levels were significantly lower for the three oldest age groups. The odds of walking moderately for recreation were also lower for those aged 62-68 years (20% lower). On the other hand, the odds of WfR at high levels were significantly higher for those aged 57-61 years (28% higher) and 62-68 years (34% higher). The random coefficients indicated significant between-neighbourhood variation in the association between each age group and at every level of WfR.

The association between the combined gender/age variable and WfR did not differ between those doing low amounts of walking (1-59 minutes per week) compared to men aged 42-46 years doing 0 minutes of walking (the reference category). However, compared to men aged 42-46 years, the odds of walking moderately for recreation were significantly higher for women aged 42-46 years (39% higher). The odds of WfR at high levels were significantly greater for men aged 57-61 (43% higher) and 62-68 years (46% higher), as well as for women in all age groups (ranging from 32% to 73% higher, particularly in the older groups). Additionally, women aged 42-46 had greater odds (39% higher) of WfR at moderate levels. There was significant between-neighbourhood variation for each gender/age group at the high recreational walking level, except for men aged 52-56 years and at the moderate level for every combined gender/age groups, except for men aged 47-51, 52-56 and 62-68 years. At the lowest walking level, statistically significant between-neighbourhood variation was observed only for women aged 47-51 years.

Table 4.3: Average neighbourhood effects and between-neighbourhood variation of gender and age differences in recreational walking

	Fixed-effects							Random coefficients (standard error)			
	None 0 mins	Low 1-59 mins		Moderate 60-149 mins		High 150 mins+		None 0 mins	Low 1-59 mins	Moderate 60-149 mins	High 150 mins+
		OR	95% CrI	OR	95% CrI	OR	95% CrI				
Gender											
Males	--	1		1		1		--	--	--	--
Females	--	1.18	0.99,1.40	**1.20**	**1.06,1.37**	**1.23**	**1.08,1.38**	--	**0.155 (0.06)****	**0.157 (0.05)****	**0.140 (0.05)****
Age											
42-46	--	1		1		1		--	--	--	--
47-51	--	0.88	0.69,1.14	0.89	0.73,1.08	1.05	0.87,1.27	--	**0.203 (0.08)***	**0.231 (0.09)****	**0.143 (0.05)****
52-56	--	**0.74**	**0.57,0.97**	0.90	0.74,1.10	1.01	0.83,1.23	--	**0.193 (0.08)***	**0.157 (0.05)****	**0.178 (0.06)****
57-61	--	**0.73**	**0.55,0.97**	0.95	0.77,1.16	**1.28**	**1.04,1.56**	--	**0.221 (0.10)***	**0.193 (0.07)****	**0.160 (0.06)****
62-68	--	**0.75**	**0.57,0.98**	**0.80**	**0.66,0.98**	**1.34**	**1.10,1.62**	--	**0.202 (0.09)***	**0.208 (0.08)***	**0.146 (0.05)****
Gender/age											
Males											
42-46	--	1		1		1		--	--	--	--
47-51	--	1.03	0.70,1.51	1.03	0.77,1.40	1.13	0.83,1.51	--	0.257 (0.13)	0.359 (0.18)	**0.219 (0.10)***
52-56	--	0.77	0.51,1.15	0.94	0.69,1.28	1.07	0.79,1.43	--	0.272 (0.16)	0.303 (0.17)	0.376 (0.23)
57-61	--	0.79	0.51,1.22	0.97	0.71,1.33	**1.43**	**1.06,1.93**	--	0.266 (0.13)	**0.221 (0.10)***	**0.239 (0.10)***
62-68	--	0.83	0.54,1.26	0.87	0.64,1.21	**1.46**	**1.08,1.96**	--	0.384 (0.28)	0.313 (0.17)	**0.212 (0.09)***
Females											
42-46	--	1.40	0.96,2.05	**1.39**	**1.03,1.87**	**1.41**	**1.05,1.90**	--	0.475 (0.28)	**0.192 (0.08)***	**0.287 (0.13)***
47-51	--	1.06	0.73,1.53	1.06	0.80,1.41	**1.36**	**1.03,1.79**	--	**0.267 (0.13)***	**0.356 (0.17)***	**0.196 (0.08)***
52-56	--	0.98	0.67,1.42	1.17	0.87,1.55	**1.32**	**1.00,1.73**	--	0.284 (0.17)	**0.206 (0.08)***	**0.200 (0.08)****
57-61	--	0.93	0.63,1.37	1.24	0.92,1.66	**1.62**	**1.22,2.14**	--	0.236 (0.12)	**0.215 (0.09)***	**0.200 (0.08)***
62-68	--	0.93	0.63,1.35	1.01	0.75,1.34	**1.73**	**1.31,2.27**	--	0.272 (0.16)	**0.239 (0.12)***	**0.191 (0.08)***

Note: Boldface indicates significance (* p<0.05; ** p<0.01)

4.5 DISCUSSION

This study tested whether gender and age differences in levels of WfT and WfR varied across neighbourhoods. The estimation of variation around the average neighbourhood effect confirmed that the relationships between gender and walking, and age and walking, are not the same across neighbourhoods. In other words, some environments might influence men and women and younger and older people similarly, while other environments might have a differential impact.

The association between gender and WfT did not differ between those doing low amounts of walking (1-59 minutes per week) compared to those doing 0 minutes of walking (the reference category), which could be due to the generic measure of WfT used involving multiple destinations. Previous research using more specific measures (the International Physical Activity Questionnaire-long form) observed that women do less WfT than men [52-55]. Older participants were less likely to walk at the moderate and high levels for transport compared to younger groups. This is consistent with previous research finding that age was negatively associated with WfT [53,56-58].

We confirmed significant gender-walking and age-walking variation in WfT across neighbourhoods, suggesting that the neighbourhood effects might not be equally distributed. There are several potential reasons for the relatively large amount of variation observed at higher levels of WfT. For instance, a highly walkable neighbourhood (characterised by high residential density, diversity of land use and street connectivity) might reveal minimal gender and age differences in WfT, while this difference might be larger in low walkable neighbourhoods. Living in walkable neighbourhoods has been consistently associated with more WfT [57,293], particularly in adults with a preference for passive transport and/or low intention to walk [290], and stronger effects were observed in women [57,194] and seniors [56], suggesting that these subgroups might require more supportive environments to increase their WfT.

Furthermore, the presence –or absence– of infrastructure important for large amounts of WfT might not be common across neighbourhoods. Evidence indicates that WfT is greater in the presence of non-residential destinations such as public transport and retail outlets [52], particularly among women [208] and older adults [65] who spend less time at work than men and younger persons. Previous spatial research suggests that retail outlets are likely to be clustered within higher density 'hubs' which also contain public services such as health and transport [53]. Previous research has found that high destination density was associated with more minutes of total walking [298], and it is likely to facilitate WfT. Moreover, women with an average number of neighbourhood destinations were more likely to walk for transport than women below the average [299].

Women were more likely than men to walk for recreation at the moderate and high levels, which differs from a Swedish study which found that men walked more for recreation than women [52]. The different results could be explained by differences in the built environment as well as social and cultural distinctions between countries.

Older participants were less likely to do WfT at low and moderate levels but more likely to engage in WfR at high levels. Other multilevel studies have observed older adults walking more for recreation [35], possibly reflecting retirement age activities [166]. Retirement has been associated with increases in WfR in a longitudinal study, suggesting that this is a critical life-stage for promoting walking [167].

The observed gender/age-walking variation in levels of WfR across neighbourhoods might also be partly explained by between-neighbourhood variation in actual crime or perceptions of crime. Previous research finds gender and age differences in perceptions of, and responses to crime; and crime has been shown to vary across neighbourhoods. Women and seniors have higher perceptions of crime, which may seem to constraint their WfR [35,95,208], while these effects are not seen in younger men [163]. Gender was a significant moderator in the relationship between perception of crime/safety, and recreational walking in a multi-country study, with women showing stronger associations than men [95]. Furthermore, seniors living in neighbourhoods with higher perceived safety had a lower rate of decline in self-reported WfR over time [48]. Therefore, neighbourhoods with low crime might have minimal gender and age-differences in WfR, whereas large gender and age-differences in WfR might be observed in high crime neighbourhoods.

Neighbourhood social cohesion might also partially explain the between-neighbourhood age and gender variation in WfR, with highly cohesive neighbourhoods likely to have minimal gender and age-differences in WfR. Neighbourhood social cohesion has been associated with increases in WfR among women [217] and seniors [300].

This study has several limitations. Walking was self-reported, which has been shown to be less accurate than objective measures of walking [131]. The participants in this study may have overestimated the amount of walking they engage in [301] or might have underreported it [302]. Furthermore, seniors might have difficulties with recall [109] and discriminating between WfT and WfR, as they might combine these activities [292]. Furthermore, while the cross-sectional design of this study limits causal conclusions, we observed between-neighbourhood variation in the associations between gender and walking and age and walking across all levels of WfT and WfR.

Recent increases in life expectancy have important implications for social and public health policies regarding seniors [29,303] who are less active, particularly older women [6,8,33]. These PA trends should guide current research to inform gender and age-responsive multilevel strategies [8], called for by the World Health Organization's *Active Ageing* frameworks [15,17], and the National Heart Foundation of Australia's *Blueprint for an active Australia*[18]. The effects of such strategies on increasing walking levels are potentially large and long-lasting in otherwise typically inactive population groups, thereby prolonging healthy life expectancy [303] and reducing health care costs to society [20].

4.6 CONCLUSION

This study advances current understanding of neighbourhood effects on walking patterns by demonstrating significant between-neighbourhood variation in the individual-level associations of gender and walking, and age and walking. These findings suggest that neighbourhood exposures might have a different impact on the walking behaviour of men and women, and young and old. Further research is required to identify whether -and to what extent- the observed between-neighbourhood variation in gender and walking and age and walking is a function of concomitant between-neighbourhood differences in socioeconomic, built environment, and social factors. The identification of the specific neighbourhood characteristics that explain this neighbourhood variation can be used by urban planners and policy makers to develop interventions aimed at increasing the walking of all population groups, irrespective of their gender or age.

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Chapter 5: Do differences in social environments explain gender differences in recreational walking across neighbourhoods?

Multilevel studies have focused on reporting the average neighbourhood effects of gender differences in recreational walking, implicitly assuming a similar influence of environments on the walking patterns of men and women. Study 1 of this thesis observed that exposure to the same neighbourhood may have a different impact on the recreational walking of women compared to men. This chapter presents the manuscript for Study 2 of this thesis, an ecological cross-sectional investigation which extends the research undertaken in Study 1 through assessing the contribution of the neighbourhood social environment to explaining the observed gender differences in WfR across neighbourhoods.

The following manuscript is pending submission to a peer-review journal: **Ghani, F.,** Rachele, JN., Loh, VHY., Washington, S. & Turrell, G. (2018). Do differences in social environments explain gender differences in recreational walking across neighbourhoods?

5.1 ABSTRACT

Background: Walking for recreation (WfR) is important for health. Within the same city, gender differences in WfR might vary significantly across neighbourhoods, although little is known about the reasons for this variation. This cross-sectional study investigated the contribution of the social environment (SE) to explaining gender differences in WfR across neighbourhoods.

Methods: This investigation used 2009 data from the How Areas in Brisbane Influence healTh and AcTivity (HABITAT) study. The sample included 7,866 residents aged 42-67 years living in 200 neighbourhoods in Brisbane, Australia (72.6% response rate). Self-reported weekly minutes of WfR were categorised into none (0 mins) and any (1-840 mins). The SE was conceptualised through neighbourhood-level perceptions of social cohesion, incivilities, and safety from crime. Analyses involved multilevel binomial logistic regression with gender as main predictor, adjusting for age, socioeconomic position, residential self-selection, and neighbourhood disadvantage. Fixed effects estimated the average gender-WfR relationship; a random coefficient (RC) for gender assessed whether this average varied across neighbourhoods; neighbourhood variances (NV) estimated the magnitude of the between-neighbourhood variation in WfR for men and women; reductions in the RC post-inclusion of cross-level interactions assessed the SE in explaining neighbourhood differences in the gender-WfR relationship; and reductions in NV post-inclusion of SE as fixed effects assessed the SE in explaining between-neighbourhood variation in WfR for men and women.

Results: On average, women were significantly more likely than men to walk for recreation prior to adjustment for covariates. Gender differences in WfR seemed to vary significantly across neighbourhoods, and the magnitude of the variation for women was twice that of men. However, the SE did not explain neighbourhood differences in the gender-WfR relationship, or the observed between-neighbourhood variation in WfR for men or women.

Conclusion: Neighbourhood-level factors seem to influence the WfR of men and women differently, with women being more sensitive to their neighbourhood environment.

In Brisbane, the SE did not appear to be one of these factors. These results favour the ongoing investigation of demographic heterogeneity around neighbourhood averages in other urban contexts to inform tailored ecological interventions that facilitate WfR for men and women everywhere, supporting active living communities.

5.2 INTRODUCTION

Gender is a consistent predictor of physical activity (PA) in adults, with women being less active than men across the life-course [6-8,304], regardless of whether PA is measured objectively or subjectively [33]. Previous research suggests that women experience more individual and environmental barriers to PA [120,159], and the social environment seems to influence their PA more than men [23]. The marked gender disparity in overall PA participation [6,8,304] is acknowledged within the World Health Organization's (WHO) *Global action plan for the prevention and control of non-communicable diseases 2013-2020* [14] and *Women, Ageing and Health: A Framework for Action* [15]. These frameworks call for ecological evidence to inform gender-responsive multilevel strategies (i.e. structural, behavioural or psychological) to increase PA in populations.

Walking is the most common form of PA among adults [29] and seems to be preferred by women [30]. Walking contributes more towards meeting the current PA guidelines of 150 mins or more per week at moderate or brisk pace [91] in women than men [61], whereas men are more likely to participate in vigorous-intensity PA [8].

Regular walking contributes to daily energy expenditure [96], reducing or postponing morbidity and mortality from non-communicable diseases [31,32], particularly among women [118]. As walking is typically undertaken within the local neighbourhood [34], environmental features might facilitate or inhibit residents' walking patterns [35].

The factors that influence walking operate at multiple levels, and differ depending on whether the intention for walking is recreation or transport [26]. This paper focuses on walking for recreation (WfR), which is usually undertaken discretionarily in outdoor settings for the purpose of leisure, exercise, or enjoying the scenery [19] and therefore, it is likely to be more influenced by an individual's perceptions of the neighbourhood's social context than objectively measured built environmental factors [19,184,185,201]. The social environment comprises residential characteristics related to the social interactions among its residents, which are important in promoting healthy cohesive communities [204]. Social environment features form part of the liveability indicators which makes a community desirable to live in [205]. Liveability indicators, in turn, align with the social determinants of health currently being examined within social-ecological frameworks to inform healthy and equitable urban design and policy [45].

Previous multilevel research observed that WfR varies by gender, with women more likely to walk for recreation than men [59,305]. To date, most neighbourhood-based studies have presented the overall (average) association between gender and WfR, overlooking the possibility that this relationship differs depending on the characteristics of neighbourhood environments. However, a previous investigation revealed that the effect of gender on WfR might vary significantly across neighbourhoods [305], suggesting that the overall relationship might not necessarily reflect the association within any particular neighbourhood. Moreover, the overall effect might potentially obfuscate important information about how neighbourhoods differentially influence the WfR of men and women.

Several studies have explored gender as a moderator in the relationship between the social environment and WfR, with stronger environmental effects observed in women [35,47]. This suggests that more social environment support might be required to encourage women to walk for recreation as a strategy for reducing the gender disparity in overall PA participation. Perhaps favourable social environments for walking generate minimal or no gender differences in WfR, whereas larger gender differences in WfR might be observed in socially fractured environments. Therefore, the impact of the neighbourhood social environment on a person's probability of WfR might vary by gender. In other words, gender differences in WfR might be moderated by the social environment (one that varies only between-neighbourhoods).

Furthermore, between-neighbourhood variation of gender differences in WfR might be attributed to gender specific sensitivity to environmental characteristics, reflecting the fact that men and women experience –and engage with– their local environments in distinct ways [62,75]. Thus, it is plausible that the social environment of a neighbourhood might have a stronger influence on the recreational walking of women compared to men. For instance, women typically have more concerns about personal safety [7], especially at night [161], which is likely to influence their recreational walking [162]. In contrast, neighbourhood safety seems to have either no impact [163] or an inverse effect [47,59] on men’s WfR.

Consistent with the principles of social-ecological models, which posit dynamic interrelations across multiple levels of influence [306], this study investigates the contribution of the social environment to explaining: (1) neighbourhood differences in the gender-WfR relationship; and (2) between-neighbourhood variation in WfR for men and women.

5.3 METHODS

Study design and data collection

This investigation uses data from the second wave (collected in 2009) of the How Areas in Brisbane Influence HealTh and AcTivity (HABITAT) multilevel study of mid-age adults living in Brisbane, (Australia). HABITAT is underpinned by a social-ecological framework, which informs the investigation of the relative contributions of environmental, social, psychological and socio-demographic factors on PA patterns. Details of HABITAT's sampling design have been published elsewhere [87]. Briefly, a multi-stage probability sampling design was used to select a stratified random sample (n=200) of Census Collection Districts (CCDs), or ‘neighbourhoods’, with a random sample of people aged 40–65 years from each CCD subsequently selected (85 persons on average). Eligible participants were mailed a survey between May and July of 2007 using a method developed by Dillman [263]. Of the 16,127 in-scope participants, 11,035 valid responses (68.4%) were received at baseline (collected in 2007), and of the 10,837 in-scope participants in the second wave, 7,866 valid responses (72.6%) were received in 2009 (Wave 2). The baseline sample was broadly representative of the Brisbane population [262]. The HABITAT Study received ethical clearance from the Queensland University of Technology Human Research Ethics Committee (Ref. No. 3967H and 1300000161).

Measures

Outcome variable

Walking for Recreation (WfR): a single question asked participants to report the total time (converted to minutes) spent walking for recreation, leisure or exercise in the previous week. This question was closely modelled on the one used in the Active Australia Survey, which has demonstrated reliability [124] and validity against accelerometer measures [125], and has been recommended for Australian population-based research [126]. The WfR variable was positively-skewed and included outlier values, which were top-coded to 840 minutes as recommended [264], equivalent to a maximum of two hours of daily walking. Exploratory analysis of WfR revealed two relatively discrete groups as previously used [307]: one reporting 0 mins of WfR in the previous week, and another reporting 1-840 mins.

Independent variable

Participants reported their gender as either male or female.

Measures of the neighbourhood social environment

Perception of social cohesion: participants were asked to respond to eight Likert-type items, ranging from strongly disagree to strongly agree, which measured perceptions of neighbourliness, trust in neighbors, shared values, and friendships and relationships with neighbours. These items closely reflect those in the Buckner Social Cohesion Scale [215], with acceptable reliability [266]. The items were submitted to a Principal Components Analysis (PCA) with Varimax rotation and combined to form a weighted linear scale (Cronbach’s alpha of 0.85).

Perception of incivilities: this was assessed through two Likert-type items that asked participants about the presence of litter or rubbish, and graffiti in the neighbourhood. The items have acceptable reliability [267] and the resultant PCA scale had a Cronbach's alpha of 0.63.

Perceptions of safety from crime: using the aforementioned approach, participants responded to six Likert-type items that asked about their neighbourhood's level of crime, whether it was a safe place for adults to walk during the day and at night, and if children were safe. The items were adapted for the Australian population from the Neighbourhood Environment Walkability Scale [268], which has acceptable reliability [187,267]. The PCA scale created from these items had a Cronbach's alpha of 0.80.

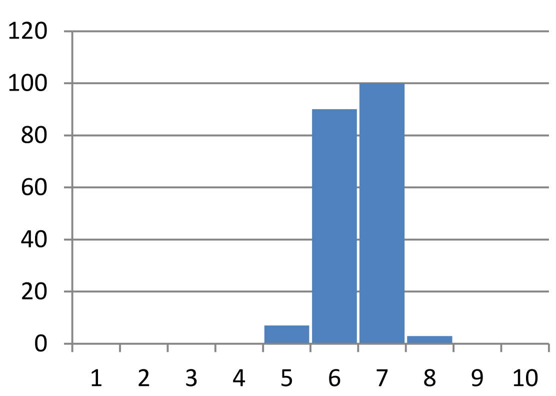
For analytic purposes, as the focus of this study was on whether different social environments (i.e. an ecological exposure) influence gender differences in WfR across neighbourhoods, neighbourhood-level perceptions of social cohesion, incivilities, and safety from crime were derived using a mean scaled score for each of the 200 neighbourhoods. An Empirical Bayes Exchangeable (EBE) estimation method was applied, producing a mean neighbourhood social environment score that accounts for the number of participants per neighbourhood, as well as the variability of the exposure within –and between– neighbourhoods [269]. This method, described in detail in previous studies [206,270], produces more precise estimates of the neighbourhood social environment than a simple aggregated mean score. Furthermore, a previously used approach considering social environment exposures as continuous measures in the statistical analyses [271] was replicated to ensure comparability between studies as recommended [181]. Therefore, the average effects can be interpreted as the likelihood of WfR for every 1 standard deviation (SD) unit increase in social environment.

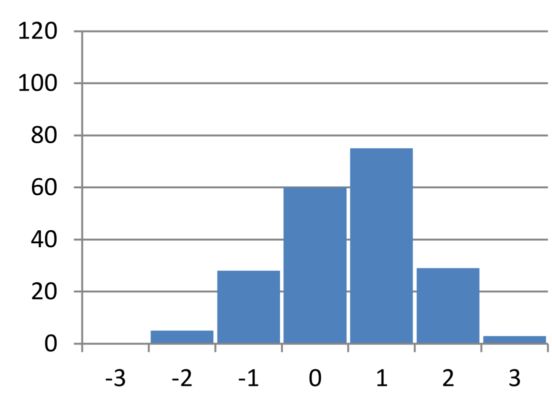
The social environment scores were operationalised in two ways. First, for descriptive purposes, the raw social environment scores of the 200 neighbourhoods were re-scaled to range from 0-10, where 10 represents the highest score on each scale (Figure 5.1). The raw scores for social cohesion across the 200 neighbourhoods ranged from 4.5 to 7.1, with a mean of 6.0 (SD 0.5); while for incivilities it ranged from 1.5 to 6.4, with a mean of 3.5 (SD 0.9); and for safety from crime it ranged from 4.4 to 7.7, with a mean of 6.2 (SD 0.6). Second, the measures were standardised for comparison, and revealed that the social environment was distributed over a relatively narrow range, with most of the neighbourhoods located within 1 standard deviation from the mean, indicating limited variation.

Figure 5.1: Distribution of social environment exposures (x axis) across the 200 HABITAT neighbourhoods (y axis)

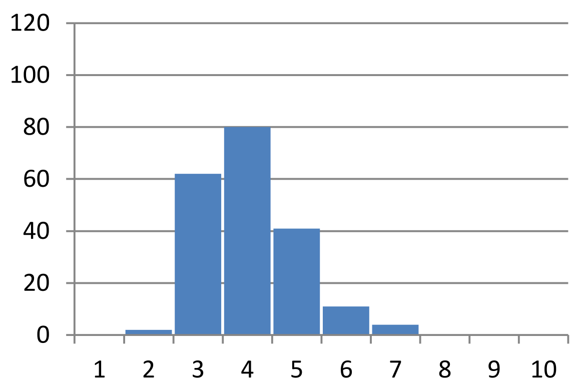
Raw scores rescaled 1-10	Standardised scores

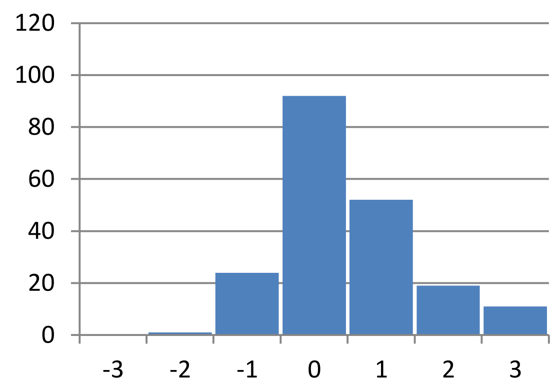
Perception of social cohesion (low to high)



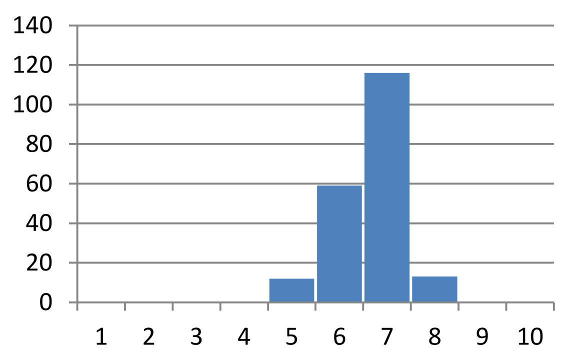


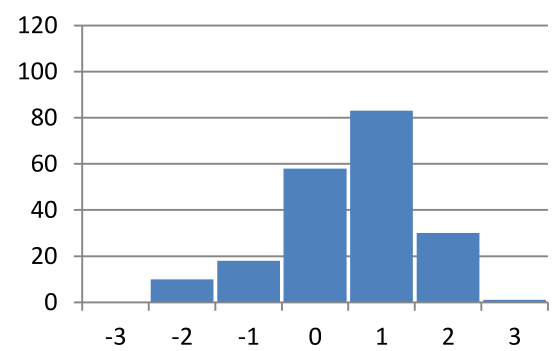
Perception of incivilities (low to high)





Perception of safety from crime (low to high)





Covariates

Participants reported their date of birth from which a year of age in 2009 was derived. The age for the analytical sample ranged from 42 to 67 years, with a mean of 53.7 years (SD 7.0).

Education: respondents provided the highest educational qualification attained, which was coded as follows: (1) bachelor degree or higher (including postgraduate diploma, master's degree, or doctorate), (2) diploma (associate or undergraduate), (3) vocational (trade or business certificate or apprenticeship), and (4) no post-school qualifications.

Occupation: respondents provided their job title, which was classified according to the Australian and New Zealand Standard Classification of Occupations (ANZSCO) [285] and recoded into five categories: (1) managers/professionals (managers and administrators, professionals and paraprofessionals); (2) white-collar employees (clerks, salespersons and personal service workers); (3) blue-collar employees (tradespersons, plant and machine operators and drivers and other labourers and related workers); (4) not in the workforce (home duties and retired); and (5) not easily classifiable (not employed, students, permanently unable to work or other category).

Household income: respondents provided an estimate of the total pre-tax annual household income through a question comprising 13 income categories. For analysis, these were re-coded into the following six categories: (1) $\geq$AU$130,000, (2) AU$129,999 – 72,800; (3) AU$72,799 – 52,000; (4) AU$51,999 – 26,000; (5) $\leq$AU$25,999; and (6) not classified (including blank responses, 'Don't know' or 'Don't want to answer').

Residential self-selection: to assess residential attitudes, participants were asked to respond to five Likert-type items at baseline (data collected in 2007), ranging from 'not at all important' to 'very important' on a number of statements regarding "How important were the following reasons for choosing your current address?". PCA with Varimax rotation identified three factors whose items had loadings of 0.50 or above, as recommended [286], and were subsequently described as 'destinations' (three items, Cronbach's alpha = 0.80) 'nature' (three items, Cronbach's alpha = 0.78) and 'family' (two items, Cronbach's alpha = 0.61).

Neighbourhood-level disadvantage: each of the 200 neighbourhoods was assigned a socioeconomic score using the Australian Bureau of Statistics' Index of Relative Socioeconomic Disadvantage (IRSD) [182]. The Index reflects each area's overall level of disadvantage based on 17 socioeconomic attributes, including education, occupation, income, unemployment, and household tenure. The derived socioeconomic scores from the HABITAT neighbourhoods were then quantised as percentiles relative to all of Brisbane [87] ranging from

1-100 (with a mean of 56.8 and SD 28.0), with lower scores denoting more disadvantaged neighbourhoods.

Statistical analyses

Of the 7,866 participants who returned a valid questionnaire in 2009, the following were excluded from the analyses: 568 (7.2%) relocated from their original neighbourhood at baseline (2007) to another address in 2009; and 162 (2.2%) were a different participant from baseline. Of the remaining 7,136 eligible participants, several had incomplete data on education (n=19), on WfR (n=199), and on residential self-selection variables (n=275), giving a total of 493 missing records (6.9% of the eligible participants). Sensitivity analyses revealed that participants who were not classified for occupation (p=0.001) or income (p=0.012) were significantly more likely to be in the missing group of 493.

A listwise deletion (rather than multiple imputation) was applied to the 493 missing records based on the following rationale: the missing data approached the recommended 5% threshold for imputation [275]; the original sample was broadly representative of the target population [262]; the efficiency gains offered by applying missing data methods (which add another layer of measurement error to the data) are often minor in large samples [276]; and the analytic sample remained large enough to address the study aims.

The final analytical sample comprised 6,643 participants nested within 200 neighbourhoods, and the demographic characteristics are presented in Table 5.1. The number of respondents per neighbourhood ranged from 8 to 99, with an average of 33 respondents (95% CI 30.6-35.8).

Table 5.1: Socio-demographic characteristics of the analytic sample by gender and minutes of recreation walked: 2009 HABITAT data

	Men			Women		
	Total	**0 mins**	**1-840 mins**	**Total**	**0 mins**	**1-840 mins**
Total (N)	**2,844**	**859**	**1,985**	**3,799**	**1,011**	**2,788**
	N	**%**	**%**	**N**	**%**	**%**
Age						
42-50 years	1,152	30.8	69.2	1,349	26.9	73.1
51-59 years	997	31.2	68.8	1,416	26.6	73.4
60-67 years	695	27.8	72.2	1,034	26.3	73.7
Education						
Bachelor degree or higher	988	24.6	75.4	1,203	23.1	76.9
Diploma/associate degree	340	25.0	75.0	421	21.4	78.6
Certificate	620	34.2	65.8	548	24.6	75.4
No post-school qualification	896	35.6	64.4	1,627	31.2	68.8
Occupation						
Professional	1,071	26.3	73.7	1,077	22.7	77.3
White collar	336	25.6	74.4	980	28.0	72.0
Blue collar	630	42.2	57.8	204	35.8	64.2
Not in workforce	506	26.1	73.9	1,055	25.4	74.6
Not easily classifiable	301	30.9	69.1	483	31.5	68.5
Income						
$130,000+	664	23.8	76.2	580	23.3	76.7
$72,800-129,999	811	27.4	72.6	889	26.5	73.5
$52,000-72,799	395	35.2	64.8	519	27.4	72.6
$26,000-51,999	465	32.9	67.1	702	25.6	74.4
Less than $25,999	234	34.2	65.8	478	34.1	65.9
Not classified	275	38.9	61.1	631	24.6	75.4

Modelling strategy

Gender was the independent variable of interest, and reference categories for analyses were non-walkers and men. Data were prepared in Stata v.14.1 [277] and analysed in *MLwiN* v.2.36 [278]. WfR was analysed as a binomial dependent variable using multilevel logistic regression through two-level random intercept Markov chain Monte Carlo (MCMC) binomial logit models (first-order marginal quasi-likelihood base estimates; burn-in=500, chain=50,000).

The modelling approach corresponded with the aims of the study. The *average neighbourhood effects* of gender differences in WfR were estimated first (adjusting for age) as shown in Equation 1, and results are reported as odds ratios (ORs) with 95% Credible Intervals (CrIs).

Equation 1:

$$\mathrm{WfR_{ij}} = \beta_{0j} + \beta_1\mathrm{gender_{ij}} + \beta_2\mathrm{age_{ij}} + \mathrm{e_{ij}} + \mathrm{u_{0j}}$$

Equation subscripts:

WfR_{ij} = walking category for resident **i** in neighbourhood **j**

β_{0j} = overall intercept (grand mean)

β_{1j} = overall slope coefficient for gender (average change across all neighbourhoods)

β_{2j} = overall slope coefficient for age (average change across all neighbourhoods)

e_{ij} = level-1 random effect (within-neighbourhood variation)

u_{0j} = level-2 random effect of the intercept (between-neighbourhood variation)

u_{ij} = level-2 random effect of the slope for gender (variation in the effect of gender on WfR across neighbourhoods)

A *random coefficient* was introduced for gender, which enabled the average neighbourhood effects of gender on the likelihood of WfR to vary across neighbourhoods. This analysis produced a neighbourhood-level random effect u_{1j} (also referred to as between-neighbourhood variation in the effect of gender on WfR), shown in Equation 2.

Equation 2:

$$\mathrm{WfR_{ij}} = \beta_{0j} + \boldsymbol{\beta_1\mathrm{gender_{ij}}} + \beta_2\mathrm{age_{ij}} + \mathrm{e_{ij}} + \mathbf{u_{1j}}$$

Further adjustment for education, occupation, household income, residential self-selection and neighbourhood disadvantage produced baseline estimates. A joint Wald test was then conducted to examine whether the effect of gender on WfR varied significantly across neighbourhoods, through assessing the null hypothesis of no between-neighbourhood variation in the likelihood of WfR for the random coefficient $(H_0\colon \sigma_{\mathrm{u01}} = \sigma^2_{\mathrm{u1}} = 0)$ [278].

The *neighbourhood-level variance functions* from the fully adjusted baseline model estimated the magnitude of between-neighbourhood variation in the probability of engaging in WfR for men and women [287]. These neighbourhood-level variance functions (which provide an indication of the gender sensitivity to the neighbourhood environment in regards to WfR), were calculated using Equation 3 (where gender = x):

Equation 3:

$$var\left(u_{0j} + u_{1j}\, x_{1ij}\right) = \sigma_{u0}^{2} + 2\sigma_{\mathrm{u01}} x_{ij} + \sigma_{\mathrm{u1}}^{2} x_{ij}^{2}.$$

The neighbourhood-level variance for men (the reference group; x=0) in the likelihood of WfR was calculated using Equation 4.

Equation 4:

$$var\left(u_{0j} + u_{1j}\, x_{1ij}\right) = var\left(u_{0j}\right) = \sigma_{u0}^{2}.$$

The neighbourhood-level variance for women (the comparison group; x=1) in the likelihood of WfR was calculated using Equation 5.

Equation 5:

$$var\left(u_{0j} + u_{1j}\, x_{1ij}\right) = var\left(u_{0j} + \mathrm{u_{1j}}\right) = \sigma_{\mathrm{u0}}^{2} + 2\sigma_{\mathrm{u01}} + \sigma_{\mathrm{u1}}^{2}$$

To assess whether differences in social environments explain neighbourhood differences in the gender-WfR relationship (i.e. whether they moderate the variation across neighbourhoods in this relationship), we followed the *Best-practice recommendations for estimating cross-level interaction effects* [288] by incorporating a *cross-level interaction* between gender at the individual-level and each of the social environment measures at the neighbourhood-level. We then assessed reductions from the baseline model in the random coefficient for gender [289].

Finally, to investigate whether differences in social environments explain the between-neighbourhood variation in WfR for men and women, we incorporated each of the social environment measures to the fully adjusted baseline model as fixed effect and assessed reductions in neighbourhood-level variance functions in the likelihood of WfR for men and for women.

5.4 RESULTS

The relationship between gender and recreational walking

The average association between gender and WfR revealed that women were more likely to walk for recreation (19% higher; OR1.19, 95% CrI 1.07-1.32) compared to men ~~(**Error! Reference source not found.**)~~.

Table 5.2 presents the results of the analytic steps addressing the aims of this study. Adjustment for additional covariates (including socio-economic position, residential self-selection and neighbourhood disadvantage) attenuated the significant average neighbourhood effects of gender differences in WfR to the null (Model 1 in Table 5.2, OR 1.12, 95% CrI 0.99-1.27).

Variation of the average gender differences in recreational walking across neighbourhoods

The Wald test of the random coefficient for gender in the baseline model (Model 1) indicated that the relationship between gender and WfR varied significantly across neighbourhoods (p-value 0.013).

Between-neighbourhood variation in the probability of recreational walking for men and women

The neighbourhood-level variance functions in the baseline model (Model 1) revealed significant between-neighbourhood variation in WfR for both men and women, although the magnitude of the variation for women was twice that of men (0.109 and 0.050 respectively).

The contribution of the social environment to explaining neighbourhood differences in the gender and walking for recreation relationship

The cross-level interaction of gender with social cohesion (Model 3) was not statistically significant, and there was no evidence that this interaction explained neighbourhood differences in the relationship between gender and WfR.

Likewise, the cross-level interaction of gender with incivilities (Model 5) was not statistically significant. However, significant main effects were observed for incivilities (OR 1.17, 95% CrI 1.04-1.32), although there was no evidence that this interaction explained neighbourhood differences in the relationship between gender and WfR.

The cross-level interaction of gender with perceptions of safety from crime (Model 7) was not statistically significant, and there was no evidence that this interaction explained neighbourhood differences in the relationship between gender and WfR.

The contribution of the social environment to explaining between-neighbourhood variation in walking for recreation for men and women

Social cohesion was not statistically associated with WfR (Model 2), and its inclusion as a fixed effect accounted for none of the between-neighbourhood variation in WfR for either men or women.

Incivilities were statistically associated with WfR (Model 4; OR 1.17, 95% CrI 1.06-1.29), although their inclusion as a fixed effect had a negligible impact in explaining the between-neighbourhood variation in WfR for either men or women.

Safety from crime was not statistically associated with WfR (Model 6), and its inclusion as a fixed effect accounted for none of the between-neighbourhood variation in WfR for either men or women.

Table 5.2: Gender differences in recreational walking, variation of this relationship across neighbourhoods, and the contribution of the social environment to explaining this variation

	Baseline		Perception of social cohesion				Perception of incivilities				Perception of safety from crime			
	M1		M2		M3		M4		M5		M6		M7	
Fixed effects [a]	OR	95% CrI	OR	95% CrI	OR	95% CrI	OR	95% CrI	OR	95% CrI	OR	95% CrI	OR	95% CrI
Men	1.00	--	1.00	--	1.00	--	1.00	--	1.00	--	1.00	--	1.00	--
Women	1.12	0.99,1.27	1.12	0.99,1.28	1.12	0.98,1.27	1.12	0.99,1.28	1.12	0.98,1.28	1.12	0.98,1.27	1.12	0.98,1.27
L2 exposure [b]	--	--	0.99	0.91,1.07	0.96	0.87,1.06	**1.17**	**1.06,1.29**	**1.17**	**1.04,1.32**	0.91	0.83,1.01	0.91	0.81,1.03
Interactions														
Males	--	--	--	--	1	--	--	--	1	--	--	--	1	--
L2*women	--	--	--	--	1.07	0.94,1.21	--	--	1.00	0.87,1.14	--	--	1.00	0.88,1.14
Random effects														
Random coefficients (s.e.) [c]														
Men	--		--		--		--		--		--		--	
Women	**0.080 (0.036)**		0.083 (0.038)		**0.081 (0.036)**		0.083 (0.036)		**0.081 (0.036)**		0.084 (0.036)		**0.082 (0.036)**	
P-value	**0.013**		0.014		**0.012**		0.011		**0.013**		0.011		**0.016**	
Variance functions (s.e.) [d]														
Men	**0.050 (0.018)**		**0.051 (0.019)**		0.050 (0.018)		**0.049 (0.017)**		0.049 (0.018)		**0.051 (0.019)**		0.051 (0.018)	
Women	**0.109 (0.025)**		**0.110 (0.025)**		0.110 (0.025)		**0.107 (0.024)**		0.107 (0.025)		**0.109 (0.025)**		0.109 (0.025)	

Note: Boldface indicates significance.
Model 1: gender differences in the likelihood of WfR (randomised at the neighbourhood level), adjusted for age, socioeconomic position (education, occupation and household income), residential self-selection and neighbourhood disadvantage.
Models 2, 4 and 6: M1 + each of the social environment measures entered into the models separately
Models 3, 5 and 7: M2, M4 & M6 + cross-level interactions of gender with each of the built environment measures
[a] Fixed effects capturing the neighbourhood average (pooled) effects of gender differences in the likelihood of WfR.
[b] L2 exposure: main effects for each level 2 environmental exposure i.e., social cohesion in M2 and M3, incivilities in M4 and M5, and safety from crime in M6 and M7.
[c] Random coefficient (with standard error) testing whether the gender differences in the likelihood of WfR are the same everywhere (reflecting the average effect) or whether the relationships vary across neighbourhoods (thus, the neighbourhood-level variance functions are reported in grey).
[d] Variance functions capturing the extent of between-neighbourhood variation in WfR for males and females (thus, the random coefficients are reported in grey).

.

5.5 DISCUSSION

Within the same capital city, gender differences in WfR seemed to vary significantly across neighbourhoods [305], although the reasons for this variation remain unknown. Since the social environments of neighbourhoods might influence (encourage or discourage) the recreational walking of women differently to men [35,47], this study investigated the contribution of the social environment to explaining gender differences in WfR across neighbourhoods.

As expected based on previous research [59,60,305], women were more likely than men to walk for recreation prior to adjustment for covariates (which attenuated the effects to the null). Further investigations revealed that men were more likely to be higher educated, in professional occupations and living in households with higher incomes, all of which has previously been associated with leisure-time PA and WfR [308,309]. On the other hand, women might spend more time in their neighbourhood, as they engage less in full-time employment [160] and more in caregiving and domestic activities compared to men [23,62,172], although these average neighbourhood effects could also partially reflect women's preference for walking rather than doing vigorous PA [30]. This evidence suggests a contextual opportunity for ecological interventions that facilitate active living and reduce the gender disparity in overall PA participation through increases in WfR.

Consistent with a previous study [305], the gender differences in WfR seemed to vary significantly across neighbourhoods, suggesting that while some neighbourhood environments might influence the WfR of men and women similarly, other environments have a differential impact. Furthermore, variation in WfR was observed between neighbourhoods for both men and women, although the magnitude of the variation for women was twice that of men. These results suggest that the neighbourhood environment might differentially shape and circumscribe the recreational walking of men and women, with women being more sensitive to environmental factors. These findings are consistent with emerging evidence across geographical settings noting stronger environmental associations in women regarding walking [164], and WfR in particular [35,60].

In this study, we investigated the contribution of the social environment (conceptualised through neighbourhood-level perceptions of social cohesion, incivilities and safety from crime) to explaining: (1) neighbourhood differences in the gender-WfR relationship; and (2) between-neighbourhood variation in WfR for men and women.

Of the social environment measures considered, only higher perceptions of incivilities were significantly related to the likelihood of WfR as a main effect in our study. This unexpected finding could be due to the likely association between incivilities and other built environment features associated with more WfR. For instance, the presence of commercial land uses might attract recreational walkers as well as graffiti and rubbish. Furthermore, regular recreational walkers may be more aware of incivilities in their local environments (i.e. same-source bias) [181].

In regards to the first aim, none of the neighbourhood-level perceptions of Brisbane's social environment produced significant cross-level interactions, nor explained neighbourhood differences in the relationship between gender and WfR. Likewise, a recent systematic review and meta-analysis of the environmental correlates of total walking did not identify any consistent moderating effects of gender [181]. However, an earlier multi-country study identified gender as a significant moderator between the perceived social environment (aesthetics and safety from crime in particular) and self-reported WfR, with women showing stronger associations than men [35]. While the evidence is inconsistent (possibly due to differences in the amount of variation in social environments across urban settings), there are indications that a more supportive social environment might be required to encourage women to walk for recreation.

Second, the present study investigated whether –and to what extent– the neighbourhood social environment explains between-neighbourhood variation in WfR for men and women. Contrary to our hypothesis, Brisbane's social environment did not noticeably reduce the neighbourhood-level variances in WfR for either men or women. Several studies exploring how men and women interact with perceived environments in regards to WfR have either noted inconsistent patterns [47] or have reported null findings [59,310]. However, perceived safety from crime was positively associated with total walking in a systematic review and meta-analysis [181]. Self-reported measures of the same neighbourhood can vary widely across individuals reflecting differences in culture and walking preferences [207], which could explain the inconsistent findings across geographical settings [181].

Given the consistency of these null findings regarding the social environment measures, we conclude that Brisbane's social environment did not seem to contribute to the gender differences in WfR observed across neighbourhoods. There are several possible reasons for these unexpected results. As observed in earlier studies [35,132], it is likely that our findings are context-specific. Cities vary widely in their cultural and structural characteristics (such as levels of welfare support, concentration of poverty and ethnic diversity) [36], and local governments shape neighbourhood environments through planning, implementation, delivery of services, infrastructure, and policies [45]. Brisbane is a medium density urban environment characterised by low crime rates and managed by a single City Council [260], located within a high income country (Australia) with well-established welfare provisions [36]. This could explain the limited variation across Brisbane's neighbourhoods –ranging from good to optimal– observed in the social environment measures. Furthermore, without Brisbane's relatively safe social environment, the observed between-neighbourhood variation of gender differences in WfR might have been larger. In contrast, urban settings characterised by extreme levels of poverty, ethnic segregation and high urban crime rates like, for instance, Chicago [209], have shown to influence levels of exercise, with stronger effects seen in women [210,211]. Our results are particularly relevant within the context of the *Brisbane Vision 2031* [80], which includes the incorporation of crime prevention through environmental design practices that facilitate active, healthy communities through safe and sustainable recreational and travel choices, including walking.

Furthermore, the gender differences in WfR observed across neighbourhoods might have been better explained through social environment measures not considered in this study, such as viewing people being active, which has previously been associated with WfR [60,132], or perhaps through built –rather than social– environment features. For instance, well-maintained pedestrian infrastructure (such as sidewalks, curbs, footpaths and recreational facilities), have previously shown associations with WfR [95,311], as have aesthetics and access to public spaces [312]. Perceived residential density, land-use mix, street connectivity, and proximity to parks were linearly associated with WfR across twelve countries [95], while residential density was the only attribute associated with WfR across four urban settings in another study [35]. The quality of recreational destinations (attractiveness of, satisfaction with, or incivilities in parks and PA facilities) was consistently associated with WfR in a review [185]. Furthermore, a gender-sensitised single-level study noted that perceived built environmental factors (such as access to shops, the presence of sidewalks, and access to recreational facilities) were more important for women in regards to WfR compared to men [60].

This study has a number of limitations. While the cross-sectional design of this study limits causal conclusions, adjustment for residential self-selection (which is rare among cross-sectional neighbourhood-based studies [93,181]), ensured more reliable estimates of the influence of environmental exposures on WfR by accounting for individual-level bias (a regular recreational walker might select a residence which facilitates their WfR), and controlled –to a certain extent– for possible reverse causation [54,69,93,181]. WfR was self-reported, which is less accurate than objective measures of walking, as it might reflect recall and/or desirability bias [109]. However, objective measures lack the contextual aspects of walking, such as its purpose and location, unless combined with Global Positioning Systems (GPS) and applied algorithms[134]. Furthermore, Likert scales (used in this study to capture perceptions of the social environment) are subject to scale perception bias (reflecting demographic, interpersonal and cross-cultural preferences), which could lead to inaccurate assumptions [207]. In addition, social environment perceptions were not specifically asked in the context of WfR, and different neighbourhood boundaries vary in relevance depending on the type of PA studied (recreational vs transport walking)[181] and across demographic populations (men vs women) [184,185]. An increased correspondence between the environmental measure, the behaviour of interest and the setting in which the behaviour takes place might produce stronger associations [44]. Finally, the limited variability in Brisbane's social environments potentially underestimated the strength of associations between the neighbourhood social environment and WfR, limiting the generalisability of findings.

Nevertheless, from an urban planning perspective, it is important to acknowledge the complexity of environmental influences on WfR. Based on previous research, women experience more individual and environmental barriers to PA participation [120,159], and the social environment appears to influence their PA more than men [23]. The marked gender disparity in PA overall participation [6,8,304] is acknowledged by WHO's related policy frameworks [14,15] which call for ecological evidence to inform gender-responsive multilevel strategies to increase PA in populations through active living opportunities.

5.6 CONCLUSION

On average, women walked more for recreation than men prior to adjustment for covariates. However, consistent with a previous investigation [305], these average associations (commonly reported in the literature) seemed to vary across neighbourhoods. In other words, neighbourhood-level factors might differentially influence the recreational walking of men and women, and women seemed more sensitive to their environments. Nonetheless, the social environment did not appear to be one of these factors in Brisbane, an urban setting where structural differences between neighbourhoods might not be as extreme as in other cities [36], hinting at other neighbourhood-level characteristics.

This study contributes to broader debates about the important role that the neighbourhood design has in facilitating the healthy lifestyle of residents who are regularly exposed to it [39,313]. As previously advocated [314], our results favour the ongoing longitudinal multilevel analyses of demographic heterogeneity around the neighbourhood averages, as they more realistically reflect the impact of neighbourhood exposures on the walking patterns of different population subgroups. Such investigations –particularly when undertaken in urban settings characterised by larger variation in their social and built environments– can inform ecological interventions which facilitate WfR opportunities everywhere for both men and women, resulting in sustainable public health, socioeconomic and environmental gains for the overall population [128], ultimately supporting the WHO's objective of a global 10% reduction in the prevalence of physical inactivity by 2025 [14] as well as the UN's Sustainable Development Goals [315].

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Chapter 6: Do differences in built environments explain age differences in transport walking across neighbourhoods?

Multilevel studies have focused on reporting the average neighbourhood effects of age differences in transport walking, implicitly assuming a similar influence of environments on the walking patterns of younger and older adults. Study 1 of this thesis observed that exposure to the same neighbourhood may have a different impact on the transport walking of younger adults compared to older adults. This chapter presents the manuscript for Study 3 of this thesis, an ecological cross-sectional investigation which extends the research undertaken in Study 1 through assessing the contribution of the neighbourhood built environment to explaining the observed age differences in WfT across neighbourhoods.

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What follows is the last submitted version of this manuscript.

6.1 ABSTRACT

Background: The neighbourhood built environment (BE) provides opportunities for regular walking for transport (WfT). Within the same city, age differences in WfT might vary significantly across neighbourhoods, although little is known about the reasons for this variation. This cross-sectional study investigated the contribution of the BE to explaining age differences in WfT across neighbourhoods.

Methods: This investigation used baseline (2007) data from the How Areas in Brisbane Influence HealTh and AcTivity (HABITAT) study. The sample included 11,035 residents aged 40-65 years living in 200 neighbourhoods in Brisbane, Australia (68.4% response rate). Self-reported weekly minutes of WfT were categorised into none (0 mins) and any (1-840 mins); age was categorised into 40-48, 49-57 and 58-65 years. Objectively assessed neighbourhood-level measures of the BE included residential density, street connectivity and land-use mix. Analyses involved multilevel binomial logistic regression with age as main predictor, adjusting for gender, socioeconomic position, residential self-selection, and neighbourhood disadvantage. Fixed effects estimated the average age-WfT relationship; random coefficients (RC) for age assessed whether these averages varied across neighbourhoods; neighbourhood variances (NV) estimated the magnitude of the between-neighbourhood variation in WfT for each age group; reductions in RC post-inclusion of cross-level interactions assessed the BE in explaining neighbourhood differences in the age-WfT relationship; and reductions in NV post-inclusion of BE as fixed effects assessed the BE in explaining between-neighbourhood variation in WfT for each age group.

Results: On average, older adults were significantly less likely to walk for transport. Age differences in WfT seemed to vary significantly across neighbourhoods, and the magnitude of the variation for older groups was twice that of their younger counterparts. The environmental measures analysed played a relatively limited role in explaining neighbourhood differences in the age-WfT relationship. Residential density and street connectivity explained up to 13% and 9% respectively of the observed between-neighbourhood variation in WfT across age groups.

Conclusion: Neighbourhood-level factors seemed to influence the WfT of younger and older adults differently, with older adults being more sensitive to their neighbourhood environment. In Brisbane, age differences in WfT were smaller in areas with higher residential density and street connectivity. These results favour the ongoing investigation of demographic heterogeneity around neighbourhood averages in other urban contexts to inform tailored ecological interventions that facilitate WfT for all age groups everywhere, supporting active ageing communities.

6.2 INTRODUCTION

Age is a consistent predictor of physical activity (PA), with older adults being less active than their younger counterparts [5]. Walking is the most common and preferred form of PA among older adults [29,167], whereas young adults are more likely to participate in vigorous-intensity PA [8]. Regular walking contributes to daily energy expenditure [96], reducing or postponing morbidity and mortality from non-communicable diseases [31,32].

Walking for transport (WfT) is undertaken with the purpose of reaching a destination such as work, the shops or public transit [18]. As an alternative to vehicular transportation, walking has synergistic co-benefits across several portfolios (health, transport, community and environment) [316] and contributes to overall PA levels in populations, particularly in older adults [76]. Seniors are likely to experience greater benefits from shifting to WfT than their younger counterparts, since it facilitates their independent living by enabling access to commercial and health services, as well as community life and opportunities for social interaction [74], which might translate into better health [317]. Therefore, the design of neighbourhoods can potentially reduce age disparities in overall PA participation through the incorporation of incidental WfT into daily routines, which has implications for health equity and social justice [128].

Active transportation is a component of active ageing, acknowledged within the social-ecological perspective underpinning the World Health Organization's *Global age-friendly cities* [16]. This framework highlights the dynamic interactions between individuals and the environment in which they live, and calls for research-based evidence to inform the necessary environmental modifications that ensures elder-friendly communities which are likely to extend the health and quality of life in older age [16,33,318]. This includes the identification of the key design elements of neighbourhoods that might delay age-related declines in WfT [58].

The built environment comprises the neighbourhood's physical features, such as pedestrian infrastructure or street lighting, and has stronger associations with WfT compared with other types of PA, including recreational walking [93]. In particular, greater residential density, street connectivity and land-use mix, (common features which characterises pedestrian-friendly neighbourhoods), are consistently associated with WfT in adults [93] and seniors [76,203]. Higher residential density also facilitates the mixed use of land (which provides a range of destinations to walk to) as well as access to public transport, while greater street connectivity facilitates transport walking by providing direct routes to destinations [295].

Previous multilevel research observed that WfT varies with age, with older adults less likely to walk for transport than their younger counterparts [58,165], possibly reflecting changes in occupational status such as retirement [166]. This evidence suggests that this is a critical life-stage for promoting transport walking[167], particularly since shopping seems the most common reason for older adults leaving their homes[169]. Further evidence is required to improve current understanding of the relationship between built environments and WfT among older adults [43].

To date, most neighbourhood-based studies have presented the overall (average) association between age and WfT [76], overlooking the possibility that this relationship differs depending on the characteristics of neighbourhood environments. However, a previous investigation revealed that the effect of age on WfT varied significantly across neighbourhoods [305], suggesting that the overall relationship was not necessarily reflective of the association within any particular neighbourhood. Moreover, the overall effect was potentially obfuscating important information about how neighbourhoods differentially influence the WfT of younger and older adults.

A few studies have explored age as a moderator of the relationship between the built environment and WfT [64,65,246], with two investigations revealing that neighbourhoods with greater land-use mix may delay the decline in WfT across time [64,65]. These results suggest that a supportive built environment might be required to encourage older adults to walk more for transport. While physical function declines with age [49] and living spaces appear to shrink in older age [319], pedestrian-friendly neighbourhoods (characterised by higher density, street connectivity and land-use mix), may generate smaller age differences in WfT, since such features are conducive to walking for all age groups. In contrast, unfavourable environments for WfT (with less residential density, fewer street intersections and low land-use mix) may produce larger age disparities in WfT, accelerating the decline of the physical and cognitive functions in older adults as a result of walking less for transport. Therefore, the impact of the neighbourhood built environment on a person's probability of WfT might depend on their age. In other words, age differences in WfT might be moderated by the built environment (one that varies only between-neighbourhoods).

Furthermore, between-neighbourhood variation of age differences in WfT might be attributed to age-specific sensitivity to environmental characteristics, reflecting the fact that younger and older adults might experience –and engage with– their local environments in distinct ways [62]. Thus, it is plausible that the built environment of a neighbourhood might have a stronger influence on the transport walking of older adults compared to their younger counterparts, due to the increasing multiple physical and social limitations associated with ageing [64,132].

Consistent with the principles of social-ecological models, which posit dynamic interrelations across multiple levels of influence [306], this study investigates the contribution of three commonly reported built environment measures (i.e. residential density, street connectivity and land-use mix) to explaining: (1) neighbourhood differences in the age-WfT relationship; and (2) between-neighbourhood variation in WfT for different age groups. The first question examines whether the effect of age on WfT varied significantly across neighbourhoods, suggesting that the overall relationship is not necessarily reflective of the association within any particular neighbourhood. The second question examines whether age differences in WfT might be moderated by the built environment (a relationship that varies only between-neighbourhoods).

6.3 METHODS

Study design and data collection

This investigation used data from the first wave (collected in 2007) of the How Areas in Brisbane Influence HealTh and AcTivity (HABITAT) multilevel study of mid-age adults living in Brisbane (Australia). HABITAT is underpinned by a social-ecological framework, which facilitates the investigation of the relative contributions of environmental, social, psychological and socio-demographic factors on PA patterns. Details of HABITAT's sampling design have been published elsewhere [87]. Briefly, a multi-stage probability sampling design was used to select a stratified random sample (n=200) of Census Collection Districts (CCDs), or ‘neighbourhoods’, with a random sample of people aged 40–65 years from each CCD subsequently selected (85 persons on average). These neighbourhoods varied in area size (mean 878,659 m^2 with a standard error 387,408 m^2, ranging from 19,970 m^2 to 70,673,182 m^2) and topology. Eligible participants were mailed a survey between May and July of 2007 using a method developed by Dillman [263]. Of the 16,127 in-scope participants, 11,035 valid responses (68.4%) were received in 2007. The baseline sample was broadly representative of the Brisbane population [262]. The HABITAT Study received ethical clearance from the Queensland University of Technology Human Research Ethics Committee (Ref. No. 3967H & 1300000161).

Measures

Outcome variable

Walking for transport (WfT): a single question asked participants to report the total time (converted to minutes) spent WfT (i.e. travelling to and from work, to do errands, or to go from place to place) in the previous week. Respondents were instructed to exclude any time spent walking for exercise or recreation when answering this question.

The WfT variable was positively-skewed and included outlier values, which were top-coded to 840 minutes as recommended [264], equivalent to a maximum of two hours of daily walking. As in an earlier HABITAT Study [58], exploratory analysis of WfT revealed two relatively discrete groups: one reporting 0 mins of WfT in the previous week (representing 65% of the sample), and another reporting 1-840 mins. Previous research noted that even small amounts of WfT, (which supports the use of a 1-840 mins category) might contribute to meeting the recommended levels of PA [283] (currently endorsing at least 150 mins of moderate intensity PA per week [91]).

Independent variable

Participants reported their date of birth, from which a year of age in 2007 was derived, and subsequently coded into three age categories: 40-48 years; 49-57 years and 58-65 years. These categories were chosen to explore how particular pre-retirement age subgroups in Australia [320] differed in their WfT. Furthermore, the 65 years cut off also corresponds with the Australian physical activity guidelines for adults aged 65 years and over [122].

Measures of the neighbourhood built environment

The selection of built environment measures was based on previous multilevel research which has identified residential density, street connectivity and land-use mix as important for WfT among older adults [76,203,321]. The three built environment measures examined in this investigation were derived from data supplied by the Brisbane City Council (the local government responsible for the geographical area covered by the HABITAT Study), and MapInfo StreetPro [272].

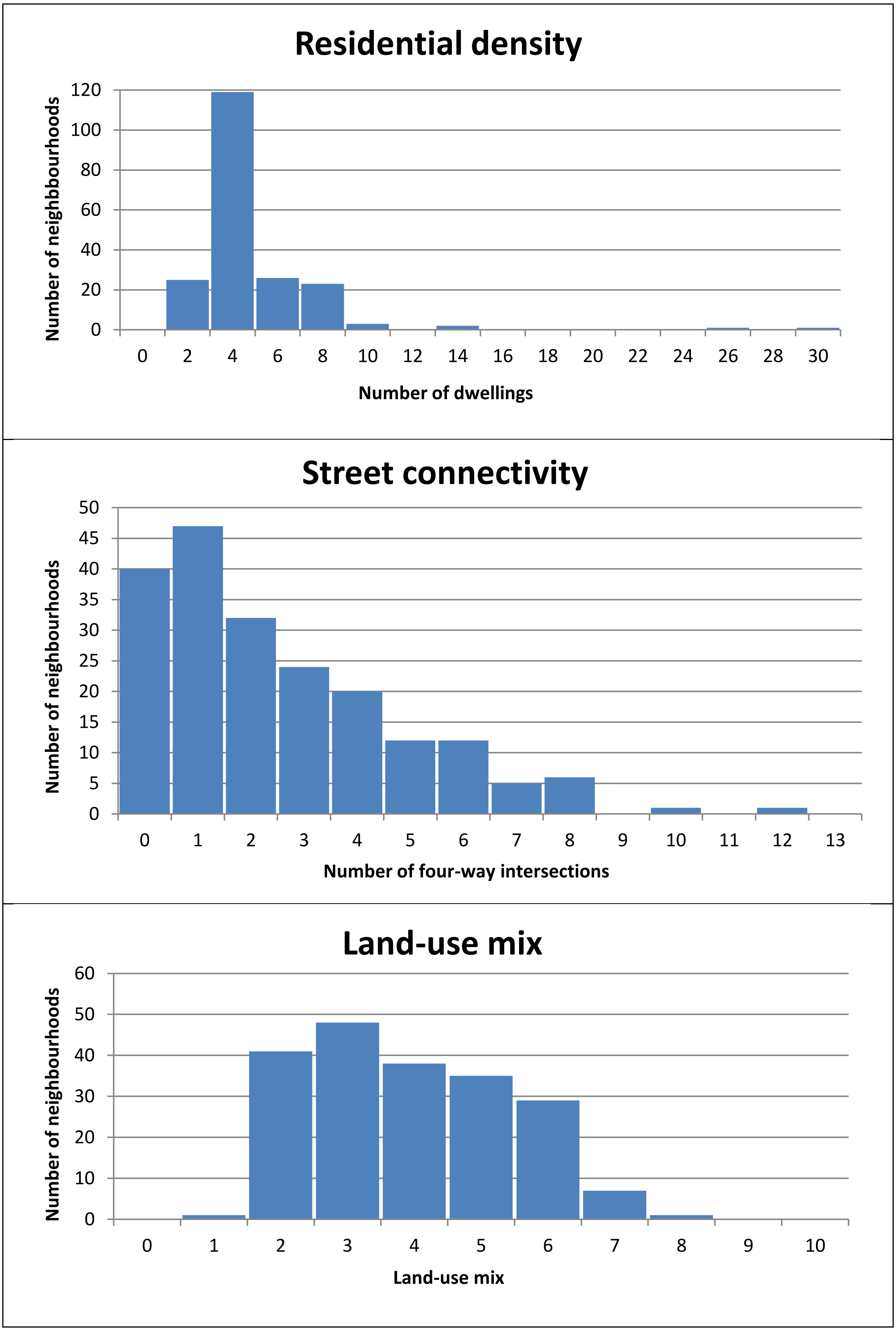
As recommended to ensure comparability between studies [181,273], continuous spatial measures of the built environment were developed for each of the 200 HABITAT neighbourhoods for overlaying on survey responses [93] using ArcMap [274]. **Error! Reference source not found.** provides further details on the built environment measures used in the analyses.

Table 6.1: Built environment measures

Measure	Definition	Formula	Unit of measurement	Summary post-transformation	Source of the data
Residential density	Measured by calculating the number of dwellings per hectare of residential land within the CCD in which the participant resided at the time of data collection	Sum of number of dwellings / Sum of the shape area in m^2 / 10000	For ease of interpretability, residential density was divided by 5, such that the coefficient could be interpreted as the likelihood of WfT for a 5 dwelling increase.	Range 0.04-28.85, mean 3.87 (SD 3.05)	Brisbane City Council Land Use Activity Database (LUAD)
Street connectivity	Measured through a count of the number of four-way or more intersections within each of the CCDs	Count of four or more street intersections.	The number of four-way or more intersections.	Range 0-12, mean 2.5 (SD 2.3)	Pitney Bowes StreetPro (2007). PSMA Street Network (August 2016)
Land-use mix	Derived as the balance of five land-use codes (retail, office, social service, recreation and residential) that quantified the proportion of land area within a CCD, using an entropy equation described previously [253]. This entropy score ranged from 0 to 1, with 0 representing complete homogeneity of land use within the CCD, and 1 indicating an even distribution of the five types of land-use.	$-\frac{\sum_k (p_{k \ln p_k)}}{\ln N}$	For ease of interpretability, the land-use mix variable was multiplied by 10, so that the coefficient could be interpreted as a 10% increase in land-use mix.	Entropy scores range 0.91-7.96, mean 3.46 (SD 1.49)	Brisbane City Council Cadastre

An exploration of Brisbane neighbourhoods (Figure 6.1) revealed that the built environment measures were positively-skewed and distributed over a relatively wide range (where 0 represents the lowest residential density, street connectivity and land-use mix), particularly for street connectivity and land-use mix.

Figure 6.1: Distribution of built environment exposures across the 200 HABITAT neighbourhoods



Covariates

Gender: participants reported their gender as either male or female.

Education: respondents provided the highest educational qualification attained, which was coded as follows: (1) bachelor degree or higher (including postgraduate diploma, master's degree, or doctorate), (2) diploma (associate or undergraduate), (3) vocational (trade or business certificate or apprenticeship), and (4) no post-school qualifications.

Occupation: respondents provided their job title, which was classified according to the Australian and New Zealand Standard Classification of Occupations (ANZSCO) [285] and recoded into five categories: (1) managers/professionals (managers and administrators, professionals and paraprofessionals); (2) white-collar employees (clerks, salespersons and personal service workers); (3) blue-collar employees (tradespersons, plant and machine operators and drivers and other labourers and related workers); (4) not in the workforce (home duties and retired); and (5) not easily classifiable (not employed, students, permanently unable to work or other category).

Household income: respondents provided an estimate of the total pre-tax annual household income through a question comprising 13 income categories. For analysis, these were re-coded into the following six categories: (1) $\geq$AU\$130,000, (2) AU\$129,999 – 72,800; (3) AU\$72,799 – 52,000; (4) AU\$51,999 – 26,000; (5) $\leq$AU\$25,999; and (6) not classified (including blank responses, 'Don't know' or 'Don't want to answer').

Residential self-selection: to assess residential attitudes, participants were asked to respond to five Likert-type items in 2007, ranging from 'not at all important' to 'very important' on a number of statements regarding 'How important were the following reasons for choosing your current address?'. Principal components analysis (PCA) with Varimax rotation identified three factors composed of items relevant for controlling for WfT self-selection with loadings of 0.50 or above, as recommended [286]. These were subsequently described as follows:

- 'destinations' (three items: ease of walking to places; closeness to public transport; and wanted to live close to shops, Cronbach's alpha = 0.80);
- 'nature' (three items: near to green-space or bushland; closeness to open space (e.g. parks); and closeness to recreational facilities, Cronbach's alpha = 0.78); and
- 'family' (two items: closeness to schools; and closeness to childcare, Cronbach's alpha = 0.62).

Neighbourhood-level disadvantage: each of the 200 neighbourhoods was assigned a socioeconomic score using the Australian Bureau of Statistics' Index of Relative Socioeconomic Disadvantage (IRSD) [182]. The Index reflects each area's overall level of disadvantage based on 17 socioeconomic attributes, including education, occupation, income, unemployment, and household tenure. The derived socioeconomic scores from the HABITAT neighbourhoods were then quantised as percentiles, relative to all of Brisbane [87] ranging from 1-100 (with a mean of 57.2 and SD 28.1), with lower scores denoting more disadvantaged neighbourhoods.

Statistical analyses

Of the 11,035 participants who returned a valid questionnaire in 2007, the following were excluded from the analyses: 47 had incomplete data for education, 178 had incomplete data for the outcome variable (WfT), and 460 had incomplete data for the residential self-selection variables, giving a total of 684 missing records (6.2% of the eligible participants). Sensitivity analyses revealed that participants who were blue collar (p=0.001), not classified for occupation (p=0.000) and not classified for income (p=0.013) were significantly more likely to be in the missing group of 684.

A listwise deletion (rather than multiple imputation) was applied to the 684 missing records based on the following rationale: the missing data approached the recommended 5% threshold for imputation [275]; the original sample was broadly representative of the targeted population [262]; the efficiency gains offered by applying missing data methods (which add another layer of measurement error to the data) are often minor in large samples [276]; and the analytic sample remained large enough to address the study objectives.

The final analytical sample comprised 10,350 participants nested within 200 neighbourhoods, and the demographic characteristics are presented in Table 6.3. The number of respondents per neighbourhood ranged from 11 to 151, with an average of 52 respondents (95% CI 48.0-55.5).

Table 6.2: Socio-demographic characteristics of the analytic sample by age group and minutes of transport walked: 2007 HABITAT data

	40-48 years		49-57 years		58-65 years	
	0 mins	**1-840 mins**	**0 mins**	**1-840 mins**	**0 mins**	**1-840mins**
Total (N)	**2,598**	**1,580**	**2,463**	**1,288**	**1,667**	**754**
	%	%	%	%	%	%
Gender						
Men	61.3	38.7	64.0	36.0	68.6	31.4
Women	63.0	37.0	66.9	33.1	69.1	30.9
Education						
Bachelor degree or higher	53.6	46.4	57.8	42.2	60.1	39.9
Diploma/associate degree	63.6	36.4	61.2	38.8	67.7	32.3
Certificate	67.3	32.7	69.9	30.1	72.0	28.0
No post-school qualification	67.9	32.1	72.0	28.0	72.2	27.8
Occupation						
Professional	59.3	40.7	62.8	37.2	66.0	34.0
White collar	61.6	38.4	64.3	35.7	69.6	30.4
Blue collar	71.4	28.6	74.9	25.1	76.3	23.7
Not in workforce	62.1	37.9	68.7	31.3	69.5	30.5
Not easily classifiable	60.2	39.8	61.9	38.1	62.7	37.3
Income						
$130,000+	62.3	37.7	65.6	34.4	70.2	29.8
$72,800-129,999	61.7	38.3	65.2	34.8	64.9	35.1
$52,000-72,799	58.6	41.4	64.7	35.3	69.7	30.3
$26,000-51,999	63.1	36.9	66.0	34.0	69.8	30.2
Less than $25,999	57.8	42.2	60.2	39.8	66.4	33.6
Not classified	68.6	31.4	70.2	29.8	72.8	27.2

Modelling strategy

Age was the independent variable of interest, and reference categories for analyses were non-walkers and the youngest age group (40-48 years). Data were prepared in Stata v.14.1 [277] and analysed in *MLwiN* v.2.36 [278]. WfT was analysed as a binomial dependent variable using multilevel logistic regression through two-level random intercept Markov chain Monte Carlo (MCMC) binomial logit models (first-order marginal quasi-likelihood base estimates; burn-in=500, chain=50,000).

The modelling approach corresponded with the aims of the study. The *average neighbourhood effects* of age differences in WfT were estimated first (adjusting for gender) as shown in Equation 1, and results are reported as odds ratios (ORs) with 95% Credible Intervals (CrIs).

Equation 1:

$$\mathrm{WfT_{ij}} = \beta_{0j} + \beta_1 \mathrm{age_{ij}} + \beta_2 \mathrm{gender_{ij}} + \mathrm{e_{ij}} + \mathrm{u_{0j}}$$

Equation subscripts:

WfT_{ij} = walking category for resident **i** in neighbourhood **j**

β_{0j} = overall intercept (grand mean)

β_{1j} = overall slope coefficient for age (average change across all neighbourhoods)

β_{2j} = overall slope coefficient for gender (average change across all neighbourhoods)

e_{ij} = level-1 random effect (within-neighbourhood variation)

u_{0j} = level-2 random effect of the intercept (between-neighbourhood variation)

u_{ij} = level-2 random effect of the slope for age (variation in the effect of age on WfT across neighbourhoods)

A *random coefficient* was introduced for each age group, which enabled the average neighbourhood effects of age on the likelihood of WfT to vary across neighbourhoods. This analysis produced a neighbourhood-level random effect u_{1j} (also referred to as between-neighbourhood variation in the effect of age on WfT), shown in Equation 2.

Equation 2:

$$\mathrm{WfT_{ij}} = \beta_{0j} + \boldsymbol{\beta_1 \mathrm{age_{ij}}} + \beta_2 \mathrm{gender_{ij}} + \mathrm{e_{ij}} + \mathbf{u_{1j}}$$

Further adjustment for education, occupation, household income, residential self-selection and neighbourhood disadvantage produced baseline estimates. A joint Wald test was then conducted to examine whether the effect of age on WfT varied significantly across neighbourhoods, through assessing the null hypothesis of no between-neighbourhood variation in the likelihood of WfT for the random coefficient

$(H_0\colon \sigma_{u01} = \sigma^2_{u1} = 0)$ [278].

The *neighbourhood-level variance functions* from the fully adjusted baseline model estimated the magnitude of between-neighbourhood variation in the probability of engaging in WfT for each age group [287]. These neighbourhood-level variance functions (which provide an indication of the age sensitivity to the neighbourhood environment in regards to WfT), were calculated using Equation 3 (where age = x):

Equation 3:

$$var(u_{0j} + u_{1j}\, x_{1ij}) = \sigma^2_{u0} + 2\sigma_{u01} x_{ij} + \sigma^2_{u1} x^2_{ij}.$$

The neighbourhood-level variance for adults aged 40-48 years (the reference group; x=0) in the likelihood of WfT was calculated using Equation 4.

Equation 4:

$$var(u_{0j} + u_{1j}\, x_{1ij}) = var(u_{0j}) = \sigma^2_{u0}.$$

The neighbourhood-level variance for adults aged 49-57 years (comparison group 1; x=1) in the likelihood of WfT was calculated using Equation 5.

Equation 5:

$$var(u_{0j} + u_{1j}\, x_{1ij}) = var(u_{0j} + \mathrm{u_{1j}}) = \sigma^2_{\mathrm{u0}} + 2\sigma_{\mathrm{u01}} + \sigma^2_{\mathrm{u1}}.$$

The neighbourhood-level variance for adults aged 58-65 years (comparison group 2; x=2) in the likelihood of WfT was calculated using Equation 6.

Equation 6:

$$var(u_{0j} + u_{1j}\, x_{1ij}) = var(u_{0j} + \mathrm{u_{1j}}) = \sigma^2_{\mathrm{u0}} + 2\sigma_{\mathrm{u12}} + \sigma^2_{\mathrm{u2}}.$$

To assess whether differences in built environments (i.e. residential density, street connectivity and land-use mix) explain neighbourhood differences in the age-WfT relationship (i.e. whether they moderate the variation across neighbourhoods in this relationship), we followed the *Best-practice recommendations for estimating cross-level interaction effects* [288], by incorporating a *cross-level interaction* between age at the individual-level and each of the built environment measures considered at the neighbourhood-level. We then assessed reductions from the fully adjusted baseline model in the random coefficients for age as recommended [289].

Finally, to investigate whether differences in built environments explain the between-neighbourhood variation in WfT for younger and older adults, we incorporated each of the built environment measures to the fully adjusted baseline model as fixed-effects and assessed reductions in neighbourhood-level variance functions in the likelihood of WfT for each age group.

6.4 RESULTS

The relationship between age and transport walking

The average association between age and WfT revealed that older age groups were less likely to walk for transport, and this was a graded association: 16% lower, (OR 0.84, 95% CrI 0.77-0.93) for those aged 49-57 years; and 27% lower, (OR 0.73, 95% CrI 0.65-0.82) for those aged 58-65 years, compared to the youngest age group (40-48 years).

Table 6.3 presents the results of the analytic steps addressing the aims of this study. The relationship between age and WfT remained statistically significant after adjustment for additional covariates, including socio-economic position, residential self-selection and neighbourhood disadvantage (Model 1 in Table 6.3; 0.82, 95% CrI 0.73-0.92 for those aged 49-57 years and 0.72, 95% CrI 0.63-0.83 for those aged 58-65 years).

Variation of the average age differences in transport walking across neighbourhoods

The Wald Test (Model 1) indicated that the relationship between age and WfT varied significantly across neighbourhoods for the 49-57 and 58-65 year olds, compared with those aged 40-48 years (p=0.006). These results suggest that the average relationship between age and WfT differed depending on the characteristics of the neighbourhood environments within which individuals resided.

Between-neighbourhood variation in the probability of transport walking for each age group

The neighbourhood-level variance functions in the baseline model (Model 1) revealed significant between-neighbourhood variation in the likelihood of WfT for each age group, although the magnitude of the variation for the two older groups (0.271 and 0.261 respectively) was twice that of the youngest group (0.132). These results suggest that older adults might be more sensitive to their neighbourhood environments in regards to WfT.

The contribution of the built environment to explaining neighbourhood differences in the age and walking for transport relationship

There were significant cross-level interactions between the older age groups and residential density (Model 3), indicating that each age-groups' propensity to walk for transport was differently influenced by the level of density in the neighbourhood environment. The addition of the cross-level interaction reduced the random coefficients by 4.4% for both the 49-57 and 58-65 year olds, suggesting that residential density explained a small part of the neighbourhood differences in the relationship between age and WfT.

The cross-level interaction between age and street connectivity (Model 5) did not approach significance. The addition of the cross-level interaction reduced the random coefficient by 3.5% for the 49-57 year olds only.

Likewise, the cross-level interaction between age and land-use mix (Model 7) did not approach significance. The addition of the cross-level interaction reduced the random coefficient by 1.8% for the 49-57 year olds only.

The contribution of the built environment to explaining between-neighbourhood variation in walking for transport for each age group

There was a significant relationship between residential density and WfT (Model 2); residents living in denser neighbourhoods were more likely to report waking for transport in the previous week. The inclusion of residential density as a fixed effect accounted for a small proportion of the between-neighbourhood variation in WfT for each of the age groups: 1.5%, 9.6%, and 13.4% for those aged 40-48, 49-57, and 58-65 years respectively.

Likewise, there was a significant relationship between street connectivity and WfT (Model 4); residents living in more connected neighbourhoods were more likely to report waking for transport in the previous week. The inclusion of street connectivity as a fixed effect accounted for a small proportion of the between-neighbourhood variation in WfT for each of the age groups: 5.3%, 8.5%, and 6.5% for those aged 40-48, 49-57, and 58-65 respectively.

The relationship between land-use mix and WfT (Model 6) did not approach significance. The inclusion of land-use mix as a fixed effect did not explain the between-neighbourhood variation in WfT for any of the age groups.

Table 6.3: Age differences in transport walking, variation of this relationship across neighbourhoods, and the contribution of the built environment to explaining this variation

	Baseline		**Residential density**				**Street connectivity**				**Land-use mix**			
	M1		M2		M3		M4		M5		M6		M7	
Fixed effects [a]	OR	95% CrI	OR	95% CrI	OR	95% CrI	OR	95% CrI	OR	95% CrI	OR	95% CrI	OR	95% CrI
40-48 years	1.00	--	1.00	--	1.00	--	1.00	--	1.00	--	1.00	--	1.00	--
49-57 years	**0.82**	**0.73,0.92**	**0.82**	**0.73,0.91**	**0.72**	**0.60,0.86**	**0.82**	**0.73,0.92**	**0.75**	**0.64,0.88**	**0.82**	**0.73,0.92**	**0.67**	**0.50,0.91**
58-65 years	**0.72**	**0.63,0.83**	**0.72**	**0.63,0.82**	**0.59**	**0.49,0.72**	**0.73**	**0.64,0.83**	**0.69**	**0.57,0.82**	**0.72**	**0.63,0.83**	**0.63**	**0.45,0.90**
L2 exposure [b]	--	--	**1.05**	**1.02,1.08**	1.02	0.99,1.06	**1.05**	**1.02,1.09**	**1.04**	**1.00,1.08**	1.00	0.95,1.05	0.98	0.92,1.04
Interactions														
40-48	--	--	--	--	1	--	--	--	1	--	--	--	1	--
L2*49-57	--	--	--	--	**1.04**	**1.00,1.08**	--	--	1.04	0.99,1.09	--	--	1.06	0.98,1.14
L2*58-65	--	--	--	--	**1.06**	**1.01,1.10**	--	--	1.02	0.97,1.08	--	--	1.04	0.95,1.13
Random effects														
Random coefficients (s.e.) [c]														
40-48 years	--		--		--		--		--		--		--	
49-57 years	**0.113 (0.038)**		0.110 (0.039)		**0.108 (0.036)**		0.117 (0.041)		**0.109 (0.039)**		0.112 (0.039)		**0.111 (0.037)**	
58-65 years	**0.114 (0.041)**		0.112 (0.042)		**0.109 (0.040)**		0.114 (0.043)		**0.115 (0.043)**		0.113 (0.044)		**0.116 (0.042)**	
P-value	**0.006**		0.009		**0.007**		0.007		**0.012**		0.010		**0.006**	
Variance functions (s.e.) [d]														
40-48 years	**0.132 (0.034)**		**0.130 (0.035)**		0.130 (0.035)		**0.125 (0.034)**		0.124 (0.034)		**0.135 (0.035)**		0.133 (0.034)	
49-57 years	**0.271 (0.051)**		**0.245 (0.046)**		0.247 (0.048)		**0.248 (0.047)**		0.245 (0.047)		**0.274 (0.051)**		0.273 (0.051)	
58-65 years	**0.261 (0.055)**		**0.226 (0.048)**		0.229 (0.049)		**0.244 (0.051)**		0.248 (0.053)		**0.262 (0.056)**		0.264 (0.055)	

Note: Boldface indicates significance.
Model 1: age differences in WfT (randomised at the neighbourhood level), adjusted for gender, socioeconomic position (education, occupation and household income), residential self-selection and neighbourhood disadvantage.
Models 2, 4 and 6 = M1 + each of the built environment measures entered into the models separately
Models 3, 5 and 7 = M2, M4 & M6 + cross-level interactions of age with each of the built environment measures
[a] Fixed effects capturing the neighbourhood average (pooled) effects of age differences in the likelihood of WfT.
[b] L2 exposure: main effects for each level 2 environmental exposure i.e., residential density in M2 and M3, street connectivity in M4 and M5, and land use mix in M6 and M7.
[c] Random coefficients (with standard error) testing whether the age differences in the likelihood of WfT are the same everywhere (reflecting the average effect) or whether the relationships vary across neighbourhoods (thus, the neighbourhood-level variance functions are reported in grey).
[d] Variance functions capturing the extent of between-neighbourhood variation in WfT for each age group (thus, the random coefficients are reported in grey).

6.5 DISCUSSION

Within the same capital city, age differences in WfT might vary significantly across neighbourhoods [305], although the reasons for this variation remain unknown. Since the built environment of neighbourhoods might influence (encourage or discourage) the transport walking of older adults differently than their younger counterparts [64,65], this study investigated the contribution of the built environment to explaining age differences in WfT across neighbourhoods.

As expected based on previous research [53,56-58,165,305], older adults were less likely to walk for transport than their younger counterparts. The time around retirement has been identified as a critical life-stage for promoting active ageing through walking [127]. Previous longitudinal studies observed post-retirement decreases in WfT [58,168], as well as increases in time spent watching television [168], indicating that WfT in pre-retirement is not being replaced with WfT in other contexts (e.g. walking to the shops) in post-retirement [168]. This evidence suggests a contextual opportunity for ecological interventions around retirement age that facilitate incidental WfT.

Consistent with a previous study [305], age differences in WfT seemed to vary significantly across neighbourhoods within Brisbane, suggesting that while some neighbourhood environments might influence younger and older adults similarly, other environments might have a differential impact on WfT. Furthermore, variation in WfT was observed between neighbourhoods for each age group, although the magnitude of the variation for older adults was twice that of their younger counterparts. These results suggest that the neighbourhood environment might differentially shape and circumscribe the transport walking of younger and older adults, with older adults being more sensitive to environmental factors. These findings are consistent with emerging evidence across geographical settings, noting that the built environment might be more relevant for older adults in regards to WfT [64,76,132], as they might be more susceptible to physical barriers because of functional limitations [64,132]. Older adults also spend more time in their neighbourhood, compared to their younger counterparts [319], which suggests an opportunity for built environment interventions that facilitate active ageing in place, and reduce the age disparity in overall PA participation through increases in WfT.

In this study, we investigated the contribution of the built environment (objectively measured using residential density, street connectivity and land-use mix) to explaining: (1) neighbourhood differences in the age-WfT relationship; and (2) between-neighbourhood variation in WfT for different age groups.

First, consistent with previous literature[76,93,203], higher residential density and street connectivity were significantly associated with the likelihood of WfT in our sample, although land-use mix was not. However, only residential density moderated the relationship between age and WfT, with older groups being more affected by residential density in their likelihood of WfT. Therefore, higher residential density might be required to encourage older adults to walk for transport, a finding consistent with emerging research noting age as a potential moderator influencing the strength of the relationship between the environment and WfT [64,65,246]. The cross-level interaction models of age with each of the built environment measures marginally reduced the baseline random coefficients, suggesting that the built environment played a relatively limited role in explaining neighbourhood differences in the age-WfT relationship. Likewise, no consistent moderating effects of age were reported by a recent systematic review and meta-analysis of the environmental correlates of total walking in older adults [181].

Second, the present study investigated whether –and to what extent– three common measures of the neighbourhood built environment explained between-neighbourhood variation in WfT for younger and older adults. As hypothesised, residential density and street connectivity partially explained between-neighbourhood variation in WfT for each age group, particularly for older adults. This is consistent with a recent review and meta-analysis of active travel in older adults, noting that self-reported WfT was positively associated with both objective and perceived residential density and street connectivity [76]. Contrary to our hypothesis (and the above mentioned meta-analysis, which noted that WfT was positively associated with objective and perceived land-use mix [76]), objective land-use mix in our study did not noticeably attenuate the observed between-neighbourhood variation for any of the age groups.

There are several possible reasons for these unexpected findings. Perceptions of land-use mix –rather than objective measures – might explain more of the observed between-neighbourhood variation of the age differences in WfT. Previous multilevel research noted perceived land-use mix diversity and accessibility as strong predictors of WfT for several age groups [64,65,76]. Furthermore, those living in neighbourhoods with lower levels of land-use mix, but who perceived them as having higher land-use mix, were more likely to walk locally for transport [201].

It is also likely that all age groups are equally impacted in the same way by land-use mix, as proximity and mix of destinations has previously been strongly associated with WfT in both younger [322] and older adults [76]. In our study (which categorised WfT as a binomial outcome, based on its distribution), land-use mix was not significantly associated with WfT.

However, an earlier HABITAT Study noted that greater land-use mix was associated with more WfT, but only at high walking levels (≥ 60 mins per week) [295], suggesting that the dichotomisation of WfT could have resulted in a loss of information. These results could also reflect methodological issues regarding the selected combination of land use codes, as varying the combination of land uses in the land-use mix calculation has shown to impact the strength of relationships with different types and amounts of walking [248].

Previous multilevel research noted that pedestrian-friendly neighbourhoods characterised by residential density, street connectivity and land-use mix are more likely to motivate older adults to walk for transport [76,203,321]. Our findings suggest that each factor individually (higher residential density and street connectivity) might generate less age disparities in WfT across neighbourhoods.

Nevertheless, from an urban planning perspective, it is important to acknowledge the complexity of environmental influences on WfT; for example, density levels that are too high might negatively impact WfT. Perceived residential density was the only variable with a significant nonlinear association with ≥ 150 mins of WfT in a large multi-country study [293], which suggests the potential benefits of investigating residential density thresholds to inform the optimal density levels to increase WfT. Furthermore, the presence of residential density, street connectivity and land-use mix might have a combined effect on WfT, particularly in older adults [321] who might require higher levels of built environment support to walk for transport [93].

Additional built environment measures previously associated with WfT in older adults, but not explored in this study, might have further explained the age differences in WfT across neighbourhoods. These include walking infrastructure (quality and quantity of pedestrian paths), street lighting (a factor likely to influence natural surveillance as well as feelings of safety) [246] and access to public transport [64]. Increases in density of public transport have previously been associated with the likelihood of WfT in adults [299,323], and it is likely to facilitate the mobility of older adults who do not have access to a vehicle [181].

Finally, the observed between-neighbourhood variation in WfT might have also been partially explained through social –rather than built– environment features, such as frequency of contacts with neighbours, neighbours' social support, or neighbourhood involvement, participation, and volunteering, each of which has been previously associated with WfT in older adults [324].

This study has a number of limitations. While the cross-sectional design of this study limits causal conclusions, adjustment for residential self-selection (which is rare among cross-sectional neighbourhood-based studies [93,181]), ensured more reliable estimates of the influence of environmental exposures on WfT by accounting for individual-level bias (e.g. a regular transport walker might select a residence which facilitates their WfT), and controlled –to a certain extent– for possible reverse causation [54,69,93,181]. WfT was self-reported, which is less accurate than objective measures of walking, as responses might reflect desirability and/or recall bias (particularly in older adults) [109]. However, objective measures lack the contextual aspects of walking, such as its purpose and location, unless they are combined with Global Positioning Systems (GPS) and applied algorithms [134]. While we adjusted for socioeconomic position, accounting for the income for different age groups, the time-budget component and different trip purposes were not considered, and could have affected WfT. Furthermore, the quality of the walking environment such as good pedestrian infrastructure (previously associated with more WfT) [246] and the spatial and geographical dimensions were not considered in the study.

Moreover, different neighbourhood boundaries vary in relevance depending on the type of PA studied (transport vs recreational walking)[181] and across demographic populations (younger vs older adults) [184,185]. In particular, the geographical scale chosen for measuring the objective built environment influences the strength of associations with WfT, with a 15 mins walk from home being the most predictive of WfT, and weakest at the CCD scale [186]. Therefore, our definition of *neighbourhood* within a census boundary (or CCD) might have weakened the associations with WfT, particularly considering that older adults might have a slower walking pace, and thus, the nearby environment might be more relevant for walking [43]. Furthermore, while built environment exposures were developed based on those commonly used in the literature [76], policy-derived exposures might have been more relevant in informing urban planning and policy that reduces age differences in WfT across neighbourhoods [325,326]. Finally, the variation in pedestrian street scapes across cities suggests that findings from single-city studies might not be generalisable [327].

6.6 CONCLUSION

Based on previous research, adults experience increasing individual and environmental barriers to PA participation as they age due to declines in their physical function [49], and built environments seem to have a stronger influence on older adult's WfT [76]. The age disparity in PA participation is acknowledged within the World Health Organization's *Global age-friendly cities* [16], which calls for ecological evidence to inform age-responsive multilevel strategies to increase PA participation through active transportation opportunities.

This study revealed that, on average, older adults walked less for transport than their younger counterparts. Consistent with a previous investigation [305], however these average associations (commonly reported in the literature) seemed to vary across neighbourhoods, and older adults seemed more sensitive to their environments in regards to WfT. In Brisbane, denser and more connected environments might have generated less age differences in WfT. Therefore, increases in residential density and street connectivity in urban planning and policy may enable WfT in all neighbourhoods for all age groups, supporting healthy ageing in place.

The present findings are particularly relevant within the context of the Brisbane City Council's *Brisbane Vision 2031* document [80], which includes the promotion of *active, healthy communities* through an integrated transport system that enables the adoption of efficient, safe and sustainable travel choices by residents, including walking.

This study contributes to broader debates about the important role that the neighbourhood design has in facilitating the healthy lifestyle of residents who are regularly exposed to it [39,313]. As previously advocated [314], our results favour the ongoing longitudinal multilevel analyses of demographic heterogeneity around the neighbourhood averages, as they more realistically reflect the influence of neighbourhood exposures on the walking patterns of different population groups. Such investigations can inform the design of age-friendly neighbourhoods that might delay age-related declines in WfT, resulting in sustainable public health, socioeconomic and environmental gains for the overall population [128], ultimately supporting the WHO's objective of a global 10% reduction in the prevalence of physical inactivity by 2025 [14] as well as the UN's Sustainable Development Goals [315].

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Chapter 7: Discussion and conclusions

7.1 OVERALL FINDINGS

The literature review in Chapter 2 revealed that over the past twenty years, active living and ageing researchers have focussed on reporting the pooled (average) neighbourhood effects on gender and age differences in walking patterns, observing that women and older adults consistently walk less for transport and more for recreation than their counterparts. However, by reporting only average neighbourhood effects of gender and age on walking, these studies implicitly assumed that all neighbourhood environments influenced the walking patterns of men and women, and younger and older adults, similarly.

As women and older adults are likely to experience more individual and environmental barriers (perceived and objective) to PA, and walking in particular [3,23,24,43], it was posited that they might respond differently to their neighbourhood environments in regards to walking patterns. This thesis confirmed that the average effects of gender and age on walking patterns varied significantly across neighbourhoods, with women and older adults being more sensitive to their environments. These findings favoured the ongoing investigation of the relative contribution of the social and built environment of neighbourhoods to explaining the gender and age differences in walking patterns observed across neighbourhoods. Collectively, these investigations build on –and extend– previous research, with a focus on informing ecological interventions that facilitate walking everywhere for everyone, particularly for those demographic groups predisposed to inactivity.

The research questions were addressed using data from the HABITAT Study, a representative multilevel dataset of 11,035 middle-age adults living within 200 Brisbane neighbourhoods at baseline (2007), and through applying the corresponding statistical multilevel analyses. The findings are reported in three studies, forming Chapters 4, 5 and 6 of this thesis.

Collectively, the three studies undertaken within the thesis:

1. Described the average neighbourhood effects on the gender and age differences in WfR and WfT through fixed effects, noting that, consistent with previous literature, and on average, women and older adults walked more for recreation, and older adults walked less for transport.

2. Assessed whether the average effects of the gender and age differences in WfR and WfT varied across neighbourhoods through random coefficients, confirming that these individual-level associations seemed to vary significantly across neighbourhoods. The observed variation suggested that the neighbourhood effects on WfR and WfT were not equally distributed across demographic groups.
3. Examined between-neighbourhood variation in walking patterns for men and women and younger and older adults, through neighbourhood-level variance functions, noting that women seemed more sensitive than men to their environments in regards to WfR, and older adults seem more sensitive than younger adults to their environments in regards to WfT;
4. Investigated the contribution of the social environment (measured through neighbourhood-level perceptions of social cohesion, incivilities, and safety from crime) to explaining: (1) neighbourhood differences in the gender-WfR relationship (by assessing reductions in the random coefficient post-inclusion of cross-level interactions); and (2) between-neighbourhood variation in WfR for men and women (by assessing reductions in variance functions for men and women, post-inclusion of social environment exposures as fixed effects). Contrary to the hypothesis, Brisbane's social environment did not seem to explain neighbourhood differences in the gender-WfR relationship or the between-neighbourhood variation for either men or women. In Brisbane, the social environment did not appear to be a neighbourhood-level factor influencing the WfR of men and women differently.
5. Investigated the contribution of the built environment (objectively measured through residential density, street connectivity and land-use mix) to explaining: (1) neighbourhood differences in the age-WfT relationship (by assessing reductions in the random coefficient post-inclusion of cross-level interactions); and (2) between-neighbourhood variation in WfT for younger and older adults (by assessing reductions in variance functions for each age group, post-inclusion of built environment exposures as fixed effects). The built environment seemed to play a limited role in explaining neighbourhood differences in the age-WfT relationship. However, Brisbane neighbourhoods with higher residential density and street connectivity might have provided a more equitable environment for WfT across age groups.

This body of evidence provides a more comprehensive understanding of how demographic groups predisposed to inactivity interact with their social and built environments in regards to WfR and WfT.

It contributes to the ongoing conceptualisation of the social-ecological model of active living (see Figure 2.2 within Chapter 2) [19] by confirming that gender and age sensitive ecological interventions to facilitating WfR and WfT are highly relevant, and can potentially produce more equitable increases in overall PA participation everywhere through walking, ultimately supporting active living and ageing communities.

7.2 FINDINGS WITHIN THE CONTEXT OF ACTIVE LIVING AND AGEING RESEARCH

The average neighbourhood effects of gender and age differences in walking have been commonly investigated and reported (Step 1). This thesis builds on – and extends – previous literature by applying an innovative way of investigating these individual-level relationships (Steps 2-5). Collectively, the investigations within this thesis confirmed the walking patterns of men and women, and younger and older persons might be differently shaped and circumscribed by different neighbourhood environments. In other words, the neighbourhood average effects of gender and age on walking patterns are an unlikely reflection on what might be actually happening. The sections below discuss the findings from each analytic step within the context of the current active living and ageing research.

1. The average neighbourhood effects of gender and age differences in recreational and transport walking

Multilevel logistic regression analyses estimated the average neighbourhood effects of the gender and age differences in WfR and WfT. Consistent with previous literature [35,53-60], and on average, women and older adults walked more for recreation, and older adults walked less for transport. The observed differences in walking are likely to be determined by a gender and age effect across the life-span linked to inequalities in education, occupation, income, personal autonomy and entertainment [23], and environmental disadvantages are likely to exacerbate them. It has also been suggested that women might lack the social support necessary to adopt and maintain regular PA, and they might even be exposed to social messages indicating that PA is not a priority [23]. These issues required further investigation within a social-ecological framework that considers both these individual and structural inequalities.

As expected based on previous research [59,60,305], women were more likely than men to walk for recreation prior to adjustment for covariates (which attenuated the effects to the null). Further investigations revealed that men were more likely to be higher educated, in professional occupations and living in households with higher incomes, all of which has previously been associated with leisure-time PA and WfR [308,309]. On the other hand, women might spend more time in their neighbourhood, as they engage less in full-time employment [160] and more in caregiving and domestic activities compared to men [23,62,172], although these average neighbourhood effects could also partially reflect women's preference for walking rather than doing vigorous PA [30]. This evidence suggests a contextual opportunity for ecological interventions that facilitate active living and reduce the gender disparity in overall PA participation through increases in WfR.

Based on previous research [53,56-58,165,305], older adults were less likely to walk for transport than their younger counterparts. The time around retirement has been identified as a critical life-stage for promoting active ageing through walking [127]. Previous longitudinal studies observed post-retirement decreases in WfT [58,168], as well as increases in time spent watching television [168], indicating that WfT in pre-retirement is not being replaced with WfT in other contexts (e.g. walking to the shops) in post-retirement [168]. This evidence suggests a contextual opportunity for ecological interventions around retirement age that facilitate incidental WfT, particularly since shopping seems the most common reason for older adults leaving their homes [169].

2. Variation around the neighbourhood averages in individual-level relationships

Random coefficients for gender and age assessed whether the average effects of the gender and age differences in WfR and WfT varied across neighbourhoods. Consistent with the hypotheses, the relationships between gender and walking, and age and walking, seemed to vary significantly across neighbourhoods, implying that the overall Brisbane relationship was not the same in every neighbourhood. This suggests that the neighbourhood effects on walking might not be equally distributed across demographic groups, with some environments possibly being more supportive of walking for everyone than others. While the innovative nature of the questions addressed in these investigations made direct comparisons with previous research difficult, it justified ongoing investigations to assess whether –and to what extent– the observed variation around the neighbourhood averages in these individual-level relationships was a function of concomitant between-neighbourhood differences in social and built environment factors.

3. Between-neighbourhood variation in walking patterns for men and women, and younger and older adults

While neighbourhood-level variance functions for gender and age revealed variation for all the demographic groups investigated, the magnitude of the variation in WfR for women was twice that of men, while older adults had twice the variation of their younger counterparts. Likewise, previous research indicated that women and older adults are likely to experience more individual and environmental barriers (perceived and objective) to PA, and walking in particular [3,23,24,43]. This body of evidence indicates that the neighbourhood environment differentially shapes and circumscribes the walking patterns of different demographic groups, with women and older adults being more sensitive to environmental factors.

Furthermore, emerging evidence across geographical settings noted stronger social environment associations in women regarding walking [164] and WfR in particular [35,60]; while built environment associations with WfT were stronger in older adults [64,76,132]. This evidence suggests a contextual opportunity for the identification of ecological interventions that facilitate active living and ageing for all demographic groups, addressing the gender and age disparities in overall PA participation through increases in walking patterns everywhere.

4. The contribution of the social environment to explaining gender differences in recreational walking across neighbourhoods

Previous multilevel research found that gender is a potential modifier between the social environment and WfR, with stronger environmental effects observed in women [35,47], suggesting that more supportive social environments might be required to encourage women to walk for recreation. Therefore, Study 2 assessed the contribution of the neighbourhood social environment (conceptualised through neighbourhood-level perceptions of social cohesion, incivilities, and safety from crime) to explaining gender differences in WfR across neighbourhoods observed in Study 1.

Contrary to the hypothesis, Brisbane’s social environment did not seem to contribute to either explaining neighbourhood differences in the gender-WfR relationship, or the observed between-neighbourhood variation in WfR for men and women. As previously suggested in earlier studies [35,132], it is likely that our findings are contextual. Cities vary widely in their cultural and structural characteristics [36], and local governments shape neighbourhood environments through the planning, implementation, and delivery of services, infrastructure, and policies [45]. Brisbane is a medium density urban environment characterised by low crime rates and managed by a single City Council [260], located within a high income country (Australia) with well-established welfare provisions [36]. This could explain the limited variation (ranging from good to optimal) observed in the social environment measures across Brisbane’s neighbourhoods. In contrast, urban settings characterised by extreme levels of poverty, ethnic segregation and high urban crime rates like Chicago [209], have shown to influence levels of PA, with stronger effects seen in women [210,211].

The observed gender differences in WfR across neighbourhoods might have been better explained through built –rather than social– environment features. Well maintained pedestrian infrastructure, such as sidewalks, curbs, footpaths and recreational facilities, have previously shown associations with WfR [95,311] as well as aesthetics and good access to public spaces [312]. Perceived residential density, land-use mix, street connectivity, and proximity to parks were linearly associated with WfR across twelve countries [95], while residential density was the only attribute associated with WfR across four urban settings in another study [35]. Furthermore, the quality of recreational destinations (attractiveness of, satisfaction with, or incivilities in parks and PA facilities) was consistently associated with WfR in a review [185]. A gender-sensitised single level study noted that for women, perceived built environmental factors such as access to shops, the presence of sidewalks, and access to recreational facilities were more important in regards to WfR compared to men [60].

5. The contribution of the built environment to explaining age differences in transport walking across neighbourhoods

Previous multilevel research noted age as a potential moderator influencing the strength of the relationship between the environment and WfT [64,65,246], suggesting that more supportive built environments might be required to encourage older adults to walk for transport. Therefore, Study 3 investigated the contribution of the neighbourhood built environment (conceptualised through objectively measured residential density, street connectivity and land-use mix) to explaining the age differences in WfT across neighbourhoods observed in Study 1. While a walkability index combining residential density, street connectivity and land-use mix was developed and analysed as an environmental explanatory variable in Study 3, this walkability measure had limited explanatory potential compared with the individual measures of residential density, street connectivity and land-use mix, perhaps due to the direction of association being in opposite direction for land-use mix. Therefore, it was decided to only report the results of each environmental measure independently assessed.

Consistent with previous literature[76,93,203], higher residential density and street connectivity were significantly associated with the likelihood of WfT in our sample, although land-use mix was not. However, only residential density moderated the relationship between age and WfT, with older groups being more affected by residential density in their likelihood of WfT. Therefore, higher residential density might be required to encourage older adults to walk for transport, a finding consistent with emerging research noting age as a potential moderator influencing the strength of the relationship between the environment and

WfT [64,65,246]. The built environment played a limited role in explaining neighbourhood differences in age-WfT relationship, which is consistent with a recent systematic review and meta-analysis of the environmental correlates of total walking in older adults noting the inconsistency of the moderating effects of age [181].

As hypothesised, residential density and street connectivity partially explained the between-neighbourhood variation in WfT observed for different age groups, particularly for the older age groups. This is consistent with the recent findings from a recent systematic review and meta-analysis of active travel in older adults [76], which observed that WfT was positively associated with objective and perceived residential density and street connectivity.

Contrary to the hypothesis, and the above mentioned meta-analysis which concluded that WfT was positively associated with objective and perceived land-use mix [76], objective land-use mix in our study did not noticeably attenuate the between-neighbourhood variation in WfT for any of the age groups. It is likely that all age groups are equally impacted in the same way by land-use mix, as proximity and mix of destinations have previously been strongly associated with WfT in both younger adults [322] and older adults [76]. These findings could also reflect methodological issues in regards to the selected combination of land use codes, as varying the combination of land uses in the land-use mix calculation has shown to impact the strength of relationships with different types and amounts of walking [248].

Study 3 findings suggest that higher residential density and street connectivity individually might generate less age disparities in WfT across neighbourhoods, particularly benefiting older adults [321] who might require a more supportive built environment to walk for transport [93]. Additional built environment measures previously associated with WfT in older adults, but not explored in Study 3, might have further explained the age differences in WfT across neighbourhoods. These include walking infrastructure (quality and quantity of pedestrian paths), street lighting (a factor likely to influence natural surveillance as well as feelings of safety) [246] and access to public transport [64]. Increases in density of public transport have previously been associated with the likelihood of WfT in adults [299,323], and it is likely to facilitate the mobility of older adults who do not have access to a vehicle [181].

7.3 STRENGTHS AND LIMITATIONS

The body of evidence provided by the three studies within this thesis should be considered in light of the following strengths and limitations, which are discussed under the following sections: design and analytical strategy; measures; statistical modelling strategy; and generalisability of findings.

7.3.1 Design and analytical strategy

The multilevel nature of the investigations within this thesis was consistent with the social-ecological framework underpinning the HABITAT Study [87]. The randomly stratified design of HABITAT ensured large samples of the targeted population of individuals around retirement age for these investigations: 11,035 participants aged 40-65 years in 2007 (Study 3) and 7,866 participants aged 42-68 years in 2009 (Study 1 and 2), living within 200 neighbourhoods in Brisbane, Australia. Waves 1 and 2 of HABITAT had relatively high response rates (68.4% and 72.6% respectively). The baseline HABITAT sample, collected 2007, was broadly representative of the targeted population, although those living in disadvantaged areas, blue-collar employees, and those who did not attain a post-school educational qualification were slightly under-represented [262].

Although participants who moved from their original neighbourhood at baseline (2007) to another address in 2009 would have provided useful insights, they were excluded from the analyses due to the small sample size, which caused additional problems with models converging due to the small cell size per neighbourhood. While the cross-sectional design of the three studies limited causal conclusions, adjustment for residential self-selection in Studies 2 and 3 (which is rare among cross-sectional neighbourhood-based studies [93,181]), ensured more reliable estimates of the influence of environmental exposures on walking patterns by accounting for individual-level bias (e.g. a regular transport walker might select a residence which facilitates their WfT), and controlled –to a certain extent– for reverse causation [54,69,93,181].

7.3.2 Measures

Consistent with the emphasis of social-ecological frameworks in assessing specific PA domains [19], this thesis considered recreational and transport walking separately. Minutes of WfR and WfT in the previous week were self-reported, which limited their accuracy compared with objective measures of walking, as responses might reflect social desirability and/or recall bias (particularly in older adults) [109]. However, the direction that self-reporting might have had on the estimates is unclear; some studies suggest that respondents are likely to overestimate the amount of walking they engage in [301] while others note that they might underreport it [302]. Furthermore, older adults might have difficulties with discriminating between WfT and WfR, as they might combine these activities on the same trip [292]. However, objective measures lack the contextual aspects of walking, such as its purpose and location, unless they are combined with Global Positioning Systems (GPS) and algorithms are applied [134]. Therefore, walking patterns are best assessed through a combination of objective and self-reported measures [134]. However, only a limited number of studies incorporate both, including HABITAT, which collected objective measures of PA through accelerometers as part of the 2014 clinical sub-study. Nevertheless, accelerometer data was not collected in Waves 1 or 2 of HABITAT (used in the investigations within this thesis as they provided the largest samples).

In Study 2, Likert scales (used to capture perceptions of the social environment) were subjected to scale perception bias (reflecting demographic, interpersonal and cross-cultural preferences), which could lead to inaccurate assumptions [207]. On the other hand, an Empirical Bayes Exchangeable (EBE) estimation method was applied, producing a mean neighbourhood social environment score that accounted for the number of participants per neighbourhood, as well as the variability of the exposure within and between the neighbourhoods [269]. This method (described in detail in Chapter 3 and utilised in previous HABITAT studies [206,270]), produced more reliable estimates of the neighbourhood social environment than a simple mean aggregated score. Furthermore, a previously used approach considering social environment exposures as continuous measures in the statistical analyses [271] was replicated to ensure comparability between studies as recommended [181].

In Study 3, and as recommended to retain information and ensure comparability between studies [181,273], continuous spatial measures of the built environment were developed for each of the 200 HABITAT neighbourhoods using ArcMap [274] for overlaying on survey responses [93].

Although Studies 2 and 3 used validated measures of the environment, the conceptualisation of the social and built environments was limited. For instance, different neighbourhood boundaries might have more or less relevance depending on the type of PA studied (transport versus recreational walking)[181] and across demographic groups (men vs women; younger vs older adults) [184,185]. In Study 2, perceptions of the social environment were not specifically asked in the context of WfR. An increased correspondence between the environmental measure, the behaviour of interest and the setting in which the behaviour takes place might have produced stronger associations [44].

An additional limitation of Study 3 is the absence of a measure of actual engagement with the environment, such as the combination of objective physical activity measurement with global positioning systems to measure environmental use. Also, in regards to Study 3, the geographical scale chosen for measuring the objective built environment influences the strength of associations with WfT, with a 15 mins walk from home being the most predictive of WfT and weakest at the CCD scale [186]. Therefore, our definition of 'neighbourhood' within a census boundary (or CCD) might have weakened the associations with WfT, particularly considering that older adults might have a slower walking pace, and thus, the nearby environment might be more relevant for walking [43]. There is also the possibility of the definition of neighbourhood (CCD) not matching the geographical definition of the respondent (i.e. participants might have reported walking outside their neighbourhood) in Studies 2 and 3, which might have weakened the associations [181].

Furthermore, it is important to notice that quantitative investigations of the influence of neighbourhood environments on walking patterns do not always capture the quality appraisal of the micro-scale pedestrian environment [69]. For instance, the land-use mix measure used in Study 3 did not account for the quality of destinations [328], which is likely to influence WfT [328]. A more comprehensive exploration of the environment (which was unfeasible within this thesis due to time constraints) could have included other factors previously associated with walking for different purposes, such as quality assessments of micro-environment features, which might have better explained the gender and age differences in walking patterns observed across neighbourhoods.

The use of covariates in Studies 2 and 3 was informed by the literature review (Chapter 2), and included individual-level socioeconomic position (education, occupation and household income), residential self-selection and neighbourhood disadvantage. However, we did not control for additional measured and unmeasured potential covariates. For instance, public transport density (which is likely to influence WfT in a positive way [202]) was not considered as a covariate in Study 3, because such information was not available by CCD.

7.3.3 Statistical modelling strategy

The multilevel nature of the HABITAT Study [87] enabled the computation of statistical multilevel analyses which addressed the innovative research questions posited by this thesis. These analyses confirmed neighbourhood variation around the average gender and age differences in walking patterns, and enabled the assessment of the relative contribution of the social and built neighbourhood environment to explaining the observed neighbourhood variation, after adjustment for individual compositional variables. The multilevel analytical approach added predictive power, description and precision to the understanding of between-neighbourhood effects on the walking patterns of different demographic groups [86].

Furthermore, the impact of multiple testing (where the more inferences are made, the more likely erroneous inferences are to occur [329]) should be considered. However, it is worth noting that confidence intervals –rather than p-values– were reported for all the statistical model outputs, as the interest was in reporting the precision of the model estimates relative to the true population parameter.

Moreover, the categorical approach to the data analyses might have reduced the ability of the regression models to determine associations between walking and environmental factors. It is, nevertheless, worth noting that despite the categorical approach undertaken, Study 3 revealed that residential density and street connectivity explained up to 13% and 9% respectively of the observed between-neighbourhood variation in WfT across age groups.

7.3.4 Generalisability of findings

As previously mentioned, the baseline HABITAT sample, collected in 2007, was broadly representative of the targeted population, although those living in disadvantaged areas, blue-collar employees, and those who did not attain a post-school educational qualification were slightly underrepresented [262]. Furthermore, the investigations within this thesis, particularly Studies 2 and 3 (where missing records accounting for approximately 6% of the eligible participants were excluded), might have been subjected to some non-response bias as discussed below.

- In Study 1, the non-respondents to the WfT question (267, representing 3.7% of the eligible participants) did not significantly differ from the respondents on the basis of age or gender; however, the non-respondents to WfR (202, 2.8% of the eligible participants) were significantly more likely to be female (OR 1.39; CI 1.04-1.87).
- In Study 2, sensitivity analyses for those missing relevant variables (education, residential self-selection and WfR) revealed that participants who were not classified for occupation ($p=0.001$) and not classified for income ($p=0.012$) were significantly more likely to be in the missing group of 493 (6.9% of the eligible participants).
- In Study 3, sensitivity analyses for those missing relevant variables (education, residential self-selection and WfT) revealed that participants who were blue collar ($p=0.001$), not classified for occupation ($p=0.000$) and not classified for income ($p=0.013$) were significantly more likely to be in the missing group of 684 (6.2% of the eligible participants).

A listwise deletion was applied to missing records, since the efficiency gains offered by applying imputation methods (which add another layer of measurement error to the data) are often minor in large samples [276]; and the samples remained large enough to address the aims of the studies (7,004 for WfT and 7,069 for WfR nested within 200 CCDs in Study 1; 6,643 in Study 2 and 10,350 in Study 3).

Furthermore, the investigations within this thesis utilised geographically localised data from Brisbane (Queensland), an urban setting characterised by limited variability in social environments across neighbourhoods [36], which might clarify the negligible contribution of the social environment to explaining gender differences in WfR across neighbourhoods. On the other hand, Brisbane had enough variation across built environments to partially explain age differences in WfT across neighbourhoods.

Furthermore, the results should be interpreted with caution due to inherent limitations in cross-section analyses combined with the problems of multiple testing; while some of the associations explored are statistically significant and others not, this might or might not be indicative of real world differences in the influence that neighbourhoods might have on different demographic groups.

7.4 POLICY IMPLICATIONS OF THIS RESEARCH

This section provides an overview of the urban planning and policy implications of the findings from this thesis.

This research program is placed within the National Health and Medical Research Council (NHMRC) Centre of Research Excellence (CRE) in Healthy, Liveable Communities. This CRE is currently generating high impact scholarly and practice-based publications aimed at informing healthy urban planning, policy and practice.

This thesis was designed not only to address a gap in the literature, but also to have community and policy relevance. The burden of NCDs partly reflects the increasing inactivity trends in populations [38], possibly from living in environments primarily designed for motor vehicle transportation rather than active transportation, particularly in Australia [28,37].

Research reveals that women and older adults are likely to experience more individual and environmental (perceived and objective) barriers to PA and walking than their counterparts [3,23,24,43]. Therefore, these demographic groups (who favour walking over more vigorous PA, and are likely to spend more time in their neighbourhoods) should be prioritised for targeted interventions due to their propensity to inactivity. However, most urban policy and development approaches insufficiently address key aspects of demographic heterogeneity in populations [3]. A comprehensive public health strategy to reverse the increasing inactivity trends in populations should consider improving the physical and social environments within which people live [3].

By providing an understanding of the relative contribution of the social and built environment of neighbourhoods to gender and age differences in walking patterns, this thesis addresses the calls from international and national policy frameworks (such as WHO's

Women, Ageing and Health: A Framework for Action [15], *Global age-friendly cities* [16], and the *Active Ageing* frameworks [15,17], as well as the National Heart Foundation of Australia's *Blueprint for an active Australia*[18]), to inform gender and age-responsive multilevel interventions that reduce the demographic disparities in PA participation through increases in walking patterns.

Contrary to our hypothesis in Study 2, the social environment in Brisbane did not seem to contribute to explaining gender differences in WfR across neighbourhoods, possibly due to the limited variation in Brisbane's social environments, ranging from good to optimal. Without Brisbane's relatively safe social environment, the observed gender differences in WfR across neighbourhoods might have been larger.

Consistent with the literature reporting that WfT has stronger associations with built environment features than WfR across geographical settings [65,93,94,147,148], results from Study 3 suggest that increasing both residential density and street connectivity is likely to produce more equitable incidental WfT across age groups, supporting the achievement of the current PA guidelines for older adults [19] and ultimately promoting age-friendly neighbourhoods.

Nevertheless, from an urban planning perspective, it is important to acknowledge the complexity of environmental influences on both WfR and WfT. For instance, density levels that are too high might negatively impact WfT. Perceived residential density was the only variable with a significant nonlinear association with $\geq$ 150 mins of WfT in a large multi-country study [293], which suggests the potential benefits of investigating residential density thresholds to inform the optimal density levels to increase WfT. Furthermore, the presence of residential density, street connectivity and land-use mix might have a combined effect on WfT, particularly in older adults [321] who might require higher levels of built environment support to walk for transport [93].

These are relevant findings within the context of the *Brisbane Vision 2031* [80], which includes the promotion of *active, healthy communities* through environmental design practices (such as an integrated transport system) which facilitate the adoption of efficient, safe and sustainable recreational and travel choices by residents, such as walking.

By extending the contribution to community life to these demographic groups, the costs associated with health and aged care would diminish [28]. Age and gender friendly neighbourhoods are also more liveable for all, since the same physical features that enable the safe mobility of vulnerable or impaired individuals (women and older adults) also benefit the mobility of other susceptible demographic groups, such as children and people with disabilities. In particular, designing or retrofitting environments to encourage active transportation has synergistic co-benefits across portfolios, including health, transport, community and environment [144], all of which support sustainable development [39] in line with the UN's Sustainable Development Goals [315].

7.5 DIRECTIONS FOR FUTURE RESEARCH

> *"To transform society in support of more fundamental health promotion, a more democratic and ecological approach to scientific study is necessary,* [where] *education between scientists and the public must take place in both directions."*
>
> — Chavis, Stucky & Wandersman, 1983 *Returning basic research to the community: A relationship between scientist and citizen* [330].

This section provides practical recommendations for prospective research investigating the contribution of the neighbourhood environment to health behaviours, in order to inform ecological interventions which facilitate and maintain healthy behavioural change.

This body of evidence contributes to broader debates about the important role that the neighbourhood design has in facilitating the healthy lifestyle of residents who are regularly exposed to it [39,313]. A social-ecological framework that takes into account the individual and structural inequalities is best placed to investigate disparities in health behaviours and outcomes across neighbourhoods. The innovative nature of the research questions, addressed through statistical multilevel analyses, have potential international research relevance. As previously advocated [314], the findings from this thesis favour the ongoing longitudinal multilevel analyses of demographic heterogeneity around the neighbourhood averages over a *mean centric approach*, as they more realistically reflect the impact of neighbourhood exposures on the walking patterns of different population sub-groups, and is consistent with the social determinants of health.

It is important to note the complexity of influences on walking, with social and built environment factors likely to act in combination with other individual factors. Furthermore, the overall goal is to increase overall PA in populations, regardless of the domain in which it was accrued [181]. Therefore, active living and ageing research informing interventions to increase PA, and walking patterns in particular, should reflect not only the capacity to undertake the physical and social tasks of daily living, but also the impact that environments have on the traditional gender roles and age-related patterns of change [21].

Such investigations –particularly when undertaken in urban settings characterised by larger variation in their social and built environments– can potentially inform ecological interventions which effectively facilitate walking opportunities everywhere for all demographic groups, particularly those predisposed to inactivity, resulting in sustainable public health, socioeconomic and environmental gains for the overall population [128], ultimately supporting the WHO's objective of a global 10% reduction in the prevalence of physical inactivity by 2025 [14] as well as the UN's Sustainable Development Goals [315].

The frequency and intensity of exposure over time are likely to determine the strength of potential neighbourhood effects. More specifically, time of exposure to a neighbourhood plays an important role in the effect of the neighbourhood on individual outcomes, with long-term exposure to neighbourhood characteristics assumed to have a stronger effect on residents than short-term exposure[331]. Therefore, future longitudinal investigations might provide further insight into the neighbourhood effects on walking behaviours. Prospective investigations should capitalise on existing multilevel longitudinal studies such as HABITAT to enable gender and age comparisons of walking over time and between places, as well as through natural experiments of those who change environments through relocation of residence, and those for whose environments change around them that are residentially stable.

Assessing walking through a combination of self-report and accelerometers would provide more comprehensive estimates of walking. Advances in new technologies and measurement methods such as accelerometers, show promise for improved PA surveillance [8]. Future studies should also consider a measure of actual engagement with the environment, such as the combination of objective physical activity measurement with global positioning systems to measure environmental use.

Furthermore, the scales currently used to capture environmental perceptions are subject to scale perception bias (reflecting demographic, interpersonal and cross-cultural preferences). Therefore, prospective studies should consider applying anchoring vignettes when collecting individuals' perceptions to detect and adjust for this type of bias [207].

Since several studies suggest that environmental perceptions of the social and built environment might be more influential on walking than objective measures of the environment [148,181,201,237], prospective studies should consider a comprehensive representation of the quality of the micro-scale pedestrian environment (e.g. perceived safety from traffic, presence and quality of crosswalks and sidewalks, quality of destinations and maintenance of buildings). Progress is being made through data collection instruments such as the Microscale Audit of Pedestrian Streetscapes (MAPS Global) which provides in-person environmental audit data on the pedestrian environment and walkability in neighbourhoods (and has been validated in five countries [332]) within a Community-based Participatory Action Research framework, where researchers collaborate with the communities affected by the issue being studied [333]. This is an excellent example of how researchers can produce evidence that enables communities to have increased control over their health outcomes through advocating for better neighbourhood environments [74].

Both micro-scale and macro-scale improvements that facilitate walking have the potential to produce long-term benefits to the communities who are regularly exposed to it, and should be inclusive of all demographic groups [181]. *New Urbanism* promotes walkable neighbourhoods, scaled to pedestrians (400m radius/five minute walk), characterised by diversity of land-use, and greater residential density and street connectivity, as well as a well-defined high quality public space [151]. Micro-scale environmental factors are also likely to contribute to explaining between-neighbourhood variation in gender and age differences in walking patterns, and may be more cost-effective and easier to retrofit than macro-scale features. Such research could inform *tactical urbanism,* which focusses on low cost micro-scale environmental improvements which are easier to implement than macro-scale interventions to street design and layout [181].

Furthermore, a smaller geographical definition of neighbourhoods, such as mesh blocks [183], or circular or network buffers within a 1600, 800 or 400m from a resident's home [93] might show stronger associations with walking, particularly in older adults, whose nearby environment might be more relevant for walking [43].

The combination of these recommendations can strengthen prospective research, which could inform healthy urban planning through development of tools such as WHO's *Health Economic Assessment of Transport for Walking and Cycling* [334], which provides policy makers with an estimation of both the health improvements and the related economic savings from increasing walking patterns in populations for a more efficient allocation of the limited resources available for interventions.

7.6 CONCLUDING REMARKS

> *"Cities have the capability of providing something for everybody, only because, and only when, they are created by everybody."*
>
> — Jane Jacobs, The Death and Life of Great American Cities [179]

Neighbourhood environments provide opportunities to incorporate walking into the daily activities of commuting, working, playing and socialising [19,26], and thus identifying the key design elements of active living and ageing communities is a research priority within the broad efforts to reverse the increasing inactivity trends in populations.

Early active living and ageing researchers investigated and reported the influence of different social and physical urban forms on health behaviours and outcomes. The focus was on answering general research questions around *What is happening?*, revealing that the neighbourhood environment, on average, impacts the walking patterns of individuals above and beyond compositional individual-level factors.

A new generation of researchers is currently addressing more refined research questions around *Why is it happening?* By sensitising the questions and exploring demographic heterogeneity around the neighbourhood averages, this thesis established that the average neighbourhood effects of gender and age differences in walking patterns (commonly reported in the active living and ageing literature), are an unlikely reflection on what might actually be happening. In fact, neighbourhood environments differentially shape and circumscribe the walking patterns of men and women, and younger and older adults, with women and older adults being more sensitive to their environments, suggesting that they might require more environmental support to walk.

Good urban design can support women as well as older adults to remain physically and socially active in their communities and age in place by improving their health and wellbeing, increasing their mobility, independence and social interactions through walking [16,28]. While Brisbane's social environment did not contribute to explaining gender differences in WfR across neighbourhoods, the age differences in WfT across neighbourhoods were partly attributed to the contextual effects of residential density and street connectivity. Thus, in designing neighbourhoods that facilitate active living and ageing communities, governments should consider denser and more connected urban forms which would produce more equitable increases in WfT across age groups.

This thesis favours the ongoing investigation of the demographic heterogeneity around the neighbourhood averages in environmentally diverse urban settings to tailor contextual interventions that increase walking everywhere for everyone, particularly for those groups which might require more environmental support to walk (as walking might be the only type of PA they engage with). Such research would inform a more efficient use of the limited resources available for interventions through equity promoting policies that address gender and age disparities in overall PA through walking.

Investments in designing and/or retrofitting neighbourhood environments to make them more walking-friendly for all demographic groups is a long-term, cost efficient and holistic approach to reversing the inactivity trends in populations, ultimately supporting more healthy, liveable and equitable communities.

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Appendices

Appendix A: Research Portfolio

This thesis includes two published papers (Studies 1 and 3), and one manuscript pending submission (Study 2). The details of these publications are outlined below.

Peer review journal articles

Study 1: **Ghani, F.,** Rachele, JN., Washington, S., Turrell, G. (2016). <u>Gender and age differences in walking for transport and recreation: Are the relationships the same in all neighborhoods?</u> *Preventive Medicine Reports* 4: 75-80.

Study 3: **Ghani, F.,** Rachele, JN., Loh, VHY., Washington, S. & Turrell, G. (2018) <u>Do differences in built environments explain age differences in transport walking across neighbourhoods?</u> *Journal of Transport and Health*. Available online from 18 April 2018.

Manuscript pending submission

Study 2: **Ghani, F.,** Rachele, JN., Loh, VHY., Washington, S. & Turrell, G. (2018). Do differences in social environments explain gender differences in recreational walking across neighbourhoods?

Study 1 - Statement of Contribution to Manuscript

Published article: **Ghani, F.,** Rachele, JN., Washington, S., Turrell, G. (2016). Gender and age differences in walking for transport and recreation: Are the relationships the same in all neighborhoods? *Preventive Medicine Reports* 4: 75-80.

Author	**Statement of Contribution**	**Signature & Date**
Fatima Ghani	I acknowledge that my contribution to the above paper is 55%. • Conception and design of the literature search • Drafting of the article and revising it for critically important intellectual content • Approval of the final version for publication and submission of the article to the journal for publication	
Jerome Rachele (Co-supervisor)	I acknowledge that my contribution to the above paper is 15%. • Provision of advice on conception of study • Provision of critical revisions to draft versions for important intellectual content • Approval of the final version for publication	
Simon Washington (Associate Supervisor)	I acknowledge that my contribution to the above paper is 5%. • Provision of critical revisions to draft versions for important intellectual content • Approval of the final version for publication	
Gavin Turrell (Principal Supervisor)	I acknowledge that my contribution to the above paper is 25%. • Provision of advice on conception of study • Provision of critical revisions to draft versions for important intellectual content • Approval of the final version for publication	

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Gender and age differences in walking for transport and recreation: Are the relationships the same in all neighborhoods?☆

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ABSTRACT

Introduction. Walking as regular physical activity (PA) is central to healthy aging, and environments influence walking. Multilevel neighborhood-based studies that only report average (fixed-effect) walking differences for gender and age implicitly assume that neighborhood environments influence the walking behavior of men and women, and younger and older persons, similarly. This study tests this assumption by examining whether gender and age differences in walking for transport (WfT) and walking for recreation (WfR) are similar or different across neighborhoods.

Methods. This paper used data from the HABITAT multilevel study, with 7,866 participants aged 42–68 years in 2009 living in 200 neighborhoods in Brisbane, Australia. Respondents reported minutes spent WfT and WfR in the previous week, categorized as: none (0 mins), low (1–59mins), moderate (60–149mins) and high (≥150 mins). Multilevel multinomial logistic models were used to estimate average differences in walking by gender and age, followed by random coefficients to examine neighborhood variation in these individual-level relationships.

Results. On average, women were more likely to engage in WfR at moderate and high levels (no gender differences found in WfT); and older persons were less likely to do WfT and more likely to do high levels of WfR. These average (Brisbane-wide) relationships varied significantly across neighborhoods.

Conclusion. Relationships between gender and walking, and age and walking, are not the same in all neighborhoods, (i.e. the Brisbane average conceals important information) suggesting that neighborhood-level factors differentially influence the walking behaviors of men and women and younger and older persons. Identifying these factors should be a priority for future research.

1. Introduction

Walking is an important health behavior that can significantly reduce or postpone morbidity and mortality (Fortes et al., 2013; Murtagh et al., 2015), particularly among women (Brown et al., 2012). It is also the most popular form of physical activity (PA) among older populations (Satariano et al., 2012; Touvier et al., 2010). Walking is typically undertaken within the local neighborhood (Van Dyck et al., 2009; Sugiyama et al., 2009) for the purposes of transport or recreation (Inoue et al., 2010). Walking can be incorporated into daily routines at minimal cost, hence it is the most modifiable form of PA among adult populations (Rhodes et al., 1999), with resultant public health, social and economic gains (Panter and Jones, 2010). However, seniors walk less at levels that contribute to recommended PA guidelines, particularly older women (Harris et al., 2009).

During the last decade, there have been numerous neighborhood-based multilevel studies of walking for transport and recreation that have included gender and age as part of their analyses (Van Dyck et al., 2013; Sundquist et al., 2011; Li et al., 2005; Shigematsu et al., 2009; Gauvin et al., 2008; Gómez et al., 2010; Van Dyck et al., 2012; Sugiyama et al., 2014; Kerr et al., 2015). Typically, these studies use gender and age as covariates or effect-modifiers (Van Dyck et al., 2013; Van Dyck et al., 2012; Sugiyama et al., 2014; Kerr et al., 2015), and only occasionally as primary predictors of substantive interest. Findings from these studies show that on average, women are less likely to walk for transport (Sundquist et al., 2011; Owen et al., 2007; Forsyth et al., 2009; Doescher et al., 2014) and recreation (Sundquist et al., 2011)

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Study 2 - Statement of Contribution to Manuscript

Ghani, F., Rachele, JN., Loh, VHY., Washington, S. & Turrell, G. (2018). Do differences in social environments explain gender differences in recreational walking across neighbourhoods? *Manuscript pending submission to a peer-review journal.*

Author	Statement of Contribution	Signature & Date
Fatima Ghani	I acknowledge that my contribution to the above paper is 55%. • Conception and design of the literature search • Drafting of the article and revising it for critically important intellectual content • Approval of the final version for publication and submission of the article to the journal for publication	
Jerome Rachele (Co-supervisor)	I acknowledge that my contribution to the above paper is 14%. • Provision of advice on conception of study • Provision of critical revisions to draft versions for important intellectual content • Approval of the final version for publication	
Venurs Hui Yee Loh (Colleague)	I acknowledge that my contribution to the above paper is 3%. • Provision of critical revisions to draft versions for important intellectual content • Approval of the final version for publication	
Simon Washington (Associate Supervisor)	I acknowledge that my contribution to the above paper is 3%. • Provision of critical revisions to draft versions for important intellectual content • Approval of the final version for publication	
Gavin Turrell (Principal Supervisor)	I acknowledge that my contribution to the above paper is 25%. • Provision of advice on conception of study • Provision of critical revisions to draft versions for important intellectual content • Approval of the final version for publication	

Study 3 - Statement of Contribution to Manuscript

Ghani, F., Rachele, JN., Loh, VHY., Washington, S. & Turrell, G. (2018) Do differences in built environments explain age differences in transport walking across neighbourhoods? *Journal of Transport and Health*. Available online from 18 April 2018.

Author	**Statement of Contribution**	**Signature & Date**
Fatima Ghani	I acknowledge that my contribution to the above paper is 55%. • Conception and design of the literature search • Drafting of the article and revising it for critically important intellectual content • Approval of the final version for publication and submission of the article to the journal for publication	
Jerome Rachele (Co-supervisor)	I acknowledge that my contribution to the above paper is 14%. • Provision of advice on conception of study • Provision of critical revisions to draft versions for important intellectual content • Approval of the final version for publication	
Venurs Hui Yee Loh (Colleague)	I acknowledge that my contribution to the above paper is 3%. • Provision of critical revisions to draft versions for important intellectual content • Approval of the final version for publication	
Simon Washington (Associate Supervisor)	I acknowledge that my contribution to the above paper is 3%. • Provision of critical revisions to draft versions for important intellectual content • Approval of the final version for publication	
Gavin Turrell (Principal Supervisor)	I acknowledge that my contribution to the above paper is 25%. • Provision of advice on conception of study • Provision of critical revisions to draft versions for important intellectual content • Approval of the final version for publication	

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Do differences in built environments explain age differences in transport walking across neighbourhoods?

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ABSTRACT

Background: The neighbourhood built environment (BE) provides opportunities for regular walking for transport (WfT). Within the same city, age differences in WfT can vary significantly across neighbourhoods, although little is known about the reasons for this variation. This cross-sectional study investigated the contribution of the BE to explaining age differences in WfT across neighbourhoods.

Methods: This investigation used baseline (2007) data from the How Areas in Brisbane Influence HealTh and AcTivity (HABITAT) Study. The sample included 11,035 residents aged 40–65 years living in 200 neighbourhoods in Brisbane, Australia (68.4% response rate). Self-reported weekly minutes of WfT were categorized into none (0 mins) and any (1–840 min); age was categorized into 40–48, 49–57 and 58–65 years. Objectively assessed neighbourhood-level measures of the BE included residential density, street connectivity and land-use mix. Analyses involved multilevel binomial logistic regression with age as main predictor, adjusting for gender, socioeconomic position, residential self-selection, and neighbourhood disadvantage.

Results: On average, older adults were significantly less likely to walk for transport. Age differences in WfT varied significantly across neighbourhoods, and the magnitude of the variation for older groups was twice that of their younger counterparts. The environmental measures analysed played a relatively limited role in explaining neighbourhood differences in the age-WfT relationship. Residential density and street connectivity explained up to 13% and 9% respectively of the observed between-neighbourhood variation in WfT across age groups.

Conclusion: Neighbourhood-level factors influenced the WfT of younger and older adults differently, with older adults being more sensitive to their neighbourhood environment. In Brisbane, age differences in WfT were smaller in areas with higher residential density and street connectivity. These results favor the ongoing investigation of demographic heterogeneity around neighbourhood averages in other urban contexts to inform tailored ecological interventions that facilitate WfT for all age groups everywhere, supporting active aging communities.

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1 0000-0002-5528-371X.

https://doi.org/10.1016/j.jth.2018.03.010

Additional research outputs

Rachele JN, **Ghani F,** Loh VH, Brown WJ, Turrell G. (2016). Associations between physical activity and the neighbourhood social environment: Baseline results from the habitat multilevel study. *Preventive Medicine*. 93:219-225.

Loh VH, Rachele JN, Brown WJ, **Ghani F,** Turrell G. 2018. Neighbourhood disadvantage and physical function: is the relationship explained by neighbourhood perceptions of safety from crime and walking for recreation? Accepted for publication by the *Journal of Physical Activity and Health*.

Loh VH, Rachele JN, Brown WJ, **Ghani F,** Washington S, Turrell G. 2018. 'Can walkability and walking for transport reduce neighbourhood inequalities in physical function? A case study among middle-aged to older adults in Brisbane, Australia. Under review by *Health & Place*.

Conference oral presentations

Ghani, F., Rachele, JN., Loh, VHY., Turrell, G. The contribution of the built environment to age differences in walking for transport, *Designing Healthy Liveable Cities Conference*, held on 19-20 October 2017 in Melbourne (Australia). Oral presentation and panel member.

Ghani, F., Rachele, JN., Loh, VHY., Turrell, G. Do differences in built environments explain age differences in transport walking across neighbourhoods? *29th International Society of Environmental Epidemiology*, held on 24-28 September 2017 in Sydney (Australia).

Ghani, F., Rachele, JN., Loh, VHY., Turrell, G. Is the relationship between age and utilitarian walking influenced by the neighbourhood built environment? *3rd International Conference on Public Health*, 27-29 July 2017, Kuala Lumpur (Malaysia).

Ghani, F., Rachele, JN., Loh, VHY., Turrell, G. Does the social environment explain between-neighbourhood variation in the gender and recreational walking relationship? *15th World Congress on Public Health,* 3-7 April 2017, Melbourne (Australia).

Awarded the Best Student Oral Presentation: Ghani, F., Rachele, JN., Washington, S., Turrell, G. Gender and age differences in walking for transport and recreation: Are the relationships the same in all neighbourhoods? *9th World Congress on Active Ageing*, 28 June-1 July 2016, Melbourne (Australia).

Ghani, F., Rachele, JN., Washington, S., Turrell, G. Neighbourhood environment and walking for transport and recreation: is the association the same for men and women and older and younger persons? *Institute of Health and Biomedical Innovation (IHBI) Inspires Conference,* 19-20 November 2015, Brisbane (Australia).

Conference poster presentations

Giles-Corti, B., Lowe, M., Arundel, J., **Ghani, F**. (as part of the NHMRC Centre for Research Excellence in Healthy, Liveable Communities) City indicators needed to promote health and monitor implementation of the New Urban Agenda, displayed at the United Nations University Booth within the *World Urban Forum*, 7-13 February 2018, Kuala Lumpur (Malaysia).

Ghani, F., Rachele, JN., Washington, S., Turrell, G. Do neighbourhood differences in the social environment explain gender differences in walking for recreation? *International Congress on Physical Activity and Health*, 16-19 November 2016, Bangkok (Thailand).

Ghani, F., Rachele, JN., Washington, S., Turrell, G. How does the built and social environment (social cohesion and crime) affect the physical activity of women and men over time? *Institute of Health and Biomedical Innovation (IHBI) Inspires Conference*, 20-21 November 2014, Brisbane (Australia).

Other academic achievements

- Awarded a scholarship by the National Centre for Longitudinal Data to attend the National Longitudinal Data Conference, 25-27 October 2016, Canberra (Australia).
- Participated in the ACU - 3 Minute Thesis Competition in Melbourne on 26 July 2016
- Manuscript reviewer for the Scandinavian Journal of Public Health.

Memberships

- 2017 Member of the International Society for Physical Activity and Health Communications Committee. In this role, I contributed to the translation of the *WHO Global action plan on physical activity 2018 – 2030* draft from English into Spanish for wider stakeholder consultation, including WHO member states.
- 2017 Member of the International Society of Environmental Epidemiology.
- 2016 Australian Catholic University's Postgraduate Student Association representative.
- 2015 IHBI Postgraduate Student Committee, Queensland University of Technology.
- 2014-17 People's Movement & Safety Working Group member (West End Village Development, Brisbane).

Appendix B: Research Ethics Approval Certificate

University Human Research Ethics Committee

HUMAN ETHICS APPROVAL CERTIFICATE

NHMRC Registered Committee Number EC00171

Date of Issue: 13/2/14 (supersedes all previously issued certificates)

Dear Prof Gavin Turrell

A UHREC should clearly communicate its decisions about a research proposal to the researcher and the final decision to approve or reject a proposal should be communicated to the researcher in writing. This Approval Certificate serves as your written notice that the proposal has met the requirements of the *National Statement on Research involving Human Participation* and has been approved on that basis. You are therefore authorised to commence activities as outlined in your proposal application, subject to any specific and standard conditions detailed in this document.

Within this Approval Certificate are:

* Project Details
* Participant Details
* Conditions of Approval (Specific and Standard)

Researchers should report to the UHREC, via the Research Ethics Coordinator, events that might affect continued ethical acceptability of the project, including, but not limited to:

(a) serious or unexpected adverse effects on participants; and
(b) proposed significant changes in the conduct, the participant profile or the risks of the proposed research.

Further information regarding your ongoing obligations regarding human based research can be found via the Research Ethics website http://www.research.qut.edu.au/ethics/ or by contacting the Research Ethics Coordinator on 07 3138 2091 or ethicscontact@qut.edu.au

If any details within this Approval Certificate are incorrect please advise the Research Ethics Unit within 10 days of receipt of this certificate.

Project Details

Category of Approval: Human Negligible-Low Risk

Approved From: 12/04/2013 **Approved Until:** 12/04/2017 (subject to annual reports)

Approval Number: 1300000161

Project Title: A longitudinal multilevel study of physical activity, sedentary behaviour, and physical function in mid-to-late adulthood

Experiment Summary: Better understand the trajectory of decline in physical function and the factors that influence this trajectory.

Investigator Details

Chief Investigator: Prof Gavin Turrell

Other Staff/Students:

Investigator Name	Type	Role
Mrs Lee-Ann Wilson	Internal	Associate Investigator
Dr Andrea Nathan	Internal	Project Manager
Ms Sophie Miller	Internal	Research Assistant

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QUT

University Human Research Ethics Committee

HUMAN ETHICS APPROVAL CERTIFICATE

NHMRC Registered Committee Number EC00171

Date of Issue: 13/2/14 (supersedes all previously issued certificates)

Conditions of Approval

Specific Conditions of Approval:
None apply

Standard Conditions of Approval:
The University's standard conditions of approval require the research team to:

1. Conduct the project in accordance with University policy, NHMRC / AVCC guidelines and regulations, and the provisions of any relevant State / Territory or Commonwealth regulations or legislation;

2. Respond to the requests and instructions of the University Human Research Ethics Committee (UHREC);

3. Advise the Research Ethics Coordinator immediately if any complaints are made, or expressions of concern are raised, in relation to the project;

4. Suspend or modify the project if the risks to participants are found to be disproportionate to the benefits, and immediately advise the Research Ethics Coordinator of this action;

5. Stop any involvement of any participant if continuation of the research may be harmful to that person, and immediately advise the Research Ethics Coordinator of this action;

6. Advise the Research Ethics Coordinator of any unforeseen development or events that might affect the continued ethical acceptability of the project;

7. Report on the progress of the approved project at least annually, or at intervals determined by the Committee;

8. (Where the research is publicly or privately funded) publish the results of the project is such a way to permit scrutiny and contribute to public knowledge; and

9. Ensure that the results of the research are made available to the participants.

Modifying your Ethical Clearance:
Requests for variations must be made via submission of a Request for Variation to Existing Clearance Form (http://www.research.qut.edu.au/ethics/forms/hum/var/var.jsp) to the Research Ethics Coordinator. Minor changes will be assessed on a case by case basis.

It generally takes 7-14 days to process and notify the Chief Investigator of the outcome of a request for a variation.

Major changes, depending upon the nature of your request, may require submission of a new application.

Audits:
All active ethical clearances are subject to random audit by the UHREC, which will include the review of the signed consent forms for participants, whether any modifications / variations to the project have been approved, and the data storage arrangements.

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