Chapter 18
Built Environment and Physical Activity

Billie Giles-Corti, Lucy Gunn, Paula Hooper, Claire Boulange, Belén Zapata Diomedi, Chris Pettit, and Sarah Foster

18.1 Introduction

There is a growing interest globally on how city planning affects health, particularly physical activity given its important role in preventing major chronic diseases (Giles-Corti et al. 2016). City planning can improve or harm human health through the opportunities created for health-promoting (or health-damaging) lifestyles.

B. Giles-Corti (✉) · L. Gunn · C. Boulange
NHMRC Centre for Research Excellence in Healthy Liveable Communities, Melbourne, VIC, Australia

Centre for Urban Research, RMIT University, Melbourne, VIC, Australia
e-mail: billie.giles-corti@rmit.edu.au; lucy.gunn@rmit.edu.au; claire.boulange@rmit.edu.au

P. Hooper
NHMRC Centre for Research Excellence in Healthy Liveable Communities, Melbourne, VIC, Australia

Centre for the Built Environment and Health, The University of Western Australia, Perth, WA, Australia
e-mail: paula.hooper@uwa.edu.au

B. Z. Diomedi
NHMRC Centre for Research Excellence in Healthy Liveable Communities, Melbourne, VIC, Australia

School of Civil Engineering, University of Queensland, St Lucia, Australia
e-mail: b.zapatadiomedi@uq.edu.au

C. Pettit
Faculty of Built Environment, University of New South Wales, Kensington, NSW, Australia
e-mail: c.pettit@unsw.edu.au

S. Foster
Centre for Urban Research, RMIT University, Melbourne, VIC, Australia
e-mail: sarah.foster@rmit.edu.au

M. Nieuwenhuijsen, H. Khreis (eds.), *Integrating Human Health into Urban and Transport Planning*, https://doi.org/10.1007/978-3-319-74983-9_18

The World Health Organization (WHO 2016a) reaffirmed this view in its 2016 Shanghai Declaration, declaring that “Health is created … in the neighbourhoods and communities where people live, love, work, shop and play” (World Health Organization 2016b). WHO also recognised that a healthy city is a sustainable city, pronouncing that “Health is one of the most effective markers of any city’s successful sustainable development …” and pledged that it would “accelerate the implementation” of the UN’s Sustainable Development Goals by investing politically and financially in health promotion (United Nations General Assembly 2015), including an emphasis on creating healthy cities (World Health Organization 2016a).

The WHO’s commitment reflects growing public, policy and scientific interest over the last decade in the effects of the built environment on the health and wellbeing of urban dwellers and health equity (WHO and UN Habitat 2016). This has been fuelled by multi-sector concerns about the effects of city planning associated with rising levels of chronic disease and obesity, low-density car-dependent suburbs on the fringes of cities as well as rapid urbanisation, population growth, transport-related air pollution, greenhouse gas emissions and climate change (Giles-Corti et al. 2016). In 2011, the UN acknowledged that multi-sector, whole-of-society action was required to curb chronic disease (United Nations 2011), and there is evidence that healthy, active lifestyles support both individual and planetary health (Watts et al. 2015). To this end, the UN’s Sustainable Development Goals include Goal 11, to create more sustainable, resilient, inclusive human settings and cities, and Goal 3, to create health and wellbeing for all (United Nations General Assembly 2015).

Scientific, community and policy concerns are based in part on a growing body of evidence on the effects of the built environment on physical activity (Althoff et al. 2017; Reis et al. 2016; Sallis et al. 2016a). A simple Web of Science search using the keywords “environment” AND “walk*” OR “physical activity” in human populations up to the year 2000 identifies only 17 relevant journal articles. However, changing the date range to 2001–2010, the same keywords reveal 570 articles and 1286 article for 2011–2018. This exponential growth reflects the emergence of a new field of active-living research focused on the built environment, with researchers from many disciplines—including public health, transport, planning, engineering and ecology—bringing their unique perspectives to answer related research questions.

With the proliferation of articles exploring the relationship between the built environment and physical activity, there is a genuine need to assess the state of current active-living research and, after almost two decades of studies, to identify what is needed to advance the field. This chapter begins identifying which physical-activity behaviours are affected by different aspects of the built environment and then reflects on factors that might be contributing to inconsistencies in the evidence. It then considers the gaps in the literature, before suggesting opportunities for new collaborative research that might change policy and practice.

18.2 Which Physical-Activity Behaviours Are Affected by Which Built-Environment Features?

Physical activity is a complex behaviour. It covers different purposes (recreational, transport, work-related), types (formal and informal sport, walking and cycling for different purposes, formal and informal exercise such as jogging and gym, domestic chores such as gardening) and intensity levels (moderate, vigorous, light). Activity occurs in different settings (home, work, neighbourhoods) and is likely to be influenced by different environmental attributes. Hence, more than a decade ago, systematic reviewers began recognising that different built-environment features were associated with different types of behaviour, prompting calls for behaviour-specific environmental exposure measures to be studied and context-specific environments (Humpel et al. 2002; Giles-Corti et al. 2005b). As active-living built-environment research has evolved, two different types of physical-activity behaviours have attracted the most attention: walking for transport and walking for recreation—particularly in residential neighbourhoods.

18.2.1 Walking for Transport

In the last 5 years, numerous systematic reviews of (mainly) cross-sectional evidence have confirmed earlier reviews that physical activity—principally walking for transport—is associated with three main built-environment features: higher residential density, mixed land use or access to local destinations required for daily living and connected street networks (either measured individually or combined into a composite "walkability" index). These associations persevere irrespective of how physical activity is measured (self-reported behaviour, accelerometry, steps) and the age of the adult population (adults or older adults) (Cerin et al. 2017; Sugiyama et al. 2012; McCormack and Shiell 2011; Van Holle et al. 2012).

However, there is a complex relationship between these variables. For example, density *alone* is unlikely to encourage physical activity. Higher-density development with few local destinations or little public transport—as is now being built in some cities—is simply high-rise sprawl and continues to foster motor-vehicle dependency and traffic congestion. Rather, the relationship between higher-density development and walking is apparent because density is generally a proxy for other environmental characteristics (including demographics; car ownership; access to local destinations, employment, shops and services; frequent public transport; connected street networks that make destinations more proximate) that directly influence choice of transport mode and hence levels of physical activity (Boarnet and Crane 2001; Transportation Research Board 2005). Numerous studies report that when both density and accessibility are included in the same model, the effects of density attenuate, suggesting that the accessibility of shops, services and public transport is more important than density per se (Transportation Research Board 2005).

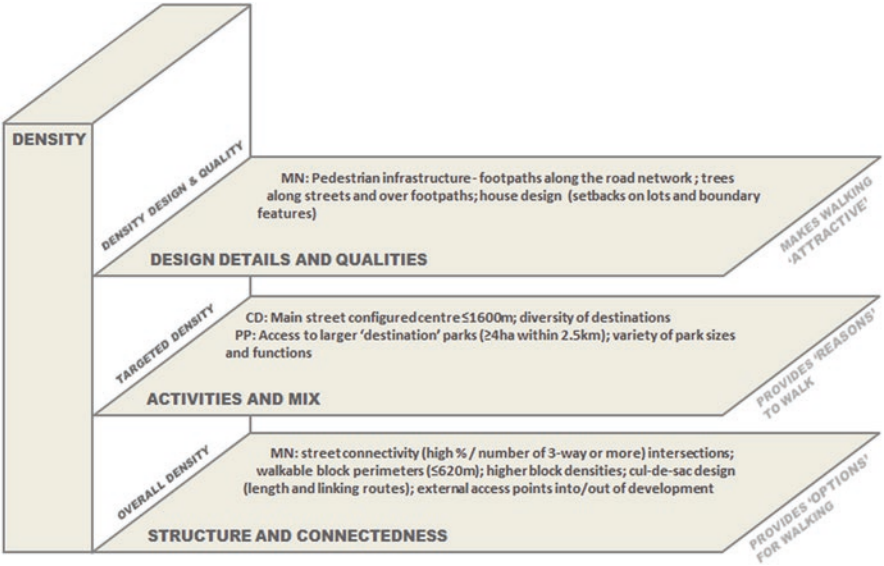

Fig. 18.1 The building blocks of a healthy, liveable neighbourhood (source: Hooper et al. 2015)

Nevertheless, increased residential density is a crucial building block in a healthy and liveable community that encourages active lifestyles. Recognising policy-makers' need for guidance on how to create such communities, Hooper and colleagues explored the interacting effects of different urban design features (Hooper et al. 2015). As shown in Fig. 18.1, the neighbourhood's structure and connectedness (for instance, street connectivity) facilitate walking, the activities and mix of destinations provide reasons to walk and the design details and qualities of the neighbourhoods make walking attractive. Higher density helps make all the other building blocks more efficient and effective: the denser the population, the greater the likelihood an area will have shops, services and accessible and frequent public transport. Nevertheless, more research is required on the levels of density that will maximise health benefits and minimise potential harm (Giles-Corti et al. 2012, 2014).

Although not widely explored in the health literature, the importance of environmental characteristics at both trip origin and destination is studied by transport academics in North America. This suggests that higher dwelling densities at both origin *and* destination increase walking and public transport use while discouraging private motor-vehicle use (Transportation Research Board 2005). The importance of the environment at both ends of the journey was highlighted in a study that found that using public transport was 16 times more likely when residents in a suburban development lived and worked within 400 m of a public transport stop, compared with those without transport access at either end of their journey (Badland et al. 2014a). The importance of environmental characteristics at both origin and destination warrants further research.

18.2.2 Walking for Recreation

Evidence of associations between the built environment and recreational walking (walking for leisure, recreation or exercise) is less consistent than for transport walking (McCormack and Shiell 2011; Sugiyama et al. 2012; Saelens and Handy 2008). In an attempt to assist policy-makers, Sugiyama and colleagues extended previous reviews by considering both access to destinations (such as parks, sports fields and playgrounds) and route attributes (sidewalks, street connectivity, aesthetics, traffic, safety) associated with walking, including recreational walking (Sugiyama et al. 2012). They confirmed that "no dominant environmental attribute" consistently predicted recreational walking. Nevertheless, they found some evidence that recreational walking was associated with access to recreational destinations such as parks and the aesthetic appeal of routes. Moreover, *all* studies reviewed that assessed the *quality* of recreational destinations revealed associations with recreational walking. So, for volitional behaviours such as recreational walking, destination quality may be an important—albeit often ignored or under-explored—element of the built environment that warrants further investigation (Kaczynski et al. 2014; Koohsari et al. 2013b; Taylor et al. 2011; Giles-Corti et al. 2005a; Sugiyama et al. 2010, 2015).

A review by Bancroft et al. (2015) focussed on the proximity and density of parks associated with objectively measured physical activity in the United States. They found "no consistent pattern of results" relating park exposure to physical activity yet observed "stronger park–physical activity associations for analyses with smaller buffer sizes" (p. 280). A strength of this review was that it comprehensively summarised findings from papers reviewed. This enabled our team to delve into the finding to better understand inconsistencies in findings. An analysis of the result summaries revealed a lack of agreement between exposure measures and standards for measuring environmental exposures that may be contributing to measurement error. This may have accounted for inconsistent findings (Koohsari et al. 2015b). Our analysis suggested that both researchers and reviewers may be neglecting to apply the same level of rigour to measuring and critiquing environmental exposures, as they do to outcome measures such as physical activity. Some of these methodological issues are now considered.

18.3 Methodological Problems Contributing to Inconsistencies in the Literature

18.3.1 Buffer Size

A major consideration for built-environment and physical-activity studies is the measurement and reporting of exposure, including whether there is sufficient variation to observe an effect. Indeed, close examination of exposure measures reveals why there may be inconsistencies in the literature (Bancroft et al. 2015). Bancroft's review observed considerable diversity in the exposure measures used. Buffers, for instance, ranged in size from 1.6 km or more down to 400 or 200 m, 50 m from a GPS/accelerometer point or the block where a child lived. Unspecified buffer distances such as "within walking distance" were defined as 10 or 20 min or distance to the nearest park. Aside from some mixed findings in a study applying two buffers (400 m and 1.6 km), no other results were significant. In contrast, in five studies incorporating smaller buffers of 400–800 m (three with children, one with adults and one with seniors), all but the seniors' study reported significant correlation with physical activity.

Bancroft and colleagues suggested that "exposure reporting bias" may explain the findings, "in which authors may have coded exposures in multiple ways and then presented only the findings most consistent with their hypotheses" (p. 27). An alternative explanation might be that, in this emerging field, investigators are (appropriately) using inductive research to explore which (if any) buffers are associated with outcomes of interest. Nevertheless, Bancroft and colleagues may be correct, and, apart from "fishing" for findings, it is also plausible that neither investigators nor reviewers pay sufficient attention to the buffer sizes that suit studying (in this case) recreational walking and, indeed, ignore the way communities are designed by urban designers. In other words, they are failing to consider what constitutes an appropriate environmental exposure for the built-environment feature or the recommended or even optimal "dose" of an environmental feature that could produce an effect.

To explain the significance of these omissions, consider applying the same approach to a hypothetical systematic review of medication use. Manufacturers of hypertension drugs, for instance, generally specify a recommended dose of their drug. If medical practitioners prescribed patients a quarter or twice the dose, what effects would we expect to observe? Moreover, if a systematic review of hypertension treatments failed to differentiate between doctors who complied with recommended doses and those who ignored them, or if the review did not consider dose at all, and simply reported inconsistent positive, negative and non-significant findings, what would we conclude? Perhaps that the review had not adequately assessed the quality of the evidence and that we should not trust its conclusions. We might also question why it got published in the first place.

The same applies to studies of environmental correlates. The importance of considering the "dose" of the intervention and the way communities are planned is highlighted in a study in Perth, Western Australia. It found that 99.1% of respondents had a park within 1.5 km of their home and 22.2% within 400 m (see Table 18.1) (McCormack et al. 2008; Sallis 2008). This is because Perth's planners and urban designers have guidelines ensuring that communities have accessible public open space. We do not know how alike or dissimilar Perth is to other cities in this regard. However, it is plausible that studies of recreational walking using large buffer sizes (1.6 km) are producing non-significant findings because there is insufficient variation in the exposure measure. Conversely, depending on the sample size, very small buffers (less than 200 m, or block size) may result in insufficient statistical

Table 18.1 Descriptive statistics for destination variables (Perth, Western Australia, 1995)

Destination	*n*	Respondents with destination within 400 m %	Respondents with destination within 1500 m %
Beach	1394	0.4	7.5
Park	1394	22.2	99.1
River	1391	0.6	7.8
School	1391	7.7	61.3
Post box	1380	41.7	99.1
Bus stop	1284	79.3	100.0
Transit station	1391	1.5	30.8
Convenience store	1391	22.7	74.4
Newsagent	1391	13.2	63.8
Shopping mall	1394	8.6	82.6

Source: McCormack et al. (2008)

power: that is, insufficient numbers of people have parks in such close proximity. Moreover, if parks are too close, one might expect *lower* levels of physical activity, not only because the parks are likely to be small and may not invite physical activity but because very little recreational walking is done *en route*. Researchers need to think carefully about the exposure measures they are adopting. A good starting point might be to consider buffer sizes found in the literature to be associated with different types of physical activity but also to review local planning policies that are governing the built forms observed in different cities (Giles-Corti et al. 2015). This would be more useful than "fishing" for appropriate exposures and would provide a rationale for selecting different-sized buffers, which are likely to vary for different exposure measures.

18.3.2 Buffer Type

Another factor leading to measurement error is the buffer type used to capture environmental exposure data, particularly radial buffers (as the crow flies), road network buffers or administrative boundaries. Radial buffers are often used due to data availability. Road network buffers are generally considered the gold standard, but if "cleaned" road network data are not available, significant work is required to topologically prepare the data in order to perform a systematic networked buffer analysis across a city. Failure to prepare data adequately increases measurement error.

In areas with cul-sacs or curvilinear street networks, radial buffers may significantly overestimate access to local destinations compared with grid or connected street networks. Figure 18.2 shows 800 m radial buffers in neighbourhoods with grid-pattern (left) and curvilinear (right) street networks, with the corresponding

Fig. 18.2 Radial buffer (circle) and road network buffer (shaded) on grid-patterned street network (left) and curvilinear-patterned street network (right)

road network buffers (shaded) based on travelling along the road network. While *radial* buffers are of equal size irrespective of the street pattern, the area of the *road network* buffer is considerably smaller in neighbourhoods with curvilinear street networks (0.6 km^2) than grid pattern (1.4 km^2). Radial buffers therefore *overestimate* the environments to which residents living in areas with curvilinear street networks are exposed. Yet, systematic reviews rarely report study results by the types of buffers used or consider the buffer types used at all.

18.3.3 Boundary Type and Size

Similarly, many studies use administrative boundaries (e.g. census tract) to measure their environmental exposures. The size of these artificial boundaries is typically based on number of households, so in higher-density neighbourhoods (inner city), the area of the administrative boundary will be substantially smaller than in lower-density (outer suburban) areas (see Fig. 18.3), further contributing to error when measuring exposure. An alternative approach to area-level measures was that adopted by Hooper (2014). Rather than using generic environmental exposure measures, she developed policy-relevant area-level measures for all dwellings within specific housing developments and found significant associations with walking. Notably, she overcame "edge" effects for study participants living on the outer edge of housing developments, by adding an 800-m buffer to the housing development to capture the environments of neighbouring housing developments. This approach better reflects how communities are planned and developed in practice

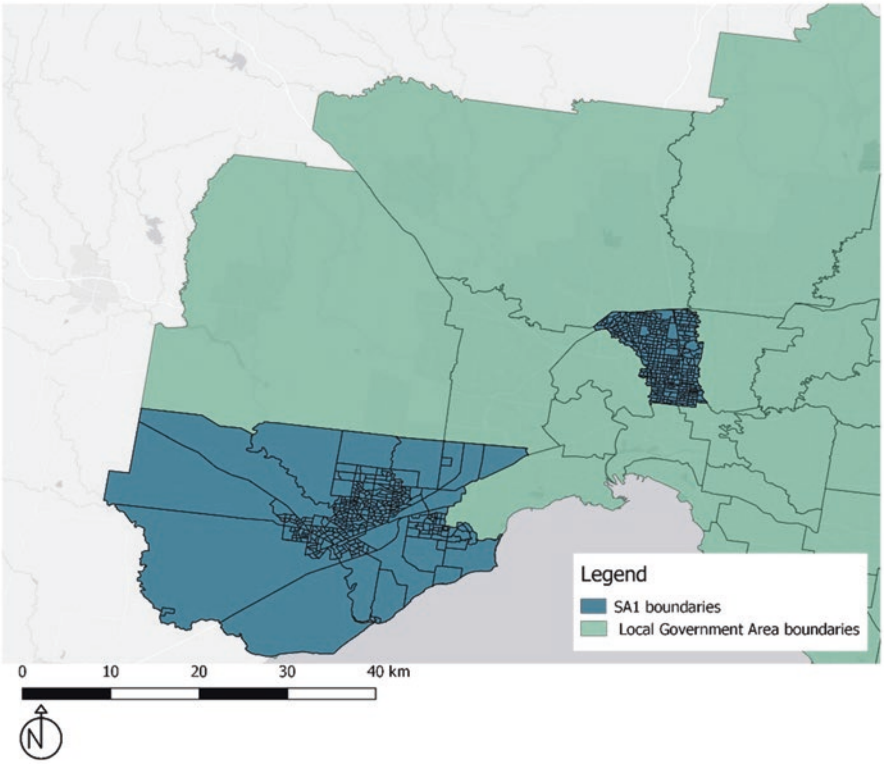

Fig. 18.3 A Victorian example of a local government and SA 1 (400 dwellings) boundaries in high-density and low-density areas

(rather than at the individual household level or over administrative boundaries) and, if housing development boundaries are available, may offer an alternative approach to using administrative boundaries.

18.3.4 Implications for Further Research and Systematic Reviews

Despite the maturity of the built environment and health field, many researchers and systematic reviewers ignore the importance of the scale, size and type of buffers used for different built-environment exposure measures. Although some reviews are now reporting whether or not administrative boundaries are used (Cerin et al. 2017), most fail to assess the quality or type (radial, road network, administrative boundary) and/or size of the buffer, nor do they consider the appropriateness of the buffer size for different types of destinations (e.g. public open space compared with a shop). This is important, because buffer size influences the variability observed in environmental exposures. Reviewers continue to combine results—irrespective of the quality of the environmental exposure measure—without differentiating between the size and types of buffers applied. With few exceptions (Ding and Gebel 2012; Panter et al. 2008), systematic reviewers simply report inconsistent or non-significant findings without any thoughtful consideration about why this might be occurring.

Similarly, as with Bancroft and colleagues' review (Bancroft et al. 2015), reviewers continue to combine findings from studies of different population age groups (adults, children, older adults), rather than reporting results separately. Environmental factors associated with walking by each of these groups may differ. It would be more instructive if results were reported separately, to make these differences apparent, rather than combining and reporting mixed or inconsistent findings. Journals could play an important role by requesting this as part of their quality assessment procedures.

Finally, some reviews combine studies in ways that do not make sense conceptually. For example, walkability is generally an urban concept, but some reviews include studies comparing urban and rural communities and small regional cities (Hajna et al. 2015). Others combine results of studies measuring perceived and objective built-environment features, despite now well-established mismatches between these different types of measures (Ball et al. 2008; Gebel et al. 2011; Koohsari et al. 2015a). While both are important for different reasons, there is little to be gained by combining studies with measures that measure different things.

Tighter guidelines are required for journals about the reporting of studies and systematic reviews that include built-environment measures. For example, future systematic reviews should report separately on studies using road network or radial buffers, and administrative boundaries of different sizes, as well as studies of different population groups. As in any research area, understanding the variables is critical, and a comprehensive review of the existing literature and its variables is required by those new to the area. As research advances and technology improves, journals should consider not publishing studies with poorly conceived exposure measures, unless they are part of a methodological study comparing measures of different types. The latter have considerable value, as they help identify and refine better measures (Brown et al. 2009; Christian et al. 2011b; Learnihan et al. 2011; Chin et al. 2008).

Some studies may continue to incorporate exposure measures known to have limitations (e.g. significant measurement error associated with large administrative boundaries or radial rather than road network buffers). This often reflects data inequities, particularly in lower-income countries where high-quality geographic information system (GIS) data are not readily available, or there are insufficient resources to clean data. However, the measurement errors and inconsistencies this is likely to produce (and the potential to attenuate findings) need to be considered when these studies are incorporated into reviews. Data providers and national statistics agencies therefore have a critical role to play in making GIS data more accessible *and* in improving data quality. Ideally, these organisations should work together to prepare and clean data to create high-value data sets that can be used for a variety of core purposes but which can also be incorporated into walkability studies, to help reduce measurement error (Chin et al. 2008). Until high-quality data are more readily available, particularly in the developing world, research funders need to fully fund the expensive process of cleaning GIS data (Jenks and Malecki 2004), and data providers and researchers should explore how they can overcome licencing barriers to enable cleaned GIS data to be shared between groups.

18.4 Where Are the Gaps?

Interventions in the built environment that are designed to reduce chronic diseases and health inequity complement urban planning efforts focused on creating cities that are more "liveable", compact and pedestrian-friendly, less automobile-dependent and more socially inclusive (Major Cities Unit 2010; Department of Infrastructure and Transport 2011; Western Australian Planning Commission 2007). Despite a rapid growth of research in this field, there is still a gap between the concept and actual creation of healthy, liveable communities (Hooper et al. 2013; Whitzman 2007; Curtis and Punter 2004). Transport and planning professionals have dismissed much public health evidence as merely "accepted wisdom", retorting: "Tell us something we don't already know" (Allender et al. 2009). While they acknowledge that health evidence adds credibility to their endeavours to create better communities, it often lacks the specificity they need to change practice—a major challenge to public health academics. The sections that follow reflect on gaps in the evidence. Further research here, if policy-relevant and codesigned with policy-makers and practitioners, could inform policy development and practice (Giles-Corti et al. 2015), perhaps providing the basis for health-promoting urban design and the "smart cities" of the future.

18.4.1 Beyond Measuring Associations, Towards Defining Thresholds

Establishing the existence and magnitude of any association between the built environment and human health has been a crucial first step in active-living research. Understanding this relationship is important, partly because changing the built environment can be costly (Cao 2010; Boarnet et al. 2008).

The next important step is to provide evidence to planners, policy-makers and designers about *how* to design walkable environments that promote healthy, active lifestyles. Attention has turned towards setting standards for *how much* of a built-environment feature leads to healthy behaviours (the "dose") and identifying any dose–response relationships. In seeking to identify thresholds for interventions, researchers must study metrics of the built environment, to inform urban design standards that can be used to develop built-environment interventions and to design communities that improve people's health.

18.4.2 Non-linear Methods

Models exploring these relationships need to consider non-linear forms that allow for a threshold to be established. Non-linear forms can be introduced in regression models via variable definitions such as polynomials, but the preferred method to date has relied on using smoothing or cubic splines in the Generalized Additive Mixed Model (GAMM) (Wood 2009). This allows for flexible, non-linear forms that are useful for uncovering dose–response, linear, non-linear and threshold relationships. To date, research using these methods has primarily been conducted by researchers in the International Physical Activity and the Environment Network (IPEN), combining comparable data from several countries.

IPEN's early studies have examined non-linear relationships between perceived built-environment measures derived from the Neighbourhood Environment Walkability Scale (NEWS) and a variety of health measures (Kerr et al. 2013). For example, a three-country study found that minutes spent in motorised transport started to decline when the perceived number of destinations exceeded 10, or the destination was perceived to be no further than 20 mins' walk away (Van Dyck et al. 2012). Other IPEN papers have found that higher levels of perceived aesthetics led to increased leisure-time walking and that higher levels of perceived walking and cycling infrastructure led to increases in moderate to vigorous leisure-time activity (Van Dyck et al. 2013, 2014). Similarly, there were non-linear relationships between various neighbourhood perceptions and walking and cycling for transport (Kerr et al. 2016). Specifically, transport walking increased for higher perceived residential density, before plateauing, yet the results for transport cycling suggested a negative overall relationship with perceived residential density. Similarly, an IPEN paper found a curvilinear relationship between objectively measured accelerometer data of daily minutes of moderate to vigorous activity, and a measure of the perceived land-use mix access, whereby only higher scores perceiving greater quantities of places and transit stops within walking distance of home led to an increase in daily minutes of moderate to vigorous activity (Cerin et al. 2014).

These IPEN papers are important, because they have tested new statistical methods and found evidence of non-linear dose–response relationships with perceived built-environment measures. However, studies of perceptions are of limited practical use to planners, policy-makers and designers. The case for designing healthy cities and for developing evidence to inform standards for built-environment interventions must incorporate *objective* measures. For example, using a series of indicator variables, Eom and Cho explored dose–response relationships between land-use mix, population and street densities and walking and private-vehicle trips (Eom and Cho 2015). They found that, in Seoul, walking increased once population densities reached between 9132 and 16,101 persons per km^2, but beyond this level of density walking decreased. Such evidence is clearly important, suggesting that once cities become too densely populated, they may discourage walking. Such "diminishing returns" also have implications for planning and investment: they suggest an optimal point for certain built-environment features for supporting healthy and active behaviours, beyond which there is limited benefit.

To this end, potentially important IPEN data from 14 cities around the world was recently published in *The Lancet*. Using GAMMs, Sallis and colleagues explored non-linear relationships between accelerometry physical-activity data and objective measures of the built environment (Sallis et al. 2016b). No dose–response or threshold relationships were found between objectively measured accelerometry data and residential, street, park or public transport density. However, another IPEN study—using similar built-environment measures and studying self-reported transport walking—found curvilinear relationships with objectively measured residential density, street connectivity and park density exposures: the residential density threshold for any transport walking was 12,000 dwellings per km^2, for street connectivity 200–250 intersections per km^2, and participants with up to 10 parks within 1 km of their home were between 2.5 and 3.5 times more likely to do any self-reported walking. In this study, only linear relationships were observed for residential density, street connectivity and land-use mix exposures for self-reported transport cycling suggesting that there are no specific threshold quantities for these exposures (Christiansen et al. 2016).

18.4.3 Lack of Specificity

One reason why the IPEN paper could not identify thresholds using objective measures of total physical activity and transport cycling is the lack of specificity between environmental exposures and behaviour. For example, total physical activity includes many types of activity, but the objective measures of the built environment studied are relevant only to transport walking. As discussed above, behaviour-specific and environment-specific models are needed (Giles-Corti et al. 2005b). Such approaches should also be applied to threshold analyses, with exposure type chosen according to the outcome variable being investigated. By way of example, Kerr et al. (2016) found that "walkable environments" did not appear to be associated with cycling. However, a person can cycle further than they can walk in a given time, so different thresholds may exist for cycling compared with walking. For instance, while many transport walking studies use buffer sizes of up to 1.6 km, a much larger buffer (such as 3.2 km) may be more relevant for cycling. Also, cycling is generally under-studied and requires further investigation.

As research in active living evolves, it remains to be seen what advice researchers will offer to policy-makers, should several different or conflicting thresholds be found for different health behaviours or health benefits, or indeed what should be done if none are found at all. For example, what will our advice be if linear relationships suggest increasing improvements in physical activity for any improvement in the built environment (Sallis et al. 2016b). We would argue that urban design should aim to maximise the number of residents able to achieve (at the very least) the recommended levels of physical activity in their local communities.

18.4.4 Comprehensive Ecological Models Incorporating Individual, Social and Environmental Factors

Examining multiple levels of influence reflects an ecological approach to research and interventions (McLeroy et al. 1988), yet the adoption of ecological models is relatively new in active-living research. Despite these models' potential usefulness in conceptualising research, Ball et al. (2006) have argued that many studies lack strong and well-conceptualised theoretical models for testing the interactions and pathways among personal, social and environmental factors.

Hence, in the last two decades, social-ecological frameworks (Barton and Tsouros 2000; Sallis et al. 2006a) have been proposed, developed and used to examine the effects of the built environment on physical activity (Giles-Corti and Donovan 2002). These models have mapped the interrelationships between individual, social, physical and policy determinants and have identified a range of urban design attributes related to physical activity—primarily for recreation and transportation purposes (Sallis et al. 2012).

Nevertheless, a major gap in the literature is studies that simultaneously incorporate multiple levels of influence: individual, social environment and built environment (Brownson et al. 2009; Lee and Moudon 2004; Panter and Jones 2010; McCormack and Shiell 2011; Mokhtarian and Cao 2008). This is becoming a particular challenge for secondary analyses of existing studies, as few studies have sought to simultaneously examine the relative influence on behaviour of these three factors (Giles-Corti and Donovan 2002, 2003). This is a prime opportunity for future research to inform comprehensive interventions.

18.4.5 Natural Experiments and Longitudinal Studies

A major criticism of built-environment research is its reliance on cross-sectional studies, which limit our ability to determine cause and effect. The main question is self-selection: does neighbourhood design change residents' behaviour, or do residents who prefer more active lifestyles simply choose to live in neighbourhoods where it is easier or more pleasant to walk? In other words, the relationship between the built environment and walking behaviour is confounded by walking preference (Cao 2010).

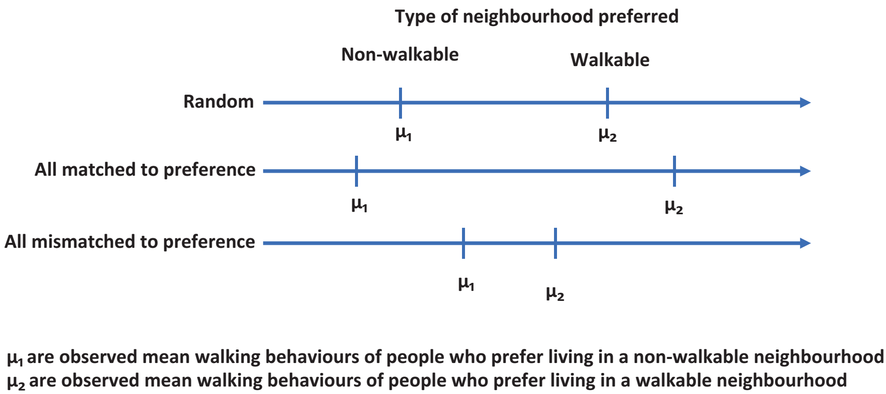

Fig. 18.4 The relationship between self-selection and misestimation (Modified from: Cao 2010)

Nevertheless, from a public health perspective, self-selection may be a moot point. In most cities, most people—irrespective of their preferences—do not live in walkable neighbourhoods. Indeed, at least in Australia, there is evidence that more than 60% of residents of low-walkable neighbourhoods (Bull et al. 2015) or non-transit-oriented developments (Kamruzzaman et al. 2016) would prefer to live in a more walkable neighbourhood or in a transit-oriented development, while fewer residents (just over 30%) of walkable neighbourhoods or transit-oriented developments would prefer to live elsewhere.

Cao's hypothesis on the effects of self-selection and misestimating the effects of neighbourhoods on walking illustrates this point (Cao 2010). Figure 18.4 shows the hypothesised mean walking levels of people based on their preference to live in non-walkable or walkable neighbourhoods: if people could be randomised to live in varying types of neighbourhoods, those who prefer non-walkable neighbourhoods are hypothesised to walk less than those who prefer walkable neighbourhoods. If, on the other hand, people could live in their preferred type of neighbourhood, then those preferring a non-walkable neighbourhood would walk less, and those preferring a walkable neighbourhood would walk more. Conversely, if people were mismatched (those who preferred a non-walkable neighbourhood were allocated to live in a walkable neighbourhood, and vice versa), Cao hypothesises that those who prefer a non-walkable neighbourhood but who live in a walkable area would walk more than they would have done if left to their own preference, and those who prefer a walkable one would walk less than they would otherwise. This is important from a public health perspective. It suggests that if more walkable communities became the norm, rather than the exception—as is currently the case in most cities—then everyone would walk more: those who prefer to walk and even those who don't, particularly if walkable communities implemented strategies to discourage driving. Given the current lack of physical activity among a large proportion of the population, the health benefits of even a modest increase in the numbers of people who are moderately physically active could be large, producing significant annual cost savings to health systems (Stephenson and Bauman 2000).

Nevertheless, systematic reviewers repeatedly call for more natural experiments and longitudinal studies as an alternative to randomised controlled trials (Merom et al. 2003; Ogilvie et al. 2007; Petticrew et al. 2005; Kaczynski and Henderson 2007; Kerr et al. 2012; McCormack and Shiell 2011; Sugiyama et al. 2012; Pearce and Maddison 2011; Lee and Moudon 2004; Panter and Jones 2010; Mokhtarian and Cao 2008; Van Cauwenberg et al. 2011; Ding and Gebel 2012; Durand et al. 2011; Saelens and Handy 2008; Cao et al. 2009; Renalds et al. 2010; Ewing et al. 2003), since—with limited exceptions (Wells and Yang 2008)—it is not feasible to randomise study participants to live in certain homes or environments. The aim of these studies is to satisfy causal inference concerns (Mokhtarian and Cao 2008), and they include panel studies that comprise participants who relocate ("movers").

Other longitudinal studies have monitored health changes over time in participants living in high- or low-walkable neighbourhoods. For example, based on ecological data, living in higher-walkable neighbourhoods appeared to protect people's health and was associated with decreased prevalence of overweight, obesity and diabetes between 2001 and 2012 (Creatore et al. 2016). At each time point, living in highly walkable areas was associated with significantly higher walking, cycling and public transit use, and lower car use, than living in the least-walkable areas. However, there was little change in daily walking and cycling frequencies; these "increased only modestly" over time in highly walkable areas. But perhaps more importantly (although not considered by the authors), as participants aged, active behaviours did not *decline* in those living in higher-walkable areas.

"Movers" studies include those that follow participants in longitudinal or panel studies who relocate to new neighbourhoods (Krizek 2003; Hirsch et al. 2014a, b, c). These have shown varying results, mainly because people who relocate often move to neighbourhoods with similar characteristics (Krizek 2003). Hence, although people relocate, environmental exposures that encourage more walking may not have changed. To overcome this problem, Hirsch and colleagues studied movers who relocated to neighbourhoods with a 10-point higher "walk score". This was associated with 16 min more weekly walking, an 11% higher chance of meeting goals for transport walking and a modest reduction in body mass index. However—not surprisingly given the study's exposure measure—there was no association with recreational walking (Hirsch et al. 2014a).

Other types of studies that are informative for built-environment and health research are natural experiment studies of the effects of policy changes on physical activity. These might involve significant changes to the built environment following transport interventions, such as congestion charging or new infrastructure for public transport or cycling (Goodman et al. 2013, 2014; Sahlqvist et al. 2013; Ogilvie et al. 2011, 2012; Panter et al. 2016, b; Heinen et al. 2015a; Martin et al. 2015; Sahlqvist et al. 2015; Merom et al. 2003 #921; Cohen et al. 2008), implementation of new urban design policies (Egan et al. 2003, 2007; Sallis 2009; Story et al. 2009) or upgrades to public open space (Veitch et al. 2014, 2017; Cohen et al. 2009a, b). In many cases, the built environment is changed *around* study participants; the question is whether the "dose" of the intervention is sufficient to change behaviour or whether people substitute one behaviour for another. In other cases, natural experiments involve monitoring people who relocate to new types of housing (Wells and Yang 2008) or to new suburbs designed according to new subdivision design codes (Giles-Corti et al. 2008). In the latter case, a unique, large-scale study conducted by our team in Perth, Western Australia, is described in Sect. 18.5.

18.4.6 Policy-Relevant and Practice-Relevant Natural Experiments

Academic research—including active-living research—is often criticised for being irrelevant or poorly linked to policy and practice (Oliver et al. 2014), even though influencing urban planning policy and practice is often a stated goal of built-environment and active-living research (Goldstein 2009). This shortcoming has led to calls for research to be better aligned with current and future policy environments and planning practices (Orton et al. 2011).

Notably, Allender and colleagues found that much of the built-environment and health evidence lacks the specificity needed by government planners to inform planning policy (Allender et al. 2009). Evidence-based active-living or public health recommendations are often provided to planners and policy-makers without any obvious links to existing policies or legislation or guidance on how to achieve change.

Planning professionals and policy-makers have said that to help translate health research into planning policy and practice, more research is required that assesses the effectiveness of planning regulations and policies in changing public health behaviours, through the evaluation and documentation of innovative communities and environmental or planning policies, programmes or codes that promote active living (Allender et al. 2009; Koohsari et al. 2013a; Durand et al. 2011; Talen 1996). Planning academics have even criticised their own field for neglecting to determine the degree to which plans (e.g. planning policies or guides for future urban development) have been implemented and adhered to, with few studies quantitatively assessing the implementation processes and success (Talen 1996).

While few studies have rigorously examined the role of specific urban planning policies in producing built environments that contribute to healthy and liveable neighbourhoods, cities are increasingly being viewed as “urban laboratories”. This reflects growing recognition of the valuable knowledge that can be created concurrently with urban development, when new ideas are implemented and their effects measured (Karvonen and Van Heur 2014).

This is also important given the rise in popularity of planning movements, such as New Urbanism and Smart Growth, that have emerged in an attempt to counter planning codes thought to be responsible for suburban sprawl. Proponents of these codes focus on recalibrating and reconfiguring the design of suburbs, based on traditional neighbourhood designs that create places for living, working and recreation (Audirac 1999) and incorporating higher-density, mixed-use, pedestrian-oriented, walkable communities (CNU 1997; Duany et al. 2000; Calthorpe 1993; Kim 2000). As more cities adopt the rhetoric of (and often explicitly refer to) these codes in their planning work, there has been interest in assessing their claims and how well they improve health and wellbeing. While a growing number of case studies and research papers measure built-environment concepts that can be linked to New Urbanism or Smart Growth principles (such as walkability and land-use mix), an explicit connection between these principles and better health has not yet been demonstrated (Durand et al. 2011). Although the principles of New Urbanism or Smart Growth make theoretical sense for creating healthier communities, there is virtually no empirical work directly assessing and linking the implementation of specific planning policies based on these principles to actual health (Talen 1996). This is a serious gap in the literature: as more communities implement planning policies based on these principles, there is a need for greater certainty about whether, and under what conditions, policy change might improve overall community health and wellbeing (Durand et al. 2011).

As new or modified planning policies, codes and movements are adopted, tested or implemented, opportunities emerge for natural experiments to monitor the effects of these interventions on active-living and health behaviours and to provide more rigorous evidence than is contained in the cross-sectional studies that dominate the literature. Evaluations of urban planning policies and codes that promote active living are important, both for providing prescriptive and policy-specific evidence to inform urban policy and practice and for strengthening academic evidence (Allender et al. 2009; Durand et al. 2011; Koohsari et al. 2013a; Taylor et al. 2011; Brownson et al. 2009). In case studies or natural experiment evaluations of planning policies and practices, results that are directly relatable to the policy and its implementation are essential. We need this type of evidence in order to know which aspects of the policy are (or are not) being implemented and to identify those that may (or may not) improve people's health (Hooper et al. n.d.; Brownson et al. 2009).

18.5 A Western Australian Example

A unique opportunity to evaluate the health benefits of urban policy in situ arose in 1998, when the Western Australian government tested its "Liveable Neighbourhoods Community Design Guidelines" (LN): a new planning policy aiming to create more sustainable, liveable and healthy communities (Western Australian Planning Commission 1997). Based on a local interpretation of New Urbanism (CNU 1997), the trial of LN, which commenced in 1997, was designed to eventually replace conventional development controls and design codes that had led to car dependence and suburban sprawl with an alternative approach to suburban neighbourhood design. LN aimed to create "more compact, pedestrian-friendly neighbourhoods, with good links to public transport services" (Western Australian Planning Commission 2000). Important aims were to reduce dependence on private motor vehicles, encourage more active forms of transport (walking, cycling and public transport) and foster a sense of community.

The RESIDE study was designed as a natural experiment in 74 new greenfield developments (19 liveable, 11 hybrid and 44 conventional) under construction across the Perth metropolitan region in 2003 (Giles-Corti et al. 2008). All people who purchased house-and-land packages in these developments (n = 10,193) were invited to participate in the study by the state water authority, which is notified of new owners after land title is transferred. Eligible participants were those currently building a home in the selected development, who intended to relocate to that home, and who were willing to complete three surveys and wear a pedometer for 1 week (on three occasions) over a 5-year period. (In 2010, additional funding was secured to conduct a fourth follow-up.) Participants completed questionnaires on four occasions: Time 1, baseline, 2003–2005, during construction of their new home and before relocation (n = 1813; 33.4% response rate); Time 2, 2004–2006, ≈1 year after relocation to their new home (n = 1465); Time 3, 2006–2008, ≈3 years after relocating (n = 1229); and Time 4, 2011–2012, ≈6–9 years after relocating (n = 565). Using a GIS, objective built-environment measures were generated for all participants at each time point, to provide a set of consistent and comparable (i.e., longitudinal) measures across the study period. These measures quantified the built-environment characteristics of participants' neighbourhoods (defined as the area accessible along the street network within 1600 m of participants' homes), including access to different types of public open space, shops and public transport; provision of footpaths, street connectivity, land-use mix, residential density and (standardised) neighbourhood walkability measures.

The intention of RESIDE was to undertake policy-relevant research and, in particular, to evaluate current state government urban design policy. Hence, findings were published not only in the academic literature (Hooper et al. n.d.) but also in a user-friendly summary for policy-makers (Bull et al. 2015). Briefly, RESIDE's longitudinal findings supported cross-sectional evidence that neighbourhood walkability (especially land-use mix and street connectivity), local access to public transport and access to a mix of different types of local destinations are important determinants of transport walking (Knuiman et al. 2014), but not of body mass index (Christian et al. 2011a). Moreover (after full adjustment for individual, social-environment and built environment factors and neighbourhood preference), RESIDE found that, following relocation, among those people who now had greater access to transport-related destinations, transport walking increased by 5.8 min per week for each type of destination gained and recreational walking by 17.6 min per week for each type of recreational destination gained (Giles-Corti et al. 2013).

However, the LN policy itself did not appear to be effective. We found no significant differences in the transport or recreational behaviours of those who relocated to neighbourhoods designed according to the LN policy, compared with others. While the policy helped to create more supportive environments, the dose of these interventions was insufficient to encourage more walking (Christian et al. 2013). We proposed a longer-term follow-up, but our findings also raised the question of whether there had been a policy failure or a failure to implement the policy as intended (Hooper et al. 2014).

Hence, a unique aspect of RESIDE was the quantification of the *actual* implementation of the policy on the ground, to better understand whether the observed behaviours were products of under-delivery of the policy or of fundamental shortcomings in the policy itself (Hooper et al. 2014). Using spatial measures tailored to the urban design features required by the policy, the evaluation identified which, and how much, of the design features had been implemented. None of the developments (including those classified as LN developments by the Department of Planning) had implemented the full suite of requirements as intended by the policy. Indeed, overall across all new developments, the LN policy was only around 50% implemented. Nevertheless, for every 10% increase in levels of overall policy compliance, the odds of participants walking for transport in the neighbourhood increased by 53% (Hooper et al. 2014), the odds of sense of community increased by 22%, the odds of good mental health increased by 8% (Hooper et al. 2014) and the odds of being a victim of crime decreased by 40% (Foster et al. 2015). These process evaluation findings were of considerable interest to the Department of Planning and led to the RESIDE findings being translated into a recent policy review. The process evaluation was also able to show which, if any, aspects of the policy were producing the desired physical-activity increases and health benefits. Moreover, it allowed the study team to communicate to the Department of Planning that the policy levers were effective but that there needed to be greater focus on achieving higher levels of implementation. RESIDE revealed the need to measure and assess actual *implementation* of planning policies. Without such evidence, natural experiments are simply academic, offering policy-makers no new information that they "don't already know" (Allender et al. 2009).

18.6 Where to Next?

Despite the wealth of knowledge garnered in the last two decades about the influence of the built environment on physical activity, there is still much to be done. First, most of the evidence to date is from developed countries, with research in developing countries only beginning to emerge very recently (Giles-Corti et al. 2016). While some correlates appear to be universal (Sallis et al. 2016b), there is still much to learn about the extent, type and quantity of interventions needed in different countries, and the conditions under which supportive built environments will be effective (Giles-Corti et al. 2016). For example, do the same interventions work (and for whom) in very hot climates or in cities that are actually, or are perceived to be, unsafe?

But even in developed countries, important questions remain about the interplay between urban design attributes at the local level and the contribution of regional planning to the overall system and whether there is an economic argument for building walkable neighbourhoods that produce co-benefits across multiple sectors.

18.6.1 Complex Systems Modelling

As discussed earlier, social-ecological models (Barton and Tsouros 2000; Sallis et al. 2006b) consider multiple levels of influence on behaviour and have been used to map the interrelationships between individuals and social, physical and policy determinants, enabling the identification of a range of local urban design attributes related to physical activity, primarily for recreation and transportation purposes (Sallis et al. 2012).

However, in the recent *Urban Design*, *Transport*, *and Health* series published in *The Lancet* (Giles-Corti et al. 2016), we argued that opportunities for active living arise out of synergies between the "Eight Ds": five local urban design and transport factors (density, design, distance to transit, destinations and desirability) and three regional factors (destination accessibility, distribution of employment and demand management). It is now clear that simply designing local neighbourhoods that encourage walking and cycling is not enough; communities need metropolitan regional planning interventions that ensure public transport access to jobs that are (typically) inequitably distributed across metropolitan regions. Furthermore, without demand management strategies to reduce the attractiveness of driving (e.g. congestion charging, manipulating the amount and cost of parking), it is unlikely that higher use of active transport will ever be achieved.

The question of how to plan and design cities that encourage active living and physical activity is multifaceted and complex. In established areas, the general conditions that support active living evolve and transform over time as the local urban fabric changes (e.g. when land undergoes zoning changes or local destinations are replaced with other types). At the same time, broader metropolitan infrastructure projects (new suburbs, road expansions, public transport upgrades, relocation of government agencies) affect established areas also. Assessing the effects of all these changes requires a complex systems approach.

In complex systems, analysis focuses on the behaviour of the system, which emerges from the interactions between the components (Von Bertalanffy 1969). This mode of thinking involves the use of either analytical deterministic models, where the model output is dependent on the parameter values and the initial conditions, or stochastic probabilistic models, where the model allows for random variation in one or more inputs over time (Ross 2014). Complex systems can be analysed using causal loop diagrams and can be operationalised using digital planning tools that support urban planning and policy-making (Boulange et al. 2017). Digital tools and planning support systems also enable end users to understand, explore and interact with these models via easy-to-use visual interfaces. Digital planning tools enable planners to simulate possible interventions before they finalise their plans and to explore myriad connected factors via an interactive mapping interface made available through a desktop GIS (Pelzer et al. 2013; Arciniegas and Janssen 2012; Boulange et al. 2017).

Research into the relationship between the built environment and physical activity could benefit in several ways from complex system modelling:

18.6.1.1 Bringing Together Researchers, Planners, Policy-Makers and Practitioners

Planning support systems based on complex systems help planners and decision-makers understand—from a variety of perspectives—how planning will affect the design and functioning of the city, depending on the outcomes of interest (e.g. health or transport). One example is the Walkability Planning Support System (Boulange et al. 2015, 2017), built in Community Viz, a now well-established ArcGIS extension (Walker and Daniels 2011). Ideally, planning support system models are designed collaboratively with a range of participants (including planners and policy-makers), to stimulate communication about how a complex system works. By participating in the design, all parties can develop a shared understanding of the main relationships and dynamics of the system and identify vulnerabilities and leverage points for changing the system structure. They can also provide valuable feedback on the outputs of the model as it is being built and refined (Newell and Proust 2009; Newell et al. 2008). Techniques such as face validity and collaborative modelling are important to build into the complex model workflow, to ensure that the end users trust the structure and behaviour of the model.

Planning support systems and interactive mapping tools such as the Australian Urban Research Infrastructure Network portal (AURIN) offer datasets from custodians such as health, housing and transport departments, to model the city as a complex system revealing previously unexplored spatio-temporal relationships (Delaney and Pettit 2014; Pettit et al. 2015). Such analysis helps us understand the various dimensions of a city, further supported by urban "big data" such as spatio-temporal housing data at the property level (Pettit et al. 2017), or effects on physical activity measured using smartphones with built-in accelerometry (Althoff et al. 2017).

Collaborative processes aimed at mapping the complex relationship between the built environment and physical activity are a novel way to communicate built environment research and increase awareness among policy-makers of the interdisciplinary nature of urban planning and research. Furthermore, the potential of urban big data becomes evident when using new, interactive mapping environments such as CityViz, which allows bicycle and other data to be used in city planning and decision-making (Goodspeed et al. in press).

For example, Fig. 18.5 shows rider travel movements in Melbourne derived from the Bicycle Network's Riderlog smartphone application. These data can be used by city planners to understand cycling patterns and behaviour across the city, such as the proportion of female versus male cyclists and their different cycling patterns. They can also be mapped and analysed to determine hot spots of increased infrastructure demand or danger for cyclists (and therefore where to invest in upgrades). Understanding patterns and demographics in cycling behaviour is important in rapidly urbanising cities (like Melbourne), particularly cities promoting more sustainable, healthy and safe transport modes.

Fig. 18.5 Urban big data: rider travel movements in Melbourne, from the Bicycle Network's Riderlog smartphone application

18.6.1.2 Validating Urban Health Indicators

CityViz and Community Viz (the Walkability Planning Support System) demonstrate that, with appropriate data, complex systems models can be built to explore how multifaceted associations between urban design features and transport systems result in health risks among population groups (Badham 2010). However, some complex systems allow for dynamic modelling; this in turn allows researchers to explore causal relationships that help us understand how cities affect people's physical and mental health (Gatzweiler et al. 2017).

These types of analyses are also useful when developing and validating *indicators* of the condition of the urban health system and of the built environment itself, offering a convenient way to store information from scenarios tested in the complex system model (Badland et al. 2017a; Murphy et al. 2017). Indicators can support good urban management and urban policy (Badland et al. 2014b; Lowe et al. 2015). In particular, they can help decision-makers measure and monitor cities' performance against population health or environmental protection standards and trigger alerts when unwanted results occur.

18.6.1.3 Simulating Urban Future Scenarios

Complex models could be built to examine the interplay of urban design attributes at the local level while accounting for the effect of regional planning on people's physical activity. This would allow researchers to work with policy-makers and practitioners to determine optimum levels of density, street connectivity and destination access to increase physical activity. At the same time, one could model commuting patterns that are active transport-friendly, for example; after a model has been validated, projection and "what if?" analyses can be undertaken. By varying input parameters, analysts can simulate interventions and estimate the repercussions of changing one or more areas of the system. Although model simulations cannot be relied upon to give accurate predictions of what will happen following interventions, they are a useful tool to describe the likely results and identify potential unintended consequences (such as harm to health) (Urban et al. 2011; Lich et al. 2013).

Simulation may be particularly useful when estimating the likely effect of urban planning policies or urban design requirements on levels of physical activity over time. Simulations could be run using agent-based modelling (ABMs), which model synthetic populations and the ways in which agents (e.g. residents in a local neighbourhood) might respond to changes in the built environment under various hypothetical changes to the transport network (Badland et al. 2017b).

In modelling urban futures and health, we need to understand the likely effects on our cities of disruptive technologies. Uber and Airbnb are two notable examples that are already challenging planners and policy-makers, and they have the potential to fundamentally change the way our cities function. Dockless bike-sharing schemes are also being implemented in many cities; these, along with other disruptive technologies and the data they can provide, need to be considered when understanding and modelling the ever-evolving complexity of the city. Finally, autonomous vehicles are being trialled in some cities, with dissemination on the horizon: what changes will they bring, especially to the physical-activity patterns of urban dwellers? Measuring and monitoring to create early warning systems of the effects of these major changes on cities and on the health and wellbeing of residents is a priority for future research.

18.6.2 Economic Evaluations

Low levels of physical activity worldwide represent a health and economic burden for individuals and societies (Ding et al. 2016; Kyu et al. 2016). But the health benefits of physical activity are rarely considered in economic evaluations of environmental interventions and policies (Mulley et al. 2013). One reason may be that studies examining the economic merit of environmental initiatives are in their infancy, with no agreement on appropriate methods (Brown et al. 2016). Lack of full consideration of the health benefits of environmental initiatives that foster physical activity may underestimate their value to society. This might lead to the misallocation of resources towards car-oriented infrastructure.

Three recent systematic reviews that include economic evaluations of active-transport initiatives (walking and cycling) indicate significant heterogeneity in approaches for the inclusion of physical-activity-related health benefits (Brown et al. 2016; Doorley et al. 2015; Mueller et al. 2015). Methods to estimate demands on infrastructure or the effectiveness of interventions are diverse and focused on transport walking and cycling, without offsetting the substitution effect from other forms of physical activity such as recreational walking and cycling (Brown et al. 2016). Likewise, quasi-experiments suggest that new transport infrastructure may not influence total physical activity (Panter et al. 2016), due to a substitution effect: people who use this infrastructure may substitute this activity for participation in other forms of physical activity, with no overall gain. This may lead economic evaluations to overestimate the health benefits.

Most evaluations to date have used a cost–benefit analysis (CBA) framework (Brown et al. 2016; Doorley et al. 2015; Mueller et al. 2015), which is consistent with methods used when appraising government initiatives (Mulley et al. 2013). But CBAs present a problem, as a monetary value needs to be placed on goods without a market value, such as health (Drummond et al. 2005). Nevertheless, in the transport field, agreed methods have been developed to evaluate non-market goods: for example, travel-time savings are now included in routine evaluations of transport projects, despite initial controversy (Mulley et al. 2013).

The World Health Organization has developed the Health Economic Assessment Tool (HEAT) as a homogeneous framework to evaluate the health benefits of interventions that promote walking and cycling (Kahlmeier et al. 2014). Although a promising effort, it quantifies the effect of walking and cycling on premature mortality only, ignoring any improvement to quality of life. Users of the tool still need to produce demand estimates from the proposed initiative, which, as highlighted, has been generally weak. In addition, HEAT (like most of the literature to date) has focused on the transport sector. The built environment is broader than this and includes the planning of cities (for instance, based on the Eight Ds). We need standardised, transparent methods for quantifying the health benefits of physical activity. This could be achieved through collaborative research between urban and transport planners and health economists. Tools such as the Walking Planning Support System model, in combination with established methods used in health economics that incorporate mortality and quality-of-life measures (Vos et al. 2010), may help us evaluate the economic merit of building neighbourhoods that promote active living. However, public health researchers also need to improve their understanding of the policy-making process, if they hope to generate health-improving change in non-health sectors such as transport and planning (Carey and Crammond 2015).

18.7 Conclusion

Research on the built environment and physical activity is maturing, and it is important that we learn from past lessons. While many built-environment features appear to influence walking for transport or recreation, there are many inconsistencies in the literature, which could in part be due to the way exposure measures are conceptualised and measured. Assumptions that researchers have access to high-quality data across cities are unfounded, particularly in many developing countries. There is a critical need to create and provide access to clean, reliable and rich data for statistical analysis and data modelling. In developed countries, researchers have access to many good urban datasets, but there are significant gaps (e.g. footpath data), and quality and availability vary between cities. Higher-quality, more accessible data will strengthen our understanding of the built environment and physical activity.

A number of promising areas of research might also support the translation of findings into policy and practice: identifying thresholds for built-environment interventions; assessing the relative influence of individual, social and built-environment features; using complex system modelling to simulate interventions; and evaluating the economics of built-environment interventions. To avoid simply confirming conventional wisdom in the planning and transport professions, researchers are encouraged to codesign research with policy-makers, practitioners and disciplines outside health. Through interdisciplinary multi-sector research, there is potential to help shape the cities in which future generations will live, work and play.

References

Allender, S., Cavill, N., Parker, M., & Foster, C. (2009). Tell us something we don't already know or do!' – The response of planning and transport professionals to public health guidance on the built environment and physical activity. *Journal of Public Health Policy, 30*, 102–116.

Althoff, T., Sosic, R., Hicks, J. L., King, A. C., Delp, S. L., & Leskovec, J. (2017). Large-scale physical activity data reveal worldwide activity inequality. *Nature, 547*, 336–339.

Arciniegas, G., & Janssen, R. (2012). Spatial decision support for collaborative land use planning workshops. *Landscape and Urban Planning, 107*, 332–342.

Audirac, I. (1999). Stated preference for pedestrian proximity: An assessment of new urbanist sense of community. *Journal of Planning Education and Research, 19*, 53–66.

Badham, J. (2010). *A compendium of modelling techniques*. Canberra: The Australian National University.

Badland, H., Foster, S., Bentley, R., Higgs, C., Roberts, R., Pettit, C., & Giles-Corti, B. (2017a). Examining associations between area-level spatial measures of housing with selected health and wellbeing behaviours and outcomes in an urban context. *Health & Place, 43*, 17–24.

Badland, H., Hickey, S., Bull, F., & Giles-Cort, B. (2014a). Public transport access and availability in the RESIDE study: Is it taking us where we need to go to? *Journal of Transport & Health, 1*, 45–49.

Badland, H., Whitzman, C., Lowe, M., Davern, M., Aye, L., Butterworth, I., Hes, D., & Giles-Corti, B. (2014b). Urban liveability: Emerging lessons from Australia for exploring the potential for indicators to measure the social determinants of health. *Social Science & Medicine, 111C*, 64–73.

Badland, H. M., Rachele, J. N., Roberts, R., & Giles-Corti, B. (2017b). Creating and applying public transport indicators to test pathways of behaviours and health through an urban transport framework. *Journal of Transport & Health, 4*, 208–215.

Ball, K., Jeffery, R., Crawford, D., Roberts, R., Salmon, J., & Timperio, A. (2008). Mismatch between perceived and objective measures of physical activity environments. *Preventive Medicine, 47*, 294–298.

Ball, K., Timperio, A. F., & Crawford, D. (2006). Understanding environmental influences on nutrition and physical activity behaviours: Where should we look and what should we count? *International Journal of Behavioral Nutrition and Physical Activity, 3*, 33.

Bancroft, C., Joshi, S., Rundle, A., Hutson, M., Chong, C., Weiss, C. C., Genkinger, J., Neckerman, K., & Lovasi, G. (2015). Association of proximity and density of parks and objectively measured physical activity in the United States: A systematic review. *Social Science & Medicine, 138*, 22–30.

Barton, H., Tsouros, C., & World Health Organization Regional Office for Europe. (2000). *Healthy urban planning: a WHO guide to planning for people*. Abingdon: Taylor & Francis.

Boarnet, M., & Crane, R. (2001). The influence of land use on travel behavior: specification and estimation strategies. *Transportation Research Part A Policy and Practice, 35*, 823–845.

Boarnet, M. G., Greenwald, M., & McMillan, T. E. (2008). Walking, urban design, and health – Toward a cost-benefit analysis framework. *Journal of Planning Education and Research, 27*, 341–358.

Boulange, C., Pettit, C., & Giles-Corti, B. (2017). The walkability planning support system: An evidence-based tool to design healthy communities. In S. Geertman, A. Allan, C. Pettit, & J. Stillwell (Eds.), *Planning support science for smarter urban futures*. Cham: Springer International Publishing.

Boulange, C., Pettit, C. J., Arciniegas, G., Badland, H., & Giles-Corti, B. (2015). A simulation-based planning support system for creating walkable neighbourhoods. In J. Ferreira & R. Goodspeed (Eds.), *The 14th international conference on computers in urban planning and urban management – planning support systems and smart cities, July 7–10th 2015* (pp. 1–22). Boston: MIT.

Brown, B. B., Yamada, I., Smith, K. R., Zick, C. D., Kowaleski-Jones, L., & Fan, J. X. (2009). Mixed land use and walkability: Variations in land use measures and relationships with BMI, overweight, and obesity. *Health & Place, 15*, 1130–1141.

Brown, V., Zapata-Diomedi, B., Moodie, M., Veerman, J. L., & Carter, R. (2016). A systematic review of economic analyses of active transport interventions that include physical activity benefits. *Transport Policy, 45*, 190–208.

Brownson, R., Hoehner, C., Day, K., Forsyth, A., & Sallis, J. (2009). Measuring the built environment for physical activity: State of the science. *American Journal of Preventive Medicine, 36*, S99–123.

Bull, F., Hooper, P., Foster, S., & Giles-Corti, B. (2015). *Living liveable: The impact of the Liveable Neighbourhoods Policy on the health and wellbeing of Perth residents*. Perth: The University of Western Australia.

Calthorpe, P. (1993). *The next American metropolis: Ecology and urban form*. New Jersey: Princeton Architectural Press.

Cao, X. (2010). Exploring causal effects of neighborhood type on walking behavor using stratification on the propensity score. *Environment and Planning A, 42*(2), 487–504.

Cao, X., Mokhtarian, P., & Handy, S. (2009). Examining the impacts of residential self-selection on travel behaviour: A focus on empirical findings. *Transport Reviews, 29*, 359–395.

Carey, G., & Crammond, B. (2015). Action on the social determinants of health: Views from inside the policy process. *Social Science & Medicine, 128*, 134–141.

Cerin, E., Cain, K. L., Conway, T. L., Van Dyck, D., Hinckson, E., Schipperijn, J., De Bourdeaudhuij, I., Owen, N., Davey, R. C., Hino, A. A., Mitas, J., Orzanco-Garralda, R., Salvo, D., Sarmiento, O. L., Christiansen, L. B., Macfarlane, D. J., Schofield, G., & Sallis, J. F. (2014). Neighborhood environments and objectively measured physical activity in 11 countries. *Med Sci Sports Exerc, 46*(12), 2253–2264.

Cerin, E., Nathan, A., van Cauwenberg, J., Barnett, D. W., Barnett, A., & Council on, E. & Physical Activity - Older Adults working, g. (2017). The neighbourhood physical environment and active travel in older adults: a systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity, 14*, 15.

Chin, G. K., Van Niel, K. P., Giles-Corti, B., & Knuiman, M. (2008). Accessibility and connectivity in physical activity studies: The impact of missing pedestrian data. *Preventive Medicine, 46*, 41–45.

Christian, H., Giles-Corti, B., Knuiman, M., Timperio, A., & Foster, S. (2011a). The influence of the built environment, social environment and health behaviors on body mass index. Results from RESIDE. *Preventive Medicine, 53*, 57–60.

Christian, H., Knuiman, M., Bull, F., Timperio, A., Foster, S., Divitini, M., Middleton, N., & Giles-Corti, B. (2013). A new urban planning code's impact on walking: The residential environments project. *American Journal of Public Health, 103*, 1219–1228.

Christian, H. E., Bull, F. C., Middleton, N. J., Knuiman, M. W., Divitini, M. L., Hooper, P., Amarasinghe, A., & Giles-Corti, B. (2011b). How important is the land use mix measure in understanding walking behaviour? Results from the RESIDE study. *International Journal of Behavioral Nutrition and Physical Activity, 8*, 55.

Christiansen, L. B., Cerin, E., Badland, H., Kerr, J., Davey, R., Troelsen, J., van Dyck, D., Mitas, J., Schofield, G., Sugiyama, T., Salvo, D., Sarmiento, O. L., Reis, R., Adams, M., Frank, L., & Sallis, J. F. (2016). International comparisons of the associations between objective measures of the built environment and transport-related walking and cycling: IPEN adult study. *J Transp Health, 3*, 467–478.

CNU. 1997. Congress for the new urbanism [online]. Congress for the new urbanism. Retrieved Sept 24 2010, from, http://www.cnu.org/.

Cohen, D., Sehgal, A., Williamson, S., Golinelli, D., McKenzie, T. L., Capone-Newton, P., & Lurie, N. (2008). Impact of a new bicycle path on physical activity. *Preventive Medicine, 46*, 80–81.

Cohen, D. A., Golinelli, D., Williamson, S., Sehgal, A., Marsh, T., & McKenzie, T. L. (2009a). Effects of park improvements on park use and physical activity: policy and programming implications. *Am J Prev Med, 37*, 475–480.

Cohen, D. A., Sehgal, A., Williamson, S., Marsh, T., Golinelli, D., & McKenzie, T. L. (2009b). New recreational facilities for the young and the old in Los Angeles: Policy and programming implications. *Journal of Public Health Policy, 30*(Suppl 1), S248–S263.

Creatore, M. I., Glazier, R. H., Moineddin, R., Fazli, G. S., Johns, A., Gozdyra, P., Matheson, F. I., Kaufman-Shriqui, V., Rosella, L. C., Manuel, D. G., & Booth, G. L. (2016). Association of neighborhood walkability with change in overweight, obesity, and diabetes. *JAMA, 315*(20), 2211.

Curtis, C., & Punter, J. (2004). Design led sustainable development: The liveable neighbourhood experiment. *The Town Planning Review, 75*, 31–65.

Delaney, P., & Pettit, C. J. (2014). Urban data hubs supporting smart cities. In S. Winter & C. Rizos (Eds.), *CEUR workshop proceedings, 07–09 April 2014* (pp. 13–25). Canberra: Research@ Locate'14.

Department of Infrastructure and Transport. (2011). *Our cities, our future. A national urban policy for a productive, sustainable and liveable future*. Canberra: Department of Infrastructure and Transport.

Ding, D., & Gebel, K. (2012). Built environment, physical activity, and obesity: What have we learned from reviewing the literature? *Health & Place, 18*, 100–105.

Ding, D., Lawson, K. D., Kolbe-Alexander, T. L., Finkelstein, E. A., Katzmarzyk, P. T., van Mechelen, W., & Pratt, M. (2016). The economic burden of physical inactivity: A global analysis of major non-communicable diseases. *The Lancet, 388*, 1311–1324.

Doorley, R., Pakrashi, V., & Ghosh, B. (2015). Quantifying the health impacts of active travel: Assessment of methodologies. *Transport Reviews, 35*, 559–582.

Drummond, M. F., Schulpher, M. J., Torrance, G. W., O'Brien, B. J., & Stoddart, G. L. (2005). *Methods for the economic evaluation of health care programmes*. Oxford: Oxford University Press.

Duany, A., Plater-Zyberk, E., & Speck, J. (2000). *Suburban nation: The rise of sprawl and the decline of the American dream*. New York: North Point Press.

Durand, C., Andalib, M., Dunton, G., Wolch, J., & Pentz, M. (2011). A systematic review of built environment factors related to physical activity and obesity risk: Implications for smart growth urban planning. *Obesity Reviews, 12*, e173–ee82.
Egan, M., Petticrew, M., Ogilvie, D., & Hamilton, V. (2003). New roads and human health: A systematic review. *American Journal of Public Health, 93*, 1463–1471.
Egan, M., Petticrew, M., Ogilvie, D., Hamilton, V., & Drever, F. (2007). "Profits before people"? A systematic review of the health and safety impacts of privatising public utilities and industries in developed countries. *Journal of Epidemiology and Community Health, 61*, 862–870.
Eom, H.-J., & Cho, G.-H. (2015). Exploring thresholds of built environment characteristics for walkable communities: Empirical evidence from the Seoul Metropolitan area. *Transportation Research Part D, 40*, 76–86.
Ewing, R., Schmid, T., Killingsworth, R., Zlot, A., & Raudenbush, S. (2003). Relationship between urban sprawl and physical activity, obesity and morbidity. *American Journal of Health Promotion, 18*, 47–57.
Foster, S., Hooper, P., Knuiman, M., Bull, F., & Giles-Corti, B. (2015). Are liveable neighbourhoods safer neighbourhoods? Testing the rhetoric on new urbanism and safety from crime in Perth, Western Australia. *Social Science & Medicine, 164*, 150–157.
Gatzweiler, F. W., Zhu, Y.-G., Roux, A. V. D., Capon, A., Donnelly, C., Salem, G., Ayad, H. M., Speizer, I., Nath, I., & Boufford, J. I. (2017). *Advancing health and wellbeing in the changing urban environment: Implementing a systems approach*. New York: Springer.
Gebel, K., Bauman, A. E., Sugiyama, T., & Owen, N. (2011). Mismatch between perceived and objectively assessed neighborhood walkability attributes: Prospective relationships with walking and weight gain. *Health & Place, 17*, 519–524.
Giles-Corti, B., Broomhall, M. H., Knuiman, M., Collins, C., Douglas, K., Ng, K., Lange, A., & Donovan, R. J. (2005a). Increasing walking: How important is distance to, attractiveness, and size of public open space? *American Journal of Preventive Medicine, 28*, 169–176.
Giles-Corti, B., Bull, F., Knuiman, M., McCormack, G., Van Niel, K., Timperio, A., Christian, H., Foster, S., Divitini, M., Middleton, N., & Boruff, B. (2013). The influence of urban design on neighbourhood walking following residential relocation: Longitudinal results from the RESIDE study. *Social Science & Medicine, 77*, 20–30.
Giles-Corti, B., & Donovan, R. J. (2002). The relative influence of individual, social and physical environmental determinants of physical activity. *Social Science and Medicine, 54*, 1793–1812.
Giles-Corti, B., & Donovan, R. J. (2003). Relative influences of individual, social environmental, and physical environmental correlates of walking. *American Journal of Public Health, 93*(9), 1583.
Giles-Corti, B., Hooper, P., Foster, S., Koohsari, M. J., & Francis, J. (2014). *Low density development: Impacts on physical activity and associated health outcomes*. Melbourne: Heart Foundation (Victorian Division).
Giles-Corti, B., Knuiman, M., Timperio, A., Van Niel, K., Pikora, T. J., Bull, F. C., Shilton, T., & Bulsara, M. (2008). Evaluation of the implementation of a state government community design policy aimed at increasing local walking: Design issues and baseline results from RESIDE, Perth Western Australia. *Preventive Medicine, 46*, 46–54.
Giles-Corti, B., Ryan, K., & Foster, S. (2012). *Increasing density in Australia: Maximising the benefits and minimising the harm*. Melbourne: National Heart Foundation of Australia.
Giles-Corti, B., Sallis, J. F., Sugiyama, T., Frank, L. D., Lowe, M., & Owen, N. (2015). Translating active living research into policy and practice: One important pathway to chronic disease prevention. *Journal of Public Health Policy, 36*, 231–243.
Giles-Corti, B., Timperio, A., Bull, F., & Pikora, T. (2005b). Understanding physical activity environmental correlates: increased specificity for ecological models. *Exercise and Sport Sciences Reviews, 33*, 175–181.
Giles-Corti, B., Vernez-Moudon, A., Reis, R., Turrell, G., Dannenberg, A. L., Badland, H., Foster, S., Lowe, M., Sallis, J. F., Stevenson, M., & Owen, N. (2016). City planning and population health: A global challenge. *Lancet, 388*, 2912–2924.

Goldstein, H. (2009). Translating research into public policy. *Journal of Public Health Policy, 30*, S16–S20.

Goodman, A., Sahlqvist, S., Ogilvie, D., & iConnect, c. (2013). Who uses new walking and cycling infrastructure and how? Longitudinal results from the UK iConnect study. *Preventive Medicine, 57*, 518–524.

Goodman, A., Sahlqvist, S., Ogilvie, D., & iConnect, C. (2014). New walking and cycling routes and increased physical activity: One- and 2-year findings from the UK iConnect Study. *American Journal of Public Health, 104*, e38–e46.

Goodspeed, R., Pelzer, P., & Pettit, C. (in press). Planning our future cities: The role computer technologies can play. In T. W. Sanchez (Ed.), *Urban planning knowledge and research*. London: Informa UK Limited.

Hajna, S., Ross, N. A., Brazeau, A. S., Belisle, P., Joseph, L., & Dasgupta, K. (2015). Associations between neighbourhood walkability and daily steps in adults: A systematic review and meta-analysis. *BMC Public Health, 15*, 768.

Heinen, E., Panter, J., Dalton, A., Jones, A., & Ogilvie, D. (2015a). Sociospatial patterning of the use of new transport infrastructure: Walking, cycling and bus travel on the Cambridgeshire guided busway. *Journal of Transport and Health, 2*, 199–211.

Heinen, E., Panter, J., Mackett, R., & Ogilvie, D. (2015b). Changes in mode of travel to work: A natural experimental study of new transport infrastructure. *International Journal of Behavioral Nutrition and Physical Activity, 12*, 81.

Hirsch, J. A., Diez Roux, A. V., Moore, K. A., Evenson, K. R., & Rodriguez, D. A. (2014a). Change in walking and body mass index following residential relocation: The multi-ethnic study of atherosclerosis. *American Journal of Public Health, 104*, e49–e56.

Hirsch, J. A., Moore, K. A., Barrientos-Gutierrez, T., Brines, S. J., Zagorski, M. A., Rodriguez, D. A., & Diez Roux, A. V. (2014b). Built environment change and change in BMI and waist circumference: Multi-ethnic study of atherosclerosis. *Obesity (Silver Spring), 22*, 2450–2457.

Hirsch, J. A., Moore, K. A., Clarke, P. J., Rodriguez, D. A., Evenson, K. R., Brines, S. J., Zagorski, M. A., & Diez Roux, A. V. (2014c). Changes in the built environment and changes in the amount of walking over time: Longitudinal results from the multi-ethnic study of atherosclerosis. *American Journal of Epidemiology, 180*, 799–809.

Hooper, P., Giles-Corti, B., & Knuiman, M. (2014). Evaluating the implementation and active living impacts of a state government planning policy designed to create walkable neighborhoods in Perth, Western Australia. *American Journal of Health Promotion, 28*, S5–S18.

Hooper, P., Knuiman, M., Foster, S., & Giles-Corti, B. (2015). The building blocks of a 'liveable neighbourhood': Identifying the key performance indicators for walking of an operational planning policy in Perth, Western Australia. *Health & Place, 36*, 173–183.

Hooper, P., Middleton, N., Knuiman, M., & Giles-Corti, B. (2013). Measurement error in studies of the built environment: Validating commercial data as objective measures of neighborhood destinations. *Journal of Physical Activity and Health, 10*, 792–804.

Hooper, P., et al. (n.d.) Living Liveable? RESIDE's evaluation of the liveable neighbourhoods planning policy on the health and wellbeing of residents (under review).

Humpel, N., Owen, N., & Leslie, E. (2002). Environmental factors associated with adults' participation in physical activity. *American Journal of Preventive Medicine, 22*, 188–199.

Jenks, R. H., & Malecki, J. M. (2004). GIS--a proven tool for public health analysis. *Journal of Environmental Health, 67*, 32–34.

Kaczynski, A., & Henderson, K. (2007). Environmental correlates of physical activity: A review of evidence about parks and recreation. *Leisure Sciences, 29*, 315–354.

Kaczynski, A. T., Besenyi, G. M., Stanis, S. A., Koohsari, M. J., Oestman, K. B., Bergstrom, R., Potwarka, L. R., & Reis, R. S. (2014). Are park proximity and park features related to park use and park-based physical activity among adults? Variations by multiple socio-demographic characteristics. *International Journal of Behavioral Nutrition and Physical Activity, 11*, 146.

Kahlmeier, S., Kelly, P., Foster, C., Gotschi, T., Cavill, N., Dinsdale, H., Woodcock, J., Schweizer, C., Rutter, H., Lieb, C., Oja, P., & Racioppi, F. (2014). *Health economic assessment tools*

(HEAT) for walking and for cycling. Methodology and user guide. Economic assessment of transport infrastructure and policies. 2014 update [Online]. Copenhagen: WHO Regional office for Europe. Retrieved Jul 7 2014, from, http://www.euro.who.int/__data/assets/pdf_file/0010/256168/ECONOMIC-ASSESSMENT-OF-TRANSPORT-INFRASTRUCTURE-AND-POLICIES.pdf.

Kamruzzaman, M., Baker, D., Washington, S., & Turrell, G. (2016). Determinants of residential dissonance: Implications for transit-oriented development in Brisbane. *International Journal of Sustainable Transportation, 10*, 960–974.

Karvonen, A., & Van Heur, B. (2014). Urban laboratories: Experiments in reworking cities. *International Journal of Urban and Regional Research, 38*, 379–392.

Kerr, J., Emond, J. A., Badland, H., Reis, R., Sarmiento, O., Carlson, J., Sallis, J. F., Cerin, E., Cain, K., Conway, T., Schofield, G., Macfarlane, D. J., Christiansen, L. B., Van Dyck, D., Davey, R., Aguinaga-Ontoso, I., Salvo, D., Sugiyama, T., Owen, N., Mitas, J., & Natarajan, L. (2016). Perceived neighborhood environmental attributes associated with walking and cycling for transport among adult residents of 17 cities in 12 countries: The IPEN study. *Environmental Health Perspectives, 124*, 290–298.

Kerr, J., Rosenberg, D., & Frank, L. (2012). The role of the built environment in healthy aging: Community design, physical activity, and health among older adults. *Journal of Planning Literature, 27*, 43–60.

Kerr, J., Sallis, J. F., Owen, N., De Bourdeaudhuij, I., Cerin, E., Sugiyama, T., Reis, R., Sarmiento, O., Fromel, K., Mitas, J., Troelsen, J., Christiansen, L. B., Macfarlane, D., Salvo, D., Schofield, G., Badland, H., Guillen-Grima, F., Aguinaga-Ontoso, I., Davey, R., Bauman, A., Saelens, B., Riddoch, C., Ainsworth, B., Pratt, M., Schmidt, T., Frank, L., Adams, M., Conway, T., Cain, K., Van Dyck, D., & Bracy, N. (2013). Advancing science and policy through a coordinated international study of physical activity and built environments: IPEN adult methods. *Journal of Physical Activity & Health, 10*, 581–601.

Kim, J. (2000). Creating communities: Does the Kentlands live up to its goals? (The promise of new urbanism). *Places, 13*, 48–55.

Knuiman, M. W., Christian, H. E., Divitini, M. L., Foster, S. A., Bull, F. C., Badland, H. M., & Giles-Corti, B. (2014). A longitudinal analysis of the influence of the neighborhood built environment on walking for transportation: The RESIDE study. *American Journal of Epidemiology, 180*, 453–461.

Koohsari, M. J., Badland, H., & Giles-Corti, B. (2013a). (Re)designing the built environment to support physical activity: Bringing public health back into urban design and planning. *Cities, 35*, 294–298.

Koohsari, M. J., Badland, H., Sugiyama, T., Mavoa, S., Christian, H., & Giles-Corti, B. (2015a). Mismatch between perceived and objectively measured land use mix and street connectivity: associations with neighborhood walking. *Journal of Urban Health, 92*, 242–252.

Koohsari, M. J., Karakiewicz, J. A., & Kaczynski, A. T. (2013b). Public open space and walking: The role of proximity, perceptual qualities of the surrounding built environment, and street configuration. *Environment and Behavior, 45*, 706–736.

Koohsari, M. J., Mavoa, S., Villanueva, K., Sugiyama, T., Badland, H., Kaczynski, A. T., Owen, N., & Giles-Corti, B. (2015b). Public open space, physical activity, urban design and public health: Concepts, methods and research agenda. *Health & Place, 33*, 75–82.

Krizek, K. J. (2003). Residential relocation and changes in urban travel – Does neighborhood-scale urban form matter? *Journal of the American Planning Association, 69*, 265–281.

Kyu, H. H., Bachman, V. F., Alexander, L. T., Mumford, J. E., Afshin, A., Estep, K., Veerman, J. L., Delwiche, K., Iannarone, M. L., Moyer, M. L., Cercy, K., Vos, T., Murray, C. J. L., & Forouzanfar, M. H. (2016). Physical activity and risk of breast cancer, colon cancer, diabetes, ischemic heart disease, and ischemic stroke events: systematic review and dose-response meta-analysis for the Global Burden of Disease Study 2013. *BMJ, 354*, i3857.

Learnihan, V., Van Niel, K. P., Giles-Corti, B., & Knuiman, M. (2011). Effect of scale on the links between walking and urban design. *Geographical Research, 49*, 183–191.

Lee, C., & Moudon, A. (2004). Physical activity and environment research in the health field: Implications for urban and transportation planning practice and research. *Journal of Planning Literature, 19*, 147–181.

Lich, K. H., Ginexi, E. M., Osgood, N. D., & Mabry, P. L. (2013). A call to address complexity in prevention science research. *Prevention Science, 14*, 279–289.

Lowe, M., Whitzman, C., Badland, H., Davern, M., Aye, L., Hes, D., Butterworth, I., & Giles-Corti, B. (2015). Planning healthy, liveable and sustainable cities: How can indicators inform policy? *Urban Policy and Research, 33*, 131–144.

Unit, M. C. (2010). *State of Australian cities, 2010*. Canberra: Major Cities Unit, Infrastructure Australia.

Martin, A., Panter, J., Suhrcke, M., & Ogilvie, D. (2015). Impact of changes in mode of travel to work on changes in body mass index: Evidence from the British Household Panel Survey. *Journal of Epidemiology and Community Health, 69*, 753–761.

McCormack, G., Giles-Corti, B., & Bulsara, M. (2008). The relationship between destination proximity, destination mix and physical activity behaviors. *Preventive Medicine, 46*, 33–40.

McCormack, G., & Shiell, A. (2011). In search of causality: A systematic review of the relationship between the built environment and physical activity among adults. *International Journal of Behavioral Nutrition and Physical Activity, 8*, 125.

McLeroy, K. R., Bibeau, D., Steckler, A., & Glanz, K. (1988). An ecological perspective on health promotion programs. *Health Education Quarterly, 15*, 351–377.

Merom, D., Bauman, A., Vita, P., & Close, G. (2003). An environmental intervention to promote walking and cycling – The impact of a newly constructed Rail Trail in Western Sydney. *Preventive Medicine, 36*, 235–242.

Mokhtarian, P., & Cao, X. (2008). Examining the impacts of residential self-selection on travel behavior: A focus on methodologies. *Transportation Research Part B, 42*, 204–228.

Mueller, N., Rojas-Rueda, D., Cole-Hunter, T., de Nazelle, A., Dons, E., Gerike, R., Götschi, T., Int Panis, L., Kahlmeier, S., & Nieuwenhuijsen, M. (2015). Health impact assessment of active transportation: A systematic review. *Preventive Medicine, 76*, 103–114.

Mulley, C., Tyson, R., McCue, P., Rissel, C., & Munro, C. (2013). Valuing active travel: Including the health benefits of sustainable transport in transportation appraisal frameworks. *Research in Transportation Business & Management, 7*, 27–34.

Murphy, M., Badland, H., Koohsari, M. J., Astell-Burt, T., Trapp, G., Villanueva, K., Mavoa, S., Davern, M., & Giles-Corti, B. (2017). Indicators of a health-promoting local food environment: a conceptual framework to inform urban planning policy and practice. *Health promotion journal of Australia, 28*, 82.

Newell, B., & Proust, K. (2009). *I see how you think: using influence diagrams to support dialogue*. Canberra: Australian National University (ANU) Centre for Dialogue.

Newell, B., Proust, K., Dyball, R., & McManus, P. (2008). Seeing obesity as a systems problem. *New South Wales Public Health Bulletin, 18*, 214–218.

Ogilvie, D., Bull, F., Cooper, A., Rutter, H., Adams, E., Brand, C., Ghali, K., Jones, T., Mutrie, N., Powell, J., Preston, J., Sahlqvist, S., Song, Y., & iConnect, C. (2012). Evaluating the travel, physical activity and carbon impacts of a 'natural experiment' in the provision of new walking and cycling infrastructure: Methods for the core module of the iConnect study. *BMJ Open, 2*, e000694.

Ogilvie, D., Bull, F., Powell, J., Cooper, A. R., Brand, C., Mutrie, N., Preston, J., Rutter, H., & iConnect, C. (2011). An applied ecological framework for evaluating infrastructure to promote walking and cycling: the iConnect study. *American Journal of Public Health, 101*, 473–481.

Ogilvie, D., Foster, C., Rothnie, H., Cavill, N., Hamilton, V., Fitzsimons, C., & Mutrie, N. (2007). Interventions to promote walking: Systematic review. *BMJ, 334*, 1204–1213.

Oliver, K., Innvar, S., Lorenc, T., Woodman, J., & Thomas, J. (2014). A systematic review of barriers to and facilitators of the use of evidence by policymakers. *BMC Health Services Research, 14*, 2.

Orton, L., Lloyd-Williams, F., Taylor-Robinson, D., O'Flaherty, M., & Capewell, S. (2011). The use of research evidence in public health decision making processes: systematic review. *PLoS One, 6*, e21704.

Panter, J. R., Heinen, E., Mackett, R., & Ogilvie, D. (2016). Impact of new transport infrastructure on walking, cycling, and physical activity. *American Journal of Preventive Medicine, 50*, e45–e53.

Panter, J. R., & Jones, A. (2010). Attitudes and the environment as determinants of active travel in adults: What do and don't we know? *Journal of Physical Activities and Health, 7*, 551–561.

Panter, J. R., Jones, A. P., & van Sluijs, E. M. (2008). Environmental determinants of active travel in youth: A review and framework for future research. *International Journal of Behavioral Nutrition and Physical Activity, 5*, 34.

Pearce, J. R., & Maddison, R. (2011). Do enhancements to the urban built environment improve physical activity levels among socially disadvantaged populations? *International Journal for Equity in Health, 10*, 28.

Pelzer, P., Arciniegas, G., Geertman, S., & de Kroes, J. (2013). *Using MapTable® to learn about sustainable urban development. Planning support systems for sustainable urban development*. New York: Springer.

Petticrew, M., Cummins, S., Ferrell, C., Findlay, A., Higgins, C., Hoyd, C., Kearns, A., & Spark, L. (2005). Natural experiments: An underused tool for public health? *Public Health, 119*, 751–757.

Pettit, C. J., Barton, J., Goldie, X., Sinnott, R., Stimson, R., & Kvan, T. (2015). The Australian urban intelligence network supporting smart cities. In G. SSJ, J. Ferreira, & J. Goodspeed (Eds.), *Planning support systems and smart cities, lecture notes in geoinformation and cartography*. Cham: Springer.

Pettit, C. J., Tice, A., & Randolph, B. (2017). Using an online spatial analytics workbench for understanding housing affordability in Sydney. Seeing cities through big data: Research, methods and applications. In P. Thakuriah, N. Tilahun, & M. Zellner (Eds.), *Urban informatics*. Cham: Springer International Publishing.

Reis, R. S., Salvo, D., Ogilvie, D., Lambert, E. V., Goenka, S., Brownson, R. C., & Lancet Physical Activity Series 2 Executive, C. (2016). Scaling up physical activity interventions worldwide: stepping up to larger and smarter approaches to get people moving. *Lancet, 388*, 1337–1348.

Renalds, A., Smith, T., & Hale, P. (2010). A systematic review of built environment and health. *Fam Comm Health, 33*, 68–78.

Ross, S. M. (2014). *Introduction to probability models*. New York: Academic.

Saelens, B., & Handy, S. (2008). Built environment correlates of walking: A review. *Medicine & Science in Sports & Exercise, 40*, S550–S566.

Sahlqvist, S., Goodman, A., Cooper, A. R., Ogilvie, D., & iConnect, c. (2013). Change in active travel and changes in recreational and total physical activity in adults: Longitudinal findings from the iConnect study. *International Journal of Behavioral Nutrition and Physical Activity, 10*, 28.

Sahlqvist, S., Goodman, A., Jones, T., Powell, J., Song, Y., Ogilvie, D., & iConnect, c. (2015). Mechanisms underpinning use of new walking and cycling infrastructure in different contexts: mixed-method analysis. *International Journal of Behavioral Nutrition and Physical Activity, 12*, 24.

Sallis, J. F. (2008). Angels in the details: comment on "The relationship between destination proximity, destination mix and physical activity behaviors". *Preventive Medicine, 46*, 6–7.

Sallis, J. F. (2009). Measuring physical activity environments: A brief history. *American Journal of Preventive Medicine, 36*, S86–S92.

Sallis, J. F., Bull, F., Burdett, R., Frank, L., Griffiths, P., Giles-Corti, B., & Stevenson, M. (2016a). Using science to guide city planning policy and practice to promote health. *Lancet, 388*(10062), 2936–2947.

Sallis, J. F., Cerin, E., Conway, T. L., Adams, M. A., Frank, L. D., Pratt, M., Salvo, D., Schipperijn, J., Smith, G., Cain, K. L., Davey, R., Kerr, J., Lai, P. C., Mitas, J., Reis, R., Sarmiento, O. L., Schofield, G., Troelsen, J., Van Dyck, D., De Bourdeaudhuij, I., & Owen, N. (2016b). Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. *Lancet, 387*(10034), 2207–2217.

Sallis, J. F., Cervero, R. B., Ascher, W., Henderson, K. A., Kraft, M. K., & Kerr, J. (2006a). An ecological approach to creating active living communities. *Annual Review of Public Health, 27*, 297–322.

Sallis, J. F., Cervero, R. B., Ascher, W., Henderson, K. A., Kraft, M. K., & Kerr, J. (2006b). An ecological approach to creating active living communities. *Annual Review of Public Health, 27*, 297–322.

Sallis, J. F., Floyd, M. F., Rodriguez, D. A., & Saelens, B. E. (2012). Role of built environments in physical activity, obesity, and cardiovascular disease. *Circulation, 125*, 729–737.

Stephenson, J., & Bauman, A. (2000). *The cost of illness attributable to physical inactivity in Australia*. Canberra: CDHAC and Australian Sports Commission.

Story, M., Giles-Corti, B., Yaroch, A., Cummins, S., Frank, L., Huang, T. T.-K., & Lewis, L. (2009). Work group IV: Future directions for measures of the food and physical activity environments. *American Journal of Preventive Medicine, 36*, S182–S188.

Sugiyama, T., Francis, J., Middleton, N. J., Owen, N., & Giles-Corti, B. (2010). Associations between recreational walking and attractiveness, size, and proximity of neighborhood open spaces. *American Journal of Public Health, 100*, 1752–1757.

Sugiyama, T., Gunn, L. D., Christian, H., Francis, J., Foster, S., Hooper, P., Owen, N., & Giles-Corti, B. (2015). Quality of public open spaces and recreational walking. *American Journal of Public Health, 105*, 2490–2495.

Sugiyama, T., Neuhaus, M., Cole, R., Giles-Corti, B., & Owen, N. (2012). Destination and route attributes associated with adults' walking: A review. *Medicine and Science in Sports and Exercise, 44*, 1275–1286.

Talen, E. (1996). Do plans get implemented? A review of evaluation in planning. *Journal of Planning Literature, 10*, 248–259.

Taylor, B. T., Fernando, P., Bauman, A. E., Williamson, A., Craig, J. C., & Redman, S. (2011). Measuring the quality of public open space using Google Earth. *American Journal of Preventive Medicine, 40*, 105–112.

Board, T. R. (2005). *Does the built environment influence physical activity? Examining the evidence*. Washington: TRB.

United Nations. (2011). *Sixty seventh session political declaration of the high level meeting of the general assembly on the prevention and control of non-communicable diseases [online]*. New York: United Nations. Retrieved from http://www.un.org/ga/search/view_doc.asp?symbol=A/66/L.1.

United Nations General Assembly. (2015). *Resolution adopted by the general assembly: Transforming our world: the 2030 agenda for sustainable development A/RES/70/1*. New York: United Nations.

Urban, J. B., Osgood, N. D., & Mabry, P. L. (2011). Developmental systems science: Exploring the application of systems science methods to developmental science questions. *Research in Human Development, 8*, 1–25.

Van Cauwenberg, J., De Bourdeaudhuij, I., De Meester, F., Van Dyck, D., Salmon, J., Clarys, P., & Deforche, B. (2011). Relationship between the physical environment and physical activity in older adults: A systematic review. *Health & Place, 17*, 458–469.

Van Dyck, D., Cerin, E., Conway, T., De Bourdeaudhuij, I., Owen, N., Kerr, J., Cardon, G., Frank, L. D., Saelens, B., & Sallis, J. (2012). Associations between perceived neighborhood environmental attributes and adults' sedentary behavior: Findings from the USA, Australia and Belgium (Report). *Social Science and Medicine, 74*, 1375.

Van Dyck, D., Cerin, E., Conway, T., De Bourdeaudhuij, I., Owen, N., Kerr, J., Cardon, G., Frank, L. D., Saelens, B., & Sallis, J. (2013). Perceived neighborhood environmental attributes associated with adults' leisure-time physical activity: Findings from Belgium, Australia and the USA (Report). *Health and Place, 19*, 59.

Van Dyck, D., Cerin, E., Conway, T. L., De Bourdeaudhuij, I., Owen, N., Kerr, J., Cardon, G., & Sallis, J. F. (2014). Interacting psychosocial and environmental correlates of leisure-time physical activity: A three-country study. *Health Psychology, 33*, 699–709.

Van Holle, V., Deforche, B., Van Cauwenberg, J., Goubert, L., Maes, L., Van de Weghe, N., & De Bourdeaudhuij, I. (2012). Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. *BMC Public Health, 12*, 807.

Veitch, J., Salmon, J., Carver, A., Timperio, A., Crawford, D., Fletcher, E., & Giles-Corti, B. (2014). A natural experiment to examine the impact of park renewal on park-use and park-based physical activity in a disadvantaged neighbourhood: The REVAMP study methods. *BMC Public Health, 14*, 600.

Veitch, J., Salmon, J., Giles-Corti, B., Crawford, D., Dullaghan, K., Carver, A., & Timperio, A. (2017). Challenges in conducting natural experiments in parks-lessons from the REVAMP study. *International Journal of Behavioral Nutrition and Physical Activity, 14*, 5.

Von Bertalanffy, L. (1969). *General system theory: Foundations, development, applications (revised edition)*. Westminster: Penguin Books.

Vos, T., Carter, R., Barendregt, J., Mihalopoulos, C., Veerman, J., Magnus, A., Cobiac, L., M Bertram & Wallace A. 2010. Retrieved Feb 1 2017, from, https://public-health.uq.edu.au/files/571/ACE-Prevention_final_report.pdf.

Walker, D., & Daniels, T. L. (2011). *The planners guide to community viz: The essential tool for a new generation of planning*. Chicago: Planners Press, American Planning Association.

Watts, N., Adger, W. N., Agnolucci, P., Blackstock, J., Byass, P., Cai, W., Chaytor, S., Colbourn, T., Collins, M., Cooper, A., Cox, P. M., Depledge, J., Drummond, P., Ekins, P., Galaz, V., Grace, D., Graham, H., Grubb, M., Haines, A., Hamilton, I., Hunter, A., Jiang, X., Li, M., Kelman, I., Liang, L., Lott, M., Lowe, R., Luo, Y., Mace, G., Maslin, M., Nilsson, M., Oreszczyn, T., Pye, S., Quinn, T., Svensdotter, M., Venevsky, S., Warner, K., Xu, B., Yang, J., Yin, Y., Yu, C., Zhang, Q., Gong, P., Montgomery, H., & Costello, A. (2015). Health and climate change: policy responses to protect public health. *Lancet, 386*(10006), 1861–1914.

Wells, N. M., & Yang, Y. (2008). Neighborhood design and walking. A quasi-experimental longitudinal study. *American Journal of Preventive Medicine, 34*, 313–319.

Western Australian Planning Commission. (1997). *Liveable neighbourhoods. Community design code: A Western Australian government sustainable cities initiative* (1st ed.). Perth: Western Australian Planning Commission.

Western Australian Planning Commission. (2000). *Liveable neighbourhoods: A Western Australian government sustainable cities initiative*. Perth: Western Australian Planning Commission.

Western Australian Planning Commission. (2007). *Liveable neighbourhoods : a Western Australian Government Sustainable Cities Initiative*. Perth: Western Australian Planning Commission.

Whitzman, C. (2007). Barriers to planning healthier cities in Victoria. *International Journal of Environmental, Cultural, Economic and Social Sustainability, 3*, 146–153.

WHO & UN Habitat. (2016). *Global report on urban health: equitable healthier cities for sustainable development, Italy*. Geneva: WHO.

Wood, S. (2009). *Generalized additive modles: An introduction using R*. Boca Raton: Chapman & Hall.

World Health Organization. (2016a). *Shanghai consensus on healthy cities. WHO 9th global conference on health promotion, healthy cities mayor forum, 2016a Shanghai*. Geneva: WHO.

World Health Organization. (2016b). *Shanghai Declaration on promoting health in the 2030 Agenda for sustainable development. WHO 9th global conference on health promotion. Shanghai*. Geneva: WHO.