

Article

Living liveable? RESIDE's evaluation of the “Liveable Neighbourhoods” planning policy on the health supportive behaviors and wellbeing of residents in Perth, Western Australia

Paula Hooper^{a,*}, Sarah Foster^{b,h}, Fiona Bull^{c,d}, Matthew Knuiman^e, Hayley Christian^f, Anna Timperio^g, Lisa Wood^e, Gina Trapp^f, Bryan Boruff^h, Jacinta Francis^f, Cecily Strange^e, Hannah Badland^b, Lucy Gunn^b, Ryan Falconerⁱ, Vincent Learnihan^j, Gavin McCormack^k, Takemi Sugiyama^{l,m,n}, Billie Giles-Corti^b

^a Australian Urban Design Research Centre, School of Design, The University of Western Australia, Perth, Australia

^b Centre for Urban Research, RMIT University, Melbourne, Victoria, Australia

^c School of Health Sciences, The University of Western Australia, Perth, Australia

^d Department of Prevention of Non-communicable Diseases, World Health Organization, Geneva, Switzerland

^e School of Population and Global Health, The University of Western Australia, Perth, Australia

^f Telethon Kids Institute, The University of Western Australia, Perth, Australia

^g Institute for Physical Activity and Nutrition (IPAN), School of Exercise and Nutrition Sciences, Deakin University, Geelong, Australia

^h School of Agriculture and Environment, The University of Western Australia, Perth, Australia

ⁱ Transport Planner, Perth, Western Australia

^j Centre for Research and Action in Public Health, Health Research Institute, University of Canberra, Canberra, ACT, Australia

^k Department of Community Health Sciences, Cumming School of Medicine, University of Calgary, NW Calgary, Alberta, Canada

^l Mary MacKillop Institute for Health Research, Australian Catholic University, Melbourne, Victoria, Australia

^m Centre for Urban Transitions, Swinburne University of Technology, Melbourne, Victoria, Australia

ⁿ Baker Heart and Diabetes Institute, Melbourne, Victoria, Australia

A B S T R A C T

Background: The RESIDENTIAL Environments (RESIDE) project is a unique longitudinal natural experiment designed to evaluate the health impacts of the “Liveable Neighbourhoods” planning policy, which was introduced by the Western Australian government to create more walkable suburbs.

Objectives: To summarize the RESIDE evidence of the impact of the planning policy on a range of health-supportive behaviours and wellbeing outcomes and to assess the consistency and direction of the estimates of associations.

Methods: An audit of 26 RESIDE research papers (from 2003 to 2012) identified the number of positive associations (statistically significant and consistent with policy expectations), negative associations (statistically significant and inconsistent with policy expectations), and null findings from multiple-exposure models between objective and perceived measures of 20 policy design requirements and 13 health-supportive behaviors and wellbeing outcomes.

Results: In total 332 eligible estimates of associations ($n = 257$ objective measures and $n = 75$ perceived measures) were identified. Positively significant findings were detected for: 57% of walking estimates with objectively measured policy design features (negative = 3%; null = 40%) ($n = 115$) and 54% perceived measures (negative = 0%; null = 33%) ($n = 27$); 42% of sense of community estimates with objectively measured of policy design features (negative = 8%; null = 50%) ($n = 12$) and 61% perceived measures (negative = 8%; null = 31%) ($n = 13$); 39% of safety or crime-related estimates with objectively measured of policy design features (negative = 22%; null = 39%) ($n = 28$) and 100% perceived measures ($n = 7$). All ($n = 4$) estimates for mental health outcomes with objectively measured policy-related design features were positively significant.

Conclusions: The synthesis of findings suggests that new suburban communities built in accordance with the “Liveable Neighbourhoods” policy have the potential to encourage health supportive behaviors and wellbeing outcomes including transport and recreation walking, and to create neighborhoods with a stronger sense of community where residents may feel safer.

* Corresponding author. Australian Urban Design Research Centre, School of Design, The University of Western Australia.

E-mail address: paula.hooper@uwa.edu.au (P. Hooper).

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1. Introduction

Over nearly two decades, an expansive body of research has evaluated urban design features that may facilitate or hinder health supportive behaviors and outcomes, including physical activity (Chanam & Moudon, 2006; Lee & Moudon, 2006; Lovasi, Moudon et al., 2008); weight status (Ding and Gebel 2012; Ewing, Schmid, Killingsworth, Zlot, & Raudenbush, 2003; Feng, Glass, Curriero, Stewart, & Schwartz, 2009; Frank, Andresen, & Schmid, 2004); mental health (Ostir, Eschbach, Markides, & Goodwin, 2003; Stafford, Chandola, & Marmot, 2007; Burton, 2015; (Hooper et al., 2020)); and sense of community (Francis, Giles-Corti, & Knuiiman, 2012; Lund, 2002).

A growing number of studies have compared communities or neighborhoods developed under different design principles or alternate planning theories, such as New Urbanism or Smart Growth, and compared the health behaviors and outcomes of the residents (Gordon & Tamminga, 2002; Trudeau, 2013). Studies comparing New Urbanist-inspired neighborhoods have found these to be associated with increases in pedestrian activity (Rodríguez, Khattak, & Evenson, 2006), the number of walking trips and engagement in casual social interaction and neighboring activities (Lund, 2003).

However, a frequently-raised criticism about research examining associations between built environments and health outcomes is that most studies are cross-sectional, which limits drawing causal inferences and does not consider issues of self-selection (i.e. do residents choose to live in areas that support their preferred behaviors, or does neighborhood design *change* their behaviors?). Moreover, few studies have examined the role of specific urban planning policies in producing communities and neighborhoods that support health-promoting behaviors and positive wellbeing outcomes.

Natural experiment studies can advance our understanding of, and add more confidence about the effectiveness of environmental approaches to promote positive health and wellbeing behaviours and outcomes. Natural experiment studies are observational studies that lack random assignment of participants to intervention groups. This is because the intervention is naturally occurring or unplanned and so the researcher does not, and usually cannot, manipulate the intervention exposure or event (Benton, Anderson, Hunter, & French, 2016). Findings from natural experiment studies lead to stronger inferences about causality than cross-sectional studies because of the temporal order of changes in environment and behaviour. For example, some natural experiment studies have evaluated physical activity levels before and after substantial environmental changes (Dill, McNeil, Broach, & Ma, 2014; Nimegeer et al., 2018; Quigg, Reeder, Gray, Holt, & Waters, 2012). A recent systematic review of natural experiment studies found considerable evidence that creating new walking, cycling, and public transportation infrastructure were related to increased physical activity (Kärmeniemi, Lankila, Ikäheimo, Koivumaa-Honkanen, & Korpelainen, 2018). The findings were most consistent for transportation-related and overall physical activity, which were especially associated with the creation of new trails for walking and cycling (Kärmeniemi et al., 2018).

Indeed, the majority of natural experiment studies have focussed on the introduction of specific features – such as walk or cycle trails. Few (if any) have focussed on neighborhood-level changes as a result of planning policies or practices. However, guidance from the Medical Research Council has suggested the need for longitudinal natural experiment studies to evaluate government policies and their implementation and as a way of understanding the impact of population-level policies on health outcomes (Craig, Cooper et al., 2012). Further, planning professionals and policy-makers argue that to progress the translation and influence of health evidence, more research is required that assesses the effectiveness of planning regulations and policies on public health behaviors through the evaluation and documentation of innovative communities, environmental or planning policies, programs, or codes that promote health-supportive behaviors (Allender, Cavill, Parker, & Foster, 2009; Sallis, Bull et al., 2016; Sallis, Story, & Lou, 2009). Case studies and

evaluations of urban planning policies, undertaken in partnership with planning professionals are necessary to identify the policies (or parts of) that produce desirable health-related outcomes (Brownson & Jones, 2009; Brownson, Royer, Ewing, & McBride, 2006; Hooper, Foster, & Giles-Corti, 2019; Orton, Lloyd-Williams, Taylor-Robinson, O'Flaherty, & Capewell, 2011). Moreover it has been argued there is a need to evaluate the health effects of land-use and transport policies more effectively to guide the development of future city planning policies and practices (Sallis, Bull et al., 2016).

In addition to evidence being globally relevant, to inform their decision-making, policy-makers often prioritize evidence that is locally applicable and directly related to the planning and policy context (Giles-Corti et al., 2015). The recognised need for local evidence is timely, as state and local governments in jurisdictions around the world, including North America and Australia, are implementing urban planning policies designed to shift growth away from low density, automobile-oriented development (Durand, Andalib, Dunton, Wolch, & Pentz, 2011). One example of this approach is New Urbanism that includes a set of principles advocating for mixed-use, pedestrian-orientated, compact developments and human-scaled neighborhoods. It hypothesizes these will promote walking, minimize car dependence and enhance safety from crime and a sense of community (Congress for the New Urbanism, 1997; Duany, Plater-Zyberk, & Speck, 2000). New Urbanism features include: high street connectivity and streets arranged in compact walkable blocks; a range of housing choices to serve people of diverse ages and income levels; a variety of and mixing of land uses to create vibrant places; schools, stores and other nearby destinations reachable by walking, bicycling or transit; higher dwelling densities; and the provision of pedestrian and bicycle infrastructure. Supporters of New Urbanism believe communities with these features increase access to a variety of local proximate opportunities, which encourages walking and cycling and discourages automobile dependence. This in turn creates a public realm that fosters spontaneous, casual, and deliberate social interactions, increased interaction and a greater sense of community, passive surveillance and safety from crime (Evans, 2003; Garde, 2004; Jacobs, 1961; Lund, 2002).

A unique opportunity to evaluate the health impacts of a New Urbanist inspired planning policy arose in 1998 when the Western Australian Government introduced the “Liveable Neighbourhoods Community Design Guidelines” planning policy (hereafter referred to as LN) (Western Australian Planning Commission, 2000). The current form of development across Perth takes the form of a distinct fringe of peripheral residential suburbs spread out along the coast, resulting in a population widely dispersed in low-density residential development with rigid spatial separation of homes, shops, and daily services and places of employment. In 2010, Perth was given the unenviable crown of being Australia's most unsustainable city on the Sustainable Cities Index, based on 15 indicators including ecological footprint, health, density, wellbeing, transport, and employment (Trigg, Richter, McMillan, O'Rourke, & Wong, 2010).

LN was a local interpretation of New Urbanism (Congress for the New Urbanism, 1997), providing an alternative approach to suburban neighborhood design and replacing the conventional development controls which had facilitated suburban sprawl and motor vehicle dependency across Perth. It contains four primary policy aims (or elements) that provide guidance for designing and creating more compact, pedestrian-friendly neighborhoods: (1) Community design: These principles determine the provision, location, and configuration of neighborhood centers to create a hub of diverse destinations that attract people to a variety of activities; (2) Movement network: LN advocates for a highly interconnected street system aimed at reducing travel distances to local centers, schools, public transport links and other destinations, and adequate infrastructure for pedestrians and cyclists; (3) Lot layout: Emphasizes higher residential densities to create more compact urban development and encourages the provision of a mixture of residential lot sizes to facilitate housing variety, choice and affordability,

and to cater for increasingly diverse household types; (4) Public parkland: LN requires a minimum contribution of 10% of the gross subdivisible land area to be provided as public parkland (Western Australian Planning Commission, 2000) and identifies different park types based on size and catchment areas to provide for a range of uses and activities.

Key goals of the LN policy were to reduce private motor vehicle dependence, encourage active forms of transport (walking, cycling, and public transport use), and to enhance the sense of community and safety (Western Australian Planning Commission, 2000). Fig. 1 outlines the conceptual model through which the policy was hypothesized to influence neighborhood design and residents' health-supportive behaviors and wellbeing outcomes and shows the four policy aims (or elements) that provide guidance for designing and creating more compact, pedestrian-friendly neighborhoods.

The introduction of LN provided an opportunity for a longitudinal, natural experiment on the impact of the new planning policy. In 2003, the RESIDential Environments project (RESIDE) began tracking 1803 people who were moving into one of 74 new housing developments in Perth, Western Australia. RESIDE aimed to assess the impact of LN on the desired outcomes and to study residential self-selection and whether participants' lifestyles, attitudes, and behaviors at baseline predicted the type of development they moved to (Giles-Corti, Knuiman et al., 2008). The longitudinal study was complemented by a process evaluation that quantified the extent to which developers had implemented LN requirements in a sub-set of liveable and conventional RESIDE housing developments ($n = 36$) (Hooper, Giles-Corti, & Knuiman, 2014). Over a ten-year period, RESIDE collaborators published more than 60 academic papers in peer-reviewed journals. These included literature reviews, papers testing different methods or spatial built environment measures, and studies estimating cross-sectional and longitudinal associations between neighborhood design features and a range of health-supportive behaviours and intermediate health and wellbeing outcomes.

The final stage of the project aimed to summarize the totality of findings from the decade-long natural experiment and to provide local

policy-makers with a comprehensive overview of the outcomes of the LN policy implementation and an indication of the potential health and wellbeing benefits of the policy. The specific objectives were: 1) To summarize the RESIDE evidence relating to urban design features of the built environment; 2) To assess which of the LN urban design features were associated with health-supportive behaviors and wellbeing outcomes; 3) To assess the consistency and direction of the estimates of associations.

2. Methods

2.1. Overview of RESIDE study methods

2.1.1. Study population

The Western Australian Department of Planning, Lands and Heritage (formerly the Department of Planning) categorized new development applications as either LN (i.e. aspiring to meet many of the LN requirements), hybrid (i.e. meeting some but not all of the LN requirements), or conventional (approved under the old policy). All liveable and conventional developments that featured land sold for housing during the recruitment period (in 2003) were included in the study. Conventional developments outnumbered the liveable and hybrid developments and thus attempts were made to match these using three criteria: stage of development, lot values, and proximity to the coast/ocean (Giles-Corti, Knuiman et al., 2008).

The RESIDE natural experiment included 74 new developments (19 LN, 11 hybrid, and 44 conventional) that were under construction across the Perth metropolitan region in 2003 (Giles-Corti, Knuiman et al., 2008). The majority were being constructed on greenfield sites (i.e. previously unused or undeveloped land areas that had been rezoned, typically from urban deferred or rural to urban land uses and projects). The remaining developments were being constructed in brownfield areas (existing urban zones being redeveloped, sometimes following rezoning from industrial or other non-residential use).

In Western Australia the state water authority (the Water

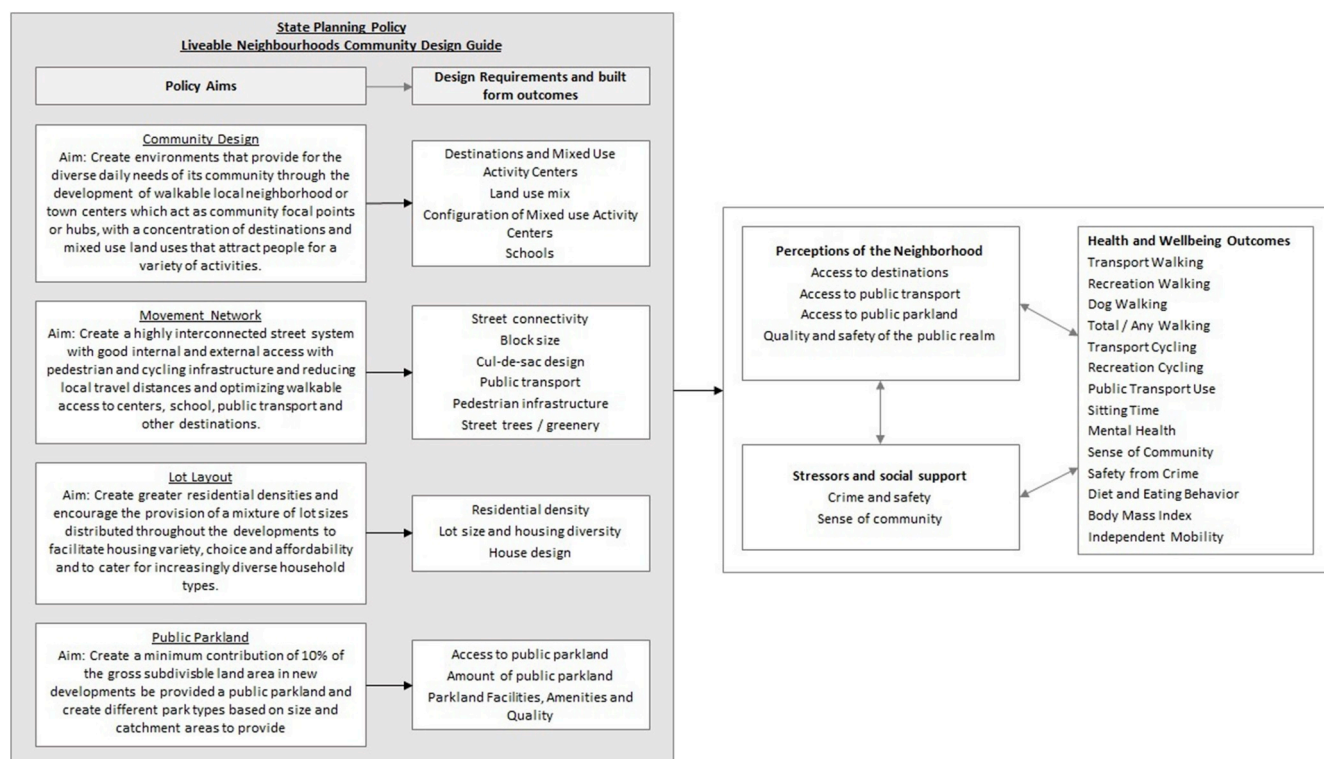


Fig. 1. Conceptual framework of how the LN policy influences neighborhood design and health and wellbeing.

Corporation) is notified of new owners upon completion of land transfer transactions. The Water Corporation invited all households that purchased house and land packages in the 74 developments ($n = 10,193$) to participate in the study (Giles-Corti, Knuiman et al., 2008). To be eligible, customers had to be ≥ 18 years of age; proficient in English; building a home in the selected development and planning to move into that home by December 2005; and indicate that they were willing to complete three surveys and wear a pedometer for one week on three separate occasions over a five-year period. Only one eligible person was selected at random from each household (Giles-Corti, Knuiman et al., 2008). The University of Western Australia's Human Research Ethics Committee provided ethics approval (#RA/4/1/479).

At baseline, the mean age of the study population ($n = 1813$) was 40 years, 60% were female, 82% were married or living with a partner, and 49% had children living at home. Just under one quarter of the sample (23%) had a bachelor's degree or higher, 43% had professional or managerial-administrator occupations, and 25% lived in households that earned AUD\$90,000 or more per year. A large proportion of participants (43%) worked 39–59 h per week and almost all (98%) had access to a motor vehicle (Giles-Corti, Knuiman et al., 2008; Hooper et al., 2014).

2.1.2. Study surveys

Participants completed a postal survey on four occasions: Time 1 (T1), at baseline in 2003–2005 during construction of their new home and before relocation ($n = 1813$; 33.4% response rate); Time 2 (T2) in 2004–2006, approximately one year after relocation to their new home ($n = 1465$); Time 3 (T3) in 2006–2008, approximately three years after relocating ($n = 1229$); and Time 4 (T4) in 2011–2012, about six to nine years after relocating ($n = 565$) (Hooper et al., 2014).

2.1.3. Objective measures of LN design features

Table 1 lists all of the objective measures of the neighborhood environments matched against the elements and design requirements of the LN policy. A participant's individual neighborhood was defined as the area that encompasses all streets and land that can be reached within a 1.6 km distance along the road network in all directions from the residential address. The current Australian public health message for adults encourages 30 min of moderate activity (including walking) on most days of the week (Department of Health, 2017). We therefore

Table 1
Design features from the “Liveable Neighbourhoods” policy and description of the objective and perceived measures of the built environment used in the RESIDE project.

“Liveable Neighbourhoods” element	“Liveable Neighbourhoods” design features
Community design	1) Destinations and mixed-use activity centers 2) Land-use mix 3) Configuration of mixed-use activity centers
Movement network	4) Access to primary schools 5) Street connectivity 6) Block size 7) Cul-de-sac design 8) Pedestrian infrastructure – sidewalks 9) Cycling infrastructure 10) Street trees/greenery/natural features
Lot layout	11) Public transport 12) Residential density 13) Lot size and housing diversity
Public parkland	14) House design 15) Amount of public parkland 16) Access to public parkland 17) Public parkland facilities, amenities, and quality
Design quality, aesthetics and safety	18) Greenness (NDVI) 19) Aesthetics, incivilities, and safety
Composite indices	20) Composite indices

defined a neighborhood as a 10 to 15-min walk from the participant's home because a destination within 15 min could be included in a 30-min circuit from the participant's home (Giles-Corti, Timperio et al., 2006). Using a geographic information system (GIS), objective measures of the built environment within participants' individual neighborhoods were generated for each of the four data collection time points (Table 1). These included measures of residential density; land-use mix; proximity (distance) to closest parks, shops and public transport stops; numbers of transport- and recreation-related destinations; street connectivity, sidewalks, and cycle paths. This provided a set of comparable longitudinal measures of participants' neighborhoods across the study period, allowing for quantification of change in the neighborhood environments as the participants moved from one neighborhood into another (i.e. as they moved homes from baseline/T1 to first follow-up/T2) and over time in the same location as their new housing developments were constructed (T2, T3, T4).

As part of the process evaluation to quantify the on-ground delivery of the LN policy in the RESIDE developments, additional objective measures specific to 44 of the LN policy requirements were developed for a subset of RESIDE developments ($n = 36$) at T3 (Hooper et al., 2014) (Table 1). These development-wide measures were created for the areas within the housing development boundaries plus an 800m Euclidean buffer of the surrounding areas. The 19 LN developments were evaluated with 17 of the 44 conventionally designed developments matched by their stage of development (i.e. the proportion of the gross development area that had been constructed), size, and location (i.e. distance from the ocean).

Field audits were undertaken to obtain objective information on the facilities and amenities within public parkland areas. Using a modified version of the Quality of Public Open Space Tool (POST), a reliable and valid audit instrument for measuring POS attributes (Broomhall, Giles-Corti, & Lange, 2004; Giles-Corti, Broomhall et al., 2005), trained assessors field-audited all parks ≥ 0.8 ha in size ($n = 354$) located within the 1.6 km neighborhood areas of participants' new residential addresses between November 2005 and February 2006 (T2). All audited parkland sites scored either 1 (present or yes) or 0 (not present or no) for 35 items across four domains: 1) activities; 2) environmental quality; 3) amenities; and 4) safety (Table 1). The data were used to create a park quality or “attractiveness” score (Giles-Corti, Broomhall et al., 2005). Further, in 2012 the development of the Public Open Space Desktop Auditing Tool (POSDAT) (Edwards et al., 2013) utilized remote audit methods combining web-based information and remote sensing to audit all parks within the 1.6 km neighborhood areas of participants' new residential addresses at T4, and the attractiveness score was re-computed for each site.

The Neighborhood Environment Safety Tool (NEST) was developed to collect objective audit data on the features of residential streets that might influence perceived safety from crime, incivilities, (i.e. graffiti and vandalism), and residents' walking habits (Foster, Giles-Corti, & Knuiman, 2011). During May and June 2007 (T2), trained assessors audited 443 residential street segments (defined as the section of street between two intersections, including both sides of the street) around a subset of participants' homes located in 61 of the 74 housing developments. Auditors recorded the presence of features that could influence the quality of the walking environment (e.g. traffic control and parking, amenities, incivilities) as well as house attributes that could impact natural surveillance of the sidewalk/street (Table 1).

2.1.4. Perceived measures of LN design features/built environment

The RESIDE surveys included subjective perceptions of the built environment as these have also been shown to be important for determining individuals' physical activity and health behaviors. At all time-points, survey items asked participants to reflect on their perceptions of their neighborhood environment and design features using a modified version of the Neighborhood Environment Walkability Scale (Cerin, Saelens, Sallis, & Frank, 2006). Perceived environmental characteristics

matching the LN design features which were assessed in the survey included land-use mix and proximity to and ease of access to non-residential land uses such as supermarkets and retail stores (community design element) and public open spaces (public parkland element); street connectivity and walking facilities (e.g. sidewalks) (movement network element); residential density (lot layout element); and aesthetics, traffic safety, and safety from crime and neighborhood satisfaction (design quality, aesthetics and safety element) (Table 1). Participants rated a series of statements (“items”) about the features on a scale of 1 to 4 (1 = strongly disagree to 4 = strongly agree), with higher scores indicating a more favorable value (i.e. perception) of the environmental characteristic.

2.2. Matching the RESIDE objective measures to the LN urban design features

Each of the four policy elements contained a list of requirements pertaining to different design features to meet the policy objectives. Twenty different urban design features were identified that were hypothesized to be important for creating healthy, livable neighborhoods (Table 1). All of the objective and perceived (exposure) measures of the environment used to quantify the neighborhood environments within the RESIDE studies were matched against each of these design features (Table 1). A fifth policy element was created that reflected the focus of a number of RESIDE analyses relating to the detail and quality of the neighborhood design and micro design features that enhance the attractiveness, safety, and desirability of the neighborhood. This fifth policy element included subjective ratings of neighborhood aesthetics or attractiveness, traffic hazards and slowing devices, street lighting, the presence of social incivilities, graffiti and vandalism, and safety from crime.

2.3. Residential self-selection factors

At baseline, participants were asked to rate the importance of 21 factors relating to neighborhood characteristics that influenced their choice of new housing development (1 = not important at all; 5 = very important). These included affordability/value; safety from crime; safety for children; distance to parks, shops and services, schools, beaches, recreational facilities, public transport and places of work; ease of walking and cycling, provision of pedestrian and cycling infrastructure, and street design to minimize traffic; and choice of lot sizes and housing types (Giles-Corti, Bull et al., 2013; Giles-Corti, Knuiman et al., 2008). These variables, or factor scales derived from these variables, have been used to adjust for residential self-selection in some of the RESIDE analyses. In the first relocation paper relating to walking, modelling revealed that adjustment for residential self-selection made little difference to the estimates of effect of the built environment variables on walking (Giles-Corti, Bull et al., 2013). Authors in subsequent analyses have therefore not always made adjustments for these, or may have adjusted for only the residential self-selection factors that were relevant to the exposure and outcomes variables of interest. Information on the specific residential self-selection factors was not extracted or evaluated for the synthesis of results in the current paper.

2.4. Health, wellbeing, and behavior outcomes

RESIDE studies evaluated 13 groups of outcomes related to health-supportive behaviors and wellbeing based on self-reported responses to surveys at baseline and during each follow-up (Fig. 1): (1) total/any walking; (2) transport walking; (3) recreation walking; (4) dog walking; (5) transport cycling; (6) recreation cycling; (7) sedentary behaviour; (8) public transport use; (9) mental health (psychological distress and positive mental wellbeing); (10) sense of community; (11) safety from crime (fear of crime and perceived crime risk); (12) diet and eating behaviors; (13) children’s independent mobility. Health and health-

supportive outcomes included walking and cycling (with each separately classified as being for transport or recreation, and according to location within or outside their neighborhood), sitting time, use of public transportation, diet, body mass index (BMI), and mental health. Outcomes related to wellbeing included sense of community/community connectedness and perceptions of crime and safety.

2.5. Review of RESIDE results

The present analysis includes all RESIDE publications that examined associations between urban design features of the LN policy and health-supportive behaviors or wellbeing outcomes. Specific inclusion criteria were: 1) The study included an objective (GIS or audit data) or perceived (self-reported) urban design (exposure) measure; 2) The urban design measure matched one of 20 LN design features (Table 1); 3) The study had been published in a peer-reviewed journal or PhD thesis (no duplicates included); 4) The study was not a review or a qualitative study.

2.6. Data extraction

Each eligible RESIDE publication and the respective analyses were coded according to the following characteristics:

- 1) Analytic design: a) Cross-sectional – results limited to associations between exposure and outcomes measured at the same, single point in time, including studies that estimated cross-sectional associations at multiple time points; or b) Longitudinal – associations between design features measured at multiple repeated time points.
- 2) Relevant RESIDE data collection time-point(s) at which analyses were undertaken: Either a single time point (cross-sectional analyses) or multiple (2+) time-points (longitudinal analyses).
- 3) Method for measuring the urban design exposure variable: Objective (GIS or field audit) or participant-reported perceptions of the built environment.
- 4) Single- or multiple-exposure models: a) Single-exposure models included a measure of only one urban design feature and a health-supportive behavior or wellbeing outcome (controlling for demographic covariates only); b) Multiple-exposure models included multiple measures of urban design features as well as demographic covariates. Only estimates from multiple-exposure models were included in the synthesis of RESIDE study results.
- 5) Direction of statistically significant associations: Each significant association (p -value < 0.05) was classified as positive if it was in the expected direction based on the *a priori* hypothesis, and as negative if it was in the opposite direction from that expected *a priori*. Associations that were not statistically significant (p value ≥ 0.05) were classified as null, regardless of their direction or magnitude.
- 6) The *a priori* hypothesis was based on the principles, ethos, and intended community outcomes of the LN planning policy and New Urbanist theory on which it was based (Congress for the New Urbanism, 1997). This planning school of thought hypothesizes that mixed-use, pedestrian-friendly neighborhoods promote walking and cycling and provide opportunities for an activated public realm that creates opportunities for social interactions, facilitates neighborhood ties and a sense of community, and is protective of good psychological (mental) health. It is also thought to create safer neighborhoods as they generate more pedestrian traffic, making the streets safer through natural surveillance or “eyes on the street”, and enable neighbors to know each other and protect their communities (Congress for the New Urbanism, 1997; Duany et al., 2000; Jacobs, 1961). Consistent with these theories, the *a priori* hypothesis for the health supportive behaviors and wellbeing outcomes studied in RESIDE were that we would observe: increased levels of walking and cycling behaviour; reduced sitting time and body mass index; improved sense of community and mental health outcomes; and a

reduction in the fear of crime, the perception of the risk of crime, and being a victim of crime.

The results of all estimated associations were extracted from eligible publications as follows:

- 1) Eligible publications often reported multiple estimates for the same exposure-outcome association. In general, we extracted and included all associations between design features (exposures) and health- and wellbeing-related outcomes in our results synthesis, including:
 - a) Estimates of associations between a specific design feature and an outcome defined in multiple ways, e.g. associations between a measure of land-use mix and different levels of walking, i.e. total walking any or none; <60 or ≥60min; <150 or ≥150min (Christian, Bull et al. 2011);
 - b) Estimates of associations between specific outcomes and each category of a categorical design feature exposure measure, e.g. associations of the outcome “sense of community” with commercial floor area classified as low, medium, or high vs. none (French et al., 2013);
 - c) Associations of a specific outcome with closely-related land-use design features, e.g. nearby transport stop at work and home, and proximate transport stop at work only (Badland, Hickey, Bull, & Giles-Corti, 2014);
 - d) Associations of a composite exposure measure (e.g. walkability index) and, where reported, its sub-components (e.g. land-use mix, residential density, and street connectivity under the respective LN design features) (Christian, Bull et al. 2011).
- 2) For papers with a primary focus on developing methods to measure an urban design feature (Christian, Bull et al. 2011), we only included the final exposure measures that were assessed and were relevant to the health or behavioral outcome of interest. For example, (Christian, Bull et al. 2011) identified two different walkability indices with: 1) a walking for recreation-specific land-use mix component for which the estimates of associations between walking for recreation and total walking were extracted; and 2) a walking for transport-specific land-use mix component for which estimates of associations between walking for transport and total walking were extracted.
- 3) When the same association was reported based on data from more than one time-point (e.g. between neighborhood sidewalks/km and recreational walking at T1, T2, T3, and T4), we included estimates from each available time point in the synthesis of results.
- 4) When studies reported estimates for associations from different longitudinal models fitted to repeated measures data on a cohort of individuals, e.g. associations between LN design features and transport walking reported by (Hooper et al., 2014), we extracted estimates from the conditional logistic regression models that included a random effect for participants which included repeated measures of a cohort of individuals.
- 5) When studies stratified their analyses by sex (based on hypothesized differences between sexes for the association between the environmental exposure and health-related outcome variables), we included estimates for each sex separately.
- 6) When studies reported associations based on models with and without adjustment for socio-demographic characteristics and other covariates, we extracted the estimates from the most fully adjusted models only. The majority of RESIDE studies consistently adjusted for socio-demographic characteristics of age, sex, income, education, occupation, and household income. Additional socio-demographic characteristics and other potential confounders (i.e. factors other than additional LN design features/exposures) were controlled for according to criteria specific to each analysis or outcome. Information on the specific respective model covariates was not extracted or evaluated for this paper's results synthesis.

7) When studies reported estimates for the same exposure-outcome association based on models that included only a single-exposure (a measure of only one urban design feature and a health-supportive behavior or wellbeing outcome controlling for socio-demographic covariates) and models that included multiple-exposures (multiple measures of urban design features included in a statistical model as well as socio-demographic covariates), we extracted estimates from the most fully-adjusted multiple-exposure model only.

8) Estimates included in the synthesis of RESIDE study results were limited to estimates based on multiple-exposure models that included ≥2 measures of LN design elements.

2.7. Synthesizing the findings

We used the association between the LN design features and health and wellbeing outcomes as the primary measure of effect. To summarize the consistency of findings across the RESIDE studies, we determined the total numbers of eligible estimates of association (from multiple-exposure models) and the number of positive associations (statistically significant and consistent with expectations), negative associations (statistically significant and inconsistent with expectations), and null findings for each health-supportive behavior or wellbeing outcome by the objective and perceived measures of each LN design feature.

3. Results

In total, 26 published articles from the RESIDE project met the inclusion criteria and were mapped to 14 LN policy-related design features. We extracted 331 estimates of associations based on multiple-exposure predictor models (Fig. 2). These included 256 estimates for objective measures of urban design features across the different LN policy elements (Fig. 2) and 75 estimates for perceived measures of the neighborhood built environment (Fig. 2). Supplementary Tables S1–S7 present the results from the individual RESIDE analyses that were summarized in this analysis.

3.1. Health-supportive behaviors and wellbeing outcomes

Fig. 3 presents the number of eligible effect estimates (associations) extracted from the different studies for each of the health and wellbeing outcomes by the direction of association. Figs. 4–8 present summary matrices for each of the LN policy elements of the eligible effect estimates of the specific design requirements (rows) against the different health and wellbeing outcomes (columns). The associations were coded as follows: positively significant ($p \leq .05$) in the expected direction based on the *a priori* hypothesis (+); negatively significant ($p \leq .05$) in the opposite direction based on the *a priori* hypothesis (−); or having no (null) significant association (○) between the 20 LN policy design features (built environment exposures) and the 14 different health-supportive behaviors and wellbeing outcomes. The totals refer to the sum of all the associations obtained from different studies by the direction of association for each of the health and wellbeing outcomes.

The majority of analyses focused on walking (any/total walking, transport walking to and from a destination, recreation walking and dog walking) as a key intended policy outcome (Western Australian Planning Commission, 2000) and health-promoting behaviour (Fig. 3). Walking outcomes accounted for 61% of all eligible effect estimates for objective measures (115 of 182 or 61.2%), and 36.0% (27 of 75) of effect estimates for perceived measures of the built environment (Fig. 3). Of these walking estimates, 57.4% (66 of 115) showed positive associations (significant and in the expected direction) with objectively-measured LN design features, and 66.7% (18 of 27) showed positive associations with perceived measures of the design features (Fig. 3).

Although increased cycling was an intended outcome of the LN policy (Western Australian Planning Commission, 2000), only five of

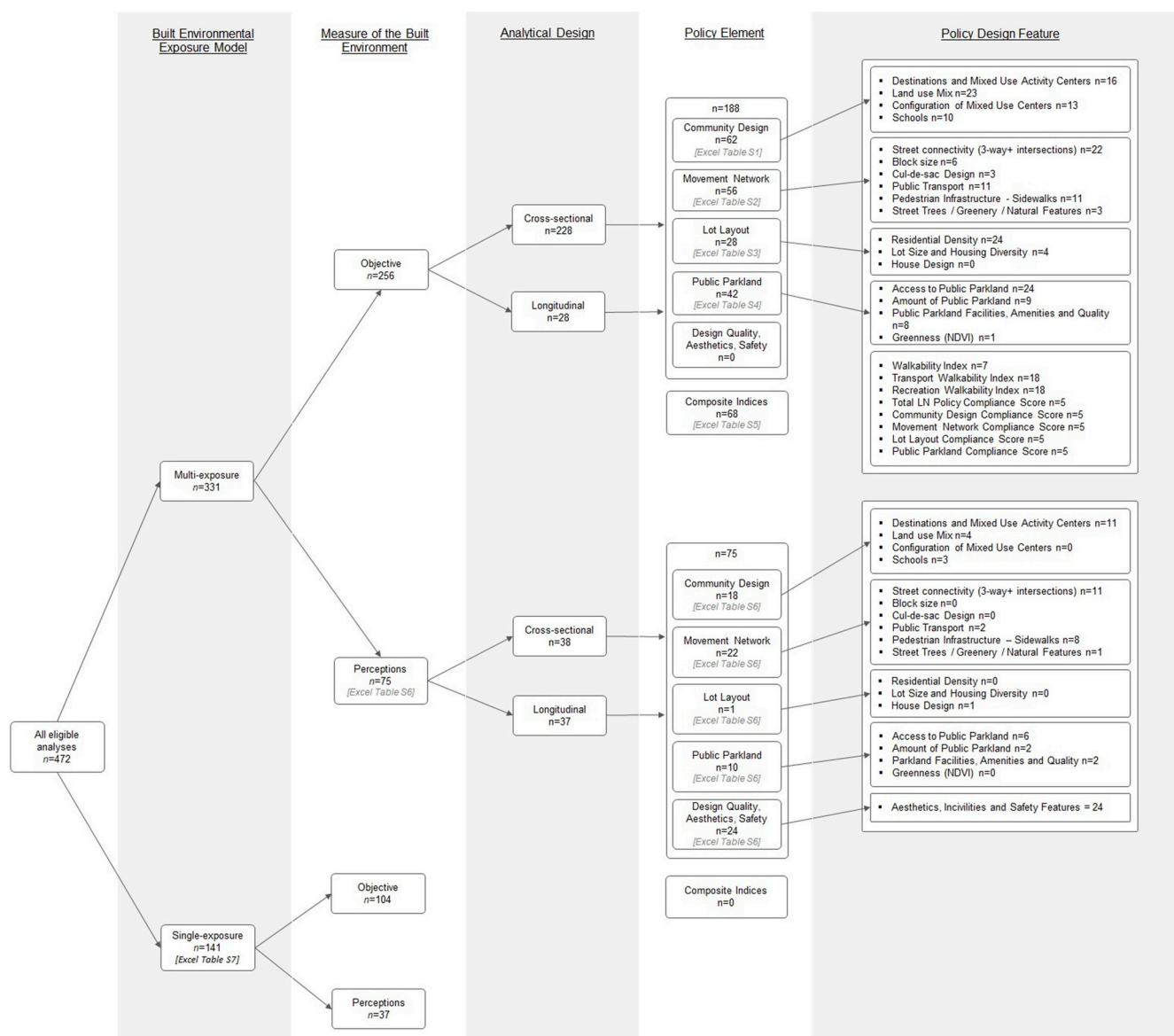


Fig. 2. Numbers of included estimates of associations by exposure model, measure of the environment, analytic design, and LN policy elements.

188 eligible estimates (2.7%) with objective measures and 20 of 75 eligible associations (26.7%) with perceived measures of LN design features focused on transport or recreation cycling as an outcome (Fig. 3). Forty percent of cycling estimates showed positive associations (significant and in the expected direction) with objective measures of LN design features, and 35.0% of estimates were positively associated with perceived measures. At baseline, 10% of RESIDE participants reported cycling for transport and 20% reported cycling for recreation (Bee-nackers, Foster et al., 2012). After relocation to their new neighborhood, 4.9% and 7.3% of respondents reported they began cycling for transport or recreation, respectively (Badland, Knuiman, Hooper, & Giles-Corti, 2013).

Eligible estimates of associations with objective measures of LN design features included 12 (of 188, or 6.4%) estimates of associations with “sense of community”, of which five (41.7%) were positively significant, six (50.0%) had a null association and one (8.3%) had a negatively significant association. There were a total of 28 (of 188, or 14.9%) estimates of associations with safety from, or fear of crime, including 11 (39.3%) positively significant, six (21.4%) negatively significant and 11 (39.3%) null associations (Fig. 3). Only four eligible estimates were identified for associations between objective measures of

LN features and a mental health outcome (psychological distress), all (100%) of which showed positively significant associations (Fig. 3).

Of the eligible estimates of associations with perceived measures of LN, 13 (of 75, or 17.3%) were for sense of community including eight (61.5%) that were positively significant, one (7.7%) that was negatively significant and four (30.8%) that were null associations. Seven (of 75, or 9.3%) associations were for safety from crime (fear of crime and perceived crime risk) with all (100%) estimates positively significantly (Fig. 3).

3.2. Community design

Eligible estimates of associations were identified with 62 objective measures and 18 perceived measures of the LN design features and 9 health and wellbeing outcomes (Fig. 4).

3.2.1. Objective measures of community design

Four LN policy design features (destinations and mixed-use centers, land-use mix, configuration of mixed-use activity centers and schools) related to the community design element were assessed against 11 different health-related outcomes, with walking, sense of community

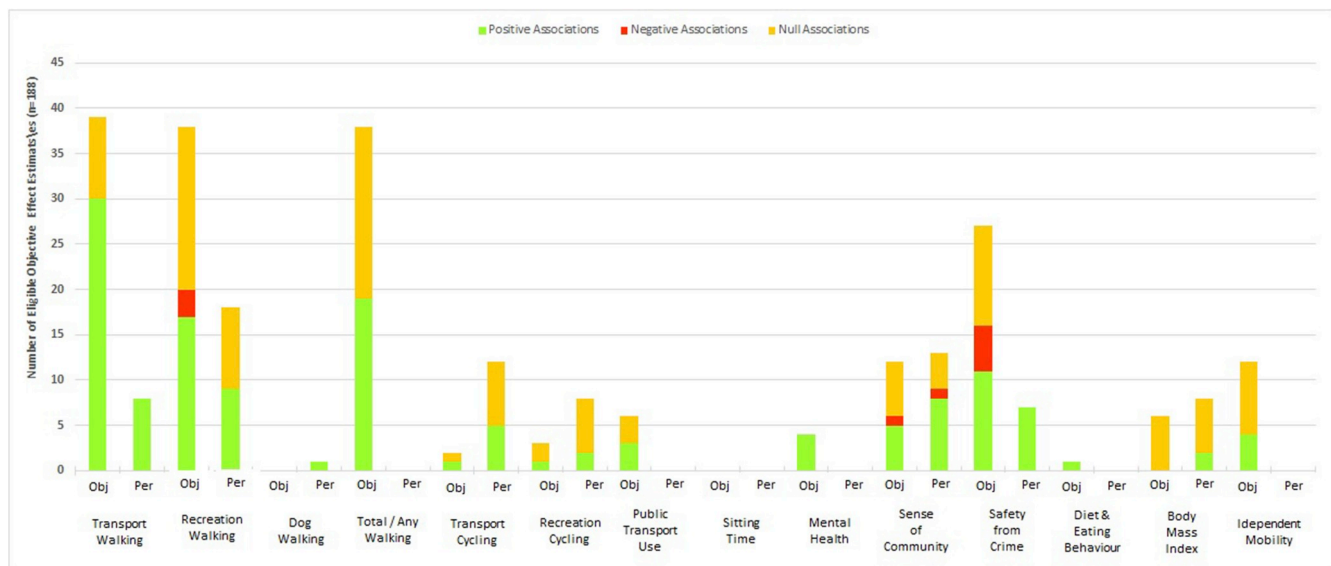


Fig. 3. Total number of objective multi-exposure analyses (n = 188) and perceived multi-exposure analyses (n = 75) by health and wellbeing outcome and the direction of statistically significant associations.

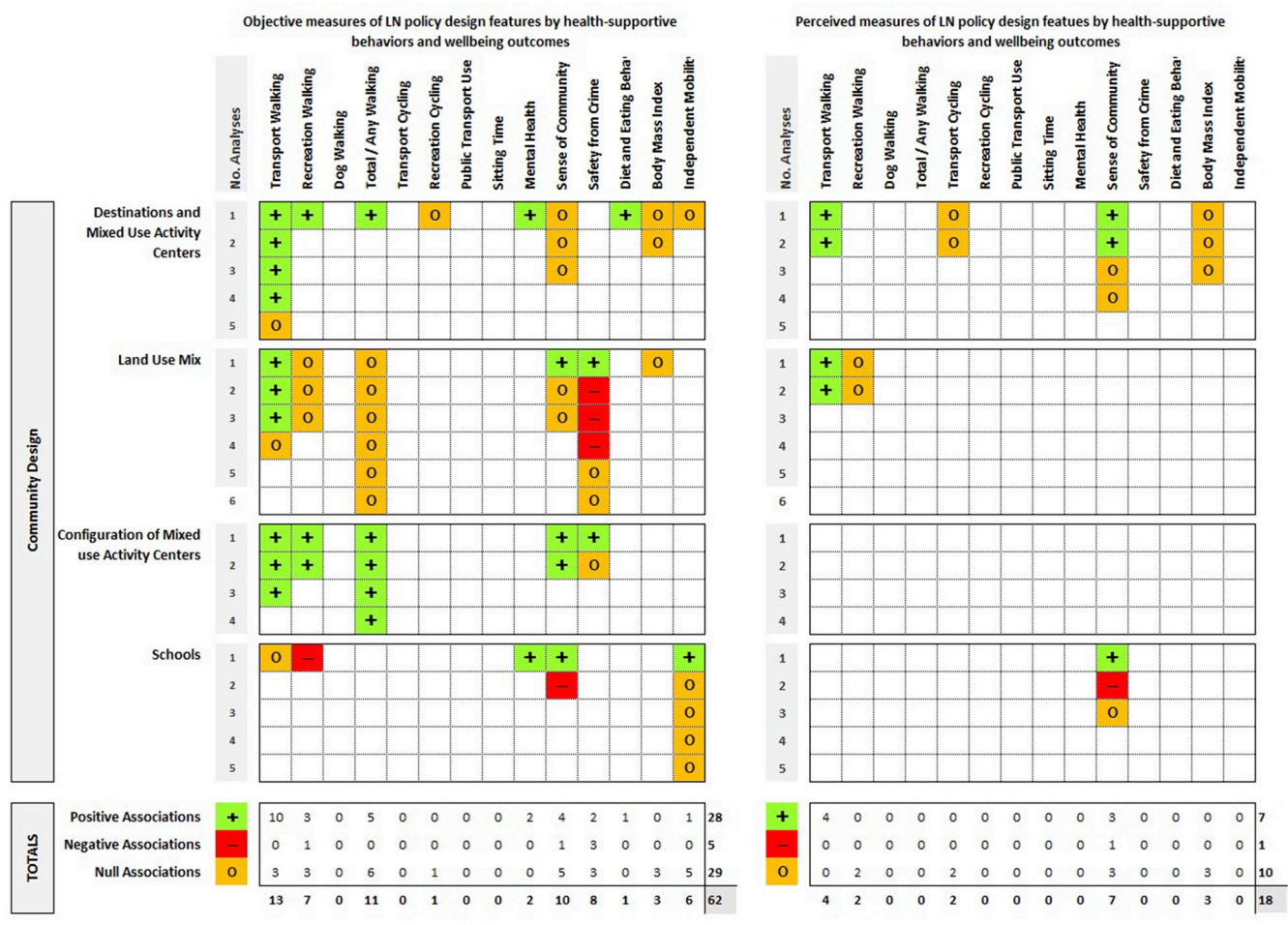


Fig. 4. Number of objective multi-exposure analyses by the direction of statistically significant associations by health and wellbeing outcome and community design features
+ Positive finding: Statistically significant association in the expected direction based on the *a priori* hypothesis; – Negative finding: Statistically significant association in the opposite direction based on the *a priori* hypothesis; ○ Null finding: Association not statistically significant; □ Association between health and wellbeing outcome and design feature not examined; “Totals” rows indicate the number of analyses by health and wellbeing outcomes that were positively, negatively, or not associated across all design features/measures of the built environment.

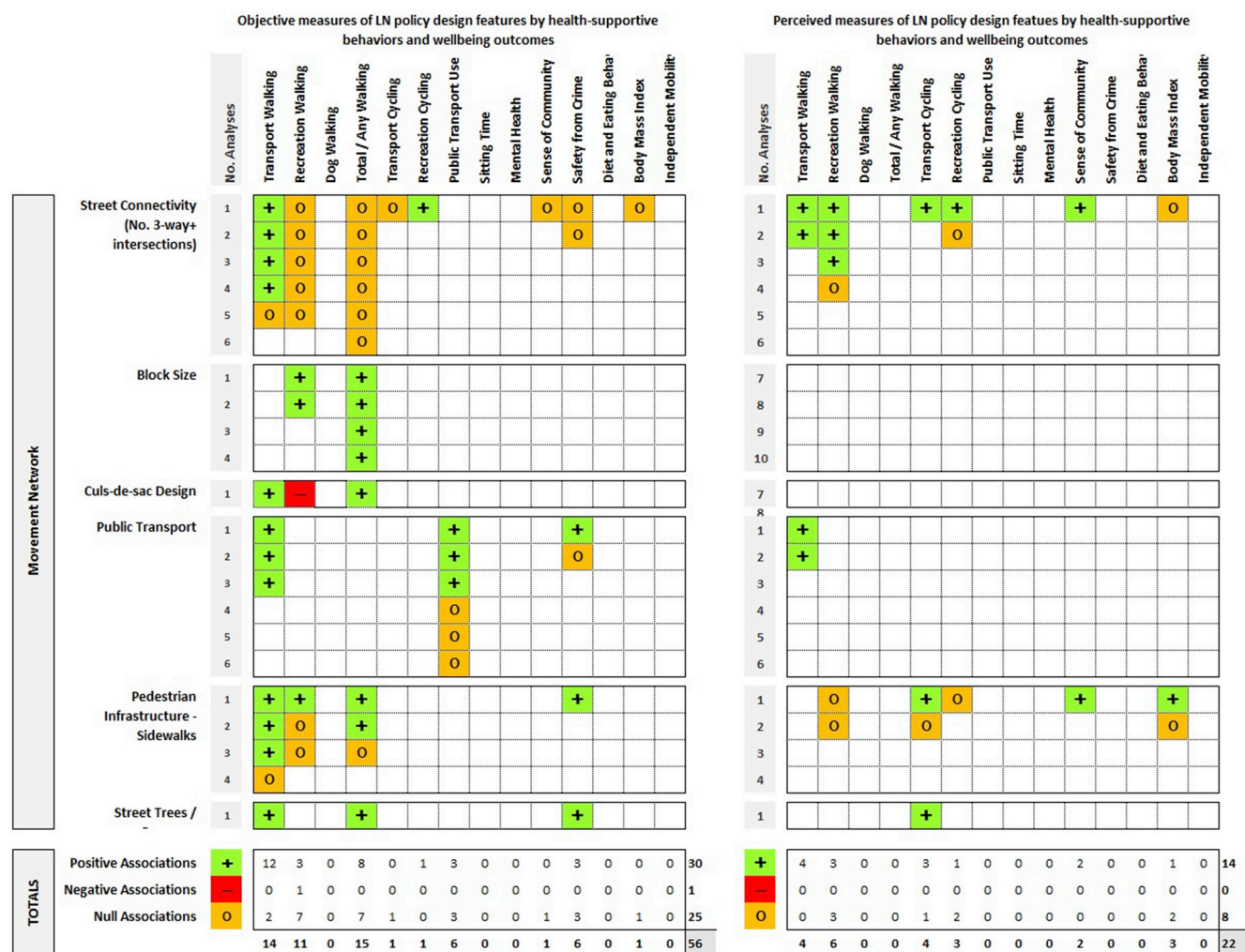


Fig. 5. Number of objective multi-exposure analyses by the direction of statistically significant associations by health and wellbeing outcome and movement network design features

+ Positive finding: Statistically significant association in the expected direction based on the *a priori* hypothesis; - Negative finding: Statistically significant association in the opposite direction based on the *a priori* hypothesis; O Null finding: Association not statistically significant; □ Association between health and wellbeing outcome and design feature not examined; "Totals" rows indicate the number of analyses by health and wellbeing outcomes that were positively, negatively, or not associated across all design features/measures of the built environment.

and safety from crime the most studied outcomes (Fig. 4). RESIDE studies measured the presence of and access to destinations and mixed-use centers in several ways, including: counts of different destinations types; counts of recreation-related destinations (e.g. parks, beaches); counts of transport-related destinations (e.g. retail shops, shopping centers, supermarkets, and post offices); access to mixed use activity centers; and entropy scores of land use mix.

Regardless of how it was measured, there was consistent evidence of associations between the community design features and transport walking (Fig. 4). The odds ratios from longitudinal analyses ranged in magnitude for doing any walking for transport (vs. none) from 1.03 (95%CI 0.82-1.29) to 1.38 (95%CI 1.02-1.87) (Supplementary Table S1) (Knuiman, Christian et al., 2014). Additional destination types present was associated with doing a greater number of minutes of transport walking a week (Giles-Corti, Bull et al., 2013). Greater diversity of destinations within the mixed-use activity centers was also associated with a greater odds of doing ≥60min of transport walking a week (OR = 1.36 95%CI 1.11-1.68) (Hooper, Knuiman, Bull, Jones & Giles-Corti, 2015; Hooper, Knuiman, Foster & Giles-Corti, 2015). Composite measures of land-use mix (the proportion of land area covered by different uses, i.e. residential, retail, commercial, and recreational) was

associated with increased odds of walking for transport (any vs none) ranging from 1.15 (95%CI 1.03-1.27) (Christian, Bull et al. 2011) to 1.29 (95%CI 1.17-1.43) in a longitudinal analysis (Knuiman, Christian et al., 2014) and a greater odds of doing ≥60min of transport walking a week (OR = 1.14 95%CI 1.01-1.29) (Christian, Bull et al. 2011) (Supplementary Table S1). All three eligible estimates for recreation walking and six estimates for any/total walking found null associations. Land-use mix scores showed no association with perceived crime risk (Foster, Christian, Wood & Giles-Corti, 2013) and body mass index (*n* = one of one estimate) (Christian, Giles-Corti, Knuiman, Timperio & Foster, 2011). Developed and retail land areas were positively significant with a reduced fear of crime in one of two estimates, but negatively significant with increased ratings of perceived crime risk for three of three estimates (Foster, Christian et al. 2013; Foster, Knuiman, Wood & Giles-Corti, 2013). The findings of associations with the other health outcomes studied were less consistent and had fewer number of eligible estimates of effect.

A key principle of the LN community design element relates to the configuration of mixed-use activity centers. Main-street centers with pedestrian-scaled, street-fronting retail layouts that encourage walking and cycling access are preferred to conventional "big-box" style centers

		Objective measures of LN policy design features by health-supportive behaviors and wellbeing outcomes															Perceived measures of LN policy design features by health-supportive behaviors and wellbeing outcomes															
		No. Analyses	Transport Walking	Recreation Walking	Dog Walking	Total / Any Walking	Transport Cycling	Recreation Cycling	Public Transport Use	Sitting Time	Mental Health	Sense of Community	Safety from Crime	Diet and Eating Beha-	Body Mass Index	Independent Mobilit-	No. Analyses	Transport Walking	Recreation Walking	Dog Walking	Total / Any Walking	Transport Cycling	Recreation Cycling	Public Transport Use	Sitting Time	Mental Health	Sense of Community	Safety from Crime	Diet and Eating Beha-	Body Mass Index	Independent Mobilit-	
Lot Layout	Residential Density	1	0	0		0	+	0				+	+		0		1															
		2	0	0		0							0																			
		3	0	0		0							0																			
		4	0	0		0							0																			
		5		0		0							+																			
		6				0																										
	Lot Size and Housing Diversity	1	+										+																			
		2											+																			
		3											+																			
		House Design	1																													
TOTALS	Positive Associations	+	1	0	0	0	1	0	0	0	0	1	3	0	0	0	6	+	0	0	0	0	0	0	0	0	0	1	0	0	0	1
	Negative Associations	-	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Null Associations	0	4	5	0	6	0	1	0	0	0	0	3	0	1	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			5	5	0	6	1	1	0	0	0	1	8	0	1	0	28											1	0	0	0	1

Fig. 6. Number of objective multi-exposure analyses by the direction of statistically significant associations by health and wellbeing outcome and lot layout design features

+ Positive finding: Statistically significant association in the expected direction based on the *a priori* hypothesis; - Negative finding: Statistically significant association in the opposite direction based on the *a priori* hypothesis; ○ Null finding: Association not statistically significant; □ Association between health and wellbeing outcome and design feature not examined; "Totals" rows indicate the number of analyses by health and wellbeing outcomes that were positively, negatively, or not associated across all design features/measures of the built environment.

that tend to cater generously for cars and can be hostile, unwelcoming and unsafe environments for pedestrians (Naess, 2005). Analyses exploring this found that having access to a big-box or main street within 1600m (versus having no neighborhood center accessible within the same distance) was positively significant with three of three estimates for transport walking (any vs. none, $n = 1$; ≥ 60 min, $n = 2$), two of two estimates for walking for recreation (any vs. none, $n = 1$; ≥ 60 min, $n = 1$); four of four total walking estimates (any vs. none, $n = 2$; ≥ 60 min, $n = 2$) (Hooper, Knuiman & Bull et al., 2015; Hooper, Knuiman & Foster et al., 2015), and two of two estimates for sense of community (high vs. low Buckner neighborhood cohesion scores) (Hooper, Foster, Knuiman, & Giles-Corti, 2020). The magnitude of association with both all walking outcomes and sense of community was greater when participants had an accessible main-street configured neighborhood center (≥ 60 mins transport walking = 1.70 (95%CI 1.05-2.68); high vs. low sense of community = 1.67 (95%CI 1.36-2.06)) compared with a big-box center (≥ 60 mins transport walking = 1.68 (95%CI 1.20-2.36); high vs. low sense of community = 1.54 (95%CI 1.02-3.30)) (Supplementary Table S1). A big-box center was positively associated with increased odds of being a victim of crime ($n = 1$), and a null association with main-street centers (Foster, Hooper, Knuiman, Bull, & Giles-Corti, 2016) (Fig. 4).

The presence of a primary school showed mixed results with transport and recreation walking and children's independent mobility and safety from crime, but one analysis showed it was positively associated with mental health (Fig. 4).

3.2.2. Perceived measures of community design

Perceived measures of destinations were positively significant with walking for transport (two of two estimates: any vs. none, $n = 2$) (Knuiman, Christian et al., 2014) and sense of community (two of four estimates) (Francis, Giles-Corti et al. 2012; French et al., 2013) but showed null associations with uptake of transport cycling for transport (two of two estimates) (Beenackers, Foster et al., 2012) and body mass index (three of three estimates) (Christian, Giles-Corti et al. 2011)

(Fig. 4).

Perceptions of a mix of land uses were associated with two of two estimates of transport walking (any vs. none, $n = 2$), but not for any (vs. none) recreation walking (two of two null associations) (Koohsari et al., 2014). The perceived presence of and access to schools was mixed across three estimates with one positively significant, one negatively significant, and one null association (Francis, Giles-Corti et al. 2012).

3.3. Movement network

Eligible estimates of associations were identified with 56 objective measures and 22 perceived measures of the LN design features and 8 health and wellbeing outcomes (Fig. 5).

3.3.1. Objective measures of the movement network

Four LN policy design features related to the design of the movement network (i.e. street connectivity, public transport, and pedestrian infrastructure, sidewalks and street trees/greenery) were measured. Street connectivity was measured and quantified in a number of ways across the different RESIDE analyses, including counts of the number of three-way or greater intersections, the number of external connections, the size (perimeter) of street blocks, the density of street blocks, and the design (length) of cul-de-sacs.

The number of street intersections was associated with five of six estimates of transport walking outcomes, with odds ratios ranging from 1.12 (95% CI 1.04-1.21) to 1.35 (95% CI 1.06-1.73) for doing any (versus none) transport walking and 1.22 (1.07-1.39) for doing ≥ 60 min of transport walking per week (Christian, Bull et al. 2011; Knuiman, Christian et al., 2014; Hooper, Knuiman & Bull et al., 2015; Hooper, Knuiman & Foster et al., 2015). Measures of block size were positively associated with recreation walking (any vs. none and ≥ 60 min) and total walking (any vs. none; ≥ 60 min; ≥ 150 min) in all analyses. The odds ratios for total walking ranged from 4.38 (95% CI 3.24-5.91) for any walking to 2.27 (95%CI 1.40-3.68) for doing ≥ 150 min of total walking (Supplementary Table S2).

		Objective measures of LN policy design features by health-supportive behaviors and wellbeing outcomes																Perceived measures of LN policy design features by health-supportive behaviors and wellbeing outcomes															
		No. Analyses	Transport Walking	Recreation Walking	Dog Walking	Total / Any Walking	Transport Cycling	Recreation Cycling	Public Transport Use	Sitting Time	Mental Health	Sense of Community	Safety from Crime	Diet and Eating Behav	Body Mass Index	Independent Mobilit	No. Analyses	Transport Walking	Recreation Walking	Dog Walking	Total / Any Walking	Transport Cycling	Recreation Cycling	Public Transport Use	Sitting Time	Mental Health	Sense of Community	Safety from Crime	Diet and Eating Behav	Body Mass Index	Independent Mobilit		
Public Parkland	Access to Public Parkland	1	+	+		+							+			+	1	+	+			+	0										
		2	+	+		+							+			+	2	+	+														
		3	+	+		+											+	3	+														
		4		+		+											0	4	0														
		5		+													0	5															
		6		+														6															
		7		+														7	+														
		8		0														8															
		9		0														9															
		10		0														10															
	Amount of Public Parkland	1	+	+		+							0				1					+	0										
		2	+	+		+							0				2																
		3	+														3																
	Parkland Facilities, Amenities and Quality	1	+	+							+		+			0	1		+							+							
		2		+							+						2																
		3		+													3																
	Greenness (NDVI)	1														0	1																
TOTALS	Positive Associations	+	7	11	0	6	0	0	0	0	2	0	3	0	0	3	32	+	0	2	1	0	2	0	0	0	0	1	0	0	0	6	
	Negative Associations	-	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	-	0	0	0	0	0	0	0	0	0	0	0	0	0		
	Null Associations	0	0	3	0	0	0	0	0	0	0	0	0	2	0	1	3	9	0	2	0	0	0	2	0	0	0	0	0	0	4		
			7	15	0	6	0	0	0	0	2	0	5	0	1	6	42		0	4	1	0	2	2	0	0	1	0	0	0	10		

Fig. 7. Number of objective multi-exposure analyses by the direction of statistically significant associations by health and wellbeing outcome and public parkland design features

+ Positive finding: Statistically significant association in the expected direction based on the *a priori* hypothesis; - Negative finding: Statistically significant association in the opposite direction based on the *a priori* hypothesis; 0 Null finding: Association not statistically significant; □ Association between health and wellbeing outcome and design feature not examined; "Totals" rows indicate the number of analyses by health and wellbeing outcomes that were positively, negatively, or not associated across all design features/measures of the built environment.

		Objective measures of LN policy design features by health-supportive behaviors and wellbeing outcomes															Perceived measures of LN policy design features by health-supportive behaviors and wellbeing outcomes																
		No. Analyses	Transport Walking	Recreation Walking	Dog Walking	Total / Any Walking	Transport Cycling	Recreation Cycling	Public Transport Use	Sitting Time	Mental Health	Sense of Community	Safety from Crime	Diet and Eating Beha-	Body Mass Index	Independent Mobilit-	No. Analyses	Transport Walking	Recreation Walking	Dog Walking	Total / Any Walking	Transport Cycling	Recreation Cycling	Public Transport Use	Sitting Time	Mental Health	Sense of Community	Safety from Crime	Diet and Eating Beha-	Body Mass Index	Independent Mobilit-		
Design Quality, Aesthetics and Safety	Aesthetics and Incivilities	1																1	+				0	0			+	+		+			
		2																	2	+			0					+		0			
		3																	3								+						
		4																	4								+						
	Traffic hazards and safety features	1																	1	0			0	+			0	+					
		2																	2	0			0										
	Crime-related safety features	1																	1	+				0			+	+					
		2																	2	+													
TOTALS	Positive Associations	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0	4	0	0	0	1	0	0	0	2	6	0	1	0	14
	Negative Associations	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Null Associations	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	4	2	0	0	0	1	0	0	1	0	10
			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	6	0	0	4	3	0	0	0	3	6	0	2	0	24

Fig. 8. Number of objective multi-exposure analyses by the direction of statistically significant associations by health and wellbeing outcome and design quality, aesthetics and safety features.

Increases in intersection density were associated with a higher odds (1.12, 95% CI 1.04-1.21) of taking up recreational cycling ($n = 1$) but not with transport cycling ($n = 1$) (Beenackers, Foster et al., 2012). Higher street intersection density was not associated with a sense of community ($n = 1$) (French et al., 2013), nor with fear of crime or perceived crime risk ($n = 2$) (Foster, Knuiman et al. 2013) or body mass index ($n = 1$) (Christian, Giles-Corti et al. 2011) (Fig. 5).

Three (of three) estimates from a longitudinal analysis indicated that walking for transport (any vs. none, $n = 3$) was positively associated with an increased number of available bus stops (odds ratios ranged from 1.88 (95%CI 1.49-2.39) to 2.07 (95%CI 1.56-2.74)) or a train station being present within 1600m of home (Knuiman, Christian et al., 2014) (Fig. 5). The findings for public transport use were mixed. Six estimates investigated access to public transport stops from home and work with public transport use. Three estimates found significant positive associations with stops located proximate to home and work (OR = 16.51 95%CI 3.46-78.73) or work only (OR = 11.57 95%CI 2.45-54.69) (Badland et al., 2014) (Supplementary Table S2). Three null associations were observed with stops close to home ($n = 2$) or a train station within 800m of the workplace ($n = 1$) (Badland et al., 2014) (Fig. 3). The presence (vs. absence) of a public transport stop within 400m showed a positively significant association with fear of crime ($n = 1$) (Foster, Giles-Corti, & Knuiman, 2010), whilst the number of public transport stops showed a null association with perceived crime risk ($n = 1$) (Foster, Christian et al. 2013).

Objective measures of sidewalk provision were quantified two ways: 1) the length (km) of sidewalks present within a participant's neighborhood (1.6 km buffer around their home) (McCormack, Shiell et al., 2012) or housing development (Hooper et al., 2014, Hooper, Knuiman & Bull et al., 2015, Hooper, Knuiman & Foster et al., 2015, Foster et al., 2016); and 2) the sidewalk to road ratio - a measure of the length of sidewalks compared with roads within the housing development (Hooper et al., 2014). Three of four estimates with transport walking (any vs. none, $n = 2$; ≥ 60 min, $n = 1$; minutes/week, $n = 1$), one of three estimates with recreation walking (any vs. none, $n = 1$; ≥ 60 min, $n = 1$; minutes/week, $n = 1$), and two of three estimates for total walking (any vs. none, $n = 1$; ≥ 60 min, $n = 1$; minutes/week, $n = 1$) showed positively significant associations for increased walking (Fig. 5), with odds ratios ranging from 1.01 (95%CI 1.00-1.02) to 3.14 (95%CI 1.89-11.06) per additional km of footpath (McCormack, Shiell et al., 2012, Hooper, Knuiman & Bull et al., 2015, Hooper, Knuiman & Foster et al., 2015, Foster et al., 2016). One estimate for safety from crime (victim of crime yes vs. no, $n = 1$) also showed a significant positive association with the length of sidewalks compared to roads (Fig. 5) (Foster et al., 2016; French et al., 2013).

The provision of street trees (the number of trees along sidewalks per km of sidewalks) was investigated with three outcomes. All three estimates for associations were positive (Fig. 5): walking for transport (any vs. none, $n = 1$), total walking (any vs. none, $n = 1$) and safety from crime (victim of crime yes vs. no) were positively significant (Fig. 5) (Hooper, Knuiman & Bull et al., 2015, Hooper, Knuiman & Foster et al., 2015) and decreased odds of being a victim of crime (Foster et al., 2016). Every additional tree per km of footpath was associated with a 2%–4% increased odds of doing any total walking or transport walking (respectively) (Hooper, Knuiman & Bull et al., 2015, Hooper, Knuiman & Foster et al., 2015).

3.3.2. Perceived measures of the movement network

Eleven estimates investigated perceptions of street connectivity (measured as RESIDE participants' perceptions of the number of three- or four-way intersections within the neighborhood street network) with six health and wellbeing outcomes. Increased perceptions of street connectivity were positively associated with two of two estimates of transport walking (any vs. none, $n = 2$) (Koohsari et al., 2014); three of four estimates of recreation walking (any vs. none, $n = 2$; minutes/week, $n = 1$; frequency/week, $n = 1$) (Koohsari et al., 2014; Christian,

Knuiman et al., 2017); one estimate for cycling for transport (any vs. none, $n = 1$) (Titze, Giles-Corti et al., 2010) and one of two estimates for cycling for recreation (any vs. none, $n = 1$; talking up cycling, $n = 1$) (Titze, Giles-Corti et al., 2010; Beenackers, Foster et al., 2012) (Fig. 5); and one estimate of sense of community (French et al., 2013). One estimate for BMI showed a null association (Christian, Giles-Corti et al. 2011).

Associations with the perceived presence of infrastructure for walking and cycling ($n = 8$) were less conclusive. One estimate found a positively significant association with increased sense of community (French et al., 2013) and one of two estimates for body mass index (Christian, Giles-Corti et al. 2011). Only one of two estimates for transport cycling (any vs. none, $n = 1$; up-take of transport cycling $n = 1$) was positively significant. Null findings were found for two of two estimates for recreation walking (minutes of walking, $n = 1$; frequency of walking, $n = 1$) and one of one estimates for recreation cycling (taking up recreation cycling, $n = 1$) (Titze, Giles-Corti et al., 2010; Beenackers, Foster et al., 2012). Two of two estimates found positively significant associations between perceptions of access to public transport stops and walking for transport (any vs. none, $n = 2$) (Badland et al., 2014) (Fig. 5). One estimate showed a positively significant association with the perceived presence of street trees and transport cycling (any vs. none) (Beenackers, Foster et al., 2012).

3.4. Lot layout

Eligible estimates of associations were identified with 28 objective measures and 1 perceived measure of the LN design features and 8 health and wellbeing outcomes (Fig. 6) (Supplementary Table S3).

3.4.1. Objective measures of lot layout

Three lot layout LN policy design features relating to lot layout (residential densities, lot sizes, and housing diversity and house design) were investigated. Overall, 20 of 24 estimates for residential density found null associations with recreation cycling, recreation walking, transport walking, and total walking and body mass index (Fig. 6). Two estimates found a positively significant association for residential density with transport cycling (any vs. none, $n = 1$, OR = 1.54 95%CI 1.04-2.26) (Beenackers, Foster et al., 2012) and sense of community ($n = 1$, (French et al., 2013)). Safety from crime outcomes ($n = 5$) were inconclusive: one estimate showed a positively significant association with fear of crime (OR = 0.72 95%CI 0.54-0.97) (Foster, Knuiman et al. 2013) with another showing a significant association between density and reported victimization of crime (OR = 1.24 95%CI 1.16-1.32) (in the unexpected direction) (Foster et al., 2016) (Supplementary Table S3). Three estimates showed null associations (fear of crime, $n = 1$; perceived crime risk, $n = 2$) with residential density measures (Foster, Knuiman et al. 2013) (Fig. 6).

Four estimates considered lot sizes and housing type as measures of housing diversity and density (since smaller lot sizes increase the number of residential dwellings possible in a given area) (Fig. 2). One estimate showed a positively significant association between increased proportions of residential land area provided as smaller, medium-density lot sizes and transport walking (any vs. none, OR = 1.04 95%CI 1.03-1.06) (Hooper, Knuiman & Bull et al., 2015, Hooper, Knuiman & Foster et al., 2015) and a reduced odds of being a victim of crime ($n = 1$; OR = 0.72 95%CI 0.56-0.95) (Foster et al., 2016). Increased mean residential lot sizes (i.e. larger lots and houses and decreased residential density) were positively associated with increased odds of being a victim of crime, whilst an increased number of different lot sizes was positively associated with decreased odds of being a victim of crime (Foster et al., 2016) (Fig. 6).

3.4.2. Perceived measures of the lot layout

Participants' perceptions of smaller house setbacks were, however, positively associated with fear of crime ($n = 1$, OR = 1.43, $p = 0.033$),

suggesting smaller setbacks are beneficial under the assumption they would increase walkability and increase surveillance of the street and public realm (Foster et al., 2010) (Fig. 6). No other studies examined the relationships between perceived measures of lot layout and health and wellbeing outcomes.

3.5. Public parkland

Eligible estimates of associations were identified with 42 objective measures and 10 perceived measures of the LN design features and 7 health and wellbeing outcomes (Fig. 7) (Supplementary Table S4).

3.5.1. Objective measures of public parkland

Four LN policy design features relating to the provision of public parkland (access to parkland; amount of parkland; the quality of the parkland and their facilities and amenities; and the levels of neighborhood greenness measured via remote sensing methods (NDVI)) were measured.

Accessibility to parkland (i.e. the distance to the closest park or binary indicators of parks being accessible within walking (400m–1600m) distances from home (yes/no) were positively significant with three of three transport walking estimates (any vs. none, $n = 1$; ≥ 60 min, $n = 2$; odds ratios ranging from 1.09 (95%CI 1.04–1.13) to 3.97 (95%CI 2.46–6.41), six of ten estimates for recreation walking (any vs. none, $n = 2$; ≥ 60 min, $n = 2$; minutes/week, $n = 1$; frequency/week, $n = 1$, odds ratios ranging from 1.08 (95%CI 1.03–1.11) to 7.50 (95%CI 1.55–13.45), and four of four estimates for total/any walking (any vs. none, $n = 2$; ≥ 60 min, $n = 2$, odds ratios ranging from 1.06 (95%CI 1.02–1.10) to 1.85 (95%CI 1.23–2.80) (Hooper, Knuiman & Bull et al., 2015, Hooper, Knuiman & Foster et al., 2015, Christian, Knuiman et al., 2017) (Fig. 7). Two of two estimates with safety from crime (reduced victimization) (Foster et al., 2016); and three of five estimates with children's independent mobility (Christian, Klinker et al., 2015) (Fig. 7) were positively significantly associated with accessibility to parkland. One estimate showed a negatively significant association between the presence of a district/regional park within 1600m of home minutes of walking for recreation (Christian, Knuiman et al., 2017).

The amount of public parkland, measured as a count of the number of parks accessible within a participant's neighborhood or housing development, was positively significant with three of three estimates for transport walking (any vs. none, $n = 3$, odds ratios ranging from 1.08 (95%CI 1.03–1.13) to 1.13 (95%CI 1.02–1.25), two of two estimates for recreation walking (any vs. none OR = 1.09 95%CI 1.06–1.13; ≥ 60 min OR = 1.09 95%CI 1.06–1.13) and two of two estimates for total/any walking (any vs. none OR = 1.06 95%CI 1.02–1.10; ≥ 60 min OR = 1.09 95%CI 1.04–1.13). Null associations were recorded for two of two estimates of fear of crime ($n = 1$) and perceived crime risk ($n = 1$) with the percentage of land area devoted as public parkland within participants' neighborhoods (Fig. 7).

The quality of public parklands, measured as a composite score of the presence of a mix of facilities and amenities (Giles-Corti, Broomhall et al., 2005) was positively significant with three of three estimates of recreation walking (any vs. none OR = 1.33 95%CI 1.01–1.76 to 1.34 95%CI 1.01–1.78; ≥ 60 min OR = 1.36 95%CI 1.12–1.69) (Sugiyama, Francis, Middleton, Owen, & Giles-Corti, 2010); one (of one) estimates of transport walking (any vs. none OR = 1.26 95%CI 1.18–1.34) (Hooper, Knuiman & Bull et al., 2015, Hooper, Knuiman & Foster et al., 2015); two of two estimates of psychological distress (low vs. high) (OR = 1.83 95%CI 1.14–2.92 and 2.26 95%CI 1.36–3.76) (Francis, Wood, Knuiman & Giles-Corti, 2012); and one estimate of safety from crime (Foster et al., 2016). A null association was found with children's independent mobility (Christian, Klinker et al., 2015).

3.5.2. Perceived measures of public parkland

Perceptions of public parkland were less conclusive. Positive perceptions of access to public parkland within a 5–15 min walk from home

(present vs. absent) were positively significant with recreation walking for two of four eligible estimates (minutes/week, $n = 1$; frequency/week, $n = 1$) (Christian, Knuiman et al., 2017) and one transport cycling estimate (cycling for transport uptake, $n = 1$) (Beenackers, Foster et al., 2012). Null associations were observed with two estimates of recreation walking (minutes/week, $n = 1$; frequency/week, $n = 1$) (Christian, Knuiman et al., 2017) and recreation cycling (cycling for recreation uptake, $n = 1$) (Beenackers, Foster et al., 2012). Transport cycling was positively significant with the presence of more parks (cycling for transport uptake, $n = 1$), but the association with recreational cycling was null (cycling for recreation uptake, $n = 1$). Positive perceptions of parkland facilities, amenities, and quality showed positively significant associations with dog walking ($n = 1$) (Cutt, Giles-Corti, & Knuiman, 2008) and sense of community ($n = 1$) (Francis, Giles-Corti et al. 2012).

3.6. Design quality, aesthetics, and safety

The detail and quality of the neighborhood design and micro design features that enhance the attractiveness, safety, and desirability of the neighborhood were assessed in 24 estimates of perceived measures (Fig. 8). There were no eligible estimates of objective measures.

Positive perceptions of neighborhood aesthetics (attractive buildings and streetscapes) and incivilities (i.e. graffiti and vandalism) were positively significant with: two of two estimates of recreation walking (minutes/week, $n = 1$; frequency/week, $n = 1$) (Christian, Knuiman et al., 2017); one estimate of recreational cycling (taking up recreation cycling, $n = 1$); one estimate of sense of community (French et al., 2013) and four of four estimates of safety from crime (perceived crime risk, $n = 2$; fear of crime, $n = 2$) (Foster, Christian et al. 2013); and one of two estimates of body mass index (Christian, Giles-Corti et al. 2011) (Fig. 2). Null associations were observed for transport cycling (cycling for transport uptake, $n = 2$), recreation cycling (cycling for recreation up-take, $n = 1$) (Beenackers, Foster et al., 2012) and BMI (Christian, Giles-Corti et al. 2011)(Fig. 8).

Seven estimates specifically investigated perceptions of traffic hazards and safety (e.g. unpleasant and busy streets and presence of traffic slowing devices and pedestrian crossings), but only two of seven found positively significant associations: perceived crime risk ($n = 1$) (Foster, Christian et al. 2013) and recreation cycling (any vs. none, $n = 1$) (Titze, Giles-Corti et al., 2010). Null estimates were found for two of two estimates for recreation walking (minutes/week, $n = 1$; frequency/week, $n = 1$) (Christian, Knuiman et al., 2017); two of two estimates of transport cycling (taking up transport cycling, $n = 2$) (Beenackers, Foster et al., 2012); and one estimate of sense of community (French et al., 2013).

Crime-related safety features (e.g. street lighting and perceptions of crime hazards) were positively associated with perceived crime risk (one of one estimate) (Foster, Christian et al. 2013), sense of community (one of one estimate) (French et al., 2013), and two of two walking for recreation estimates (minutes/week, $n = 1$; frequency/week, $n = 1$) (Christian, Knuiman et al., 2017). A null association was found with one estimate of recreation cycling (taking up recreation cycling, $n = 1$) (Beenackers, Foster et al., 2012).

4. Discussion

4.1. Living livable? Impact of the "Liveable Neighbourhoods" planning policy

This paper aimed to assess the consistency and direction of findings across the totality of RESIDE studies evaluating the LN policy as an indication of the benefits of a new major urban development policy on health supportive behaviors and wellbeing outcomes, and to provide policy-makers with a comprehensive overview of the outcomes following its trial implementation.

The review included 332 estimated associations from multiple-exposure predictor models extracted from 26 RESIDE papers. It

showed that new communities built in accordance with the LN policy principles and design features have the potential to promote the health and wellbeing of residents by creating neighborhoods that encourage transport and recreational walking and have a stronger sense of community where residents feel safer.

It is important to consider these results with respect to the fundamental tenets of causal inference in epidemiology. All lend support for, and enhance the prospect of causality if the hypothesized relationships between the environmental exposures (as a result of the policy) and health outcomes is evaluated against the fundamental tenets of causal inference in epidemiology (often referred to as the Bradford Hill Criteria) (Hill, 1965, (Fedak, Bernal, Capshaw, & Gross, 2015), i.e., strength of associations, temporality, consistency and plausibility/coherence.

Hill (Hill, 1965) suggested that the larger an association between exposure and outcome, the more likely it is to be causal. The strength of association was assessed in this study both in terms of the level of statistical significance and the magnitude of association. Moreover, Hill's consistency criterion of plausibility/coherence is upheld when multiple studies using a variety of locations, populations, and methods show a consistent association between two variables (Hill, 1965). Our findings consistently found medium-strong associations and were consistent with New Urbanism claims of the benefits of designing pedestrian-friendly neighborhoods that assumes a causal relationship between the built environment and pedestrian and community outcomes. This is reflected in academic literature within a number of substantive fields such as New Urbanism and Smart Growth debates in North America, and various compact city discourses in Europe (Næss, 2016). Our findings were also largely consistent with the international literature from the physical activity, active living, transport and public health fields (Ding and Gebel 2012; Durand et al., 2011; Feng et al., 2009; Sallis, Floyd, Rodríguez, & Saelens, 2012; Wanner, Gotschi, Martin-Diener, Kahlmeier, & Martin, 2012). Hill's criterion of plausibility and coherence are satisfied as the relationships observed are consistent with the current body of knowledge regarding an association and the cause-and-effect story makes sense with all knowledge available to the research team (Hill, 1965).

The RESIDE study, and summary results presented here, also included longitudinal evidence (Foster, Christian et al. 2013; Giles-Corti, Bull et al., 2013; Knuiman, Christian et al., 2014; Christian, Knuiman et al., 2017), which increases our confidence in the associations observed. According to the Bradford Hill Criteria (Hill, 1965) study designs that ensure a temporal progression between the two measures are more persuasive in causal inference. Moreover, the quantification of the level of urban policy implementation (Christian, Knuiman et al., 2017; Falconer, Newman, & Giles-Corti, 2010; Hooper et al., 2014; Hooper, Knuiman & Bull et al., 2015; Hooper, Knuiman & Foster et al., 2015) provides unique insights that help explain our findings, and help guide future policy development.

A growing number of studies have compared communities or neighborhoods developed under different design principles or alternate planning theories, such as New Urbanism or Smart Growth, and compared the health behaviors and outcomes of the residents (Gordon & Tamminga, 2002; Trudeau, 2013). However, these studies typically measure and characterize the built environment with regards to how it relates to New Urbanist principles or planning policies. To our knowledge, no studies have explicitly assessed or quantified the implementation of specific planning policies or design codes and empirically evaluated their impact on health-promoting behaviours and positive wellbeing outcomes.

The study was designed to compare 74 housing developments, 19 of which of which were approved as consistent with the LN policy during its trial period. The process evaluation was designed to specifically assess the fidelity of policy implementation both overall and within each policy element (Hooper et al., 2014) and found that many of the easier to implement policy requirements were quite consistently adopted by the development industry with few differences in the implementation of the

policy irrespective of whether housing developments were approved under the LN or the state's conventional policy (Hooper et al., 2014). However, overall the policy was only partially implemented and the level of implementation was similar in all developments included in the study (Hooper et al., 2014). Nevertheless, each 10% increase in implementation increased the odds of walking by 53% (Hooper et al., 2014), of having higher sense of community by 21% (Hooper, Foster, Knuiman, & Giles-Corti, 2020) and of lower psychological distress (i.e. better mental health) by 14% (Hooper, Foster, Knuiman, & Giles-Corti, 2020), and decreased the odds of being a victim of crime by 40% (Foster et al., 2016).

The findings indicated that the policy was worthy of wider dissemination, but a greater emphasis on policy implementation was needed. The identified policy implementation gap highlighted the importance of process evaluation and the need for a longitudinal study design. It also highlighted the value of undertaking research in partnership with policy-makers within local contexts, because partnerships with policy-makers and local research have been identified as enablers of research uptake (Allender et al., 2009; Giles-Corti et al., 2015; Oliver, Innvar, Lorenc, Woodman, & Thomas, 2014).

4.2. Unpacking the positive and consistent findings

The LN policy aimed to increase walking and cycling, and public transport use, and these were thus the primary outcomes of interest. The most studied and consistent evidence we observed related to transport walking. Consistent with previous research (Sallis et al., 2009), LN design features that promoted walking included creating a pedestrian-friendly movement network (e.g. street connectivity, sidewalks, public transport access, street trees and greenery) and providing access to local destinations through well-implemented community design features (e.g. access to local shops, services, and community facilities, and particularly a main street activity center).

The longitudinal results were consistent with the cross-sectional findings, supporting a relationship between access to a variety of local destinations and transport walking. For example, residents who gained access to a mix of neighborhood destinations after relocating to a more supportive neighborhood increased their local walking, highlighting that transport walking may be responsive to the presence of local destinations (Giles-Corti, Bull et al., 2013). Longitudinal analysis using participant data from all four time-points confirmed that land-use mix had a stronger relationship with local transport walking than either street connectivity or residential density (Knuiman, Christian et al., 2014). Nevertheless, street connectivity and residential density provide the underlying foundation of walkable pedestrian-friendly neighborhoods because together they determine the structure, connectedness, and accessibility of local destinations, and this provides residents with a reason to walk (Hooper, Knuiman & Bull et al., 2015; Hooper, Knuiman & Foster et al., 2015) and sufficient resident populations to make local businesses viable. Qualitative research undertaken as part of RESIDE, for example, suggested that local destinations provided residents with opportunities for social interaction, particularly for mothers of young children (Strange, Fisher, Howat & Wood, 2014; Strange, Fisher, Howat & Wood, 2014), and this might encourage residents to walk locally. However, we also identified a significant policy implementation gap in the community design element of the policy. Community design determines the presence of local shops and services, but it was the least well implemented policy element of LN (Hooper et al., 2014) despite the benefits of access to local destinations for local walking, as well as a sense of community and mental health (Francis, Giles-Corti et al. 2012; Francis, Wood et al. 2012; French et al., 2013; Hooper, Foster, Knuiman, & Giles-Corti, 2020). Future research could explore factors that affect the early provision of shops and services when new areas are developed.

Recreational walking was also associated with access to public open space, particularly higher quality public open space (Giles-Corti, Broomhall et al., 2005; Sugiyama, Gunn et al., 2015). Our longitudinal

analyses found that after relocation, residents did around 23 min more recreational walking for each additional type of public open space (e.g. park, sports oval, or beach) they gained (Giles-Corti, Bull et al., 2013).

Crime statistics obtained from the Western Australian Police indicated the spatial locations of reported crimes relating to (1) actual and attempted burglary and (2) crimes committed against the person in public space (e.g., threats, disorderly behaviour, assault; robbery) for the calendar year corresponding with the RESIDE questionnaire. Perceived safety from crime (including fear of crime, perceived crime risk, and self-reports of being a victim of crime) and sense of community were positively associated with the presence of sidewalks, street trees, public transport and public open space access, neighborhood aesthetics, and safety features. This indicates that residents in areas built under the LN policy feel safer. Despite this, we found no significant associations between LN compliance (overall, or by element) and objective measures of crimes reported to police (including actual or attempted burglary, or crimes committed against the person in public spaces) (Foster et al., 2016).

It was theorised that personal crime in public space might influence residents' perceptions of safety more than those committed in the private realm (i.e., burglary). However, violent crime tends to cluster in lower socio-economic and unstable residential neighbourhoods, whereas burglary affects the full spectrum of society (Sampson, Raudenbush, & Earls, 1997) and can generate fear in sectors of society, where other crimes are rare (Skogan & Maxfield, 1980). In general, however, fear of crime is disproportionate with actual crime (Hale, 1996) and is a more difficult concept to define and measure than actual crimes, which are tangible events. This distinction is worth noting within the context of our study sample, which comprised new suburban homeowners living in freshly built suburbs, which generally had low levels of relative socio-economic disadvantage rather than a cross-section of society as a whole. Moreover, the findings indicated that these neighborhoods were relatively safe and most participants perceived few problems (Foster, Giles-Corti, & Knuiman, 2014); however, fear of crime did appear to deter walkers (Foster et al., 2014). However, despite being a relatively affluent sample, the established associations between gender, age, education and household income, and fear of crime were evident. Indeed, research suggests that residents in neighbourhoods undergoing rapid change are more likely to be fearful (Krannich, Berry, & Greider, 1989). While this finding was based on rapidly urbanizing rural environments, they parallel the sudden transformation that occurs when new housing developments are constructed on the urban fringe. Thus, community and environmental interventions that reduce unwarranted fear of crime might help increase the uptake of walking in these suburbs (Foster et al., 2014).

4.3. Explanation of inconsistent and null findings

We observed inconsistencies and null associations between a number of LN design features and behavioral and health outcomes (Fig. 3). Whilst smaller lot sizes were associated with transport walking, there were inconsistent findings in relation to residential density (measured by *net* residential density). A number of factors may have contributed to these results. Smaller lot sizes in part determine an area's population density, because the smaller the lots, the greater the number of people who might live in an area. However, residential density alone is insufficient to foster health-supportive behaviours. Rather, density supports other urban design features (such as the presence of local destinations) by increasing the number of local residents, which enhances the viability of a local economy (Forsyth, Oakes, Schmitz, & Hearst, 2007, Hooper, Knuiman & Bull et al., 2015, Hooper, Knuiman & Foster et al., 2015). In addition, in RESIDE we measured net density rather than gross density, which may also have contributed to our findings (see study limitations for a more detailed discussion).

Few RESIDE participants cycled for transport or recreational purposes. This may have contributed to the inconsistent and/or null

findings observed and prohibits making inferences about urban design features that would encourage suburban cycling. More research is required to understand why cycling levels in outer suburban areas are so low, including exploring regional planning issues (Beenackers, Foster et al., 2012; Giles-Corti, Vernez-Moudon et al., 2016) such as whether a lack of cycling infrastructure linking outer suburban developments with employment, transport hubs, and/or activity centers inhibits potential cyclists (Heesch, Giles-Corti, & Turrell, 2015).

4.4. Exploration of perceived versus objective measures of the neighborhood

Relationships between perceived access to destinations and transport walking were stronger than associations with equivalent objective measures of access to destinations (Knuiman, Christian et al., 2014). Further, when both perceived and objective measures were included in the same (multi-variable exposure) models, associations attenuated, with objective measures becoming non-significant while perceptions remained positively significant (Knuiman, Christian et al., 2014). This is potentially because perceptions are more proximal to an individual's decision-making (Knuiman, Christian et al., 2014), and in more supportive environments, people have more positive perceptions. This requires further investigation.

4.5. Challenges associated with conducting natural experiments and undertaking policy-relevant research – lessons learnt from RESIDE

4.5.1. Participant sampling

RESIDE sampled people building new homes and relocating to new (mainly) outer suburban developments, some of which were developed using a new design code. The repeated follow-up of participants in their new homes enabled us to monitor how new housing developments changed over time, and how this affected participants' health-supportive behaviors and wellbeing. While this approach was practical and efficient, recruiting only new home buyers (i.e. owner-occupiers) limited the heterogeneity of the study sample to a "middle-class" demographic and its representativeness of the wider Perth population. This was unavoidable given RESIDE aimed to study the impact of 1) a planning policy intended to improve the built form of greenfield developments; and 2) self-selection, which required that we survey study participants before they relocated and after they moved in order to monitor changes in the built environment. This limits the options for generalizing the RESIDE findings to other higher-density urban or rural settings or lower SES populations. Nonetheless, the results are directly applicable and relevant to residents of the low density, greenfield developments and communities that continue to be built on the urban fringes of metropolitan areas throughout Australia and North America and in some cities in Europe.

4.5.2. Participant attrition

Loss to follow-up is an important consideration as it is a potential source of bias in longitudinal research affecting observed estimates of built environment effects on health outcomes. In RESIDE only 10% of participants moved again after the one-year follow-up (Knuiman, Christian et al., 2014) and participant retention was high from T1 through T3 (81% T1-T2; 84% T2-T3). However, drop-out rates were highest at T4 (46% retention). Study participants were recruited initially for T1 to T3, and T4 was an additional data collection approximately three years after T3. The higher attrition rates are likely a consequence of time between surveys and, in hindsight, may also be due to participant burden – because T4 involved a longer survey comprising additional questions on a broader range of behavioural (e.g. diet) and wellbeing (e.g. positive mental wellbeing) outcomes, and a focus on participants children's health-supportive behaviors and wellbeing outcomes.

An analysis of participant attrition in the RESIDE cohort revealed

that drop-out was associated with certain demographic characteristics (age, sex, having children at home). These were included as adjustment variables in all subsequent RESIDE analyses of relevant behaviors. If attrition is related to covariates only and not to prior or missing values of the behavioral outcome, then all suitable regression models for longitudinal data that include these covariates should provide unbiased exposure effect estimates (Knuiman, Christian et al., 2014). Further, there are subject-level regression models for longitudinal data that remain unbiased even if drop-out is related to prior (but not missing) values of the behavioral outcome (Knuiman, Christian et al., 2014). However, it is likely that there will always be unknown or unmeasured covariates related to attrition and it is impossible to assess from available data if drop-out is related to missing values of the behavioral outcome. Unbiased estimates can therefore never be confidently claimed.

4.5.3. Lack of heterogeneity in new neighborhoods

At baseline, participants were located in suburbs across metropolitan Perth including older, established, and diverse inner suburbs, which enhanced the variability of neighborhood environments (Christian, Knuiman et al., 2013; Giles-Corti, Bull et al., 2013). In contrast, the new low-density outer suburban neighborhoods to which participants relocated were fairly homogenous, with significantly fewer destination types and amenities (Christian, Knuiman et al., 2013; Giles-Corti, Bull et al., 2013). Consequently, it is plausible that associations between the urban design features and health outcomes are underestimated because of insufficient variability in the built environment exposure measures (Sallis, 2009). This may be particularly true for residential density. The null findings observed in cross-sectional studies between density and walking for transport and recreation and total walking after relocation at T2, T3, and T4 may be due to the lack of variability in the exposure measure (i.e. density) in the new residential areas at the time of evaluation, rather than to residential density itself.

4.5.4. The evolution of new neighborhoods

The construction of housing developments is generally sequenced, and the order in which land and infrastructure are developed appears to be dictated by several factors, including a balance between marketing or sales purposes and economic considerations. For example, developers appear to regard public open space as an important aesthetic feature that is instrumental to land sales and as such is typically installed early (Grose 2009, 2010). In contrast, community infrastructure such as neighborhood centers, health services, schools, and public transport are often delayed until there is a critical mass of residents to warrant these services being provided (Christian, Knuiman et al., 2013; Christian, Knuiman et al., 2017; Giles-Corti, Bull et al., 2013; Hooper et al., 2014), further highlighting the importance of dwelling density.

Our longitudinal analyses allowed changes in the new developments to be tracked over time. We found that following relocation, only 11% of RESIDE participants increased their levels of access to local transport-related destinations (e.g. shops and public transport stops) whilst 99% increased their levels of access to at least one additional park (Giles-Corti, Bull et al., 2013). After relocation, transport walking declined (models adjusted for changes in work status, number of hours worked weekly, and time to travel to work) and recreational walking increased, regardless of baseline socio-demographic variables, other types of walking, socio-demographic “change” variables, self-selection factors about why participants relocated to their neighborhood, and individual and social environmental factors. Although other factors cannot be ruled out, these results were consistent with our hypothesis that changes in access to local infrastructure would be associated with changes in behavior (Giles-Corti, Bull et al., 2013). This hypothesis was supported by subsequent analyses which found that as new design features and community facilities were provided, transport (Giles-Corti, Bull et al., 2013; Knuiman, Christian et al., 2014) and recreational walking (Giles-Corti, Bull et al., 2013) changed. This suggested that residents’

behaviours changed in response to the evolving neighborhood. Nevertheless, although longitudinal data, appropriately analyzed, is subject to less bias and thus provides stronger evidence of a causal effect, it cannot provide absolute proof of a causal effect.

4.5.5. The need for integrated regional planning and consideration of development scale

The RESIDE study highlighted the importance of considering the scale of housing developments being studied. LN was intended to be applied on large-scale structure plans or regional-sized developments to allow for “the regional structuring of walkable, mixed use neighborhoods” (Western Australian Planning Commission, 2000). However, the RESIDE housing developments varied in size and scale from master-planned communities to smaller subdivisions of 100–200 residential lots which had insufficient scale to master-plan significant activity centers or public transport hubs or to provide the diversity and density of housing required to support them (Falconer et al., 2010).

Smaller developments planned in an *ad hoc*, piecemeal fashion make it difficult to ensure shops, services, places of work, other community facilities, and public open spaces are equitably distributed and within walking distances of residences. The benefits of local walkable neighborhoods may be overwhelmed by the poor regional transport and broader land-use contexts in which the RESIDE developments were built. In addition, whilst LN recognised the importance of providing local employment opportunities, in reality there were insufficient employment opportunities within the developments or their immediate surrounds (Falconer et al., 2010). Few residents living in RESIDE neighborhoods had viable public transport options, and work-trip substitutability analyses revealed that, irrespective of the neighborhood type they lived in, there were significant time burdens for people using public transport compared with using a private vehicle for the journey to and from work, with average additional daily commuting times of approximately 80 min (Falconer et al., 2010).

4.5.6. Measurement and methodological considerations

Rather than replicate existing measures, natural experiments need to consider how best to measure behavioral outcomes and environmental exposures to suit the type of policy being evaluated. For example, as the RESIDE study focused on the impact of an urban design policy on local behaviors, it was necessary to develop new measures with an emphasis on context-specific behavior measures and behavior-specific environmental exposure measures (Giles-Corti, Timperio et al., 2006). We therefore carefully considered how to measure the built environment; how to operationalize and measure the “neighborhood” (Learnihan, Van Niel, Giles-Corti, & Knuiman, 2011); how to compile the optimal mix of land-uses for inclusion in the walkability index when considering different types of walking (Christian, Bull et al., 2011); how to conceptualize and measure fear of crime (Foster & Giles-Corti, 2008); how to advance the study of the influence of public open space on recreational walking and mental health by taking into account its attractiveness, size, and proximity (Francis, Wood et al., 2012; Giles-Corti, Broomhall et al., 2005; Sugiyama et al., 2010; Sugiyama, Gunn et al., 2015); and how to develop policy-relevant measures that provided metrics of policy implementation (Hooper et al., 2019; Hooper et al., 2014).

Finally, when RESIDE commenced there were very few longitudinal studies of the built environment and health. It was therefore also necessary to carefully consider how to design this type of longitudinal natural experiment study (Giles-Corti, Knuiman et al., 2008); how to measure behaviors over time in this context (Giles-Corti, Timperio et al., 2006); and how to assess the appropriateness of different statistical modelling methods (Knuiman, Christian et al., 2014). Studies with less than 12 months of follow-up may not provide enough time for residents to be affected by the intervention or for full implementation of the policy to occur (Mayne, Auchincloss, & Michael, 2015). In addition, studies with only two-time points to assess change may not provide a valid measure of change and will not allow for a full exploration of the

evolution of the policy impact/s.

4.6. Study limitations

Despite the various strengths of the RESIDE study, there are important limitations that require acknowledgment. Firstly, we relied on self-reported measures of health-supportive behaviors and these measures may therefore be subject to bias. Since RESIDE commenced in 2003, GPS technology and “big data” obtained via smart phone tracking technologies have been developed to measure the location of physical activity, which may have facilitated a more accurate identification of behaviors undertaken within and outside the neighborhood.

While we considered intermediate outcomes (such as BMI and sense of community) and other wellbeing outcomes (such as mental health), our conclusions are based primarily on the most numerous analyses. These reflect the primary LN objective related to walking, and to a lesser extent, its other objectives related to sense of community, safety, and public transport use.

Our team made decisions about how to measure certain environmental exposure variables, in ways that could be challenged. For example, in this study we measured net residential density rather than gross density. It is plausible that net density (for which the denominator is the total residential land) is less important for creating walkable neighborhoods than gross density (for which the denominator is the total area, taking into account roads, public open space and amenities). Differences produced from these approaches to measuring density could be the subject of further research.

Whilst results from linear models for quantitative behavioral outcomes (such as minutes of recreational walking) provide an estimate of the absolute effect of an exposure measure on a behavior, many of the RESIDE results are from logistic models for binary behavioral outcomes (such as yes/no for doing any walking for recreation in a neighborhood), providing an odds ratio which is an estimate of the relative effect of an exposure measure on the prevalence (odds) of a behaviour. Odds ratios can be converted into an estimate of the absolute effect of the exposure using the prevalence of the behaviour. For example, if the prevalence of recreational walking is around 50%, an odds ratio of 1.5 for the association of a binary (i.e. presence vs absence) design feature in relation to recreational walking corresponds to an increase of 45%–55% (i.e. a 10% absolute increase) in recreational walking for the presence vs absence of that design feature.

The protracted nature of planning and development processes and the provision of community infrastructure, particularly for large regional-scaled or master-planned developments, poses challenges for natural experiments as researchers have no control over the timelines and must wait for the development to unfold to measure and examine the exposure and behavioral outcomes of interest. For example, there was a housing development boom in Perth when RESIDE commenced. During this period there was a shortage of bricks, and this delayed the completion of homes and study participants' relocation to their new neighborhoods. This is a study limitation over which research teams have no control and highlights the need for funders of natural experiments to be flexible in order to accommodate unanticipated changes that arise, and for there to be flexibility in the planning of follow-up phases. However, the full implementation of the intervention is also beyond the control of researchers. Our process evaluation of the implementation of LN design features revealed that *none* of the developments (including LN developments) had implemented the full suite of policy requirements (Knuiman, Christian et al., 2014). This highlights the importance of collecting tailored measures of policy implementation to help explain why interventions do (or don't) work.

Finally, the purpose of this paper was to assess the consistency and direction of findings across the totality of RESIDE research evaluating the LN policy, as an indication of the potential benefits (or otherwise) of a major urban development policy on health-supportive behaviors and wellbeing, and to provide policy-makers with a comprehensive

overview of outcomes (to date) following trial implementation of the LN policy. The results of our assessment should be interpreted with care, as the synthesis is based on findings from a single project and study population, in contrast with a systematic review of findings across different studies and populations. Our findings were however consistent with the broader international literature, including a number of recent systematic reviews on the topic that found similar findings in a variety of countries, cultures and population and demographic groups (Casa-grande, Whitt-Glover, Lancaster, Odoms-Young, & Gary, 2009; Clark, 2007; Ferdinand, Sen, Rahrurkar, Engler, & Menachemi, 2012; Kärmeniemi et al., 2018; Renalds, Smith, & Hale, 2010; Smith, Hosking et al., 2017) and a systematic review of naturally occurring experiments (Mayne et al., 2015). Traditional observational studies are largely unable to assess health behavior-related impacts from new policy implementation. Thus, a key advantage of natural experiment studies, such as the RESIDE study and analyses summarized here, is the ability to focus on policy-relevant changes and real-world efficacy (Mayne et al., 2015). More natural experiment studies are needed to strengthen the evidence-base and also explore to whether timing of exposure and/or longer and repeat exposures enhances or reduces impacts on positive health-related outcomes.

5. Conclusions

Despite incomplete and uneven implementation of the LN policy principles, there were substantial positive and significant findings observed between the neighborhood environments and a range of health and wellbeing outcomes. The consistency of RESIDE's results suggest that residents living in neighborhoods that incorporate liveable urban design features appear to have better health-supportive behavior and wellbeing outcomes, principally by encouraging more local walking but also by enhancing sense of community, feelings of safety, and mental health. Nevertheless, policy is only as good as its implementation and RESIDE's process evaluation showed that the effectiveness of the LN policy was limited by its incomplete implementation. Creating truly livable communities that promote health requires greater focus on ensuring that good design elements are fully implemented in a timely manner, combined with integrated regional planning that ensures access to employment and public transport, and the early provision of social infrastructure. This highlights the value of assessing the level of policy implementation in future studies evaluating policy, and the need for greater emphasis in policy-making on strategies to enhance (and monitor) policy implementation.

A number of urban design features were found to be consistently associated with walking, sense of community, and safety-related outcomes, which was consistent with international literature. Potentially, rather than being guidelines, these design features could be mandatory requirements in future suburban design policies. Moreover, specific urban design requirements identified in the LN policy itself could be trialled in other countries and contexts as a starting point for policy-relevant research that could inform future evidence-based urban design policy.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ssmph.2020.100538>.

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