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http://hdl.handle.net/11187/2187

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Activity-Friendly Built Environment Attributes and Adult Adiposity

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Abstract

Physically-active and sedentary behaviors are determinants of adult weight gain and are associated with built-environment attributes. We reviewed recent evidence on built-environment attributes with adult adiposity. Of 41 relevant papers identified, 34 reported cross-sectional, six recorded prospective findings, and one included both cross-sectional and prospective designs. In 15 cross-sectional examinations of composite built environment indices (walkability; composite other), seven identified significant positive relationships in the expected direction; of 42 instances examining particular walkability elements (density, connectivity, land use mix), 13 were positive. Of 44 instances examining proximity of utilitarian and recreational destinations, there were 13 positive associations; and, of 41 instances examining pedestrian-environment attributes, 12 were positive. In the seven prospective studies, 20 sets of relationships were identified – nine were significant and in the expected direction. Evidence on built environment/adiposity relationships remains modest and could be strengthened through improvements in measurement methods and with further evidence from prospective studies.

Keywords: body mass index · waist circumference · built environment · walkability · pedestrian infrastructure · aesthetics · safety · recreational facilities · parks · population density · destinations · street connectivity · land use mix · urban design · physical activity · walking · sedentary behavior · sitting · cross-sectional study · prospective study
Introduction

Excess adiposity is a highly-prevalent human phenotype in the adult populations of industrialized and developing countries. Overweight and obesity are associated adversely with biomarkers of risk for the major chronic diseases – type 2 diabetes, cardiovascular disease, and breast and colon cancer; and, with premature mortality from these and other diseases [1]. The key determinant of high rates of overweight and obesity in adult populations is chronic positive energy balance – an excessive and sustained higher energy intake in the context of lower energy expenditure [1]. In this review paper, we focus on evidence that might provide insights into how to change a potentially-modifiable determinant of high rates of excess adult adiposity – energy expenditure, as is influenced by lack of physical activity and sedentary behavior (too much sitting).

Physical activity and sedentary behavior: a key distinction

In addition to physical activity – typically moderate-to-vigorous activity (MVPA; for example, walking, running, bicycling) – which has been a predominant concern for studies on energy expenditure and health [2], there is now an additional agenda to address sedentary behavior. This emphasis has been stimulated in part by findings from population studies using accelerometers, which show that many adults can spend 10 or more hours of their day in sedentary behaviors [3, 4]. High volumes of time spent sitting can play a significant role in low energy expenditure. MVPA typically requires an energy expenditure of 3 to 8 METs (metabolic equivalents; put simply, multiples of the basal metabolic rate or resting energy expenditure). However, the findings from population studies using objective measurement indicate that MVPA accounts for only modest amounts of energy expenditure for a high proportion of the adult population [5].
Sitting time is ubiquitous through automobile commuting, office-based work and through watching television and engaging in other forms of sitting in domestic environment and during leisure time [6, 7]. When adults sit, they can spend long periods of time in the energy-expenditure range of 1.0 to 1.5 METs. A simple comparison of the contributions of MVPA and sitting time to energy expenditure during waking hours is informative [8]: For example, if two hours of the daily sitting time of a typical adult were to be replaced by two hours of light-intensity activity (involving energy expenditure of about 2.5 METs), this reduction in sitting would be an increase in energy expenditure somewhat greater than that associated with doing 30 min of walking (involving about 3.5 METs). Another way to look at this would be to consider that two additional hours of sitting each day could negate the energy expenditure achieved by meeting the 30 min per day physical activity and health recommendation on MVPA [9].

Population-health strategy, primary prevention, and the built environment

Our concern here is, however, not to address the links of the built environment with physical activity and sedentary behavior. These environment/behavior links and associated conceptual and methodological issues have been addressed elsewhere in review papers [10, 11●●]. Here, our purpose is to review recent research findings that can help to identify potential links of environmental attributes with adult adiposity – the mediation of environment/adiposity relationship through physical activity and sedentary behavior is a further research agenda and beyond the scope of our present review. Documenting and synthesizing the evidence on environment/adiposity relationship is one key element of the evidence required to inform the primary prevention of overweight and obesity. Our perspective follows the logic of Geoffrey Rose and focusing on unhealthy populations rather than unhealthy individuals – that is, shifting the population-distribution for adiposity to the left [12]. Broad-reaching and sustainable changes that can influence a high proportion of the total population will require
environmental and policy initiatives. Such initiatives would focus on attributes of the built environment – defined as “the human-made space in which people live, work, and recreate on a day-to-day basis” [13], and it includes “homes, schools, workplaces, parks/recreation areas, greenways, business areas and transportation systems” [14].

**Ecological models: a focus on environments**

An ecological model of health behavior [15, 16] has been a key guiding framework for the relevant studies. Ecological models specify multiple levels of factors that act as determinants of health-related behaviors, including individual-level factors such as beliefs, intentions and biological attributes, social influences from peers, families or workplaces, and environmental factors such as street networks, access to destinations, and neighborhood amenities. Ecological models focus particularly on ‘behavior settings’—aspects of environments in which people spend significant portions of their time, which can promote certain behaviors and discourage others [16]. Ecological models have been applied more recently to understanding the environmental influences on sedentary behaviors [7]. Within an ecological framework, the built environment would be postulated to influence residents’ adiposity through two distinct health behaviors: physical activity and sedentary behavior. Compare, for example, residents of suburban residential developments to those who live in dense, mixed-use inner-city neighborhoods. Those living in the suburbs would spend long periods of time sitting in cars (to commute, for recreational excursions and for errands). The inner-urban residents would have more active-transportation options, including walking or bicycling to get to and from places. Considering sedentary behaviors, it is likely to be the case that where there are fewer local amenities within walking distance, including parks, it is more likely that residents will spend more time indoors and more time watching television [17, 18].
Environmental attributes hypothesized to be important as determinants of active and sedentary time have been identified through interdisciplinary research initiatives involving public health, epidemiological, behavioral and transport and urban design researchers. There has been a sustained program of research particularly through the *Active Living Research* program supported by the Robert Wood Johnson Foundation [19] – which includes studies on environmental attributes conducive to physical activity and that can support lifestyles less likely to lead to overweight and obesity. Multi-country environment/physical activity research initiatives are also in progress through the *International Physical Activity and the Environment* (IPEN) project [20]. Initial multi-country evidence is now available, supporting the hypothesis that neighborhood environmental attributes appear to have a significant role in physical activity [21, 18, 22].

**Neighborhood walkability: a key built-environmental construct**

The *neighborhood walkability* construct has been a key idea in understanding environment/physical activity relationships [23, 24]. Neighbourhood walkability is determined mainly by proximity and connectivity. Proximity involves mixed land uses with shorter distances between residences and destinations such as stores or work places. Connectivity relates to variety of routes to destinations and their directness; this is usually associated with grid patterns of interconnecting streets. These components of walkability often occur together and it is argued that they have synergistic influences, reducing distances between complementary activities [25]. Walkability attributes may be assessed objectively using Geographic Information System methodologies [26]. However, although objective-measurement approaches provide power and precision, there is also an important role in this research agenda for understanding how environmental attributes are perceived. Studies among Australian adults have identified, for example, significant associations of high neighborhood walkability with more walking for transport [25] and with less sitting in cars.
during leisure time [27]. A significant advance for the field has been the development of the *Neighborhood Environment Walkability Scale* (NEWS) instrument [28], which was developed in the USA and has been validated for use in other countries [29●●]. Concordance and mismatch between objectively-measured and perceived environmental attributes can impact on physical activity behavior and of weight gain. For example, adults who perceived their high-walkable neighborhoods to be low-walkable gained a significant amount more weight over a four-year period and were those whose perceptions of their neighborhoods were concordant with the actual high-walkability attributes [30●].

*Context and aims of this review*

Evidence on the relationships of activity-friendly built-environment attributes with adult adiposity can help to fine-tune and add impetus to environmental and policy initiatives for the prevention of overweight and obesity, particularly in concert with evidence on food-environment/obesity relationships [31]. Previous reviews on environment/adiposity relationships [32, 33] have covered evidence up to late 2009. We conducted a systematic literature review to identify peer-reviewed, English-language research papers reporting evidence on relationships of activity-friendly built environment attributes with indices of adiposity in adults, published since January 2010.

*Method*

*Database search strategy.* A literature search was conducted in October 2013 with PubMed, Web of Science, and Google Scholar using three sets of search terms: environmental attributes (environment, walkability, urban, neighborhood, public open space, green space, park, or transport), physical activity and sedentary behavior (physical activity, walking, active living, sitting, sedentary, television viewing, screen time), and obesity (overweight, obesity, obese, adiposity, weight, body mass index).
**Inclusion and exclusion criteria.** Empirical studies that examined associations of adults’ obesity with built environment attributes were included in this study. Excluded studies were those focusing on food environments and those targeting children and adolescents. The searches were limited to peer-reviewed, English-language publications since January 2010.

**Data extraction.** Information extracted included study locations, sample size, study design, adiposity measures, environmental attributes, measurement methods for outcome and exposure variables (objective or self-report measures), results, and covariates. All articles were screened independently by two authors (MJK and SM).

Results were coded into “significant association in an expected direction”, “mixed association”, “non-significant association”, and “significant association in an unexpected direction”. “Mixed” associations apply to a situation where significant associations were reported only for subsamples. Only the results of models adjusted for socio-demographic variables were reported when a study showed both unadjusted and adjusted models.

**Results**

Overall, 41 articles were identified for this review (Appendices A and B). Of these, 34 were cross-sectional [34-67], and six were prospective studies [68-73]. One study also included both cross-sectional and prospective studies [74]. The majority of studies (n = 23) were conducted in the USA [34-37, 39, 45-47●, 49, 50, 52-54, 58, 60, 63, 65-71, 73], and this included five of the prospective studies [68-71, 73]. The remainder of studies were conducted in Canada (n = 4, including 1 prospective) [74, 59, 61, 62], the United Kingdom (n = 4, including 1 prospective) [38, 42, 43, 72], Australia (n= 2) [41●, 57], France (n=2) [40, 51], Brazil (n = 1) [48], Egypt (n = 1) [55], Belgium (n=1) [64] and Nigeria (n = 1) [56]. Most studies sampled the general adult population (n = 32), with the remainder examining specific populations such as middle-aged adults (n = 1) [40], older adults (n = 3) [44, 46, 50], men (n
The outcome measures used for cross-sectional studies were BMI (continuous) and/or being overweight or obese (categorical). The definitions of overweight or obese were consistent across the studies reviewed, with overweight being defined as $25 \leq BMI < 30 \text{ kg/m}^2$, and obesity as $BMI \geq 30 \text{ kg/m}^2$. Two studies included waist circumference or waist-to-height ratio as outcome measures [51, 64]. The outcome measures for prospective studies were change in BMI, incidence of obesity, or weight-related change indices. Just over half of the studies ($n = 22$) used only self-reported outcome measures [34, 35, 74, 36, 41-43, 45, 46, 48-50, 53, 54, 57, 59, 61, 62, 65, 69, 70, 73], and one study used a combination of objectively measured and self-reported BMI [44].

The measures of the built environment were more varied. A broad range of environmental attributes were used in the studies. They were classified into four major categories: composite indices; walkability component; destination; and pedestrian environment. The composite category included walkability, and other combined indices. The walkability components were density, connectivity, and land use mix. The destination-related items included utilitarian destinations, transit stops, recreational facilities, and park attributes (access, size, and quality). The pedestrian environment category included pedestrian infrastructure, safety from traffic, safety from crime, aesthetics, and greenness. There was variation in whether the built environment measures were determined objectively (Geographic Information Systems or audit) or using participants’ perceptions. Most studies used only objective measures of the built environment ($n = 33$), six studies used only perceived measures [34, 35, 44, 45, 56, 60], and two studies included both objective and perceived measures [41, 51].
In Tables 1 and 2, the summary categories of environmental attributes are based on the environmental-attribute measures described in column 4 of Appendix A and Appendix B. The applicable summary categories for each of the environmental exposure measures showed in the Appendices are identified in square brackets. Since many of the studies reviewed have reported multiple findings on environment/adiposity relationships and because how these relationships were examined varied from study to study, we refer in our reporting with or to ‘instances’ of such relationships being examined or to particular ‘findings’ – rather than to ‘studies’.

**Cross-sectional study findings**

Tables 1 summarizes the findings for the cross-sectional studies.

_____________________________

**Composite indices**

Almost half of the instances where the cross-sectional association of adiposity with composite environmental measures were examined found significant associations in an expected direction. Several indices consisting of a range of attributes such as distance to city center, residential density, walking infrastructure, and recreational facilities were associated with lower levels of adiposity in 5 out of 8 instances examining this construct [47●, 49, 53, 60]. However, more than 70% of the instances examining walkability reported non-significant associations between walkability and adiposity measures.

**Walkability components**
Of the cross-sectional findings on associations between adiposity and walkability components, 30% reported significant associations in an expected direction [38, 44, 51, 57, 59, 65, 66]. Land use mix was the most consistently associated with obesity (4 out of 9 studies) [44, 57, 59, 36].

**Destinations**

Only 30% of the instances of associations found significant associations between adiposity and destination-related measures [35, 36, 46, 48, 51, 52, 54, 56, 58, 63, 66]. However, the access to utilitarian destinations was consistently associated with obesity with 5 out of 7 instances reporting significant associations in an expected direction [51, 52, 56, 58]. Although a larger number of studies have examined how neighbourhood recreational facilities, in particular parks, are related to residents’ obesity, significant associations were found only in 20% of the instances examined [35, 36, 48, 54, 61-63, 66].

**Pedestrian environments**

Cross-sectional studies examining the association between pedestrian environmental attributes and adiposity found generally low levels of significant associations [36, 44, 52, 56, 60-62]. Aesthetics (44%) and safety from traffic (40%) were relatively consistently associated with adiposity in an expected direction [41, 56, 60, 51]. But, studies have found in some instances, safety from crime, aesthetics, and greenness to be positively associated with obesity-related measures (unexpected direction) [43, 51, 52, 62].

**Prospective study findings**

Tables 2 summarizes the findings for the prospective studies.
Composite indices

A composite measure other than walkability was considered in two prospective-study instances, and in both instances this attribute was significantly associated with adiposity in an expected direction [70●]. Walkability was only assessed in one prospective study and no significant association was found [74].

Walkability components

Walkability components were assessed in eight instances in the prospective studies. Non-significant association with obesity was reported in most of the instances (75%) [71, 72]. One study reported a significant association between density and adiposity in an expected direction [73], while another study reported a significant association between land use mix and adiposity in an unexpected direction [72].

Destinations

Of eight instances where destination-related attributes were examined in prospective studies, over 60% of the instances reported a significant association with adiposity in an expected direction. [69, 72]. All of these instances were for utilitarian destinations or recreational facilities. Transit stops and park attributes were examined once each and no significant association was found in either case [72].

Pedestrian environments

Pedestrian infrastructure was assessed once in a prospective study. A significant association in an expected direction was found between safety from traffic and adiposity [74].
Discussion

This review examined recent studies (published since 2010) on the relationships of environmental attributes with adult adiposity. Most of the studies identified were cross-sectional, but the presence of several prospective studies indicates that research in this area is moving toward obtaining scientifically stronger evidence on the impact of environments on adult adiposity. The majority of the studies (about three quarters) were conducted in North America, but studies from South American and African countries were also found, suggesting that the environment-health relationships are also receiving attention in developing countries.

Overall, the environmental attributes investigated in the studies reviewed were not consistently associated with adiposity measures. Of the relationships examined in the studies, 32% of the cross-sectional findings and 45% of the prospective findings were significant in an expected direction. However, the four categories used to classify environmental attributes showed different levels of association with adiposity. In cross-sectional studies, almost half (47%) of the findings were significant for composite environmental indices, but around 30% of them were significant in the other categories focusing on individual environmental attributes. (The number for prospective studies may be too small to compare these different categories.) This suggests that a combination of multiple environmental factors may be more relevant to adult residents’ adiposity levels than are single environmental attributes such as individual walkability components, destinations, and pedestrian environments. Energy expenditure, one side of the energy balance equation, involves a range of behaviors, including physical activity and sedentary behavior for transport and during leisure time. Although this review did not examine behavioral mechanisms through which the environment impacts on obesity, it can be argued that indices involving multiple environmental factors are relevant to obesity because of their potential to capture several expenditure-related behaviors [75]. In other words, a single environmental attribute, which may be related to a particular single
behavior within a broad spectrum of daily behaviors, may not be enough to have a bearing on residents’ weight status.

Within the studies using composite indices, walkability index, which is known to be associated with walking [25, 76] was found to be mostly unrelated to obesity measures both cross-sectionally and prospectively. Instead, a stronger cross-sectional and prospective association was observed for other composite indices. Such composite measures associated cross-sectionally with adiposity included a sprawl index, which is a combination of residential density and block size [49], a measure consisting of attributes such as aesthetics, recreational facilities, pedestrian infrastructure, and traffic volume [60], the combination of the period when a suburb was developed and commuting time [47●], and distance to a central business district of an urban area (which is likely to be a proxy indicator of many potentially relevant measures, such as density and access to utilitarian destinations) [53]. Another composite measure consisting of pedestrian infrastructure, access to transit stops, connectivity, and residential density was prospectively associated with weight gain and incidence of obesity [70●].

In addition to the composite measures, significant findings were observed consistently for utilitarian destinations. For cross-sectional relationships, availability of shops and services was associated with lower BMI or lower odds of obesity in more than 70% of the instances examined. Two out of three prospective findings also showed the density of non-residential destinations to be associated with less weight gain. Although the presence of transit stops was not closely related to obesity-related measures, which may be partly due to not considering service factors (e.g., service routes, frequency), lack of local destinations appears to be a factor contributing to adult obesity levels.
These findings suggest that both local (neighborhood level) and larger scale environments (city level) may be relevant to adults’ obesity. These two settings are related to two distinct daily behaviors: local shopping/errands and commuting. It is possible to hypothesize that adults living in activity-friendly neighborhoods (with many accessible destinations) that are located in a vicinity of a central business district are less likely to be obese because of their participation in more physical activity and less sitting (for driving) for multiple purposes. As discussed in the Introduction, ecological models advocate approaches addressing multiple influences (individual, social, and environmental) on physical activity. The same principle may apply within the scope of environments. In order to address obesity through environmental initiatives, neighborhood environments may have to facilitate active living in multiple ways.

The recommended best practice of reporting results at a variety of geographical scales when measuring the built environment for physical activity remains to be addressed in this research field [24●●], as none of the 41 studies reported findings at more than one scale. The scale and neighborhood definition used to measure the built environment can determine whether or not associations are found. Different scales are likely to be appropriate for different built environment measures.

Individual walkability components, such as residential density, connectivity, and land use mix, were not closely associated with obesity, particularly in prospective studies. Each of these attributes was found associated with walking behaviors in existing studies [77, 78]. Similarly, pedestrian environmental attributes were found not strongly associated with obesity measures. An earlier review found that these route-related attributes were also not closely related to walking behaviors [11●●]. It is possible that the amount or frequency of physical activity facilitated by each of these attributes may not be enough to influence adiposity levels.
It was found that the availability of recreational destinations and park attributes (including quality of local parks) was not closely associated with obesity in cross-sectional studies, but the former was associated prospectively with obesity measures. These findings are difficult to interpret, but there are potential explanations. On one hand, it is possible that the use of recreational facilities is a discretionary activity unlike shopping and commuting, thus the simple presence of such facilities may not have large impact on residents’ adiposity levels. On the other hand, once individuals have established a habit of leisure-time physical activity using recreational facilities, it has a potential to influence their weight status. The presence of facilities may be essential to maintain recreational physical activity. This inconsistency in the findings of recreational facilities warrants further investigation.

Based on the findings of this review, transport-related physical activity, such as walking or cycling for shopping and for commuting, is a primary target behavior that needs to be considered in future environmental interventions to reduce obesity. As discussed above, access to utilitarian destinations and composite environmental measures, which include attributes relevant to commuting, were related to obesity. Given that recreational facilities and parks that would facilitate leisure-time physical activity were not associated (at least in cross-sectional studies), with obesity increasing physical activity for transport through environmental initiatives seems to be a promising strategy to reduce the prevalence of overweight and obesity. Targeting transport-related physical activity, in particular active commuting is potentially effective as this can happen daily for a substantial period of time. Long-term habitual physical activity is known to have impact on health outcomes including obesity [79, 80]. In addition, walking and cycling for transport would replace sitting in a car, which is one of the major components of daily sedentary behavior. Since prolonged sitting is independently associated with obesity, facilitating active modes of transport is expected to have additional effect from reduced sitting time.
Recommendations for future research

- Examine to what extent the accumulation of activity-friendly attributes has impact on adiposity. The number of positive environmental attributes has been found to be linearly associated with the odds of meeting physical activity guidelines [75].

- Understand behavioral mechanisms between environment and obesity: more specifically, examine which domain of physical activity (for transport; for recreation) account for larger effect on obesity.

- Transit-oriented development (TOD) [81] appears to fit the description of environments that can be developed to help to reduce obesity. Prospective and quasi-experimental studies of such developments would be highly informative.

- Understand interactions between interventions to reduce obesity (focusing on individuals) and environmental factors: How community-level interventions work may depend on neighborhood environments. Research can examine effect modification of interventions by environmental attributes.

- Research on occupational environments, where a large amount of sitting can take place, would be highly informative. Future research could examine if spatial and functional aspects of office environments are associated with workers’ obesity.

Conclusions

Neighborhood built-environment attributes that are conducive to active living in multiple ways have the potential to influence obesity levels. However, the relevant supportive evidence is as yet modest. Walking and cycling for transport, once established as habitual, can be an “automatic” behavior that does not involve conscious reflection, as is the case for habitual behaviors involving sitting. In order to influence such automatic, environmentally-
triggered behaviors that are conducive to overweight and obesity, activity-friendly built-environment initiatives are likely to be an effective approach, with the potential for large-scale, population wide impact [82].

**Acknowledgments**

Koohsari is supported by a National Health and Medical Research Council of Australia (NHMRC) Program Grant [#569940] and by the Victorian Government’s Operational Infrastructure Support Program. Owen is supported by a NHMRC Program Grant [#569940], a Senior Principal Research Fellowship [NHMRC #1003960] and the Victorian Government’s Operational Infrastructure Support Program. Mavoa is supported by Community Indicators Victoria, which is funded by VicHealth.
References

Papers of particular interest, published recently, have been highlighted as:

● Of importance

●● Of major importance


This paper provides a comprehensive perspective and guidelines on the use of methodologically sound and practically relevant methods to characterize built-environment attributes associated with physical activity.


30. Gebel K, Bauman AE, Sugiyama T, Owen N. Mismatch between perceived and objectively assessed neighborhood walkability attributes: prospective relationships with walking and weight gain. Health Place. 2011;17(2):519-24. This study provides evidence that adults who live in neighborhoods that are objectively determined to be high-walkable but good to see their neighborhoods as low walkable become less active and gain more weight over the subsequent four years.


This study provides evidence from a unique Australian built-environment and health study on the interactions of built environment attributes with the social environment and other health behaviors as these can influence adult adiposity.


This study provides evidence that residents of urban areas with higher population density and with older, more traditional styles of housing developments have more-favorable indices of objectively-measured fitness and adiposity.


    Large-scale prospective study with some 18,000 African-American women, showing that the risks of weight gain and obesity are higher for residents of rural and low-density suburban neighbourhoods.


### Tables

Table 1. Built-environment attributes and adult adiposity: summary of findings from cross-sectional studies

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<th>Significant Unexpected</th>
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Table 2. Built-environment attributes and adult adiposity: summary of findings from prospective studies

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## Appendices

### Appendix A. Built-environment attributes and adult adiposity: characteristics and findings of cross-sectional studies

<table>
<thead>
<tr>
<th>Lead author</th>
<th>Country</th>
<th>Sample</th>
<th>Outcome measures</th>
<th>[categories relating to Tables 1 and 2] Exposure measure</th>
<th>Results</th>
<th>Covariates</th>
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<tbody>
<tr>
<td>Adams (2011) USA [34]</td>
<td>2199 adults (20-65 yrs)</td>
<td>BMI (R)</td>
<td>[Composite other] a combined category of walkability and access to recreational facilities (P)</td>
<td>N</td>
<td>SD-I, time at current address</td>
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<tr>
<td>Brown (2013) USA [37]</td>
<td>3,528 adults (25-64 yrs)</td>
<td>1. BMI (O) 2. Obesity (O)</td>
<td>[Density] population density (O)</td>
<td>1. N 2. N</td>
<td>SD-I, HB, Average caloric intake, Hours of accelerometer wear, Location</td>
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<tr>
<td>Study</td>
<td>Sample Size</td>
<td>Study Population</td>
<td>Environment and Neighbourhood Attributes</td>
<td>Mix</td>
<td>SD-I, HS</td>
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<tr>
<td>Casagrande (2011) USA [39]</td>
<td>3,493 adults (30-64 yrs)</td>
<td>Obesity (O)</td>
<td>[Pedestrian infrastructure] pedestrian walking environment (O)</td>
<td>Mix</td>
<td>SD-I, HS</td>
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<tr>
<td>Charreire (2012) France [40]</td>
<td>1,309 middle-aged adults</td>
<td>BMI (O)</td>
<td>[Composite other] built environment patterns based on green spaces, proximity of facilities (destinations) and cycle paths (O)</td>
<td>N</td>
<td>SD-I</td>
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</table>
| Christian (2011) Australia [41●] | 1,151 adults (mean age=40) | BMI (R) | a. [Walkability] neighbourhood walkability (O)  
b. [Density] residential density (O)  
c. [Connectivity] street connectivity (O)  
d. [Land use mix] land use mix (O)  
e. [Greenness] greenness index (O)  
f. [Recreational facilities] physical activity destinations (O)  
g. [Utilitarian destinations] land use mix-access (P)  
h. [Aesthetics] aesthetics (P)  
i. [Pedestrian infrastructure] walking infrastructure (P)  
j. [Connectivity] street connectivity (P)  
k. [Safety from traffic] pedestrian/traffic safety (P)  
l. [Aesthetics] graffiti and vandalism (P)  
m. [Recreational facilities] physical activity destinations (P)  
n. [Safety from crime] safety from crime (P)  
a. N  
b. N  
c. N  
d. N  
e. N  
f. N  
g. N  
h. N  
i. N  
j. N  
k. –S  
l. –S  
m. N  
n. –S  | SD-I,PA, Sedentary leisure time, Diet |
<p>| Coombes (2010) UK [42]     | 6,821 adults (&gt;16 yrs) | Overweight or Obese (R) | [Park attribute] distance to formal green space (O) | N  | SD-I, SD-A, HS, neighbourhood variables associated with |</p>
<table>
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<tr>
<th>Study</th>
<th>Country</th>
<th>Sample Size</th>
<th>Outcome</th>
<th>Factors</th>
<th>SDI-I, SDI-A,</th>
<th>Functional Characteristics</th>
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<tr>
<td>Fish (2010) USA [45]</td>
<td>2,255 adults (&gt;=18 yrs, mean age=39.6)</td>
<td>BMI (R)</td>
<td>[Safety from crime] neighbourhood safety (P)</td>
<td>–S</td>
<td>SD-I,SD-A, HS, HB</td>
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<tr>
<td>Hoehner (2011) USA [47●]</td>
<td>16,543 adults (18-90 yrs)</td>
<td>BMI (O)</td>
<td>a. [Density] high density factor (population and housing unit density) (O) b. [Composite other] traditional core factor (older homes and residents with shorter commute times) (O)</td>
<td>a. Mix b. –S</td>
<td>SD-I, PA, Cardiorespiratory fitness</td>
<td></td>
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<tr>
<td>Jaime (2011) Brazil [48]</td>
<td>2,122 adults (&gt;= 18 yrs)</td>
<td>Overweight (R)</td>
<td>a. [Recreational facilities] density of parks and public sports facilities (O) b. [Transit stops] accessibility of public transport system (O)</td>
<td>a. –S b. N</td>
<td>SD-A</td>
<td></td>
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<tr>
<td>James (2013)</td>
<td>136,592 adults</td>
<td>BMI (R)</td>
<td>[Composite other] county sprawl index (higher county sprawl index values indicate a more)</td>
<td>–S</td>
<td>SD-I, HB, Location</td>
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<tr>
<td>Study</td>
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<td>Sample Description</td>
<td>Outcome Measure</td>
<td>Study Details</td>
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<tr>
<td>King (2011)</td>
<td>USA</td>
<td>719 older adults (+66 yrs)</td>
<td>BMI (R) [Walkability] neighbourhood walkability (O)</td>
<td>-S Location, Length of time at current address</td>
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<tr>
<td>Leal (2012)</td>
<td>France</td>
<td>7,230 adults (30-79 years) for BMI</td>
<td>1. BMI (O) 2. Waist circumference (O)</td>
<td>a. [Density] population density (O) b. [Density] proportion of built surface (O) c. [Density] mean building height (O) d. [Connectivity] connectivity (O) e. [Connectivity] street density (O) f. [Park area] proportion of area with parks (O) g. [Aesthetics] neighbourhood deterioration (P) h. [Composite other] active living potential (P) i. [Recreational facilities] no. of sports facilities (O) j. [Utilitarian destinations] number of basic services (O)</td>
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<tr>
<td>Lovasi (2012)</td>
<td>USA</td>
<td>13,102 adults (30+ years)</td>
<td>BMI (O)</td>
<td>a. [Utilitarian destinations] presence of a sidewalk cafe (O) b. [Greenness] street tree density (O) c. [Aesthetics] % of streets rated acceptably clean (O) d. [Safety from crime] homicide rate (O) e. [Safety from traffic] pedestrian-</td>
<td>-S SD-I, SD-A, Walkability of the 1-km buffer</td>
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Legend:
- SD-I, SD-A, PA, Diet
- N
- S
- +S
<table>
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<th>Study</th>
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<td>USA [54]</td>
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<td>Egypt [55]</td>
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<td>SD-I, SD-A, HS</td>
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<td>Nigeria [56]</td>
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<td>SD-I, Location</td>
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</table>
| Pereira (2013)                          | Australia     | 10,208 adults (16+ years)          | Overweight or obese (R)       | a. [Greenness] mean greenness (NDVI) (O)  
   b. [Land use mix] variation in greenness (NDVI) (O) | –S         | -S                           | SD-I                                           |                          |
|                                          |               |                                    |                                |                                              |           |                |                    |                          |
| Pitts (2012)                            | USA           | 197 adult females                  | BMI (O)                        | [Utilitarian destinations] walkScore (O)                                                   | –S         | SD-I                        |                          |                          |
|                                          |               |                                    |                                |                                              |           |                |                    |                          |
| Poulou (2010)                           | Canada        | Study 1: 3,787,244 adults (20+ years) |
|                                          |               | Study 2: 1,630,974 adults (20+ years) | BMI (R)                        | a. [Land use mix] land-use mix (O)  
   b. [Density] residential density (O)  
   c. [Connectivity] street connectivity (O)  
   d. [Walkability] walkability index (O) | –S         | SD-I                        | SD-I, HS, HB, Social |                          |
|                                          |               |                                    |                                |                                              |           |                |                    |                          |
| Powell-Wiley (2013)                     | USA           | 5,907 adults (18-65 years)         | Obesity (O)                    | a. [Aesthetics] favourable neighbourhood perception (P)  
   b. [Safety from crime] neighbourhood violence (P)  
   c. [Composite other] physical environment (litter, lack of recreation areas, food shops, sidewalks, noise, traffic) (P) | –S         | SD-I                        | SD-I, time in neighbourhood |                          |
|                                          |               |                                    |                                |                                              |           |                |                    |                          |
| Prince (2011)                           | Canada        | 3,883 adults (18+ years)           | Overweight or obese (R)        | a. [Pedestrian infrastructure] total bike and walk path length (O)  
   b. [Recreational facilities] indoor recreation facilities per 1,000 people (O)  
   c. [Recreational facilities] winter outdoor recreation facilities per 1,000 people (O)  
   d. [Recreational facilities] summer outdoor recreation facilities per 1,000 people (O)  
   e. [Park attribute] park area (O)  
   f. [Park attribute] area of green space (O) | –S         | SD-I, HB, Diet               | SD-I, HB, Season                         |                          |
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<th>Study</th>
<th>Sample Size</th>
<th>Measures</th>
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<td>Prince (2012) Canada</td>
<td>4,727 adults (18+ years)</td>
<td>BMI (R) a. [Pedestrian infrastructure] total bike and walk path length (O) b. [Recreational facilities] indoor recreation facilities per 1,000 people (O) c. [Recreational facilities] winter outdoor recreation facilities per 1,000 people (O) d. [Recreational facilities] summer outdoor recreation facilities per 1,000 people (O) e. [Park attribute] park area (O) f. [Park attribute] area of green space (O) g. [Safety from crime] crime rates (O)</td>
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<td>Rundle (2013) USA</td>
<td>13,102 adults</td>
<td>BMI (O) a. [Park attribute] proportion of neighbourhood as park (O) b. [Park attribute] proportion of neighbourhood as large park (O) c. [Park attribute] proportion of neighbourhood as small park (O) d. [Park attribute] park cleanliness (O) e. [Park attribute] number of park recreational facilities (O) f. [Park attribute] number of types of park recreational facilities (O)</td>
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<td>Van Dyck (2010) Belgium</td>
<td>1200 adults (20-65 years)</td>
<td>1. BMI (R) 2. Waist-to-height ratio (O) [Walkability] walkability index (O) 1. N 2. N</td>
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<td>Wang (2013) USA</td>
<td>251,247 adults (18+ years)</td>
<td>Obesity (R) a. [Connectivity] street connectivity (O) b. [Connectivity] population-adjusted street connectivity (O) a. N b. –S</td>
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<td>Wen (2012) USA</td>
<td>9,739 adults (20-64 years)</td>
<td>Obesity (O) a. [Density] population density (O) b. [Connectivity] street connectivity (O) c. [Park attribute] distance to a. –S b. –S e. +S</td>
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</table>
| Wen (2011) USA [67] | 735,975 adults (25-64 years) | Obesity (O) | a. [Greenness] greenness (O)  
b. [Park attribute] access to parks (O) | a. –S  
b. N | SD-I, SDI-A, residential isolation (area-level), immigration (area-level) |

R, reported; O, objectively-measured; M, partly reported and partly objectively-measured; P, perceived; –S, negative association; +S, positive association; N, non-significant; Mix, significant positive or negative association only in subgroups; SD-I, socio-demographic (individual level); SD-A, socio-demographic (area level) PA, physical activity; HB, health behaviors other than physical activity and diet; HS, health status
Appendix B. Built-environment attributes and adult adiposity: characteristics and findings of longitudinal studies

<table>
<thead>
<tr>
<th>Lead author, Country [reference citation]</th>
<th>Sample</th>
<th>Outcome measures</th>
<th>[categories relating to Tables 1 and 2] Exposure measures</th>
<th>Results</th>
<th>Covariates</th>
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</thead>
<tbody>
<tr>
<td>Auchincloss (2013) USA [68]</td>
<td>4,008 adults (45-84 yrs)</td>
<td>Change in obesity (O)</td>
<td>[Composite other] walking environment (pleasant and easy to walk places) (P)</td>
<td>N</td>
<td>SD-I, PA, Diet, HB, Baseline BMI</td>
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</table>
| Berry (2010) Canada [74]                | 500 adults (18+ yrs) | Change in BMI (R) | a. [Safety from traffic] traffic (P)  
   b. [Walkability] neighbourhood walkability (O) | a. +S  
   b. N | SD-I, SD-A, PA, HB, Diet |
| Black (2010) USA [69]                   | 48,506 adults | Change in obesity (R) | a. [Recreational Facilities] neighbourhood food and physical activity amenities (O) | a. –S   | SD-I |
| Coogan (2011) USA [70•]                 | 17,968 African-American Women | 1. Weight gain (R)  
   2. Obesity (R) | [Composite other] urbanicity score (lower scores indicate rural or low-density suburban neighbourhoods) (O) | 1. –S  
   2. –S | SD-I, PA, HB, HS, Diet |
| Michael (2013) USA [71]                 | 1,008 older women (65+ years) | 1. Change in BMI (O)  
   2. Change in obesity (O) | a. [Connectivity] street connectivity (O)  
   b. [Connectivity] street density (O) | 1.a. N  
   1.b. N  
   2.a. N  
   2.b. N | SD-I, HS |
| Sarkar (2013) UK [72]                   | 684 adult men | Change in BMI (O) | a. [Land use mix] land use mix (O)  
   b. [Transit stops] density of bus stops (O)  
   c. [Utilitarian destinations] density of retail (O)  
   d. [Utilitarian destinations] density of churches (O)  
   e. [Utilitarian destinations] density of community services (O)  
   f. [Recreational facilities] density of recreation & leisure facilities (O)  
   g. [Park attribute] network distance to green space (O)  
   h. [Recreational facilities] network distance to sports facility (O) | a. +S  
   b. N  
   c. –S  
   d. –S  
   e. N  
   f. –S  
   g. N  
   h. +S  
   i. N | SD-I, HB, HS |
| Zhao (2010) USA [73] | 703,544 adults (18+ years) | 1. Change in BMI (R)  
2. Change in obesity (R) | [Density] change in population density (O) | 1. N  
2. –S | SD-I, SD-A |