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What kind of built environment favours walking? A systematic review of the walkability indices

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Abstract

Neighbourhood walkability provides important insights if an environment encourages (or discourages) walking. One of the most commonly used approaches to measure neighbourhood walkability is the walkability index. Walkability index is constructed as a composite measure of variables that are considered to influence walking. Typically, these include the characteristics of the built environment, the quality of the walking environment (safety and security) and pedestrian characteristics. However, there is a continued lack of a systematic understanding on the association between built environment variables with walking, which has important implications to effective planning and policymaking. By systematically reviewing publications between year 2000 and 2016, this paper examines the various factors of the built environment associated with walking in developing the walkability index, their combination, and the methods adopted to construct as well as evaluate the index. Results show that the association of walkability index to walking without prior validation of each variables of the built environment may not be able to inform or formulate appropriate strategy to improve walkability nor inform policy makers to formulate the right strategy. Nevertheless, objectively measured composite index of walkability have the potential to be an important planning tool to support policy recommendations. This research recommends that more research is needed to improve measures of the built environment so that the effectiveness of walkability index as a planning and policy tool is enhanced.

1. Introduction

Walking is considered as a primary form of transport. For physically abled individuals, all trips generally start and end with a walk trip, for example, when people walk to their vehicles or to access public transport stations. Walking can also be a standalone mode to undertake a leisure trip (e.g. to walk their dog) or a utilitarian trip (e.g. to walk to work) (Saelens et al., 2003b). While walking levels change depending on one's trip purpose, travel distance, trip destinations and transport availability, the characteristics of the built environment can also place considerable influence on people's decision to walk. Take for example, residents in walk-friendly neighbourhoods that are densely populated, have shops, services, restaurants, public transport and parks close by may walk more as compared with residents in less friendly places (Du Toit et al., 2007, Sallis et al., 2016). It is presumed that built environment features can facilitate or constrain walking (Saelens and Handy, 2008, Transportation Research Board Committee On Physical Activity Health and Land, 2005).

The link between walking and the neighbourhood built environment is well established in the extant literature (Frank et al., 2005, Lin and Moudon, 2010). The extent to which the built environment supports its residents to walk for leisure, exercise, or recreation is termed as walkability (Leslie et al., 2007; Mayne et al. 2013). Walking and walkable communities, in which more people walk, recently, are viewed to offer attractive benefits in the context of key public policy challenges, such as urban sprawl, traffic congestion, social fragmentation, and obesity (Du Toit et al., 2007, Krizek et al., 2009). One way to tackle these challenges is through improved walking intervention programs. The changes in the built environment targeted to increase access, attractiveness, safety, comfort, and security could result in a behavioural change leading to higher walking and in addition could stimulate changes in perceptions, and attitudes as well as other psychological changes such as a desire and motivation to walk (Krizek et al., 2009). It is therefore essential to understand characteristics of the built environment that favours walking and walkability which will then help improve transport planners' understanding of important factors to consider in the design of walkable and walk-friendly neighbourhoods as well as support policy recommendations. Studies suggest design interventions to improve walkability of neighbourhoods can be used to promote walking and sustainable outcomes (Wei, 2016, Rundle, 2016).

Walkability is a multidimensional concept. In some literature walkability is studied as a transportation mode (Ewing and Cervero, 2010, Handy et al., 2002), in others, as an aspect of neighbourhood wellbeing (Frank et al., 2010a, Rogers et al., 2011), yet in some others as an important element of solutions to diminish various health related issues such as type 2 diabetics, heart diseases, obesity etc. (Glazier, 2014)(Frank et al 2006; kligerman et al 2007, Booth et al 2005, Saelens et al 2003, Creatore et al 2016). One of the most commonly used approaches to evaluate neighbourhood walkability is the walkability index. Within the academic literature, there is considerable diversity in research on walkability index with papers published in social science (Sundquist, 2011, Wood, 2010), health (Sundquist, 2015, Hanibuchi, 2015, Frank, 2010), transportation (Christiansen et al., 2016, Clark, 2014, Christiansen, 2014, Manaugh, 2011), urban planning (Lotfi and Koohsari, 2011, Du Toit et al., 2007), and geography (Jun, 2015, Learnihan, 2011). These studies show that the use of walkability index to measure neighbourhood walkability have become common practice. However there exists considerable variation in the choice of built environment variables and the way these variables are evaluated. Brownson (2009) find three categories of built environment data commonly used by scholars to evaluate walkability: 1) perceived measures obtained by telephone interview or self-administered questionnaires; 2) observational measures obtained using systematic observational methods (audits); and 3) archival data sets that are often layered and analysed with GIS. It is unclear what characteristics of the built environment best facilitate walking (Saelens and Handy, 2008, Heath et al., 2006) because the results are not consistent, for example, few study suggests land use mix is associated with walking (Christiansen et al., 2016, Eriksson et al., 2012, Frank et al., 2005), whereas in other study land use mix was insignificant with walking (Wei et al., 2016, Sugiyama, 2015, Clark et al., 2013, McCormack et al., 2012). Similarly, in some study street connectivity influences walking (Wei et al., 2016, Christiansen et al., 2016, Frank et al., 2005), while Clark et al. (2013), McCormack et al. (2012), Eriksson et al. (2012) find no association between street connectivity and walking. This lack of consistency regarding the association between built environment variables and walking is a problem. The tool to measure the attractiveness to walking of a particular environment is critical to evidence-based decision making. Therefore this study aims to systematically review the literature on walkability index developed using built environment variables objectively measured using GIS to identify: 1) the built environment variables examined and used in evaluating walkability and in developing walkability index; 2) the methods of measures to evaluate each built environment variables. More detail is presented in section 2.2 for choosing only GIS based walkability index.

The use of walkability index to measure neighbourhood walkability has become common practice, because, by attaching a score on how walking levels are influenced by the features of the built environment (Clark et al., 2013), walkability index provides a relative measure of the extent to which a community is attractive to walking relative to other communities. Mayne et al. (2013) writes that the use of a walkability index captures the natural co-variation between built environment variables and addresses multicollinearity issues in statistical models (Clark et al., 2013, Mayne et al., 2013). Walkability index can be an important planning and policy tool that can inform policymakers and assist them in choosing right strategies to achieve sustainable outcomes at various levels from street to neighbourhood to city by providing measure of the extent to which built environment features play an important role in measuring attractiveness to walking. We need to first understand the variables that favour walking. Secondly, it is important to understand how walkability index is developed and constructed because the way in which an index is developed, constructed, and used would lead to different results. It is important to understand the role of indices in effectively measuring the attractiveness of a particular neighbourhood to walking. The understanding of the scope and extent of built environment influence on walking and walkability, relative to other neighbourhoods/cities would steer transport planners and policy makers in the right direction to identify specific interventions and measures associated with improving walkability and walking conditions. When the factors of the built environment that matters for walking is known, this can be an input to designs; effective environment, supportive and encouraging walking, can be designed (Forsyth et al., 2008), as well as this knowledge can be translated into regulations and guidelines concerning transportation, land use, and policies concerning climate change, health, liveability and overall quality of life.

The rest of the paper is organized into four sections. Section 2 on methods discusses the search strategy and data sources along with inclusion and exclusion criteria followed by data extraction and synthesis for this study. Section 3 presents the results of this study. Section 4 discusses the findings followed by conclusion in section 5.

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2. Method

2.1 Search strategy and data sources

This section has two goals: 1) identify the characteristics that make up a built environment that favour walking and 2) determine how these built environment variables are measured as input towards the development of a walkability index.

By searching four databases namely Scopus, PubMed Central, ProQuest Research Library, Web of Science to identify articles for the review between 2000 and 2016. This study used the following search parameters: 'Walkability index' within keyword and phrase searches within titles and abstracts. We used 'walkability index' as the only search word because in this article we want to review all studies that have either used or constructed walkability index using GIS derived objective measures of the built environment to assess the level of walking. The articles were confined to published literature in the English language from year 2000 to year 2016. The search was conducted in April 2016 therefore some relevant studies might have been excluded. All the articles were entered into the referencing software Endnote. There were 379 articles after removing for duplicates. Furthermore, publications were only included if the study was peer reviewed, had an available abstract, was accessible via scientific literature or the internet. The repository in endnote was further refined to contain only articles published in a peer reviewed journal paper.

In the first stage of the literature search, titles and abstracts of identified articles (467) were checked for relevance and additional articles known to the authors were assessed for possible inclusion. From these we removed duplicate references and studies that were not peer reviewed, were off topic, or reported only subjective measures or field measurements of built environment, and review papers. In the second stage, full-text articles were retrieved and considered for inclusion (81). In the final stage, the reference list of retrieved full-text articles were scanned for inclusion. Thirty-five of eighty one articles were selected for review (**Table 1**).

2.2 Inclusion and exclusion criteria

We included studies that have developed 'walkability index' with the use of built environment characteristics to assess built environment features which favour walking. Further, the components of the 'walkability index' had to be measured using spatial analysis tool. This excluded studies that developed 'walkability index' based on surveys, e.g. neighbourhood environment walkability scale (Saelens et al., 2003a); and studies that measured the built environment characteristics obtained from systematic observations or audits that quantify those characteristics. While survey studies may reveal how individuals perceive the built environment, this method is considered as "subjective". Two individuals may have different perception of the same environment, and may report common survey research issues of reliability, validity, low response rates and a biased sample of respondents (Duncan et al 2011). Audit tools measure the built environment characteristics through direct observations and could potentially be utilized to translate or validate the developed walkability index but, this method is resource intensive (time demanding, costly, requires special skills) (Duncan et.al 2011). (Hajna et al., 2013) studied neighbourhood walkability and find strong correlation between GIS based measures and the objective measures from field audits, they conclude that it is reasonable to use GIS-based measures in place of field measures using audits. In a different study, Lin and Moudon (2010) find objective measures of the built environment had stronger association with walking than subjective measures. Objective measures of the built environment not only explain walking better but may potentially be developed to create standardised measures of the built environment. Therefore, we chose to investigate only studies that used the GIS derived objective measures of the built environment. We also excluded 1) walkability assessment tools such as Google's 'Walkscore' and AURIN's walkability tool, and 2) studies on active school for transport and studies that developed school walkability index (Giles-Corti et al., 2011). 'Walkscore' and AURIN's walkability tool provide a measure of walkability - 'Walkscore' for instance is commercially very popular and is used extensively by real estate companies in evaluating value of a property but review of these tools is beyond the scope of this study. There are studies that have reviewed these tools and cross validated them, for example (Duncan et al., 2011). According to Duncan et al (2011), 'Walkscore' is useful in determining walkability of a place but cannot be used universally to determine the neighbourhood walkability. Further 'Walkscore' cannot measure walkability at multiple geographic scales (Manaugh, 2011). We did not included school walkability index in this study because the focus of this review is to understand the walkability of a neighbourhood to identify what features of the built environment favour walking and not focused walkability specific to one attractor such as a school. While we acknowledge the importance of school walkability index study findings and their contribution in promoting active travel to and from schools, these studies are out of scope of this review.

2.3 Data Extraction and synthesis

For each included study, we extracted, summarized and tabulated the following information: location of the walkability studied, geographic scale of walkability studied, objective built environment variables measured, methods of measure of the built environment and the method used to develop walkability index. We categorized studies according to the approach taken to study the walkability of geographic scale studied. We summarized the study in terms of the built environment variables studied and tabulated the variables used in each study to create a walkability index. In

Table 1 we present the variables included by each study to develop the walkability index.

Table 1: Summary of built environment variable used in developing walkability index and their association with walking

Variable	Study	+ve association	-ve association
Population density	(Hanibuchi et al., 2015), (Hajna et al., 2015), (Glazier et al., 2014), (Clark et al., 2013), (Neckerman et al., 2009)	(Clark, 2014)	(Glazier, 2014)
Residential density	(Rundle et al., 2016), (Christiansen et al., 2016), (Sugiyama, 2015), (Sundquist et al., 2015), (Reyer et al., 2014), (Glazier et al., 2014), (Mayne et al., 2013), (Hajna et al., 2013), (Freeman et al., 2013), (McCormack et al., 2012), (Eriksson et al., 2012), (Van Dyck et al., 2011), (Sundquist et al., 2011), (Learnihan et al., 2011), (Dygryn et al., 2010)	(Eriksson, 2012, Clark, 2014, Glazier, 2014, Sugiyama, 2015)	(McCormack, 2012)
Dwelling density	(Wei et al., 2016), (Badland et al., 2009), (Leslie et al., 2007), (Owen et al., 2007), (Leslie et al., 2005)	(Wei, 2016)	
Net residential density	(Jun and Hur, 2015), (Frank, 2015), (de Sa and Ardern, 2014), (Christian et al., 2011), (Manaugh and El-Geneidy, 2011), (Wood et al., 2010), (Frank et al., 2010), (Frank et al., 2006), (Frank et al., 2005)		
Street connectivity	(Wei et al., 2016), (Sundquist et al., 2015), (Glazier et al., 2014), (Clark et al., 2013), (Hajna et al., 2013), (McCormack et al., 2012), (Eriksson et al., 2012), (Van Dyck et al., 2011), (Christian et al., 2011), (Sundquist et al., 2011), (Learnihan et al., 2011), (Manaugh and El-Geneidy, 2011), (Wood et al., 2010), (Weiss et al., 2010), (Dygryn et al., 2010), (Badland et al., 2009), (Leslie et al., 2007), (Frank et al., 2006), (Leslie et al., 2005), (Frank et al., 2005)	(Frank, 2005, Christiansen et al., 2016, Wei, 2016)	(Eriksson, 2012, McCormack, 2012, Clark, 2014)
Intersection density	(Rundle et al., 2016), (Christiansen et al., 2016), (Sugiyama, 2015), (Jun and Hur, 2015), (Hajna et al., 2015), (Frank, 2015), (Reyer et al., 2014), (de Sa and Ardern, 2014), (Mayne et al., 2013), (Freeman et al., 2013), (Frank et al., 2010), (Neckerman et al., 2009)		
Road density	(Hanibuchi et al., 2015)		
Land use mix	(Wei et al., 2016), (Rundle et al., 2016), (Christiansen et al., 2016), (Sugiyama, 2015), (Sundquist et al., 2015), (Jun and Hur, 2015), (Hajna et al., 2015), (Frank, 2015), (Reyer et al., 2014), (de Sa and Ardern, 2014), (Mayne et al., 2013), (Clark et al., 2013), (Hajna et al., 2013), (Freeman et al., 2013), (McCormack et al., 2012), (Eriksson et al., 2012), (Van Dyck et al., 2011), (Christian et al., 2011), (Sundquist et al., 2011), (Learnihan et al., 2011), (Manaugh and El-Geneidy, 2011), (Wood et al., 2010), (Weiss et al., 2010), (Frank et al., 2010), (Dygryn et al., 2010), (Neckerman et al., 2009), (Badland et al., 2009), (Leslie et al., 2007), (Frank et al., 2006), (Leslie et al., 2005), (Frank et al., 2005)	(Leslie, 2005, Christiansen et al., 2016)	(McCormack, 2012, Clark, 2014, Sugiyama, 2015, Wei, 2016)
Pedestrian infrastructure	(Clark et al., 2013)	(Clark et al., 2013)	
Retail floor area ratio	(Sugiyama, 2015), (Jun and Hur, 2015), (Frank, 2015), (Reyer et al., 2014), (Mayne et al., 2013), (Clark et al., 2013), (Learnihan et al., 2011), (Wood et al., 2010), (Frank et al., 2010), (Dygryn et al., 2010), (Neckerman et al., 2009), (Badland et al., 2009), (Frank et al., 2006)	(Wei, 2016)	(Clark, 2014)
Net retail area	(Leslie et al., 2007), (Leslie et al., 2005)		
Access to retail area	(Hanibuchi et al., 2015),		
Access to parks	(Hanibuchi et al., 2015),		
Parks	(Christiansen et al., 2016), (Freeman et al., 2013), (Neckerman et al., 2009)	(Christiansen et al., 2016)	
Subway stop density	(Rundle et al., 2016),		
Walkable destinations	(Glazier et al., 2014)	(Glazier et al., 2014)	

3. Results

Results show that while studies have used a wide range of variables, including several measures to quantify the walkability index, the most used variables are land use mix (26), followed by street connectivity (17), residential density and retail floor area ratio (10), possibly because of the ease of use of these variables. Other notable variables are subway stop density, park density and availability of walkable destinations. Two ways to create the index is observed: 1) the built environment variables are normalized and then combined into an index (arithmetic sum); some studies adopted a range of weights for each variable while others used equal weights for each variable, depending on the context of these studies; and 2) the values are classified into deciles or quintiles first then summed. However, in both approaches, by measuring the walkability index, researchers were able to explain walkability levels and the extent to which they are significant in explaining the level of walking.

3.1 Study sample characteristics

The majority of studies reviewed were undertaken in the USA (Wei et al., 2016, Rundle et al., 2016, Jun and Hur, 2015, Freeman et al., 2013, Eriksson et al., 2012, Wood et al., 2010, Weiss et al., 2010, Frank et al., 2010b, Neckerman et al., 2009), Canada (Hajna et al., 2015, Frank, 2015, Glazier et al., 2014, de Sa and Ardern, 2014, Hajna et al., 2013, Clark et al., 2013, Manaugh and El-Geneidy, 2011), Australia (Sugiyama, 2015, Mayne et al., 2013, McCormack et al., 2012, Learnihan et al., 2011, Christian et al., 2011, Owen et al., 2007, Leslie et al., 2007), Sweden (Sundquist et al., 2015), Germany (Reyer et al., 2014), Belgium (Hanibuchi et al., 2015), Japan (Hanibuchi et al., 2015) and New Zealand (Badland et al., 2009). Study on walkability using the objective measures of the built environment in developing cities are less, however, this does not imply that walkability is not investigated in such context. In fact, Krambeck (2006) developed the 'Global Walkability Index' where she studied walkability in both developed and developing countries. The number of walkability index studies using GIS based measures were higher in developed countries because of availability of datasets required to perform such analysis and therefore the lack of studies using GIS based measures in developing countries could be in part due to unavailability of data or lack of reliable data, limited access to or unaffordable GIS data layers (Duncan et al., 2011). For example, Lotfi and Koohsari (2011) applied objectively measured walkability index to study walkability of Tehran but their results were limited, because of lack of valid data.

To understand characteristics of the built environment favouring walking, we systematically reviewed the literature that used objectively measured built environment variables in constructing composite measure of walking. We find the use of built environment variables varied across studies in developing walkability index. We also find not every study reviewed in this study established association between the built environment variables used and walking. Only seven (7) out of 35 studies examined the association between the built environments variables used in walkability index development with walking. The association of walkability index to walking without prior validity of each variables of the built environment may not be able to appropriately inform policy to formulate the right strategy to improve walkability.

3.2 Measuring the built environment

To understand how walkability is measured, it is necessary to understand the features of the built environment associated with walking. In studies that have developed walkability index, several built environment variables are utilised in constructing walkability index as a composite measure of walkability. Some of the variables studied are dwelling density, population density, residential density, net residential density, street connectivity, intersection density, road density, land use mix, retail floor area ratio, net retail area ratio, subway stop density, access to parks, access to retail areas, pedestrian infrastructure, subway stop density, walkable destinations; these variables are used in different combinations in the reviewed literature to prepare walkability index.

Several studies have either used different ways to measure, or displayed variations in the measure of, the same built environment variable, resulting in the lack of consistency in measuring the said variable. As an example, while the variable “street connectivity” is based on the number of intersections, several studies report the use of different numbers of intersection: (i) 3 or more intersecting streets (Badland, 2009, Frank, 2005, Learnihan, 2011, Leslie, 2007, Owen, 2007, Sundquist, 2011, Van Dyck, 2011, Wei, 2016, Wood, 2010); (ii) 2 or more intersecting streets (Clark, 2014, Dygryn, 2010, Eriksson, 2012, Glazier, 2014, Hajna, 2015, Sundquist, 2015) and (iii) 4 or more intersections (Hajna, 2013). However, none of these studies provided a clear rationale for their choice of measure of street connectivity.

Similarly, land use mix is determined using entropy index in some study and the Herfindahl-Hirschman index in others. Both of these indices determine the concentration of each land use type with respect to all other land use types. The value ranges between 0 and 1 where 1 signify heterogeneity or diversity. Because of this differentiation, the land use types considered in the calculation might not reveal the actual influence the land use mix exerts on walking. Not all land use types supports walking or induce walking, therefore this measure fails to capture the complementarity of land uses (Mitchell Hess et al., 2001).

Another variable is the retail floor area which in Jun and Hur (2015) refers to the land parcels in commercial use and is measured by the ratio of total ground floor area to total area of the household. It is the ratio of retail floor area in square meters and total amount of commercial land use in square meters (Mayne et al., 2013, Freeman et al., 2013, Christian et al., 2011, Wood et al., 2010, Frank et al., 2010b, Badland et al., 2009). In Dygryn et al. (2010), Frank et al. (2006), on the other hand, this is the ratio of retail building floor area footprint to retail land floor area footprint.

Further, net residential density is the number of dwellings per square kilometre of buffer areas devoted to residential use (Jun and Hur, 2015, de Sa and Ardern, 2014, Christian et al., 2011, Frank et al., 2005). Wood et al. (2010) measured it as the number of residential units per residential acre within the households buffer while in Frank et al. (2010b) it is the ratio of residential units to the land area devoted to residential use per block group.

In addition to the differentiated methods of measures of built environment variables, the different ways of naming similar measure, e.g. street connectivity, intersection density, unique intersection density all measure the linkage of street networks and the directness of the path between destinations, potentially adds to the researcher’s confusion.

4. Discussion

The review of objectively measured walkability index in the literature identified sixteen different objectively measured characteristics variable of the built environment linked to walking. The choice of variables varied across studies, owning mostly to factors such as presence/absence of certain features such as parks and data availability. The most popular variables studied to understand walkability are land use mix, street connectivity, residential density, and retail floor area ratio.

The results on the association between built environment variables and walking found from this review is mixed. Residential density is positively associated to walking on some studies while it is not associated to walking in others; interestingly Christiansen et al. (2016) suggests that there might be optimum threshold values for residential density beyond which higher residential densities have a negative impact. Future research could look at this association between walking and residential density across neighbourhoods with varying residential density and walking to investigate this further.

Further, in some places, street connectivity is seen to have an association with walking while in others it is insignificant with walking. The reason why the relation between street connectivity and walking is not clear could also attribute to the fact that there is no one methodology for measuring street connectivity and the definition of street connectivity differs with the studies. The measures of street connectivity only determine the properties of the street at local level. Future research could look into methods that can evaluate the properties of the street at both local and global scale.

Likewise, many studies have explored the relation between Land use mix association and walking. Land use types are found significant for walkability. Generally, studies have combined different land use types in constructing the land use mix measures, however, these measures do not account for the complementarity of each land use types. Combination of these land use types into single index is the current practice to capture its effect on walking and walkability. However, it would be interesting to see advanced approaches to define and measure land use types apart from a straightforward combination in future.

5. Conclusion

This study systematically reviewed the literature on walkability index developed using built environment variables objectively measured using GIS from year 2000 to 2016. This review contributed to understanding the aspects of built environment variables objectively measured using GIS in developing walkability index and methods of measures to evaluate each built environment variables. This study also outlined some potential areas of exploration to improve the measures of built environment variables. Based on our findings no reasonable robust conclusions can be drawn on the best characteristics variable of the built environment that favour walking and their methods of measures in relation to overall walkability and walking. Variables like residential density, street connectivity and land use are found to be associated with walking but the way these variables are measured are limited. It is recommended that future research look at improving methods to measure built environment variables.

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