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Walk score® and its potential contribution to the study of active transport and walkability: A critical and systematic review

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ABSTRACT

The Walk Score® index has become increasingly applied in studies of walking and walkability. The index assesses the "walking potential" of a place through a combination of three elements: the shortest distance to a group of preselected destinations, the block length, and the intersection density around the origin. The Index links a gravity-based measure (distance accessibility), with topological accessibility (street connectivity) measured by two complementary indicators that act as penalties in the final score (linearly expanded in the range 0–100). A systematic review of Scopus® and Web of Science® was conducted with 42 journal articles eventually being evaluated. Research was primarily undertaken in North American urban geographies. Analysis of walkability using Walk Score® is inconsistent. Twenty-nine papers do not exclusively relying on Walk Score® as a single measurement of walkability and add further estimates to better capture the multiple dimensions of walkability. In 33 studies the Walk Score® was used as an independent variable, and only once as a mediating-moderating variable. In eight papers (18%) the Walk Score® was a part of a bivariate correlation model. On no occasion was it used as a dependent variable. Results tend to only partly support the validity of Walk Score®. The paper concludes that the Index is best understood as a surrogate measure of the density of the built environment of a specific neighborhood that indicates utilitarian walking potential. Implications for, and potential areas of, future research are discussed.

1. Introduction

A September 2017 feature article in *The Guardian* asked "Where's is the world's most walkable city?" (Laker, 2017). The article attracted more than 2200 shares and 500 comments in less than 48 hours and highlights the increased concerns of planners, researchers and the wide public over walking (Alvanides, 2014). Walking and walkability, the capacity to walk at a location, are a significant focus for improving the quality of the built environment (Hall et al., 2018). Identified benefits of increased walking for transport and leisure include not only reductions in traffic congestion, air pollution, and emissions (Talen and Koschinsky, 2013; Forsyth, 2015), but also improvements in public and private health (Doyle et al., 2006; Durand et al., 2011), community relations and positive sense of place (Leyden, 2003), and improvements in economic and real estate performance (Leinberger and Alfonzo, 2012; Trowbridge et al., 2014). As a form of transport, walking therefore has the potential to contribute simultaneously to all three pillars of

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sustainability (economy, society, the environment).

Walkability can be broadly defined as the extent to which an environment, usually the built environment, enables walking (Kelly et al., 2011) and is pedestrian friendly (Gebel et al., 2009; Moura et al., 2017). However, the notion of 'walkable' is multi-dimensional (Forsyth and Southworth, 2008), with studies emphasising different environmental features or means of developing walkable environments, including areas being traversable, compact, physically enticing and safe, while others deal with the outcomes potentially fostered by such environments, such as making places lively, enhancing sustainable transportation options, and encouraging outdoor exercise and leisure (Forsyth, 2015; Saelens and Handy, 2008; Hall and Ram, 2018).

In order to assist in improving the quantity and quality of walkability, two main research approaches have been adopted. First, a substantial effort has been given to developing walkability measures (Ewing and Handy, 2009; Gebel et al., 2009; Hoedl et al., 2010; Iacono et al., 2010; Lwin and Murayama, 2011; Horacek et al., 2012; Vale et al., 2016). These include qualitative and quantitative measures of the built, external and social environment (Southworth, 2005; Lo, 2009; Riggs, 2015); trip purpose (Forsyth et al., 2008); as well as the gender and cultural context within which walking occurs (Forsyth, 2015; Hall et al. 2017). A second minor stream is the provision of reviews that aim to synthesise knowledge regarding the walkability concept. However, this task faces many challenges, since the notion is shared by different disciplines each with their own framing of the concept. Hajna et al. (2015a) quantitatively analysed six papers, finding that walkable neighbourhoods enhance 766 more steps per trip than less walkable neighbourhoods. Other studies have adopted qualitative practices. On the basis of a review of 77 papers, Rothman et al. (2012) argued that the majority of built environment features had inconsistent associations with either walking or injury of children (4–12), or had not been tested for either one of the outcomes. Grasser et al. (2013) focused on adults and qualitatively concluded weak correlations of walkability with physical activity for transport and weight-related outcomes on the basis of a sample of 34 papers. The purpose of the current work is to elaborate further the analysis of walkability, providing a novel analysis that combines the two practices, and offering an overview of research that has used a specific walkability measure, Walk Score®, which is also available for use by the general public.

1.1. The Walk Score® index

A method that is being increasingly adopted in the analysis of walkability is that of the Walk Score® index. Walk Score® is a company that uses a patented system to offer a range of walkability, planning, health, transport, and real estate data. In addition to the walkability measure of Walk Score® they also offer measures of Transit Score (a measure of transit accessibility), bike score (bike accessibility), opportunity score (measures ease of accessibility to nearby jobs without a car adjusted for population), pedestrian friendliness, public transit data, score details for particular walking destination locations, and travel time analysis.

Walk Score's mission is to promote walkable neighbourhoods. The Walk Score® index is part of a suite of products designed "to make it easy for people to evaluate walkability and transportation" (walkScore.com). Walk Score® methodology combines three elements: the shortest distance to a group of preselected destinations (such as commerce/services, e.g. public transport, restaurants, shopping, parks/green spaces, and schools), the block length, and the intersection density around the origin. Data sources include Google, Education.com, Open Street Map, the U.S. Census, and users (Walk Score® 2017). Walk Score® links a gravity-based measure (distance accessibility), with topological accessibility (street connectivity) measured by two complementary indicators that act as penalties in the final score (linearly expanded in the range 0–100) (Vale et al., 2016). Prior to 2010 the Walk Score® algorithm used a one mile Euclidean distance buffer (Carr et al., 2010) but currently the buffer is determined by the network (Manaugh and El-Geneidy, 2012; Hirsch et al., 2013; Vale et al., 2016).

The company states on its web site that Walk Score® data is available in the United States, Canada, Australia, and New Zealand, although the web site can be used to produce walk score rankings for locations in other countries. Walk Score® was purchased by a real estate agency, Redfin, to provide an additional service to the costumers of the two companies by providing a business synergy. The missions of the two companies were merged to "encourage people to make sustainable choices about where to live" (Kelman, 2014). It should therefore not be surprising that research on housing as a dependent variable is also increasingly conducted using Walk Score® (Kim and Woo, 2016; Li et al., 2014, 2015; Pivo and Fisher, 2011; Renne et al., 2016).

Walk Score® has been used in a number of studies on walkability, particularly for purposes of health and physical activity research (Vale et al., 2016), with a number of studies concluding that it provides a valid means of assessing neighborhood accessibility for walking (e.g. Duncan et al., 2011, Duncan et al., 2013, Duncan et al., 2016). The method is also regarded as attractive because it provides a convenient and inexpensive research option for exploring the relationship between access to walkable amenities and physical activity (Carr et al., 2010, 2011). Therefore, perhaps not surprisingly, use and acceptance of Walk Score® as a means to assess walkability has increased over time (Vale et al., 2016). Although several reviews have been conducted on assessments of walkability (e.g. Southworth, 2005; Moudon et al., 2006; Ewing and Handy, 2009; Lo, 2009; Talen and Koschinsky, 2013; Forsyth, 2015; Vale et al., 2016; Ram and Hall, 2018), no review has yet been conducted specifically on the use of Walk Score®. Therefore, based on a systematic review of the academic literature found in the Scopus and Web of Science databases this paper aims to answer the following questions: (1) what are the findings of Walk Score® studies; (2) do different uses of Walk Score® generate different results?; and (3) what should be the priorities for future Walk Score® research?

2. Method

In January 2017 a systematic search was conducted of the Web of Science® and Scopus® bibliometric databases using the occurrence of the terms "Walk Score" or "walkscore" in the title, abstract or keywords of publications. Eighty-six publications were

Table 1
Overview of papers using Walk Score®.

	Author	Journal	Country	Method of Walk Score®	Sample size	# of additional measures of walkability (other than Walk Score®)	Using of primary/secondary data	Function of Walk Score® in analysis	Other independent variables in equation	Dependent variable/bivariate correlation	Transport measures	Socio-demographic analysis (significant if not mentioned otherwise)	Hypothesis testing
1	Barnes et al. (2016)	Journal of Transport & Health	Canada	Network	2557	–	Secondary	Independent variable	Transit Score®	Transport walking/using transport	Transport mode/Transit Score®	Age groups	Supported
2	Brown et al. (2013)	American Journal of Preventive Medicine	USA	Straight line	391	–	Secondary	Independent variable	Distance to business district	Purposive walking		Several measures-Non significant	Supported
3	Brown et al. (2014)	American Journal of Preventive Medicine	USA	Straight lines	391	–	Secondary	Moderator	Distance to business district	Purposive walking		Habitual PA	Supported
4	Carr et al. (2010)	American Journal of Preventive Medicine	USA	Straight lines	296	3	Primary	Bivariate correlation		PA environment measures	Transport infrastructure		Partially supported
5	Carr et al. (2011)	British Journal of Sports Medicine	USA	Straight lines	379	3	Primary	Bivariate correlation		Amenities			Supported
6	Chiu et al. (2015)	Health Reports	Canada	Network	2114	1	Secondary	Independent variable		Obesity/overweight Leisure walking		Various socio-demographic	Partial supported
7	Chiu et al. (2016)	Environmental Health Perspectives (Online)	Canada	Network	106,337	–	Secondary	Bivariate correlation	Moving	Hypertension		Adjusted + matching between groups	Supported
8	Cole et al. (2015)	Health & Place	Australia	Straight lines	16,944	–	Secondary	Independent variable		Odds to home based walking	Transport mode	Adjusted – car and work status	Partially supported (two groups)
9	Duncan et al. (2011)	International Journal of Environmental Research and Public Health	USA	Straight lines	733	3	Primary	Bivariate correlation		GIS indicators	Transport infrastructure		Partially supported
10	Duncan et al. (2013)	GeoJournal	USA	Straight lines	1292	3	Primary	Bivariate correlation	Transit Score®	GIS indicators	Transport infrastructure/Transit Score®		Supported
11	Duncan et al. (2016)	International Journal of Environmental Research and Public Health	France	Straight lines	227	–	Primary	Independent variable		Odds of walking/#of steps	Transport mode	Adjusted various socio-demographic	Partially supported (two groups)

(*continued on next page*)

Table 1 (*continued*)

	Author	Journal	Country	Method of Walk Score®	Sample size	# of additional measures of walkability (other than Walk Score®)	Using of primary/ secondary data	Function of Walk Score® in analysis	Other independent variables in equation	Dependent variable/ bivariate correlation	Transport measures	Socio-demographic analysis (significant if not mentioned otherwise)	Hypothesis testing
12	Gell et al. (2015)	Disability and Health Journal	USA	Straight lines	28	3	Primary	Independent variable	Block length and density	Active transport	Transport mode	Defined group	Supported
13	Hajna et al. (2015b)	BMJ Open	Canada	Straight lines	2949	1	Primary	Independent variable	GIS measurements	Utilitarian walking/#of steps		Adjusted various socio-demographic	Partially supported (only regarding Unitarian walking)
14	Halat et al. (2015)	Transportation Research Record	USA	Straight lines	14,390	2	Secondary	Independent variable	Distance to PT	Home-work travel behavior (transport mode)	Transport infrastructure/ Transport mode		Supported
15	Herrick et al. (2016)	Public Health Nutrition	USA	Straight lines	15,522	–	Secondary	Independent variable	Socio demographic	Diabetes		Various socio-demographic	Supported
16	Hirsch et al. (2013)	American Journal of Preventive Medicine	USA	Both methods	4552	–	Secondary	Independent variable	Transit Score®	Odds to walking/ minutes of walking	Transit Score®	Adjusted various socio-demographic	Partially supported
17	Hirsch et al. (2014)	American Journal of Public Health	USA	Network	701	–	Secondary	Independent variable	Moving	Exposure to campaign/ BMI		Two analyses- adjusted and non-adjusted	Partially supported
18	Kelley et al. (2016)	Journal of Physical Activity and Health	USA	Straight lines	906	–	Secondary	independent		Walking for transport		Gender differences	Partially supported
19	Kim and Woo (2016)	Sustainability	USA	Network	420 (blocks)	1	Secondary	Independent variable	Traffic infrastructure	Housing	Transport infrastructure	Block socio-demographic statistics	Supported
20	Lee et al. (2016)	International Journal of Environmental Research and Public Health	USA	Network	500	1	Secondary	Bivariate correlation		Cardio-vascular GIS app.	Transport infrastructure	Neighborhood socio-demographic statistics	Supported
21	Li et al. (2014)	Transportation Research Record	USA	Both methods	3899	2	Secondary	Independent variable	Pedestrian accidents/GIS measures	Housing	Transport infrastructure		Partially supported
22	Li et al. (2015)	Journal of Planning Education and Research	USA	Both methods	21,686	2	Secondary	Independent variable	Pedestrian accidents/GIS measures	Housing	Transport infrastructure		Partially supported
23	Nykiforuk et al. (2016)	Preventive Medicine Reports	Canada	network	2181	3	Primary	Bivariate correlation		Street level observation			Partially supported

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Table 1 (*continued*)

	Author	Journal	Country	Method of Walk Score®	Sample size	# of additional measures of walkability (other than Walk Score®)	Using of primary/ secondary data	Function of Walk Score® in analysis	Other independent variables in equation	Dependent variable/ bivariate correlation	Transport measures	Socio-demographic analysis (significant if not mentioned otherwise)	Hypothesis testing
24	Phillips et al. (2015)	Archives of Sexual Behavior	USA	Straight lines	376	2	Secondary	Independent variable	Transit Score®	HIV		Individual and cluster socio-demographic	Supported
25	Jilcott Pitts et al. (2015)	Ecology of Food and Nutrition	USA	Straight lines	197	2	Primary	Independent variable	Distance to food	BMI		Female only	Supported
26	Pivo and Fisher (2011)	Real Estate Economics	USA	Straight lines	47,263	2	Secondary	Independentvariable	Distance to PT	Housing	Transport infrastructure		Partially supported
27	Renne et al. (2016)	Housing Policy Debate	USA	NA	4399	1	Secondary	Independent variable	PT cost	Housing	Transport infrastructure/ Transport mode		Partially supported
28	Reyer et al. (2014)	International Journal of Environmental Research and Public Health	Germany	Other (self made)	1871	3	Primary	Independentvariable	Land use	Walking distance		Sex (significant) income and age (non significant)	Partially supported
29	Riley et al. (2013)	Health & Place,	Canada	Straight lines	230	2	Primary	Independent variable	Intervention of PA, walkability	Physical activity		Matching groups	Not supported
30	Sriram et al. (2016)	American Journal of Preventive Medicine	USA	Network	6526	1	Secondary	Independent variable	GIS measures	Obesity/ overweight		Gender differences and adjusted socio-demographic	Partially supported
31	Takahashi et al. (2012)	Risk Management and Healthcare Policy	USA	Straight lines	53	–	Primary	Independent variable	Activity/health	Active transport	Transport mode	Adults 70–85	Not supported
32	Talen et al. (2013)	Landscape and Urban Planning	USA	Network	300	–	Primary	Independent variable	GIS measures	LEED-ND			Not supported
33	Thielman et al. (2015)	Preventive Medicine	Canada	Network	151,318	1	Secondary	Independent Variable		Physical activity		Age groups/town size	Partially supported
34	Towne et al. (2016)	Journal of Community Health	USA	NA	394	3	Primary	Independent variable	Neighborhood cohesion	Physical activity		Various socio-demographic	Partially supported
35	Tuckel and Milczarski (2015)	American Journal of Health Behavior	USA	NA	1224	2	Primary	Independent variable	Perceptions of walkability	Walking behaviors		Adjusted various socio-demographic	Partially supported
36	Wasfi et al. (2016a)	Journal of Transport & Health	Canada	NA	2976	–	Secondary	Independent variable		Utilitarian walking		Gender	Partially supported

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Table 1 (*continued*)

	Author	Journal	Country	Method of Walk Score®	Sample size	# of additional measures of walkability (other than Walk Score®)	Using of primary/ secondary data	Function of Walk Score® in analysis	Other independent variables in equation	Dependent variable/ bivariate correlation	Transport measures	Socio-demographic analysis (significant if not mentioned otherwise)	Hypothesis testing
37	Wasfi et al. (2016b)	American Journal of Public Health	Canada	NA	2935	1	Secondary	Independent variable		BMI		Various socio-demographic	Supported
38	Xu and Wang (2015a)	Health & Place	USA	Straight lines	328,156	1	Secondary	Independent variable	Intersection density/socio demographic	Physical activity/BMI		Race, poverty	Partially supported
39	Xu and Wang (2015b)	Cartography and Geographic Information Science	USA	Straight lines	3109	1	Secondary	Independent variable	Intersection density	Obesity		Various socio-demographic	Partially supported
40	Xu et al. (2015)	Applied Geography,	USA	Straight lines	21,961	2	Secondary	Independent variable	Distance to PT	Obesity	Transport infrastructure	Various socio-demographic	Not supported
41	Yin and Wang (2016)	Applied Geography	USA	NA	3592	1	Primary	Bivariate correlation		Sight of sky			Supported
42	Zhu et al. (2014)	Preventive Medicine	USA	NA	449	3	Primary	Independent variable	Before/after analysis	Social cohesion	Transport mode		Partially supported

GIS – Geographic Information System; LEED-ND – Leadership in Energy and Environmental Design for Neighborhood Development; PA – Physical activity; PT – Public transport.

identified in the Web of Science® database, and 83 in Scopus® with the selected terms. After reading of papers for appropriateness, removal of duplicates, and the removal of conference abstracts 42 publications were identified as utilizing Walk Score® in the assessment of walking, walkability, transport, and/or the built environment. All the reviewed papers are described in Table 1 together with the variables for assessment.

Twenty-eight different journals with relevant content were identified with the largest number of publications being found in the *American Journal of Preventive Medicine* (5) and *International Journal of Environmental Research and Public Health* (4) (Table 1). Over three-quarters of publications were found in health related journals. The publications were analysed by both authors in order to identify study attributes and cross-check the results. The following section presents an analysis of these papers.

3. Assessment of selected publications

3.1. Country of study

Research on the application of Walk Score® has been conducted in only five countries, with over ninety percent being Canadian and United States based. Duncan et al. (2016) also noted that the vast majority of research that has utilized Walk Score® in examining walkability has been conducted in North American urban settings. The implications of such a limited range of locations for the application of Walk Score® in other environments has not been fully explored.

3.2. Walkability and Walk Score®

Although the overt focus on Walk Score® appears to be on walking and walkability, the analysis of walking is inconsistent. Only five of the 42 papers presented a definition of walkability that is not related directly to the Walk Score® research tool or other empirical assessments. None of these papers used the Walk Score® as a single estimate of walkability (Table 2). This situation reflects the observation that walkability has been conceptualized and defined in different ways, including proximity to destinations; street-connectivity, light traffic and appropriate pedestrian infrastructure; aesthetics; higher residential density; mixed land use; and a safe walking environment (Pikora et al., 2003; Ewing and Handy, 2009; Lo, 2009; McCormack and Shiell, 2011; Forsyth, 2015; Nykiforuk et al., 2016; Vale et al., 2016), all of which have demonstrated associations with destination and leisure walking. Nevertheless, such a situation has led to difficulties in comparing research findings and has provided only limited capacity to generalize and validate results (Schopflocher et al., 2014; Nykiforuk et al., 2016).

Most papers (29 papers of 42, 69%) do not exclusively rely on Walk Score® as a single measurement of walkability and added further estimates in order to better capture the multiple dimensions of walkability. Fig. 1 presents the frequency of use additional estimates to walkability, besides the Walk Score® index. Eleven papers added a single estimate to Walk Score®, mainly using a built environment index (Hajna et al., 2015b; Kim and Woo, 2016; Lee et al., 2016; Renne et al., 2016; Xu and Wang, 2015a,b; Yin and Wang, 2016), or a transport/purposive walking measure (Thielman et al., 2015; Wasfi et al., 2016b) or all walking behaviors (Xu and Wang, 2015a). One paper addressed perceptions (Chiu et al., 2015). Eighteen studies used two (n = 9) or three (n = 9) estimates for walkability on top of the Walk Score®. These estimates include the built environment (Carr et al., 2010, Duncan et al., 2011, 2013; Gell et al., 2015; Halat et al., 2015; Jilcott Pitts et al., 2012; Li et al., 2014; Li et al., 2015; Nykiforuk et al., 2016; Pivo and Fisher, 2011; Reyer et al., 2014; Riley et al., 2013; Tuckel and Milczarski, 2015; Xu et al., 2015), crime (Carr et al., 2010; Gell et al., 2015; Halat et al., 2015; Li et al., 2014; Li et al., 2015), different types of walking (purposive walking – Carr et al., 2010; Jilcott Pitts et al., 2012; Reyer et al., 2014; all walking types – Gell et al., 2015; Nykiforuk et al., 2016; Phillips et al., 2015; Pivo and Fisher, 2011; Riley et al., 2013; Zhu et al., 2014; Leisure – Carr et al., 2010, 2011; Towne et al., 2016; Home based – Duncan et al., 2011, 2013; Towne et al., 2016; Zhu et al., 2014), amenities (Carr et al., 2011; Duncan et al., 2011, 2013; Nykiforuk et al., 2016; Reyer et al., 2014; Xu

Table 2
Definitions for walkability.

Paper	Definition of walkability
Carr et al. (2011) (p. 2)	Walkability can be defined as a neighborhood's capacity to support lifestyle physical activity
Duncan et al. (2011) (p. 4161)	Collectively, these features that promote various forms of physical activity (such as walking) can be referred to as ‘neighborhood walkability’ and often include access to walking destinations such as retail stores and parks, and community design features such as street connectivity and sidewalk access
Hajna et al. (2015b) (p. 2)	The variables that best capture design, diversity and density are street connectivity, land use mix and residential density (collectively referred to as neighborhood walkability)
Pivo and Fisher (2011) (p. 186–7)	We define walkability as the degree to which an area within walking distance of a property encourages walking trips from the property to other destinations. It interacts with the property users' walking preferences and capabilities to produce the timing, quantity and distance of walking trips that occur. Several different physical and social attributes of the area around a property can affect walkability. As such, it is a multidimensional construct composed of different factors that together comprise a single theoretical concept. Contributing attributes include urban density, land use mixing, street connectivity (i.e., the directness of links and the density of connections), traffic volume, distance to destinations, sidewalk width and continuity, city block size, topographic slope, perceived safety and aesthetics …
Reyer et al. (2014) p. 5850	This is defined in different disciplines in different manners. Its essence is defined here as “the extent to which the built environment is walking-friendly” (Abley, 2005)

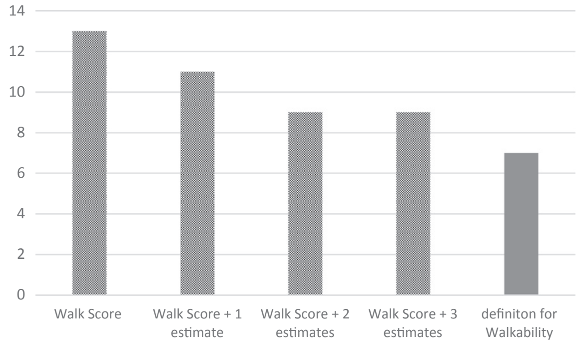

Fig. 1. The frequency of use in additional estimates for walkability, besides the Walk Score® index.

et al., 2015) and perceptions (Towne et al., 2016; Tuckel and Milczarski, 2015; Zhu et al., 2014).

3.3. What is walking?

At first sight this question seems strange, but a closer examination of the Walk Score® studies reveals that the tool has been used to assess three different types of walking: purposive walking (e.g. as mode of transport), all types of walking (regardless of purpose), and as a physical activity. Out of the seven studies that focus on the association between purposive/transport walking and Walk Score®, five based their analysis on straight lines between origin and destination (Brown et al., 2013, 2014; Gell et al., 2015; Kelley et al., 2016; Takahashi et al., 2012), one on network analysis (Barnes et al., 2016), and one did not mention its method (Wasfi et al., 2016a). All studies, except Takahashi et al. (2012) that focused on older participants (70–85 years old), supported the association between Walk Score® and purposive walking. Two of them narrowed this connection only to men (Kelley et al., 2016; Wasfi et al., 2016a).

Six studies focused on the association between Walk Score® and all types of walking. Three of them were based solely or entirely on straight line analysis (Hirsch et al., 2013; Reyer et al., 2014; Tuckel and Milczarski, 2015). Besides Reyer et al. 2014, who used an adapted Walk Score®, and indicated a significant but very small effect, none of the studies fully supported the connection between walking (in general) and the Walk Score® measure. Cole et al. (2015) and Duncan et al. (2016) found that only very low and very high Walk Score® measures can be associated to walking in general. Other studies failed to associate the Walk Score® to recreational and leisure walking (Hajna et al., 2015b; Hirsch et al., 2013; Tuckel and Milczarski, 2015). A similar situation was found regarding physical and leisure activity. Riley et al.'s (2013) analysis of straight lines and Chiu et al. (2015) network analysis did not support this connection, while Thielman et al. (2015) (network analysis) found an inverse association between Walk Score® measures and leisure walking in young adults in large population centres. Towne et al. (2016) indicated an association between Walk Score® and physical activity, but this was limited to high vs. low Walk Score® measures. In sum, regardless of the calculation method (network or straight lines) the seventeen papers that closely examined the connection between Walk Score® and walking indicated a close connection to purposive walking, primarily among men.

3.4. Walk Score® and data-driven analysis

Of the 42 papers, over half (25 papers, 60%), add Walk Score® calculations to available secondary databases, in attempting to find causal relations and patterns in the data, what Kitchin (2014) refers to as data driven science. Data driven studies added Walk Score® calculations to preventive medicine and health related data (Barnes et al., 2016; Brown et al., 2013, 2014; Chiu et al., 2015; Chiu et al., 2016; Cole et al., 2015; Herrick et al., 2016; Hirsch et al., 2013, 2014; Kelley et al., 2016; Phillips et al. 2015; Sriram et al., 2016; Thielman et al., 2015; Wasfi et al., 2016a,b; Xu and Wang, 2015a,b; Xu et al., 2015) and to housing information and prices (Kim and Woo, 2016; Li et al., 2014; Li et al., 2015; Pivo and Fisher, 2011; Renne et al., 2016). Halat et al. (2015) used a different approach when linking crime statistics with Walk Score® and predicted transport mode share. Data driven works were based on large samples (mean sample size ($n = 25$) = 28,692, SD = 70,187, median = 3899) in comparison to those that also utilized primary data – what Kitchin (2014) describes as knowledge driven studies (mean sample size ($n = 17$) = 690, SD = 924, median = 311). The studies that included a primary research component addressed a wider area of investigation, including urban trip analyses (Duncan et al., 2016; Gell et al., 2015); self-report walking surveys among old and special populations (Hajna et al., 2015b; Takahashi et al., 2012; Towne et al., 2016; Tuckel and Milczarski, 2015); analysis of the food environment (Jilcott Pitts et al., 2012); and the influence of the community on walking (Zhu et al., 2014).

3.5. The function of Walk Score® in the conceptual models of Walk Score® studies

There are two main conceptual models of the function of Walk Score® in the studies examined: causal models in which the Walk Score® can be operated as an independent variable, dependent variable or a mediating/mediator variable, and a variable in a correlation model in which the Walk Score® is associated with another variable. In 33 of the 42 (79%) studies the Walk Score® was used as an independent variable, only once as a mediating-moderating variable (Brown et al., 2014) and on no occasion as a dependent variable. In eight papers (18%) the Walk Score® was a part of a bivariate correlation model (Carr et al., 2010, 2011; Chiu et al., 2016; Duncan et al., 2011, 2013; Lee et al., 2016; Nykiforuk et al., 2016; Yin and Wang, 2016).

A closer examination of the use of Walk Score® as an independent variable indicated that most studies did not rely on it as a stand-alone variable. Frequently, the Walk Score® was coupled to transport related measures such as distance to public transport (Pivo and Fisher, 2011; Halat et al., 2015; Xu et al., 2015), public transport costs (Renne et al., 2016); Transit Score® (Barnes et al., 2016; Hirsch et al., 2013; Phillips et al. 2015); and the number of traffic collisions involving pedestrians (Li et al., 2014, 2015). Built environment characteristics were also added to Walk Score®, including transport infrastructure (highways, bicycle lanes, sidewalks) (Kim and Woo, 2016); land use (Reyer et al., 2014); intersection density (Xu and Wang, 2015a,b); distance to central business district (Brown et al., 2014); and block length and density (Gell et al., 2015). The use of socio-demographic variables has become more prevalent in late studies (Herrick et al., 2016; Xu and Wang, 2015a). Finally, in some studies additional aspects of walkability were also added to the Walk Score® as independent variables, based on GIS measures of walkable places (Hajna et al., 2015b; Li et al., 2014, 2015; Riley et al., 2013) and neighborhood cohesion (Towne et al., 2016).

3.6. *The dependent variables in the conceptual models*

The Walk Score® was used mainly to predict walking and travel behaviors (Barnes et al., 2016; Brown et al., 2013, 2014; Cole et al., 2015; Duncan et al., 2016; Gell et al., 2015; Hajna et al., 2015b; Halat et al., 2015; Hirsch et al., 2013, 2014; Kelley et al., 2016; Reyer et al., 2014; Takahashi et al., 2012; Tuckel and Milczarski, 2015; Wasfi et al., 2016a) and to assess health related risks and physical activity (Chiu et al., 2015; Herrick et al., 2016; Phillips et al., 2015; Jilcott Pitts et al., 2012; Riley et al., 2013; Sriram et al., 2016; Thielman et al., 2015; Towne et al., 2016; Wasfi et al., 2016b; Xu and Wang, 2015a,b; Xu et al., 2015). These two categories of outcomes are closely related to the idea of Walk Score® and thus suggest a possible overlap and potential spatial autocorrelation. Purposive walking, for example, is closely related to all the concepts that were mentioned above. Furthermore, validation studies of the Walk Score® established its construct and convergence validity on positive correlations with walking behaviors (Carr et al., 2010, 2011; Duncan et al., 2011, 2013) and health related measures (Chiu et al., 2016; Lee et al., 2016). Hence, a close relationship may inherently exist between Walk Score® as an independent variable and physical and travel behaviors measures as a dependent variable.

3.7. *Relationship of walking to other transport modes*

In addition to utilitarian and leisure walking, people also make decisions with respect to walking in conjunction with their use of other transport modes, e.g. automobile, bicycle, and public transport. Southworth (2005), as well as Vale et al. (2016), noted that linkages between walking and other transport modes, especially public transport, is an important factor in assessing walkability.

The current review indicates that Walk Score® studies tend to overlook the relationships between walking and other transport modes. Twenty-four papers (57%) did not include any transport information in their analysis (Fig. 2). The other papers addressed information regarding transport infrastructures (bike lanes, public station location) and regulation (speed limit) (Carr et al., 2010; Duncan et al., 2011, 2013; Halat et al., 2015; Kim and Woo, 2016; Lee et al., 2016; Li et al., 2014, 2015; Pivo and Fisher, 2011; Renne et al., 2016; Xu et al. 2015); transport mode (private cars, public transport, taxi, bikes) (Barnes et al., 2016; Cole et al., 2015; Duncan et al., 2016; Gell et al., 2015; Halat et al., 2015; Renne et al., 2016; Takahashi et al., 2012; Zhu et al., 2014); and the Transit Score® index (Barnes et al., 2016; Duncan et al., 2013; Hirsch et al., 2013). Only four papers used more than one item of transport (Barnes et al., 2016; Duncan et al., 2013; Halat et al., 2015; Renne et al., 2016). Although the Transit Score® index was introduced in 2010 (Prnewswire.com, 2010), the tool has not become widely used among students of walkability and active transport, although its potential value has been noted (Frank and Ulmer, 2013; Oswald et al., 2016). The limited impact of Transit Score® potentially corresponds to the marginal importance attached to linkage issues within Walk Score® studies as well as potential gaps in the availability of such data (Frank and Ulmer, 2013).

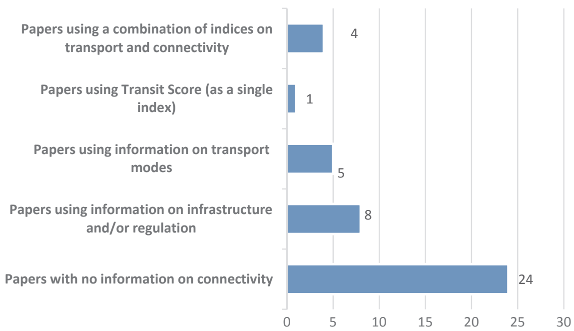

Fig. 2. Frequency of linkage of walking to transport in the reviewed papers (n = 42).

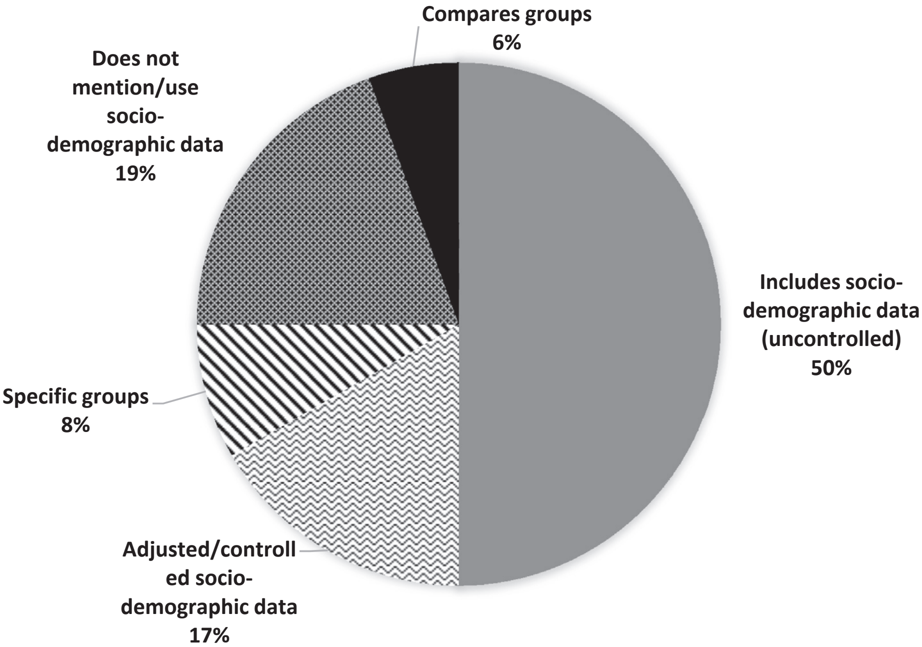

Fig. 3. Types of socio-demographic analyses in Walk Score® papers on human activity (n = 36).

3.8. The Walk Score® and walkers

Thirty-six of the 42 reviewed papers addressed human related activities and subjects (physical activities, accessibilities to amenities, relevance of the index to users and planners, health issues) while the remaining six papers focused on properties and research tools. Nevertheless, the approaches of the papers on human related activities (n = 36) varied between including socio-demographic data (individual or area based) in the analysis (n = 18, 50%), overlooking socio-demographic data (n = 7), controlling the socio-demographic data in the statistical analysis (n = 6), focusing on specific socio-demographic groups, such as women or older people (n = 3), and comparing similar groups based on socio-demographic data (n = 2) (Fig. 3).

Among the papers that addressed socio-demographic data, all but one (Brown et al., 2013) found them as significant factors in walking or physical activity. The significant factors were varied, and included: age (Thielman et al., 2015; Towne et al., 2016; Xu et al., 2015; Xu and Wang, 2015b; Wasfi et al., 2016a,b; Barnes et al., 2016); gender (Kelley et al., 2016; Reyer et al., 2014; Xu et al., 2015; Xu and Wang, 2015b; Wasfi et al., 2016a,b); and financial variables (income, poverty, property ownership– Chiu et al., 2015; Lee et al., 2016; Xu et al., 2015; Xu and Wang 2015a,b). Six works used adjusted analyses, and controlled socio-demographic data with five of them focusing on health related issues (Cole et al., 2015; Duncan et al., 2016; Hajna et al., 2015b; Hirsch et al., 2013; Sriram et al., 2016) and one on perceptions of neighborhood walkability (Tuckel and Milczarski, 2015).

Three papers examined specific groups of walkers: females (Jilcott Pitts et al., 2012), people with walking disabilities (Gell et al., 2015), and adults aged 70–85 (Takahashi et al., 2012), and two works compared between groups that shared similar socio demographic backgrounds (Chiu et al., 2016; Riley et al., 2013). All of these works were on health related issues, and while not directly focusing on socio-demographic data based their analysis on individual differences and similarities.

In seven papers, socio-demographic data was not used at all. Four of these works focused on the validation of Walk Score® by comparing it to other measurements (Carr et al., 2010, 2011; Duncan et al., 2011; Duncan et al., 2013). In addition, Halat et al. (2015) did not refer to socio-demographic data in their study regarding transport mode choice and Zhu et al. (2014) did not refer to socio-demographic profiles in their study on changes in physical activity and social interaction after moving. This may raise questions regarding the reliability of validations of Walk Score® as well some of the findings from its application, as Nykiforuk et al. (2016) noted in their work that examined the urban-rural context for physical activity: “we suggest caution in interpreting Walk Score® for planning and evaluating health promotion interventions, since the strength of association between destinations and walking may vary across different municipal types” (p. 532). The above caution was directed to different built environments, but it potentially has implications for different socio-demographic conditions as well.

3.9. Does Walk Score® support the research hypotheses?

Two key questions arise from this systematic review: Are the Walk Score® studies supported by their hypotheses? And, is the Walk Score® a reliable and valid research tool? Based on the review of the 42 papers, the best answer to these questions is ‘it depends’. As Grasser et al. (2013) mentioned, the diversity in methods, variables and respondents prevent any attempt for direct comparison between walkability papers. Hence the qualitative analysis revealed that only 15 papers (35%) show results that fully support the hypotheses regarding the Walk Score®. Walk Score® was found as a significant predictor of walking and active transport (Barnes et al., 2016; Gell et al., 2015); a significant predictor of purposive walking (Brown et al., 2013; Wasfi et al., 2016b); a significant mediator between distance to central business district and purposive walking (Brown et al., 2014); significantly associated with environmental measurements (Carr et al., 2011; Duncan et al., 2013; Yin and Wang, 2016); a significant predictor of transport mode (Halat et al., 2015); a significant predictor of health related measurements (Chiu et al., 2016; Herrick et al., 2016; Phillips et al., 2015; Jilcott Pitts et al., 2012); and a significant predictor of property values (Lee et al., 2016; Kim and Woo, 2016).

In more than half of the papers (n = 23, 55%) the results only partially supported the hypotheses. Carr et al. (2010) found a positive association between Walk Score® and the physical activity environment, but also reported a positive correlation between crime and Walk Score®. In other cases (Chiu et al., 2015; Hajna et al., 2015b; Hirsch et al., 2013; Thielman et al., 2015; Tuckel and Milczarski, 2015), Walk Score® was found to be a significant predictor of purposive walking alone, although the hypotheses were directed to other types of walking as well (i.e. leisure walking, all types of walking, daily steps). Reyer et al. (2014) found the Walk Score® was a significant predictor of active transport, but reported on a very low explained variance. Xu and Wang (2015a) reported on some outliners in which Walk Score® was positively associated with obesity. Pivo and Fisher (2011) indicated that Walk Score® predicted values of properties but was not associated with return on investment. Nykiforuk et al. (2016) limited their interpretation to urban settings. Duncan et al. (2011) noted that the associations between Walk Score® and neighborhood measurements are higher at the 1600 m buffer. Kelley et al. (2016) noted that the relations between Walk Score® and transport walking existed only for men. Similar limitations were found by Wasfi et al. (2016a) and Xu and Wang (2015b) where the inverse association between Walk Score® and BMI was found only for men. Hirsch et al. (2014) pointed at similarities in results at low levels of walkability, and stronger results in a controlled analysis. Housing related studies (Li et al., 2014, 2015; Renne et al., 2016) argued that the associations between Walk Score® and property value are relevant only in higher levels of Walk Score®. Similarly, only higher levels of Walk Score® were found as negatively associated with obesity (Sriram et al., 2016). Finally, physical activity and walking were found as positively associated to Walk Score® only if very low levels were compared to the high levels of Walk score® (Cole et al., 2015; Duncan et al., 2016; Towne et al., 2016; Zhu et al., 2014).

Four studies (9.5%) demonstrated results that did not support research hypotheses. Riley et al. (2013) found that a higher Walk Score® did not influence physical activity; Takahashi et al. (2012) indicated an insignificant association between Walk Score® and active transport; and Xu et al. (2015) noted that Walk Score® was an insignificant predictor of obesity. Talen et al. (2013) did not found a significant association between the Walk Score® index and the LEED-ND measurement (a neighborhood rating system developed in an effort to extend the certification of sustainability beyond green buildings).

In sum, in all the areas of walkability research (health, planning and transport activity) mixed results were found. It seems that stronger evidence of the validity of Walk Score® is demonstrated when higher levels of Walk Score® are compared to lower levels (a dichotomy comparison instead of continuous analysis), and when purposive walking is studied. Socio-demographic variables are found to be significant but are not always incorporated into studies.

4. Discussion, conclusions and suggestions for future research

This paper has provided a systematic review of Walk Score® studies. The growth of research that uses this metric is indicative and its capacity to integrate a range of spatial data in an accessible manner reflects the increasing shift towards data driven science (Kitchin, 2014). However, critical to the success of such integration is the quality and appropriateness of the original data sets for the purpose to which they are used. The ready availability of such a low cost and easily acquired metric for research purposes is clearly attractive to government, the private sector and public good researchers alike, especially when trying to encourage active transport and the well-being and sustainability of individuals and places. Nevertheless, this review has identified a number of areas in which greater caution in the use of Walk Score® is required as well potential further questions and challenges and suggestions for future research. These are summarized in Table 3.

4.1. Main findings of Walk Score® studies

Walking is clearly a significant human activity and encouragement of active transport is recognized as having substantial personal and collective benefits. Nevertheless, although increasingly utilized. The Walk Score® is an index of the built environment not of walking nor possibly even walkability per se (Forsyth, 2015). The results of this review suggests that the gap between the human activity of walking and Walk Score® generates mixed approaches results when analyzing the tool and its study subjects. Walk Score® is therefore best understood not as a synonym of walkability, but as a measurement for the purposive or utilitarian "walking potential" of a place (Vale et al., 2016; Taleai and Amiri 2017).

The main finding of this review indicated a pattern of mixed results. A possible explanation for this pattern could be derived from the gap that was found between the construct of walkability, which represents environmental, social and mobility-related issues and the Walk Score® assessment tool. Interestingly, this was noted by Carr et al. (2010) in one of the first assessments of Walk Score® that recommended "Walk Score be used simply as a proxy for estimating neighborhood density and access to amenities rather than a global measure of neighborhood walkability. Researchers using Walk Score in future studies are encouraged to utilize supplementary measures of the PA environment that are not addressed by Walk Score® including crime, aesthetics, topography and weather" (p. 4). Later Duncan et al. (2013) pointed that "Walk Score is valid for only certain neighborhood walkability and transit availability aspects (such as density of retail destinations, density of recreational open space, intersection density, residential density and density of subway stops), but not others (such as median pedestrian route directness, sidewalk completeness and average speed limit)" (p. 412).

Table 3
Issues arising in generalizing from Walk Score® studies.

Issue	Problems and questions	Suggestions for future research
Country of study: The vast majority of research that has utilized Walk Score® has been conducted in North America	The implications of such a limited range of locations for the application of Walk Score® has not been fully explored	Research in other developed countries as well as in developing and transition economies as Walk Score® becomes available
Definition of walkability: walkability has been conceptualized and defined in different ways, including proximity to destinations; street-connectivity, light traffic and appropriate pedestrian infrastructure; aesthetics; higher residential density; mixed land use; and a safe walking environment, all of which have demonstrated associations with destination and leisure walking	There are difficulties in comparing research findings and there is only limited capacity to generalize and validate results	To develop an acceptable definition for walkability within and between fields of study
Walkability and Walk Score® are partially overlapping concepts: Most papers (69%) do not exclusively rely on Walk Score® as a single measurement of walkability and added further estimates in order to better capture the multiple dimensions of walkability	Walk Score® was used as a measurement (or partial measurement) for purposive walking. Walking for leisure is not covered by the Walk Score® measure	Developing a reliable measurement (and potentially a plugin to Walk Score®) for leisure walking
Data driven analysis: Half of the papers are data driven and lack theoretical foundations	What transport theories underlie walking and walkability?	Conceptualize an interdisciplinary model for walkability and walking
Walk Score® as an independent variable: Walk Score® is usually used as an independent variable in studies of walking behaviors	The validity and reliability of the Walk Score® measure was not tested as a dependent variable of an explanatory model (only in correctional models). The use of Walk Score® as an independent variable suggesting a potential for autocorrelation with other variables	Use Walk Score® as a dependent variable in models of walkability to further test its validity and reliability
Connection to other transport modes: Walk Score® studies tend to overlook the relationships between walking and other transport modes	What are the connections between walking and use of other transport modes?	Exploring the impact of connections to transport modes on walking and walkability
Socio demographic profile of walkers: Various approaches have been adopted in addressing socio-demographic variables, ranging from including them in the analysis, adjusting socio-demographic variables and overlooking them altogether	Can findings be extended to all or other populations?	Greater attention to the socio-demographic aspects of walking, including: gender, race, age, minorities, culture, religious imperatives, and income
Limited support for Walk Score® as a measure of walkability: There are mixed results as to the validity of Walk Score® as a measure of walkability in all areas of walkability research (health, planning and transport activity). The stronger evidence of the validity of Walk Score® is demonstrated when higher levels of Walk Score® are compared to lower levels (a dichotomy comparison instead of continuous analysis), and when purposive walking is studied	How valid is Walk Score® as a measure of walkability?	Expanding the scope of walkability studies to other disciplines – including leisure, and tourism and economics. Meta-analysis of studies

Importantly, such caution has not necessarily been recognized in applications of the tool, especially those based mostly on secondary and pre-existing data, but also, as noted in section 3.8, the majority of research results only partly supports the validity of Walk Score® with the range of environments within which it is applied remaining limited.

4.2. Different methods and results

Critical to developing a better understanding of the metric and its potential application for active transport planning is increased field checking of its application so that it can be better calibrated/validated against objectively measured data (Frank and Ulmer, 2013). The original Walk Score® distance decay function, for example, was described by Walk Score® (2011) as being “based on our reading of travel surveys, we think the distance decay function reflects actual walking behavior” (p.5), rather than being calibrated against actual data.

Undoubtedly, there will be some relationship to what is contained in the transport and walkability literature with respect to the scores assigned to distance decay functions, but as this review and other research suggests there will also be a number of built environment, socio-cultural, gender, cohort, health and other factors that substantially influence walking behavior and which need to be considered for more effective active transport and health interventions.

The findings of this review indicate the Walk Score® assessment is sensitive to the purpose of walking (e.g. utilitarian, recreational) as well as to the gender of the walker. However, the review shows that elaborations of the Walk Score® analysis, from straight line to networks did not yield different patterns of results. The sensitivity of the Walk Score® tool to type of walking and gender has clear implications not just for academic research, but also to behavioral and planning interventions that are based on the Walk Score® assessment. Other considerations in implementation should also address the size of the urban destination. Given that improvements in walkability appear easier to implement in large population centres with dense neighbourhoods, such as older inner-city areas, than in medium and small size centres (Millward and Spinney, 2011; Nykiforuk et al., 2016). Although it should also be noted that, depending on the objectives in encouraging increased active transport, the value of a planning policy focussed solely on the walker's home neighborhood is debatable, since the majority of walking trips do not originate from the home (Millward et al., 2013). The relationship between urban land-use patterns, the nature of the built environment, the identity of the walker and her/his purpose therefore require careful consideration with as much or even greater attention being needed for the value of Walk Score® for home and non-home based walking.

Frank and Ulmer (2013) made a number of suggestions for improvements to Walk Score® including population density, urban form (e.g. building height and lot coverage), traffic volume, pedestrian/cycling infrastructure, and topography. A number of similar observations with respect to greater consideration of the built environment by Walk Score® have also been made elsewhere in the literature (e.g. Duncan et al., 2013; Hirsch et al., 2013; Nykiforuk et al., 2016), while amenity values are also important (Zuniga-Teran et al., 2017), especially for leisure walkers and tourists (Ram and Hall, 2018). Nevertheless, Walk Score® interprets walking as a form of derived demand rather than as a leisure and active transport activity in its own right, and although Walk Score® incorporates amenity categories where walking occurs, "it does not measure walking at these destinations, nor permit researchers to distinguish what proportion of a Walk Score® derives from these versus more sedentary destinations. Arguably, Walk Score® assumes a contestable normative dimension, by assigning walking to the consumption of a particular set of goods and services" (Nykiforuk et al., 2016, p. 536), and perhaps contributing further, even if unintentionally, to the further marketization of leisure consumption and active transport.

4.3. Implications for policy

For policy makers and urban planners, the paper reviews the Walk Score® measure and its advantages and disadvantages. The review suggests that the Walk Score® measure cannot be used by planners as a single measurement for walkability, but can provide important information on the walking features of a place. Furthermore, the analysis shows that socio-demographic profile of walkers must be taken into consideration when trying to promote walking, together with a greater attention to the purpose of walking (recreational or purposive). Transport planners, in particular, should develop better connectivity between different transport modes and walking facilities. Finally, the Walk Score® measurement represents a common assessment tool in which urban planners, researchers, public health specialists, real estate practitioners and transport developers can share and utilize in their studies. Hence, improving its measurability and learning how to use it more wisely may potentially assist in developing a more integrated approach to the assessment of walking in built environments

4.4. Priorities for future Walk Score® research

The review shows that the Walk Score® has clear advantages in assessing purposive walking of resident in specific built environments. However, the three conditions that appear needed for Walk Score® to accurately assess walkability (purposive walking, residents, tangible environmental factors) means that other dimensions of walkability, such as leisure walking, non-tangible variables influencing walking behavior, and non-residents, require the adoption of other forms of assessment.

In addition to potential changes to the Walk Score® algorithm itself, future Walk Score® research should clearly distinguish between walkability as a concept and Walk Score® as an assessment tool in both undertaking research and in the communication of results. Walk Score® is a potentially useful tool for measuring characteristics of the built environment but its capacity to measure overall walkability, outside of very specific walking behavior, currently appears limited. Given the growth of data driven science Walk Score® remains a potentially useful tool for researchers with its capacity to develop as a measure of utilitarian walkability. The metric will undoubtedly remain significant in the study of larger built environments especially if used in conjunction with other socio-cultural data. However, greater transparency with respect to changes in the factors that determine the Walk Score® for particular locations will be required if researchers are to use Walk Score® as a tool for longitudinal analysis. The potential of Walk Score® to contribute to research on active and sustainable transport would also greatly benefit from further studies as to its applicability to more leisure oriented walking and other pedestrian environments beyond the home, linkage to other transport modes, and a wider variety of environments.

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