Bulletin of Geography. Socio-economic Series, No. 46 (2019): 7–21
http://doi.org/10.2478/bog-2019-0031

ISSN 1732–4254 quarterly

BULLETIN OF GEOGRAPHY. SOCIO–ECONOMIC SERIES

journal homepages:
https://content.sciendo.com/view/journals/bog/bog-overview.xml
http://apcz.umk.pl/czasopisma/index.php/BGSS/index

Local walkability index: assessing built environment influence on walking

Marzieh Reisi[1, CDFMR], **Mozhgan Ahmadi Nadoushan**[2, CDFMR], **Lu Aye**[3, CDFMR]

University of Kurdistan, Department of Natural Resources, Iran, [1]email: m.reisi@uok.ac.ir, http://orcid.org/0000-0003-1700-4975 *(corresponding author),* [2]email: m.ahmadi1984@gmail.com, http://orcid.org/0000-0002-9269-1317, [3]email: l.aye@unimelb.edu.au, http://orcid.org/0000-0002-5495-1683

How to cite:
Reisi, M. Nadoushan, M.A. and Aye L. (2019). Local walkability index: assessing built environment influence on walking. *Bulletin of Geography. Socio-economic Series*, 46(46): 7-21. DOI: http://doi.org/10.2478/bog-2019-0031

Abstract. Walking is a more sustainable transport mode, and governments around the world are trying to deliver highly walkable areas to their people. Due to its importance, walkability has been a research topic in recent years. Vast empirical studies have reported evidence related to the influence of built environment on walking as a major physical activity. Considering the recent literature, this study developed a framework to quantify walkability by applying a set of indicators related to built environment. The indicators were normalised, weighted and integrated into an overall walkability index. The research was conducted on Chaharbagh Street, which is a major and ancient street in the Isfahan metropolitan area, Iran. The proposed framework would be helpful in investigations of whether a specific area is an appropriate option for a car-free plan based on its built environment features. The outcome of the study could be applied to understand issues related to pedestrian infrastructure and to propose corrective actions.

Article details:
Received: 17 February 2019
Revised: 15 July 2019
Accepted: 31 July 2019

Key words:
Environment,
Sustainability,
Town & city planning,
Transport planning

Contents:

---

1. Introduction

Walking, due to its minimal costs, is a more sustainable transport mode (Gallin, 2001). Despite the importance of walking, the current level of walking in communities is not adequate to provide health benefits, and people need more walking activities to achieve public health objectives (Giles-Corti, Donovan, 2003). Walking is one of the most popular forms of physical activity among adults (Bahrainy et al., 2015). Urban planners are interested in walking as a means of reducing vehicle miles travelled and greenhouse gas emissions (Tribby et al., 2016). Insufficient physical activity is a major risk, causing excess weight and obesity, diabetes and heart diseases (US Department of Health and Human Services, 1996).

In recent years, urban design and public health have been closely related to walkable localities (Ewing, Handy, 2009), as the ease of walking in a neighbourhood affects the liveability of urban areas and the physical activity of citizens (Burden et al., 2002). Walkability is an important concept in the context of transportation engineering, urban planning and health disciplines (Bhadra et al., 2016). Improving walkability and promoting walking in urban areas leads to wealth, health and urban sustainability (Gallin, 2001; Zayed, 2016). Consequently, policy interventions have been undertaken in urban design worldwide to promote physical activities and walking (Rebecchi et al., 2019; Sallis et al., 1998). There are numerous definitions of walkability in the current literature. Walkability can be defined as the suitability of the urban road environment for pedestrians. Walkability is also defined as supports provided by the built environment to encourage walking, including pedestrian comfort and safety, connecting people with various destinations within a reasonable amount of time and effort, and offering visual interest on journeys throughout the network (Southworth, 2005; Galanis, Eliou, 2011).

According to the public health literature, it is argued that physical environment could influence physical activity behaviours (Leslie et al., 2007). Thus, considerable efforts have been made to find a correlation between the physical environment of an area and the physical activities of people, with particular focus on walking (Hawthorne, 1989; Frank, Pivo, 1994; Bauman et al., 1996; Wright et al., 1996; Sallis et al., 1998; Owen et al., 2004). In various studies investigating walking behaviour, accessibility, connectivity, convenience, safety, aesthetic features and attractiveness were the main suggested factors affecting walking activities (Hawthorne, 1989; Bauman et al., 1996; Wright et al., 1996; Galanis, 2011; Humpel et al., 2002; Pikora et al., 2003; Giles-Corti et al., 2003; Galanis, Eliou, 2011; Tal, Handy, 2012; Motamed, Bitaraf, 2016). Ball et al. (2001) and Powell et al. (2003) found a strong relationship between convenience and level of walking. Saelens et al. (2003) believed that choice of transport for leisure, exercise or recreation depends on land use, distance, connectivity and pedestrian infrastructure. In the Asian context, land use diversity, footpath availability and quality, safety, facilities for disabled, and pedestrian amenities all influence walking trips (Efroymson, 2012). Galanis et al. (2011) measured 30 indicators, including pedestrian infrastructure, road segment, corner and crosswalk indicators in six selected roads in Greece through street audits and claimed that the measured indicators could be applied to evaluate walkability features of the pedestrian infrastructure across urban streets.

Although many attempts have been made to identify built environment indicators affecting walking, only a limited number of studies aggregate various indicators to create a single walkability index (WI) (USDG, 2007; Walkscore, 2019; CAI-Asia, 2011). Aggregating individual indicators into an index is a practical approach helping to measure various dimensions of built environment that cannot be captured completely by individual indicators alone (Zhou et al., 2007; Saisana, 2011). Frank et al. (2010) developed a walkability index for Metro Vancouver comprising residential, commercial density, land use mix and street connectivity indicators. However, a large number of effective indicators specifically related to safety are disregarded in the study. Krambeck et al. (2006) developed a global WI in specific parts of the world considering 45 indicators related to safety, convenience, attractiveness and policy support. The indicators were integrated into a single index, but there are some limitations related to integration. First, the indicators were not measured directly (i.e. to quantify the indicators, pedestrians were asked to scale each indicator using a scale from 1 to 5), which involves subjective quantification of the indicators. Secondly, despite the differing importances of the indicators, they received the same weighting during aggregation, which skews the overall index.

Gallin (2001) also defined 11 indicators affecting level of services (LOS) for pedestrians, including physical characteristics, location and user indicators. To quantify the indicators, a score of 0 to 4 was given to the selected path based on its characteristics. The score for each indicator was then multiplied by the relative weight assigned to each indicator based on stakeholders' opinions, on a scale of 1 to 5. The individual weighted score for each indicator was summed to obtain a total weighted score for the path segment. As in the previous study, indicator quantification was subjective in this research and cannot provide the true condition of the study area. Moreover, the sensitivity of priorities was not analysed.

Despite promising results, there are some challenges associated with previous studies. Many of the studies focused on self-reported perceptions of built environment factors rather than direct measurements (Humpel et al., 2002; Pikora et al., 2003). Moreover, the relative importance of built environment factors on walking behaviour has not been determined (Pikora et al., 2003). For example, San Francisco Department of Public Health (2009) developed the Pedestrian Environmental Quality Index (PEQI) to assess pedestrian safety considering a range of built environmental features including number of lanes, sidewalk width, sidewalk surface, trees, and public seating. Although using analyst-collected data provides a real understanding of street features, the indicators are not differentiated based on importance. Therefore, there is a clear need to refine measures applied for assessing the potential of a built environment for walking.

Considering the limitation of developing WI using actual measurement of built environment features, and to help in achieving public health goals related to physical activity, this research aims to develop a WI for a street in Isfahan, Iran. To achieve this aim, the built environment features were measured directly in the study area, weighted by a recognised weighting method, and aggregated into a single index.

2. Material and methods

2.1. Study area

Isfahan city, with an area of 267.6 km^2, is located at 32º39′8.86″ Northern latitude and 51º40′28.63″ Eastern longitude. With a population of 1,602,110, it is the third most populous city in Iran. Isfahan citizens experience a desert climate with an average annual temperature of 16.7ºC and 125 mm annual rainfall. According to census data, inter-city traffic accidents caused 399 deaths and 15,343 injuries in 2017, putting Isfahan in third place in Iran in terms of traffic accident frequency (National Census, 2017).

Chaharbagh Abbasi Street (Chaharbagh, for short) is one of the main historical, cultural, commercial and entertainment centres in the Isfahan metropolitan area, Iran. This historical street hosts a large number of offices, business centres and hotels and is regarded as Isfahan's central district. The neighbourhood suburbs of Chaharbagh are home to 22,900 persons making 22,130 daily trips in the surrounding areas (Saghayi & Sadeghi, 2013). Moreover, connecting people to the neighbourhood hospital and medical centres, historical buildings and Zayanderoud bayside, a large number of cars are attracted to the street. Table 1 summarises some basic characteristics of Chaharbagh Street.

Chaharbagh is a part of Isfahan's identity, and attracts pedestrians for walking, due to its particular spatial features. "Car-free Tuesday" is a local arrangement currently operating in Chaharbagh Street to motivate walking habits among Isfahan citizens. It aims to reduce traffic, fuel consumption, noise and air pollutants through specific urban design and planning for promoting active transport. Therefore, better urban design to improve walkability along the street is urgently needed.

By quantifying built environment features and identifying WI, this research investigation tries to evaluate the street's suitability for the "car-free" plan. The results of the investigation would help the local government to improve the walking experience in Chaharbagh Street. Moreover, it also would be beneficial for successful expansion of the plan to other parts of the metropolitan area, and would conse-

Table 1. Chaharbagh characteristics

Length	1.16 km
Number of car lanes	2
Number of sidewalks	3 (Two frontage sidewalks and one along the middle of street)
Sidewalk width	Min:1 m for frontages Max: 1.5 m for middle sidewalk
Bicycle lanes	2 (along the middle of the street)

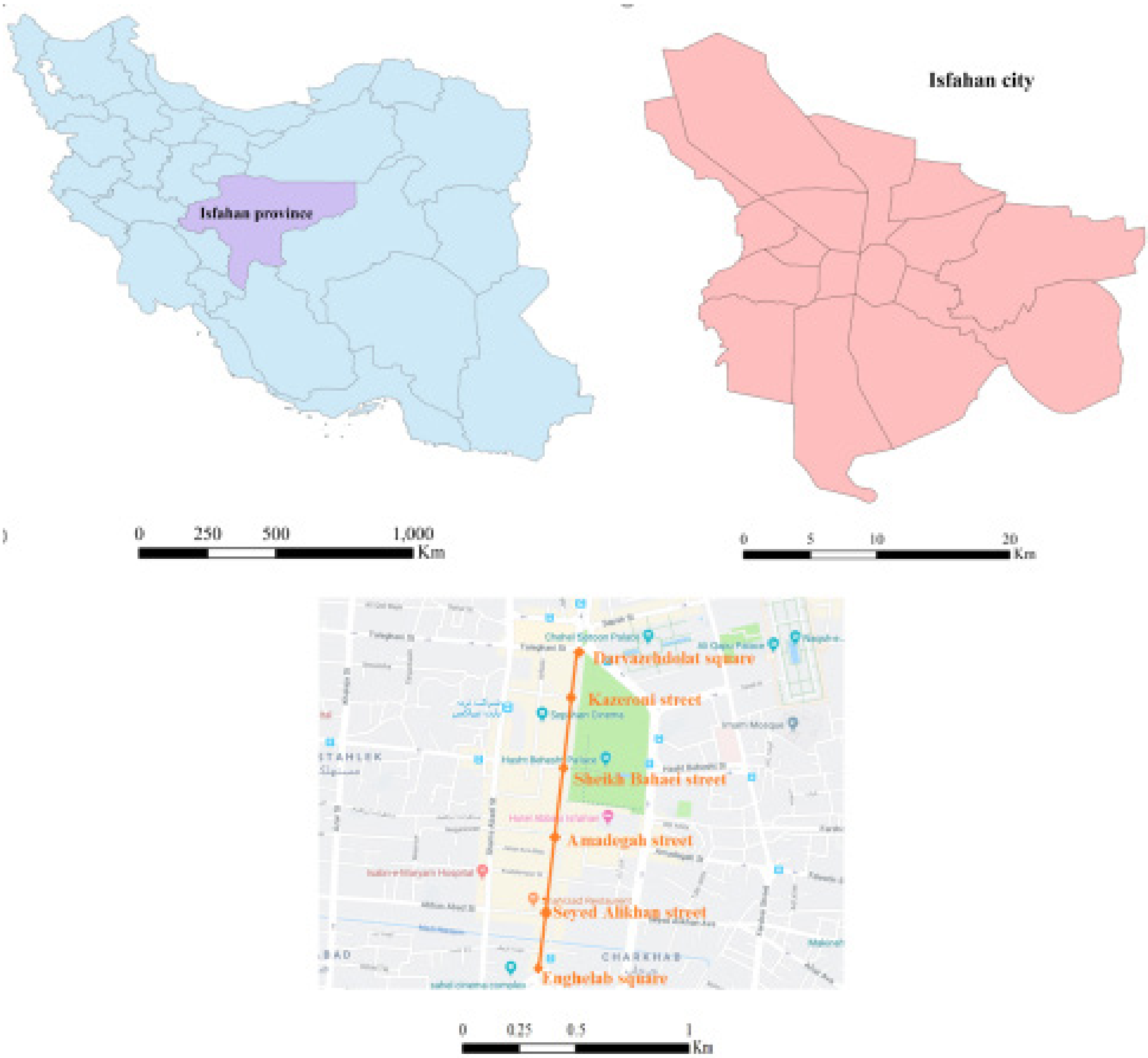

Fig.1. Study area

quently reduce transport-related environmental impacts.

To be able to normalise the indicators in the following steps, Chaharbagh Street was divided into five segments (Fig. 1):

Kazeroni,
Sheikh Bahayi,
Amadegah,
Seyed Alikhan,
Enghelab.

The segments have the same length, and each section provides specific services to citizens.

Figure 2 provides a representative view of Chaharbagh's atmosphere.

2.2. Methods

The development of the WI in this investigation is described in several steps, namely:

Selecting built environment indicators that affect walking activities,
Quantifying selected indicators,
Normalising the indicators,
Weighting the indicators,
Indicator aggregation and index composition

2.2.1. Indicator selection

The selection of indicators is the first step in developing indices such as WI. Indicators are quantitative variables that are useful for demonstrating a complex phenomenon (EEA, 2005). It is challenging to select a set of indicators that provides a comprehensive overview of the considered topic (Castillo, Pitfield, 2010). In this investigation, indicators were selected based on various selection criteria including relevancy, measurability, simplicity and data availability. Each indicator must be closely related to the definition of walkability, quantifiable and understandable by users, and the required data must be available easily and at a reasonable cost (Li et al., 2009; Dur et al., 2010; Zito, Salvo, 2011; Haghshenas, Vaziri, 2012). Reviewing the literature listing walking-related indicators (Hawthorne, 1989; Jacobs, 1993; Atash, 1994; Bauman et al., 1996; Wright et al., 1996; Gallin, 2001; Burden et al., 2002; Pikora et al., 2003; Motamed, Bitaraf, 2016) and by considering the selection criteria, 13 indicators were selected in three categories, namely: safety, quality and attractiveness (Table 2). Safety indicators are considered in response to the need to provide a liveable and safe environment for people. Quality indicators are related to the physical and structural characteristics of the street. Attractiveness indicators influence people's desire to access the place on foot.

2.2.2. Indicator quantification

The authors visited the street several times to measure the 13 selected indicators in the selected segments (i.e. counting the numbers or measuring the selected indicators) (Table 2).

2.2.3. Indicator normalisation

As the selected indicators were measured in different units, they cannot be aggregated. Therefore, it is necessary to convert the indicators to dimensionless numbers before aggregation. This process is called normalisation (Nardo et al., 2005). The selected indicators in this study contain both positive and negative values. Increasing values of positive and negative indicators have positive and negative effects on walkability, respectively. In other words, by increasing positive indicators, WI increases as well. Meanwhile, by increasing negative indicators, WI would decrease (e.g. number of lights is a positive indicator improving walkability, while obstructions are negative indicators reducing walkability). The normalisation equation differs for positive and negative indicators. Equation 1 shows the normalisation process for positive and negative indicators (Krajnc, Glavic, 2005).

$$I_N^{+} = \frac{I^{+} - I_{min}^{+}}{I_{max}^{+} - I_{min}^{+}}$$

$$I_N^{-} = \frac{I_{max}^{-} - I_{\square}^{-}}{I_{max}^{-} - I_{min}^{-}}$$

where: I_N, normalised indicator I; "+", for positive indicator; "–", for negative indicator; min, minimum value of indicator considering 4 segments; max, maximum value of indicator considering 4 segments.

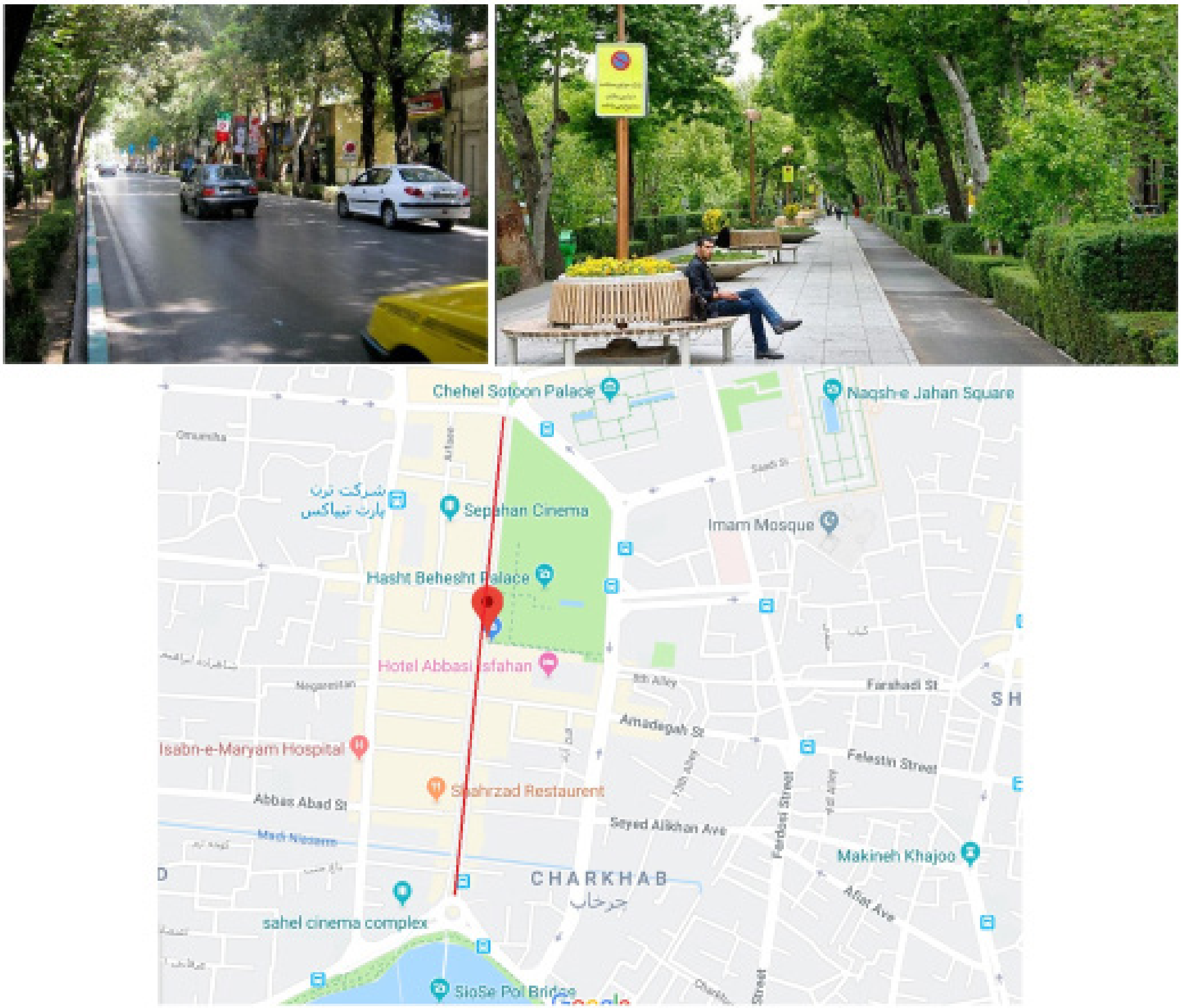

Fig. 2. Chaharbagh's atmosphere (http://www.qudsonline.ir, https://www.google.com/maps)

2.2.4. Indicator weighting

Weight of indicator shows the relative importance and influence that each considered indicator has on walkability. As the weights given to various indicators influence the outcome of the created indices, a transparent method is needed for weighting (Freudenberg, 2003; Juwana, 2012). Analytical Hierarchy Process (AHP) was applied for weighting indicators in this study. AHP is a multi-criterion decision-making method, helping decision-makers by decomposing a complex problem into a hierarchical structure of aim and related criteria and sub-criteria. To find indicator weights, AHP performs pairwise comparisons among indicators in each level of the hierarchy. Pairwise comparisons are made between pairs of indicators, showing the importance of one indicator compared to the other. The importance is quantified based on experts' judgments on a scale of 1 to 9, where 1 indicates equal importance of paired indicators, while 9 indicates that one indicator is nine times more important than the other (Saaty, 1990; Albayrak, Erensal, 2004; Sharna et al., 2008; Gorener, 2012). Considering pairwise comparisons, the relative weight of each indicator is calculated. Priorities are not assigned arbitrarily in AHP but are derived based on experts' judgments and preferences. Therefore, the priorities have mathematical validity (Mu, Pereyra-Rojas, 2016). One of the main aspects of pairwise comparisons which should be considered during AHP is consistency of judgments. Consistency ratio (CR), which demonstrates the coherence of judgments, should be 0.1 at maximum. In other words, CR of 0.10 or less would be acceptable (Borajee, Yakchali, 2011; Aragonés-Beltrán et al., 2014). The weighting procedure using AHP is described in detail in Appendix 1.

2.2.5. Indicator aggregation and index composition

The indicators were aggregated using the weighted linear combination (WLC) method (Mahini, Gholamalifard, 2006) (Eq. 2). WLC is a form of index overlay technique, considering the normalised value and relative weights of indicators in aggregation (Al-shabeeb, 2015).

$$WI = \sum W_{ij} X_{ij}$$

where:
WI = Walkability index
W_i = Weight of indicator *i* in category *j*
X_i = Normalised value of indicator *i* in category *j*

The normalised value of each indicator in each category was multiplied by the relative weights of the indicators extracted using AHP in the previous stage. The weighted values of indicators in each category were then integrated into a sub-index. In the final stage, the weight of each category was multiplied by the sub-index value and aggregated into the single WI (Gallin, 2011).

3. Results

Pairwise comparisons and weight assignment based on the AHP method were conducted using Expert Choice software. The problem (walkability index development) was decomposed into a hierarchical structure comprising goal, categories and indicators (Fig. 3). In each level, the indicators were compared pairwise according to their level of influence, using the judgments of local experts in urban planning and design, transport planning and public health. The calculated weights of categories and indicators are illustrated in Figs 4–7. As the CR was 0.02, the judgments were considered consistent and could be applied for weight calculation.

The normalised value for each indicator was then multiplied by its relative weight. The individual weighted scores for each indicator were summed to obtain a sub-index for each category and then the weighted sub-indices for each category were summed to get the final value of WI for the selected street segments (Table 3). The developed indices are applicable for evaluating the current situation of built environment features in Chaharbagh and their capability to promote walking. Segment 3 was ranked top in safety and attractiveness. Segment 1 was ranked top in safety. Considering overall WI, Segments 1 and 4 were ranked as the most and least walkable segments, respectively.

The priorities assigned to each segment are mainly influenced by the weights given to the evaluated indicators. Therefore, it would be beneficial to perform a “what-if” analysis to see how the final priorities would change if the indicator weights were different. This process is called sensitivity analysis (Mu, Pereyra-Rojas, 2016). A sensitivity analysis was conducted to test the accuracy and robustness of multi-criterion decisions through variation of indicators. In other words, it can be applied for model validation. Indicators’ values and weights could be evaluated in sensitivity analysis. However, due to their subjectivity, indicator weights are more important than values in sensitivity analysis. If the ranking of the alternatives remains unchanged after sensitivity analysis, it could be concluded that the results of the multi-criterion decision analysis are sufficiently accurate and robust. Otherwise, the indicator weights should be redefined (Goh, Noborio, 2015; Rikalovic et al., 2015).

To test the sensitivity of the AHP model developed in this study, the indicator weights were varied by ±20%. The results showed that the priorities of segments were not changed as a result of a 20% change in the weight of indicators (Fig. 8).

4. Highlights

The contribution of the current study to the field could be summarised as follows:

- A framework to quantify walkability using a set of indicators was developed.
- Thirteen physical environment indicators were integrated into a single walkability index.

Table 1. Chaharbagh characteristics

Length	1.16 km
Number of car lanes	2
Number of sidewalks	3 (Two frontage sidewalks and one along the middle of street)
Sidewalk width	Min:1 m for frontages Max: 1.5 m for middle sidewalk
Bicycle lanes	2 (along the middle of the street)

Table 2. Selected built-environment indicators affecting walkability

Category	Indicator	Ways of measurement	Overall along entire street
Safety	Lighting	Number of lights	86
	Crossing availability	Number of facilities provided to assist in the safe crossing of Chaharbagh Street by pedestrians, including median refuges, pelican crossings, guarded crossings, crosswalks, underpasses and overpasses	7
	Potential for vehicle conflicts	Number of potential vehicle conflict points along Chaharbagh including intersections	8
Quality	Sidewalk width	Average sidewalk width along the street including middle and frontages [m]	1.16 m
	Obstructions	Number of obstacles e.g. poles, signs, chairs along sidewalks, both middle and frontages. Stairs are considered an obstruction if no alternative is available for people with mobility disabilities	53
	Support facilities	Number of facilities that assist pedestrians during their journey along the entire street, including tactile paving, colour-contrast kerbing, kerb ramps, lane markings signage, landings on long ramps	19
	Facilities for disabled people	Number of ramps for disabled people along the road and sidewalks	4
Amenities and Attractions	Natural features (trees) or parks	Area (m^2) along Chaharbagh	21,400 m^2
	Cinemas, cultural centres (historical places, architecture)	Number	5
	Retail trade/ gastronomy / services	Area (m^2)	45,600 m^2
	Fixed furniture: presence of benches and other places to rest	Number	23
	Public toilets	Number	2
	Public transportation	Number of stations	3

- The framework could be applied for corrective actions in urban design.

5. Discussion and Conclusions

This investigation quantified 13 built environment indicators under three categories (safety, quality, attractiveness) affecting walkability in Chaharbagh Street. A walkability index was defined and developed by assigning weights to the indicators by their importance, and integrating them into a single WI. It provides a quantitative benchmark to explore walkability potential provided by the street, as well as determining factors contributing to the resultant WI. The effect of built environment intervention on walkability of an area is widely accepted (Frank et al., 2006; Christian et al., 2011; Boulange et al., 2017). While other studies applied public inputs for qualifying built environment features, in this study built environment features and their effects on walkability were investigated and quantified based on field measurements. Therefore, the

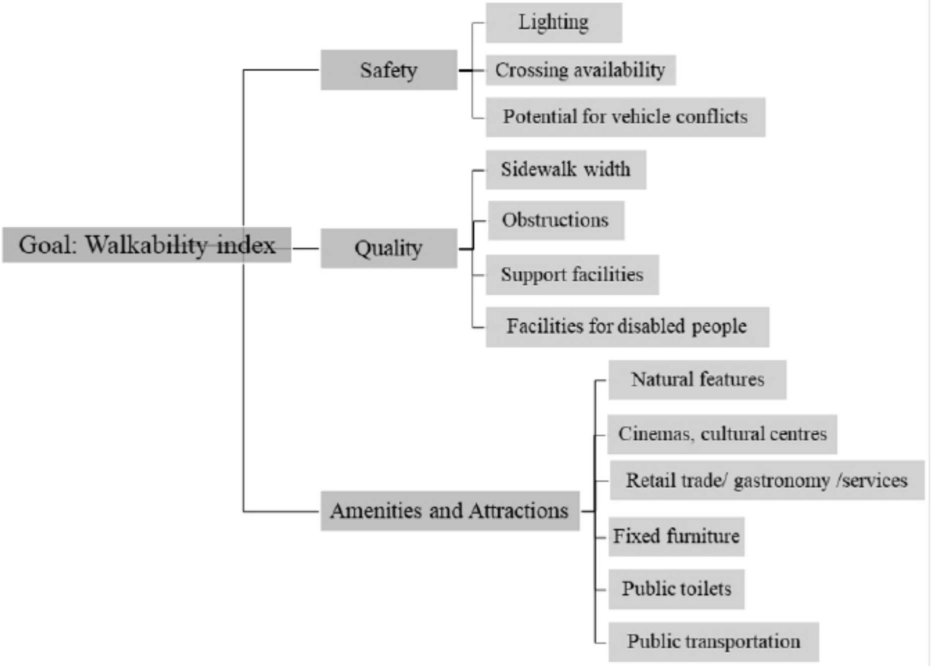

Fig. 3. Hierarchical structure of the aim

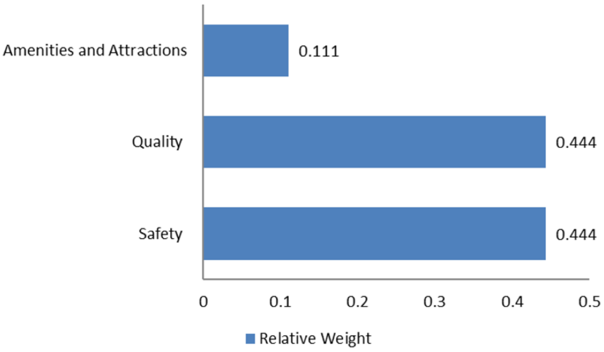

Fig. 4. Category weights using AHP

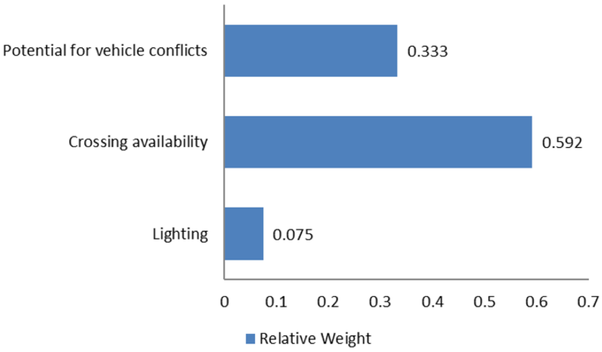

Fig. 5. Safety indicator weights using AHP

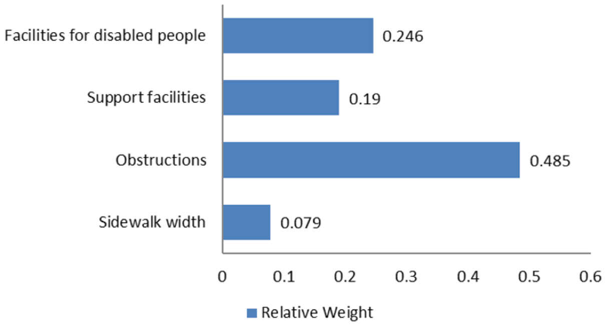

Fig. 6. Quality indicator weights using AHP

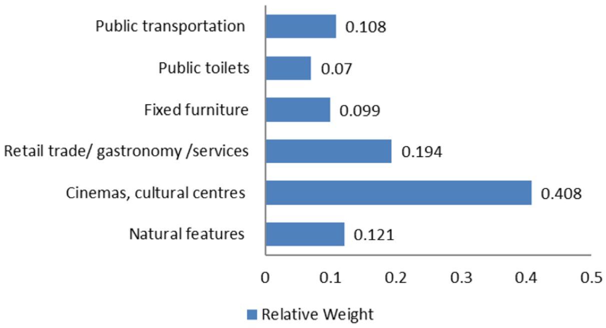

Fig. 7. Attractiveness indicator weights using AHP

Table 3. Sub-indices and WI for selected segments

Segment	Safety	Quality	Attractiveness	WI
1	0.328	0.216	0.122	0.248
2	0.185	0.200	0.258	0.201
3	0.189	0.228	0.267	0.217
4	0.106	0.175	0.217	0.153
5	0.192	0.181	0.136	0.180

results of the study could be a starting point for developing evidence-based urban planning strategies to promote walking. The transparent and understandable approach to indicator selection, quantification, weighting and index development could also help decision-makers in finding characteristics of the built environment that need improvement to reach high walkability levels. Moreover, with reduced funds for motorised transport, finding areas with the potential to offset automobile use, and to reduce traffic congestion and air pollutants, is rewarding.

Despite introducing car-free Tuesday to promote walking, no built environment interventions are conducted to encourage walking in Chaharbagh. Therefore, to promote walking, the right mix of interventions is needed for the study area. The developed indicators and the overall WI in this study are well suited to evaluating the Chaharbagh pedestrian system and determining improvements needed for the street. According to the results, the existing support facilities, crossing availability, facilities for the disabled, public toilets and public transport stations are insufficient to encourage walking, and improvements are needed in these aspects. On the other hand, the whole street provides outstanding mixed use, which attracts a large number of people to Chaharbagh Street. With sub-indices and overall WI below 0.5 in all segments, it could be concluded that Chaharbagh Street design could not be supportive for a car-free plan in its current form and more facilities are needed to encourage walking. In other words, safety, design and attractiveness are not at a level to encourage walking as a means to reduce the environmental impacts of other modes of transport.

Despite the applicability of the obtained results for urban planning, some challenges are associated with the investigation, including:

1. Selection of walkability indicators: Selecting a set of indicators which provides a comprehensive overview of the considered system is challenging (Castillo, Pitfield, 2010). While selecting a small number of indicators is convenient, it may overlook important impacts. On the other hand, a large number of indicators is comprehensive, but collection and analysis costs may be prohibitive. Relevancy, measurability, simplicity and data availability were considered important selection criteria in this investigation.

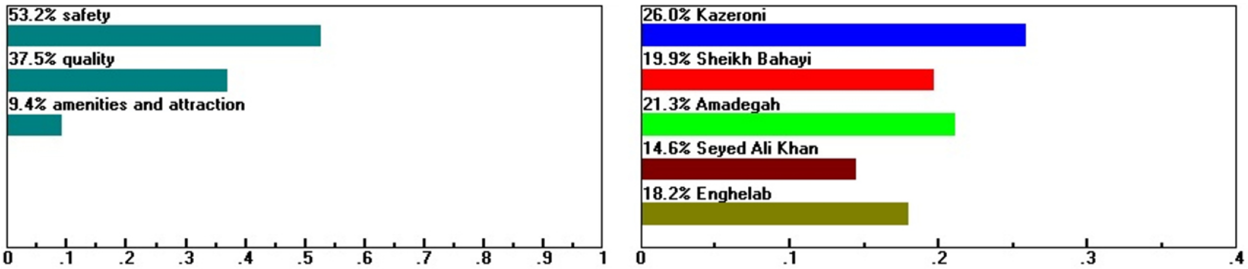

Fig. 8. Sensitivity analysis for +20% changes in 'Safety' weight

2. Weighting: Assigned weights using pairwise comparisons could be highly subjective, as they are subject to experts' judgments. However, the acceptable consistency ratio and robustness of assigned weights confirmed that a high level of agreement among respondents was achieved in this study and the results are valid.
3. Single index development: Despite wide-ranging benefits of composite indices, there are ideas both for and against indices. There are some ideas against composite indices due to the subjectivity in their creation (Cherchye et al., 2004). Moreover, it is believed that no single index can answer all questions and there is a need for multiple indicators (Jollands, 2003). On the other hand, some researchers considered composite indices to be valuable communication tools because they limit the amount of presented information and allow for quick and easy comparisons (Freudenberg, 2003). These two ideas are two sides of the coin and it can be concluded that indicator aggregation is successful if clear assumptions and methodology are used and if the index can be disaggregated to its components (Jollands, 2003).

Overall, considering the usefulness of applying a walkability index for urban design and planning, it is recommended to identify WI for other parts of Isfahan Metropolitan or even Iran. It would be beneficial for the local governments in designing more liveable cities and promoting public health.

References

Al-Shabeeb, A.R.R. (2015). A modified analytical hierarchy process method to select sites for groundwater recharge in Jordan, Department of Geography.

Albayrak, E. and Erensal, Y.C. (2004). Using analytic hierarchy process (AHP) to improve human performance: An application of multiple criteria decision making problem. *Journal of Intelligent Manufacturing*, 15(4): 491-503. DOI: https://doi.org/10.1023/B:JIMS.0000034112.00652.4c

Alonso, J.A. and Lamata, M.T. (2006). Consistency in the analytic hierarchy process: a new approach. *International journal of uncertainty, fuzziness and knowledge-based systems*, 14(4): 445-459. DOI: https://doi.org/10.1142/S0218488518500095

Aragonés-Beltrán, P. Chaparro-González, F. Pastor-Ferrando, J.P. and Pla-Rubio, A. (2014) An AHP (Analytic Hierarchy Process)/ANP (Analytic Network Process)-based multi-criteria decision approach for the selection of solar-thermal power plant investment projects. *Energy*, 66: 222-238. DOI: https://doi.org/10.1016/j.energy.2013.12.016

Atash, F. (1994). Redesigning suburbia for walking and transit: Emerging concepts. *Journal of urban planning and development*, 120(1): 48-57. DOI: https://doi.org/10.1061/(ASCE)0733-9488

Bahrainy, H. Khosravi, H. Aliakbari, F. and Khosravi, F. (2015). The Impact of Built Environment on Walkability, Case Study: North-West of Shiraz. *Armanshahr Architecture & Urban Development*, 8(14): 105-117.

Ball, K. Bauman, A. Leslie, E. and Owen, N. (2001). Perceived environmental aesthetics and convenience and company are associated with walking for exercise among Australian adults. *Preventive medicine*, 33(5): 434-440. DOI: https://doi.org/10.1006/pmed.2001.0912

Bauman, A. Wallner, F. Miners, A. and Westley-Wise, V. (1996). No ifs no buts Illawarra physical activity project: Baseline research report. Warrong, NSW: Commonwealth Department of Health and Family Services.

Bhadra, S. Tanbir Sazid, A.K.M. and Esraz-Ul-Zannat, M. (2016). A GIS Based Walkability Measurement within the Built Environment of Khulna City, Bangladesh. *Journal of Bangladesh Institute of Planners*, 8: 145-158.

Borajee, M. and Yakchali, S.H. (2011). Using the AHP-ELECTRE III integrated method in a competitive profile matrix. International Conference on Financial Management and Economics, Hong Kong.

Boulange, C. Pettit, C. and Giles-Corti, B. (2017). The walkability planning support system: An evidence-based tool to design healthy communities. International Conference on Computers in Urban Planning and Urban Management, Australia.

Brownson, R.C. Baker, E.A. Housemann, R.A. Brennan, L.K. and Bacak, S.J. (2001). Environmental and policy determinants of physical activity in the United States. *American journal of public health*, 91(12): 1995-2003. DOI: https://doi.org/10.2105/AJPH.2018.304649

Burden, D. Davis, D. Sprowls, S. Zykofsky, P. and Wallwork, M. (2002). Street Design Guidelines for Healthy Neighborhoods. Calif: Center for Livable Communities.

CAI-Asia. (2011). Walkability in Indian Cities, the Clean Air Initiative for Asian Cities. Clean Air Initiative for Asian Cities Center (http://www.cleanairinitiative.org).

Castillo, H. and Pitfield, D.E. (2010). ELASTIC–A methodological framework for identifying and selecting sustainable transport indicators. *Transportation Research Part D: Transport and Environment*, 15(4): 179-188. DOI: https://doi.org/10.1016/j.trd.2014.11.017

Cherchye, L. Moesen, W. and Puyenbroeck, T. (2004). Legitimately diverse, yet comparable: on synthesizing social inclusion performance in the EU. *JCMS: Journal of Common Market Studies*, 42(5): 919-955. DOI: https://doi.org/10.1111/jcms.12519

Christian, H.E. Bull, F.C. Middleton, N.J. Knuiman, M.W. Divitini, M.L. Hooper, P. and Giles-Corti, B. (2011). How important is the land use mix measure in understanding walking behaviour? Results from the RESIDE study. *International Journal of Behavioral Nutrition and Physical Activity*, 8(1): 55. DOI: 10.1186/s12966-015-0269-2

Dur, F. Yigitcanlar, T. and Bunker, J. (2010). Towards sustainable urban futures: evaluating urban sustainability performance of the Gold Coast, Australia. Proceedings of the 14th IPHS conference: urban transformation: controversies, contrasts and challenges.

EEA. (2005). EEA core set of indicators:Guide. Retrieved from Copenhagen.

Efroymson, D. (2012), Moving dangerously, moving pleasurably: Improving walkability in Dhaka: Using a BRT walkability strategy to make Dhaka's transportation infrastructure Pedestrian-Friendly.

Ewing, R. and Handy, S. (2009). Measuring the unmeasurable: Urban design qualities related to walkability. *Journal of Urban Design*, 14(1): 65-84. DOI: doi.org/10.1080/13574809.2018.1554997

Frank, L. Devline, A. Johnstone, S. and Loon, J. (2010). Neighbourhood Design, Travel, and Health in Metro Vancouver: Using a Walkability Index. University of British Columbia.

Frank, L.D. and Pivo, G. (1994). Impacts of mixed use and density on utilization of three modes of travel: single-occupant vehicle, transit, and walking. *Transportation research record*, 1466: 44-52. DOI: https://doi.org/10.3141/2323-07

Freudenberg, M. (2003). Composite indicators of country performance. OECD Publishing.

Galanis, A. and Eliou, N. (2011). Evaluation of the pedestrian infrastructure using walkability indicators. *WSEAS Transactions on Environment and Development*. 7(12): 385-394. DOI: https://doi.org/10.1016/S0950-0618 (02)00004-1

Gallin, N. (2001). Quantifying pedestrian friendliness-guidelines for assessing pedestrian level of service. Road and Transport Research, 10(1): 47-55. DOI: https://doi.org/10.1007/s11116-006-9107-3

Giles-Corti, B. and Donovan, R.J. (2003). Relative influences of individual, social environmental, and physical environmental correlates of walking. *American journal of public health*, 93(9): 1583-1589. DOI: https://doi.org/10.2105/AJPH.2018.304585

Goh, E.G. and Noborio, K. (2015). Sensitivity Analysis and Validation for Numerical Simulation of Water Infiltration into Unsaturated Soil. International scholarly research notices.

Görener, A. (2012). Comparing AHP and ANP: an application of strategic decisions making in a manufacturing company. *International Journal of Business and Social Science*, 3(11). DOI: https://doi.org/10.30845/ijbss

Haghshenas, H. and Vaziri, M. (2012). Urban sustainable transportation indicators for global comparison. *Ecological Indicators*, 15(1): 115-121. DOI: https://doi.org/10.1016/j.ecolind.2006.01.003

Hawthorne, W. (1989). Why Ontarians Walk, Why Ontarians Don't Walk More: A Study into the Walking Habits of Ontarians: Energy Probe Research Foundation.

Humpel, N., Owen, N. and Leslie, E. (2002). Environmental factors associated with adults' participation in physical activity: a review. *American Journal of preventive medicine*, 22(3):188-199. DOI: https://doi.org/10.5455/ajpmph.281781

Jacobs, A.B. (1993). Great streets. *ACCESS Magazine*, 1(3).

Jollands, N. (2003). The usefulness of aggregate indicators in policy making and evaluation: a discussion with application to eco-efficiency indicators in New Zealand.

Juwana, I. (2012). Development of a water sustainability index for West Java,Indonesia. Victoria university.

Krajnc, D. and Glavič, P. (2005). A model for integrated assessment of sustainable development. Resources, *Conservation and Recycling*, 43(2): 189-208. DOI: https://doi.org/10.1016/j.resconrec.2004.06.002

Krambeck, H.V. (2006). The global walkability index. (Master's), Massachusetts Institute of Technology.

Leslie, E., Coffee, N., Frank, L. and Owen, N. (2007). Walkability of local communities: Using geographic information systems to objectively assess relevant environmental attributes. *Health & Place*, 13: 111-122. DOI: https://doi.org/10.1016/j.healthplace.2005.11.001

Li, F., Liu, X., Hu, D., Wang, R., Yang, W., Li, D. and Zhao, D. (2009). Measurement indicators and an evaluation approach for assessing urban sustainable development: A case study for China's Jining City. *Landscape and Urban Planning*, 90(3): 134-142. DOI: https://doi.org/10.1016/j.landurbplan.2008.10.022

Mahini, A.S. and Gholamalifard, M. (2006). Siting MSW landfills with a weighted linear combination methodology in a GIS environment. *International Journal of Environmental Science & Technology*, 3(4), 435-445. DOI: https://doi.org/10.1016/j.wasman.2010.01.015

Motamed, B. and Bitaraf, A. (2016). An empirical assessment of the walking environment in a megacity: Case study of Valiasr Street ArchNet-IJAR, 10(3). DOI: https://doi.org/10.26687/archnet-ijar.v10i3.1024

Mu, E. and Pereyra-Rojas, M. (2016). Practical Decision Making: An Introduction to the Analytic Hierarchy Process (ahp) Using Super Decisions (Vol. 2): Springer.

Nardo, M., Saisana, M., Saltelli, A. and Tarantola, S. (2005). Tools for composite indicators building.

National Census. (2017). Traffic accident census. http://transportsafety.ir/

Owen, N., Humpel, N., Leslie, E., Bauman, A. and Sallis, J.F. (2004). Understanding environmental influences on walking: review and research agenda. *American Journal of preventive medicine*, 27(1): 67-76. DOI: https://doi.org/10.1016/j.amepre.2004.03.006

Pikora, T., Giles-Corti, B., Bull, F., Jamrozik, K. and Donovan, R. (2003). Developing a framework for assessment of the environmental determinants of walking and cycling. *Social science & medicine*, 56(8): 1693-1703. DOI: 10.1016/S0277-9536(02)00163-6.

Powell, K.E., Martin, L.M. and Chowdhury, P.P. (2003). Places to walk: convenience and regular physical activity. *American Journal of public health*, 93(9): 1519-1521. DOI: https://doi.org/10.2105/AJPH.93.9.1519

Rebecchi, A., Buffoli, M., Dettori, M., Appolloni, L., Azara, A., Castiglia, P., D'Alessandro, D., Capolongo, S. (2019). Walkable Environments and Healthy Urban Moves: Urban Context Features Assessment Framework Experienced in Milan. *Sustainability*, 11 (10): 1-18. DOI: https://doi.org/10.3390/su11102778

Rikalovic, A., Cosic, I., Labati, R.D. and Piuri, V. (2015). A Comprehensive Method for Industrial Site Selection: The Macro-Location Analysis. *IEEE Systems Journal*, 11(4): 2971-2980. DOI: https://doi.org/10.1109/JSYST.2015.2444471

Saaty, T.L. (1990a). Decision making for leaders: the analytic hierarchy process for decisions in a complex world: RWS publications.

Saaty, T.L. (1990b). How to make a decision: the analytic hierarchy process. *European Journal of operational research*, 48(1): 9-26. DOI: https://doi.org/10.1016/0377-2217(90)90057

Saelens, B.E. Sallis, J.F. and Frank, L.D. (2003). Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. *Annals of behavioral medicine*, 25(2): 80-91. DOI: https://doi.org/10.1207/S15324796ABM2502_03

Saghayi, M. Sadeghi, Z. (2013). Mid-term planning for using bicycle to achieve sustainable development: Isfahan center case study, *Urban Planning and Research*, 4(12): 95-116.

Saisana, M. (2011). Weighting methods, Seminar on composite Indicators: From Theory to Practice, Ispra.

Sallis, J. Bauman, A. and Pratt, M. (1998). Environmental and policy interventions to promote physical activity. *American Journal of preventive medicine*, 15(4): 379-397. DOI: https://doi.org/10.1016/S0749-3797(98)00076-2

San Francisco Department of Public Health. (2008). The Pedestrian Environmental Quality Index (PEQI): An assessment of the physical condition of streets and intersections, San Francisco: San Francisco Department of Public Health.

Sharma, M.J. Moon, I. and Bae, H. (2008). Analytic hierarchy process to assess and optimize distribution network. *Applied Mathematics and Computation*, 202(1): 256-265. DOI: https://doi.org/10.1016/j.procs.2015.07.005

Southworth, M. (2005). Designing the walkable city. *Journal of urban planning and development*, 131(4): 246-257. DOI: https://doi.org/10.1061/(ASCE)0733-9488

Tal, G. and Handy, S. (2012). Measuring nonmotorized accessibility and connectivity in a robust pedestrian network. *Transportation Research Record: Journal of the Transportation Research Board*, 2299(1): 48-56. DOI: https://doi.org/10.3141/2299-06

Tribby, C.P. Miller, H.J. Brown, B.B. Werner, C.M. and Smith, K.R. (2016). Assessing Built Environment Walkability using Activity-Space Summary Measures. *J Transp Land Use*, 9(1): 187–207. DOI: https://doi.org/10.5198/jtlu.2015.625

US Department of Health and Human Services. (1996). Physical activity and health: a report of the Surgeon General: Diane Publishing.

USDG. (2007). Urban Street Design Guidelines. City of Charlotte, Charlotte, NC.

Walkscore. (2019). www.walkscore.com.

Wright, C. MacDougall, C. Atkinson, R. and Booth, B. (1996). Exercise in daily life: supportive environments. Canberra, Commonwealth Government of Australia.

Zayed, M.A.A. (2016). The effect of landscape elements on walkability in Egyptian gated communities. *ArchNet-IJAR, Archnet International Journal of Architectural Research*, 10(2): 113-129. DOI: https://doi.org/10.26687/archnet-ijar.v10i2.956

Zhou, P. Ang, B. and Poh, K. (2007). A mathematical programming approach to constructing composite indicators. *Ecological economics*, 62(2): 291-297. DOI: https://doi.org/10.1016/j.ecolecon.2006.12.020

Zito, P. and Salvo, G. (2011). Toward an urban transport sustainability index: an European comparison. *European Transport Research Review*, 3(4): 179-195. *DOI*: https://doi.org/10.1007/s12544-011-0059-0

Appendix

The pairwise comparison matrix of the indicators involved in the decision was completed by experts using a value from 1 to 9 to reflect the experts' relative preference (also called "judgment") in each of the compared pairs. For example, according to experts' judgments, safety is very much more important than quality (i.e. the intersection of the row "safety" and column "quality" contains the value 7). For reverse comparison, the importance of "quality" relative to the importance of "safety" would be the reciprocal of this value (quality/safety = 1/7) as shown in Table A1. When the importance of an indicator is compared with itself, the input value is 1, which corresponds to an intensity of equal importance.

It is worth noting that for combining the judgments of various experts, the geometric mean was applied to form one single pairwise comparison matrix (Saaty, 1990).

TA1

The procedure of calculating indicator weights from a pairwise comparison matrix has several steps including:

1) Adding the values in each column,

2) Dividing each cell by the total of the column,

3) Calculating the average value of each row to find final weights (Mu, Pereyra-Rojas, 2016).

After calculating the weights, it is necessary to check the consistency of the judgments. In a comparison matrix, if a value of 2 is provided as the importance of the first indicator over the second and a value of 3 is assigned as the importance of the

Table A1. Pair wise comparison matrix for categories

	Safety	**Quality**	**Attractiveness**
Safety	1	7	8
Quality	1/7	1	2
Attractiveness	1/8	1/2	1

second indicator with respect to the third, the importance of the first indicator with respect to the third should be 2×3 = 6, for a consistent judgment. Assigning a value other than 6 would result in a level of inconsistency in the matrix of judgments. Therefore, some inconsistency is expected in AHP analysis as the result of the subjective preferences of experts (Mu, Pereyra-Rojas, 2016). To calculate consistency for the study, several steps were undertaken:

1) Each value in the first column of the comparison matrix was multiplied by the first indicator weight. This process was continued for all columns of the comparison matrix, resulting in a weighted matrix.

2) The values in each row of the weighted matrix were added to obtain values called "weighted sum".

3) The elements of the weighted sum were divided by the corresponding indicator weight and averaged to extract λmax.

4) The consistency index (CI) was calculated using Eq. A1:

$$\mathrm{C.I} = {(\lambda_{\max} - n)}/{(n-1)}$$

Where n = number of compared indicators

5) Consistency ratio was obtained using Eq. A2:

$$\mathrm{CR} = {\mathrm{CI}}/{\mathrm{RI}}$$

Where RI = Random consistent index presented by (Alonso, Lamata, 2006) based on number of selected indicators.

As mentioned earlier, all steps for weights and consistency calculation were conducted using Expert Choice software in this study.

Ministry of Science and Higher Education
Republic of Poland

The proofreading of articles, positively reviewed and approved for publishing in the 'Bulletin of Geography. Socio-economic Series', was financed from the funds of the Ministry of Science and Higher Education earmarked for activities popularizing science, in line with Agreement No 695/P-DUN/2018.