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Application of multi-criteria decision analysis methods for assessing walkability: A case study in Porto Alegre, Brazil

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A R T I C L E I N F O

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A B S T R A C T

The concept of walkability refers to the extent to which a neighbourhood is walking-friendly. Several walkability indexes have been developed to quantify and evaluate the pedestrian environment. These indexes differ in terms of type of data, methods and goals. The indexes variables may present either uniform or distinct weights, defined by arbitrary, empirical or other diverse weighting methods. This paper pursues the determination of a weighted walkability index, constructed on the basis of the relative importance of their attributes. Weights were determined by the application of the Fuzzy Analytic Hierarchy Process (FAHP), a robust multi-criteria method which considers the experts' uncertainty in decision making. Moreover, FAHP weights were compared with the attribute weights obtained from other simpler methods, and a chi-square test for homogeneity was computed to compare the obtained values. The three most important walkability attributes were: *Public Security*, *Traffic Safety* and *Pavement Quality*, similar results to the ones found in the literature. The application to a case study in the city of Porto Alegre, Brazil, allowed categorizing the studied neighbourhoods and to analyse the effect of changes on attributes in walkability.

1. Introduction

Walking trips are vital for the sustainable development of urban spaces: they improve the quality of life, reduce the cost of transport, reduce environmental impacts, and offer more equity of access to urban activities (Brownson et al., 2009; Tribby et al., 2016; Zhu and Chen, 2016). Streets, sidewalks, parks, squares, and other characteristics of the urban environment have an important role in encouraging this transportation mode, so they can make some places more inviting and more walkable than others (Ewing and Clemente, 2013). Studies show that the urban environment can influence walking behaviour. There are more than 200 studies in the literature (e.g. Sung and Lee, 2015; Curiel-Esparza et al., 2016; Singh, 2016; Lindelöw et al., 2017; Moura et al., 2017; Tribby et al., 2017), at least 13 literature reviews (e.g. Saelens et al., 2003; Saelens and Handy, 2008; Pont et al., 2009; Vale et al., 2016), and two meta-analyses (Ewing and Cervero, 2001, 2010) that verify, to a greater or lesser extent, this relationship (Tian and Ewing, 2017).

The walkability concept has been used in several studies to describe the quality of walking conditions, including safety, comfort, and convenience. Walkability refers to the extent to which the urban environment is walking-friendly (Burden, 2001; Litman, 2003). Several walkability indices have been presented to quantify and evaluate the pedestrian environment, such as those developed by

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Bradshaw (1993), City of Portland (1998), Allan (2001), Ray and Bracke (2002), Moudon et al. (2002), Dannenberg (2004), Krambeck (2006), Walkscore.com (2010), Vargo et al. (2012), Sayyadi and Awasthi (2013), Gori et al. (2014), Li et al. (2016), Wey and Chiu (2013) and Moura et al. (2017). In recent years, the use and popularity of walkability indices has risen.

However, these indices differ in terms of (i) the type of data used (e.g. qualitative, quantitative, GIS, objective, and/or subjective assessments of the urban environment); (ii) the method (e.g. audit instruments, levels of service indicators, checklists); (iii) the unit of analysis (e.g. pedestrian infrastructure, segment, or area); (iv) the goal (e.g. to evaluate pedestrian structures, to assess the potential of specific new projects to increase walking, to ascertain pedestrian conditions in a city); and (v) the variables considered (Zegras, 2010).

The implementation of a walkability index constitutes a complex multi-criteria decision problem that requires the weighting and aggregation of different criteria that may themselves come into conflict or may depend on uncertain information. Decision-support systems based on multi-criteria methods or social choice techniques are very suitable to study and rank the relative influence of these factors and to develop a weighted walkability index.

Walkability indexes developed in several cities rely on equal weighting; that is, all variables are given the same weight (e.g. Bradshaw, 1993; Krambeck, 2006; Walkscore.com, 2010). This does not adequately represent how individuals with different perceptions, cultural values, and socioeconomic characteristics influence the measurement of the quality of the urban environment for walking. Moreover, if variables are grouped into dimensions, as is common practice with physical features that make up the urban environment, and those are further aggregated into the composite index (i.e. walkability measure), then applying equal weighting to the variables may result in an unbalanced structure in the composite index (OECD, 2008). Some efforts have been performed to aggregate the several dimensions of walking using multi-criteria decision analysis (MCDA) methods (e.g. Analytical Hierarchy Process, fuzzy set theory and Analytical Network Process) (e.g. Wey and Chiu, 2013; Mateo-Babiano, 2016; Ewing and Handy, 2009; Chiang and Lei, 2016; Park et al., 2014). However, these studies present different characteristics and still there is not a consensus about the method to aggregate the several dimensions and the importance of indicators. Some studies used ratings from an expert panel (e.g. Ewing and Handy, 2009; Chiang and Lei, 2016), others analysed specific pedestrian structures or areas (e.g. Park et al., 2014; Mehta, 2008) and some of them focused on a microscale level (Ewing and Handy, 2009; Shafaghat, 2013). Moreover, few researches on this subject have been developed on cities from developing countries, especially in the Latin America context. The existing studies are scarce and analyse large capital cities such as Bogotá (Cervero et al., 2009), Santiago de Chile (Zegras, 2010) and Mexico City (Guerra, 2014; Guerra et al., 2018). The relationship between urban form and walking can vary substantially in smaller cities (Guerra et al., 2018).

This paper pursues three objectives. The first is to determine the importance of the urban environment characteristics to encourage walking trips from the point of view of the pedestrian, using a robust approach, the Fuzzy Analytic Hierarchy Process (FAHP) for a median size developing-country city, Porto Alegre (Brazil). The second is to compare the values obtained by FAHP with those from other, simpler multi-criteria decision analysis techniques (Kendall rank correlation method and six different Social Choice Functions – SCFs). The third is to analyse the existence of differences between various population strata (genders, age groups, neighbourhoods, people who walk less and more and others) in the walkability evaluation.

The contributions of this paper are twofold. Firstly, this work investigates the importance of the urban environment characteristics to encourage walking trips in a different context from those generally reported in the literature. A question arises about whether these reported relationships between urban environment characteristics and walkability hold in Latin American cities and whether they are relevant for policymaking. There is limited literature available concerning Latin American cities and the studies report different correlations between urban environment characteristics and travel behaviour as those found in studies from European and U.S. cities. Some relationships were stronger than those observed in the United States (for example, the studies conducted by Zegras (2010), Larrañaga et al. (2016) and Guerra et al. (2018). Others were weaker or even inexistent (Cervero et al., 2009). Secondly, from the methodological point of view, the paper explores the application of different MCDA techniques and the comparison of their robustness and consistency, and the coherency of the results. It is relevant to note that SCFs have been widely used in the literature, mainly in social and economic studies (Alcantud et al., 2013; Gabel and Shipan, 2004; Serrano et al., 2014) but they have not been previously used in walkability assessment.

The paper is organized as follows. Section 2 describes the methodology; Section 3 presents the data collection; Sections 4 and 5 present and discuss the obtained results; and finally Section 6 provides the conclusions and suggestions for further research.

2. Methodology

This paper proposes a comparison of three different MCDA methods: the FAHP (the fuzzy version of the AHP method), the Kendall rank correlation method, and six different SCFs. MCDA methods are tools that work with multiple variables that affect the same problem in order to help in decision making by ranking and/or weighting these criteria and evaluating and/or sorting possible alternatives or options according to these multiple criteria (Awasthi et al., 2010; Herva and Roca, 2013; Nogués and González-González, 2014; Arce et al., 2015; Soltani et al., 2015; Sun et al., 2015). AHP method family is very employed in criteria weighting and alternative selection decision problems and different approaches may be found in the literature with excellent results (Kahraman et al., 2003; Tudela et al., 2006; Sayyadi and Awasthi, 2013; Nosal and Solecka, 2014; Li et al., 2016). In addition, fuzzy approaches for MCDA methods and especially FAHP have increased significantly in the last years, so they appear as the most employed MCDA methods in the literature, also in the engineering field (Mardani et al., 2015; Kubler et al., 2016).

Moreover, the elements of the decision process can be obtained by various techniques, such as the Delphi method, expert panels, focus group discussions, or research questionnaires as well as literature reviews (Curiel-Esparza et al., 2016). The values obtained by