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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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ABSTRACT

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

FAHP and Kendall rank correlation method were compared using the chi-square test for homogeneity, in order to determine whether there is a significant difference between the values obtained from both methods. The null hypothesis for the homogeneity test states that both populations (values from FAHP and from Kendall method) are homogeneous or equal with respect to urban environment characteristics' importance. The alternate hypothesis claims that they are not. On the other hand, the comparison with the SCFs ranking was performed in a qualitative way, contrasting the ranking obtained by FAHP and Kendall against the ranking obtained using SCFs.

The techniques employed in this research are described in the subsections below. The weighted sum of the valuations of the criteria represents the weighted walkability index.

2.1. Fuzzy Analytic hierarchy Process (FAHP)

The study of the variables affecting neighbourhoods' walkability is surrounded by an environment of great uncertainty, not only due to the nature of decision making on transportation engineering, but also due to the subjectivity and personal character of the evaluations made by citizens. In fact, the probability of occurrence of the factors and the available information about them can be confusing, ambiguous, or inaccurate (Awasthi et al., 2010; Herva and Roca, 2013; Arce et al., 2015).

So, in these cases it is reasonable to think that the evaluation of these variables would be significantly better with the construction of a fuzzy linguistic model, which would be able to model these inaccurate assessments more precisely than a standard multi-criteria method (Awasthi et al., 2010; Arce et al., 2015). Therefore, the FAHP, a fuzzy adaptation of the Analytic Hierarchy Process (AHP), was chosen as the weighting method for this study, since it is one of the most powerful and trustable tools in this field. Besides that, it allows an accurate fuzzy treatment of the citizens' opinions used to evaluate the relative importance of the considered criteria (Brugha, 2004; Herva and Roca, 2013; Ruiz-Padillo et al., 2016a).

AHP is a multiple-criteria decision method from the American school of MCDA methods (Nosal and Solecka, 2014). Basically, it obtains weightings and choices from a square matrix of pairwise comparisons between variables. In this matrix, each element represents the extent to which the row variable is more important than the column variable. For the evaluations, the method uses a predefined scale, called Saaty's fundamental scale, which takes values of 1/9, 1/8, …, ½, 1, 2, …, 8, and 9. With this matrix, the principal eigenvector related to the principal eigenvalue (λ_{max}) is calculated. This eigenvector constitutes the set of relative importance values (weights) of the decision problem (Saaty, 1980; Lau et al., 2003).

From the pairwise comparisons, fuzzy matrices are constructed for each level of hierarchy. When various respondents or decision-makers exist, the individual matrices are aggregated to reach the representative average matrices of the sampled population. For this, the geometric mean of each fuzzy individual element from the matrices is used (Saaty, 1980; Ruiz-Padillo et al., 2016a). Finally, the obtained results must be presented as dimensionless numbers. Among all the different normalization techniques, the present research used the linear procedure.

However, the traditional conception of the AHP does not reflect the way in which the human brain makes decisions or subjective evaluations, as individuals use an inaccurate and imprecise model. Sometimes, decision makers show themselves to be hesitant to attribute numerical values to pairwise comparisons or incapable of doing so. Therefore, it is especially interesting to use linguistic expressions closer to the natural language for the evaluation of relative weights and to link them to Saaty's scale. Then, these evaluations can be modelled by fuzzy numbers to construct the criteria comparison matrices (Zadeh, 1994; Kahraman et al., 2003; Lau et al., 2003). The present work uses triangular fuzzy numbers, denoted by (a, b, c,), to represent the concept that the fuzzy amount "x is approximately equal to the value of b" (a > b > c).

Table 1 presents the scale of linguistic labels used in this research and their correspondence with the direct and reciprocal fuzzy scales for the FAHP (similar to Saaty's fundamental scale). The procedures of calculation must follow the principles of fuzzy numbers theory, because the comparison matrices are fuzzy and the results obtained are fuzzy numbers too. Thus, the FAHP also requires the application of tools to obtain the traditional results (or "crisp" results, in opposition to fuzzy ones) for the vector of weights. This process is called "defuzzification". In the standard FAHP, the fuzzy centroid defuzzification technique is used: the crisp value associated to the fuzzy number (a, b, c) is obtained by $(a + b + c)/3$ (Lau et al., 2003; Ruiz-Padillo et al., 2016a).

Like the traditional AHP, the FAHP assumes a few inaccuracies when estimating the pairwise comparisons of the criteria and calculating the vector of weights. Therefore, it is necessary to analyse the consistency of the process through the so-called Consistency Ratio (CR), which measures the accuracy of the eigenvector's estimation as a vector of weights. The CR is obtained through the comparison of the Consistency Index (CI) of the eigenvector with the appropriate average random consistency index (RI) for the size

Table 1
Correspondence scale between triangular fuzzy numbers and the linguistic labels used in the research.
Source: adapted from Lau et al. (2003).

Intensity of importance	Linguistic term	Fuzzy triangular scale	Reciprocal fuzzy triangular scale
	Exactly the same	(1, 1, 1)	(1, 1, 1)
1	Equally important	(1/3, 1, 3)	(1/3, 1, 3)
3	Moderately more important	(1, 3, 5)	(1/5, 1/3, 1)
5	More important	(3, 5, 7)	(1/7, 1/5, 1/3)
7	Much more important	(5, 7, 9)	(1/9, 1/7, 1/5)
9	Extremely more important	(7, 9, 9)	(1/9, 1/9, 1/7)

of the comparison matrix, by Eq. (1) (Saaty, 1980):

$$CR = \frac{CI}{RI} \tag{1}$$

where the RI value comes from a sample of 500 inverse reciprocal matrices, randomly generated using Saaty's fundamental scale, and the CI of the matrix can be obtained by Eq. (2):

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

where λ_{max} is the principal eigenvector related to the principal eigenvalue, defuzzified by choosing the fuzzy number central value [in the case of the fuzzy number (a, b, c), this would be the value of b], and n is the size of the matrix.

If the CR is not smaller than 10% (for n = 5), 8% (for n = 4), or 5% (for n = 3), it is recommended that the problem and the evaluations of the comparisons be reviewed (Ruiz-Padillo et al., 2016a).

2.2. Kendall rank correlation method

The Kendall rank correlation method (Kendall, 1970) is a weighting technique from the European school of MCDA methods, with a different calculation logic and without a fuzzy treatment. Values are assigned in descending order to each criterion from their qualitative ordinations. In the case of multiple decision makers (as in the case of the respondents of this research), the average position of each criterion, compared to the others in the same hierarchy level, was calculated through the arithmetic mean of the upward ordinations of each individual. Weights are obtained by normalization of these mean values.

Suppose that criterion i is given the position $r_{i,j}$ by respondent number j, where there are in total n variables and m respondents. Then the mean ordination value given to criterion i is

$$R_i = \frac{1}{m} \sum_{j=1}^{m} r_{i,j} \tag{3}$$

Because the lower the value of the rank of each criterion, the more important it is, and therefore the greater weight it must have in relation to the objective of the study, the normalization of the mean values must be made from the inverse values of R_i. Therefore, the weight of the criterion i is obtained as shown in the Eq. (4):

$$w_i = \frac{\frac{1}{R_i}}{\sum_{i=1}^{n} \frac{1}{R_i}} \tag{4}$$

2.3. Social choice functions

Answers obtained through questionnaires to which decision makers have responded can be understood as the results of voting. Thus, techniques used in the analysis of elections can be applied to obtain results from different methods. The SCFs are methodologies frequently used in researches on elections (Alcantud et al., 2013; Gabel and Shipan, 2004; Serrano et al., 2014), as they offer different forms of ranking candidates. However, SCF can be employed as a decision support system with the objective of ranking or selecting factors or criteria as candidates.

Between the great variety of existing SCFs, the present study applied the six most frequently used ones: Plurality, Borda, Copeland, Simpson, Schulze, and Raynaud, as they are recognized for their efficiency and are applicable to the current variables (Green-Armytage, 2004; Srdjevic, 2007; Ruiz-Padillo et al., 2016b).

In short, SCFs take the candidates ordered by the preferences of voters (in this case, a sample of citizens) as input and then return the chosen candidates or a ranking of them (Ruiz-Padillo et al., 2016b). Briefly, the selected SCFs consist of:

- Plurality Method: Plurality is the most common and most used SCF nowadays. Originally, it is used to determine a single winner, although it can be adapted to provide a top-to-bottom ranking by counting each candidate's total number of votes from the respondents. Thus, the victory is given to the candidate (variable) with more votes, the second place in the ranking to the candidate with the second larger number of votes, and then successively (Bahyrycz, 2012).
- Borda Count Method: This voting method uses a ranking of preferences. This ordering assigns points to each candidate: for n candidates, it contributes n - 1 points to the highest ranked candidate, n - 2 points to the second highest ranked one, and so on. It assigns no points to the lowest ranked candidate. The winner is the candidate with the highest sum of points, and a complete ordering is possible according to these sums of points (Alcantud et al., 2013; Zavadskas et al., 2017).
- Copeland Method: This method assigns the winner by the strict simple-majority rule and uses a value, called Copeland Score, to classify the candidates. The Copeland Score of a candidate is the difference between its pairwise victories and its pairwise losses when compared with each of the other candidates (Alcantud et al., 2013; Zavadskas et al., 2017).
- Simpson Method: This Method consists on determining the ranking of the candidates based on the comparison of the worst defeats of each candidate (i.e. its pairwise defeat with the larger difference from the winner) and sorting the variables according to them, in decreasing order. Candidates that had no losses are classified by the intensities of its victories (Bubboloni and Gori, 2016).

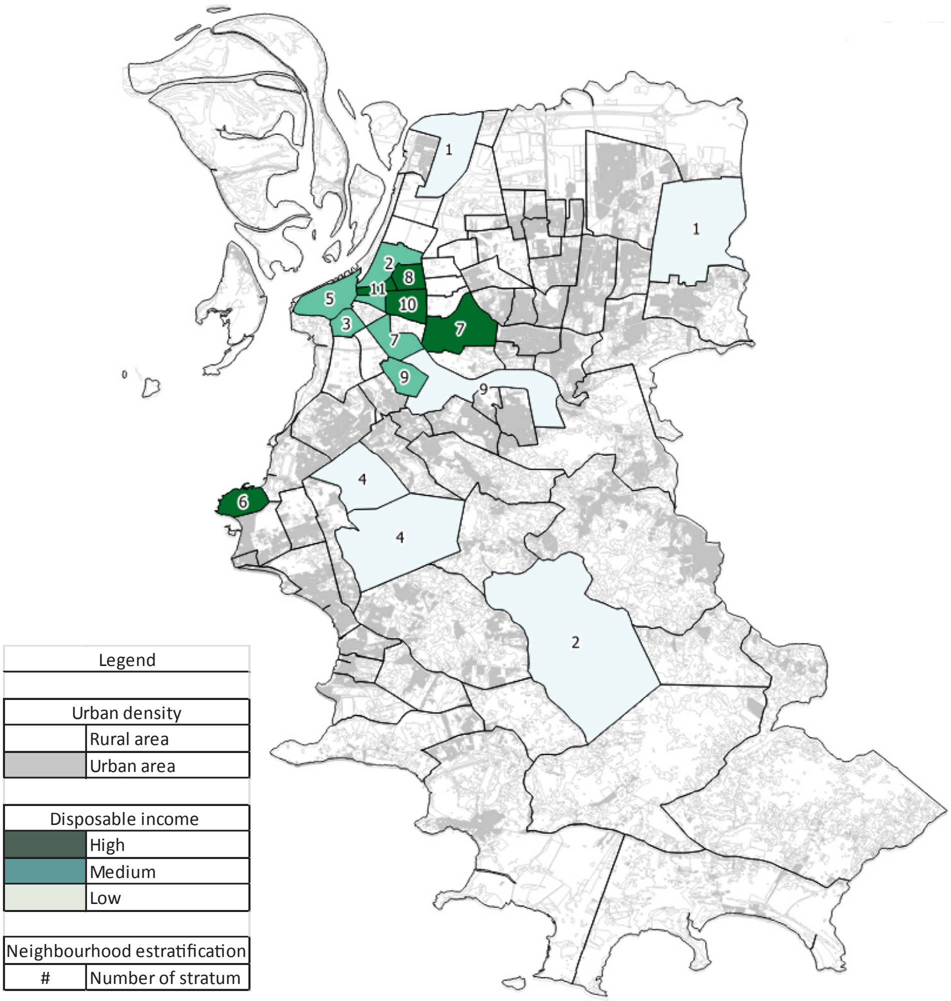

Fig. 1. Distribution of the researched neighbourhoods and their socioeconomic characteristics.

– Schulze Method: It uses the concept of intermediate wins in the pairwise comparisons, rather than just wins and losses between candidates. "Chains", or transitive defeats, allow candidates to be sorted in a final ranking (Schulze, 2003).
– Raynaud Method: Finally, Raynaud Method determines that the candidate with the worst pairwise defeat (i.e. the defeat by a larger margin) is eliminated, and so on until only one candidate remains (the winner). When a candidate is eliminated, all of its pairwise comparisons are also removed, so they will not influence the other results. The Raynaud ranking can be obtained from this sequential removal in reverse order (Green-Armytage, 2004).

The main methodological difference between SCFs and the FAHP/Kendall method is that the SCFs present just a ranking as the final result, with no calculation of the variables' weights.

3. Data collection and conception of the questionnaire

3.1. Sample

Online interviews were conducted between September and November 2016, with 176 individuals from neighbourhoods of Porto Alegre city (Brazil), classified into 11 strata (Fig. 1). The sample size was determined by a stratified random sampling process, with the sample proportional to the size of each stratum. The adopted confidence level was 95%, the coefficient of variation was 20%, and the level of accuracy was 5%. The sample was selected through a sampling method in two stages: census tract and individuals. Census tracts are territorial units constituted by a continuous area, located in an urban or rural context, with a size and number of households that allow the data collection by a census taker.

In the first stage, all census tracts were classified according to three variables: motorization rate, density of commercial and service establishments, and average slope. A previous study conducted in Porto Alegre (Larrañaga et al., 2016) showed that walking trips are influenced by these characteristics. Analysing the histograms of these variables, the following ranges of values were chosen: (i) motorization rate (MR = number of cars/number of households): high (≥0.6) and low (< 0.6); (ii) average slope: high (≥7%) and low (< 7%); and (iii) density of commercial and service establishments (DC = number of establishments per square kilometre): high (≥3000), average (500 ≥ DC > 3000), and low (< 500). Twelve strata were determined (however, one of them did not include a residential neighbourhood, so 11 strata were analysed). Fig. 1 presents the selected neighbourhoods, including information on household disposable income and urban density of the population.

In a second stage, 16 individuals in each census sector were selected by random sampling. The distribution of the respondents by age and gender was taken into account during the selection of the sample, ensuring that the distributions observed in the 2010 census (the last one realized in Brazil) were maintained.

The survey was applied via the Internet using the online research tool *Qualtrics* (Snow, 2012) and electronic spreadsheets. This survey method was chosen due to its advantages of low cost and the lack of influence of the researcher on the respondent.

3.2. Research variables

The literature reports an extensive list of urban environment metrics to assess walkability (approximately 200), many of them redundant. These metrics were usually grouped into walkability dimensions. The clustering and dimensions used varied among the authors. Some of them grouped into seven components, based on expertise, were named as the 7C's of walkability. These components are: Connectivity, Convenience, Comfort, Conviviality, Conspicuousness, Coexistence and Commitment (Moura et al., 2017; Brebbia and Ricci, 2017). Others (Chiang and Lei, 2016; Cerin et al., 2006; Vale et al., 2016) measured walkability based on the Neighbourhood Environment Walkability Scale (NEWS) developed by Saelens et al. (2003) and the 5D's developed by Cervero and Kockelman (1997) and Ewing et al. (2009). Other authors (Krambeck, 2006; U.S. Environmental Protection Agency, 2008; Stantec, 2010) grouped into two components: (i) safety and security and (ii) convenience and attractiveness. The present paper adopted this last classification. Table 2 compares the metrics proposed with those adopted in this study. To minimize the cognitive difficulty of respondents and enable the decision experiment, a limited number of the urban environment characteristics within each component were selected to assess walkability based on a set of previous studies for the same study field (Larrañaga and Cybis, 2014; Larrañaga et al., 2016) and a literature review.

Public security and *Traffic safety* are especially important in the Latin American context due to the high levels of insecurity across much of the region (Instituto Igaraparé, 2018; WHO, 2018). The nature of insecurity in Latin America reflects how unevenly the region has developed economically and socially since the boom years of the 2000s. In addition to security and safety, the state and cleanliness of pavement, streets, and sidewalks have shown a significant effect on neighborhood satisfaction for walking (Inter-American Development Bank, 2010). The provision of amenities (like seating, public restrooms, etc.) and adapted facilities for people with disabilities are still neglected in most Latin American cities, and the presence of these elements is not a consistent issue to explain walkability.

A total of eight attributes that influence the perception of walkability conditions were selected (Table 3).

3.3. Research questionnaire

The selected features were arranged in a hierarchical structure of criteria and subcriteria in order to apply the MCDA techniques. The adopted structure followed the axioms of the applicability of the FAHP method: homogeneity of the elements in each hierarchical level, dependence in relation to the upper level, and completeness of the established hierarchy, besides the known requirement of evaluation reciprocity. For that, three criteria were considered: *conditions of the pavement, security/safety, and characteristics of the route*, and, as subcriteria, the eight attributes mentioned above (Fig. 2).

The questionnaire was structured into five sections: (1) an introduction presenting the study and informing the respondent of how to answer the perception questions about the walking trips made in their neighbourhood; (2) control data (age, gender, among others); (3) sequential presentation of the different groups of criteria and subcriteria; the respondent was asked to sort the criteria and subcriteria from higher to lower importance in relation to the decision problem objective in order to obtain the input data of the Kendall method and SCFs; (4) pairwise comparisons of the attributes, using the previously defined linguistic scale (Table 1) to obtain the necessary data for the application of the FAHP method; and (5) an evaluation of the features of the residential neighbourhood, consisting of an evaluation of each attribute and a general evaluation of the neighbourhood (using a five-point Likert scale type format). All questions were related to the utilitarian trip made in the area of the neighbourhood where the respondent lives. The attributes *attractiveness* and *connectivity* were presented with text and images to facilitate comprehension. Examples of the questionnaire are presented in Fig. 3 (for the third section of the questionnaire), Fig. 4 (fourth section) and Fig. 5 (fifth section).

4. Results and discussion

4.1. FAHP and Kendall methods

The FAHP method was applied to the mean fuzzy matrices obtained from the research sample, in relation with the pairwise comparisons of the criteria and subcriteria. Thus, the weight vectors and the principal eigenvalues were calculated. All of these values were defuzzified and provided the absolute weights and the CRs of each group (in percentage), presented in Table 4.

Table 2
Comparison between the walkability criteria reported in the literature and adopted in the study.

Walkability component	Elements	Metric proposed in the literature	Metric adopted	Exclusion criteria
Safety and security	–	Security	*Public security*	–
		Safety	*Traffic safety*	–
Convenience and attractiveness	Urban form	Street connectivity	*Connectivity*	–
		Block size	Not included	97% of the blocks are less than 400 m (Porto Alegre data analysed with GIS software tools)
		Destinations proximity	*Number of shops and services*	–
		Mix of uses	*Number of shops and services*	–
		Street characteristics	*Slope*	–
		Density	Not included	Density can usefully describe existing urban form in quantitative terms but its ability to capture qualitative characteristics is limited
		Transit service	Not included	Only utilitarian walking trips were assessed, walking trips for transport were not considered in the study
	Quality of the environment	Welcome/Appeal	*Attractiveness*	–
		Comfort	Not included	The provision of seating, temporary wind or sun shelter, and public restrooms is extremely infrequent in Porto Alegre
		Convenience and Efficiency (complementary destinations)	*Number of shops and services*	–
		Complexity (color, texture, and building articulation)	*Attractiveness*	–
	Pedestrian infrastructure	Sidewalks	*Quality of the pavement* *Pavement width*	–
		Accessibility	Not included	The city is not yet adapted for people with disabilities
		Street Crossings	*Traffic safety*	–
		Transit Amenities	Not included	Only utilitarian walking trips were assessed, walking trips for transport were not considered in the study
		Street Amenities	*Attractiveness*	–
		Street Lighting	Not included	Only utilitarian walking trips during day were assessed. Night walking trips are not frequent in Porto Alegre. Survey conducted showed that only 0.02% of total walking trips were performed overnight (Larrañaga and Cybis, 2014)
		Parkades/Driveways	Not included	Multi storey car park are not usual in the studied neighborhoods of Porto Alegre
		Off-street Parking (large parking lots)	Not included	Only utilitarian walking trips were assessed, walking trips for transport were not considered in the study

Table 3
Criteria employed in the research.

Attribute	Description	References
Quality of the pavement	Quality of project, construction and maintenance of the pavement (type of floor, materials used, regularity and flatness of the surface, etc.)	Middleton (2009), Kelly et al. (2011), Larrañaga and Cybis (2014), Moura et al. (2017)
Pavement width	Effective pavement width for walking, considering the presence of obstacles (such as street furniture, lampposts, etc.) that may restrict the available width for walking	Kelly et al. (2011), Kamargianni et al. (2012), Kim et al. (2014), Moura et al. (2017)
Slope	Inclination of the street, particularly of the pavement	Koh and Wong (2013), Larrañaga and Cybis (2014), Larrañaga et al. (2016), Kim et al. (2014)
Public security	Presence of policing and the incidence of assaults and thefts in the neighbourhood surroundings during the day	Koh and Wong (2013), Lovasi et al. (2013), Larrañaga and Cybis (2014), Larrañaga et al. (2016), Moura et al. (2017), Tribby et al. (2017)
Traffic safety	Pedestrians' sense of safety while walking in the neighbourhood, due to the presence of a high vehicle traffic flow, existence of crosswalks, and so on	Kelly et al. (2011), Kaparias et al. (2012), Chiang and Lei (2016), Larrañaga et al. (2016), Singleton and Wang (2014), Kim et al. (2014), Moura et al. (2017), Tribby et al. (2017)
Attractiveness	Visual and aesthetic aspects of the urban environment, such as the quality of the buildings and street furniture and the cleanliness of the pavement	Kelly et al. (2011), Kaparias et al. (2012), Koh and Wong (2013), Kim et al. (2014), Chiang and Lei (2016), Tribby et al. (2017)
Number of shops and services	Number of shops and services near the residence (bakeries, markets, lotteries, pharmacies, restaurants, bars, etc.)	Koh and Wong (2013), Lovasi et al. (2013), Kim et al. (2014), Sung and Lee (2015), Lindelöw et al. (2017), Moura et al. (2017), Tribby et al. (2017)
Connectivity	Alternative routes between origin and destination	Koh and Wong (2013), Larrañaga et al. (2016), Kim et al. (2014), Sung and Lee (2015), Moura et al. (2017)

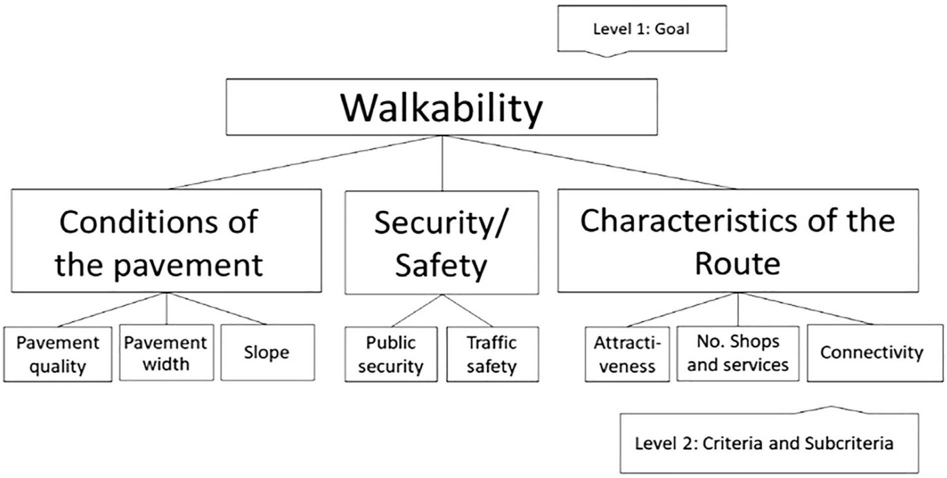

Fig. 2. Hierarchical system for weighting of the research attributes.

In the case of the subcriteria group *security/safety*, the FAHP is not applicable, as it has only two elements. So, the only representative value of the 2 × 2 matrix was defuzzified, which allows the relative importance (weight) between the two subcriteria to be calculated. Therefore, there is no CR for it. All of the other cases presented much lower CR values than the limits defined by Saaty to determine whether the results were consistent. The results of the first level of hierarchy (criterion), especially, presented a low CR (0.03%, value much lower than 10%), which gives maximum reliability to the values.

Furthermore, the criteria's weights and the weights of each group of subcriteria were also calculated through the Kendall method, using the mean positions (see also Table 4).

Thus, with the two sets of weight values for each group of criteria, the weighting of the eight aspects (subcriteria) was obtained, as a result of the aggregation of the values through the previously established hierarchy, simply by multiplying the obtained weight of each subcriterion by the criterion weight on which it depended. Therefore, the final weights of the aspects are presented in descending order in Table 5 for both MCDA methods (FAHP and Kendall).

The chi-square test for homogeneity was computed to compare FAHP and Kendall methods' values. The test statistic was 0.09, lower than the critical value (chi-square for 0.05 level of significance and 7 degrees of freedom), accepting the null hypothesis that both method are equal with respect to urban environment characteristicś importance. However, the absolute values are different because the Kendall method does not consider the relative importance of the aspects or the respondent's uncertainty. This way, Kendall method reaches similar but more inaccurate results with simpler input data.

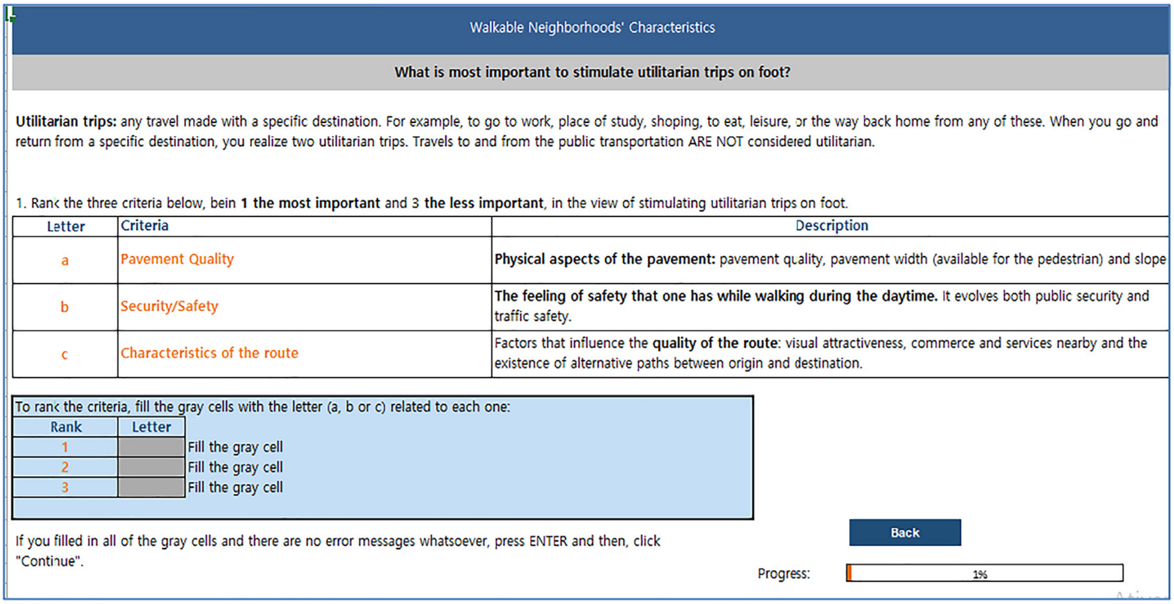

Fig. 3. Example of a sorting question from the virtual questionnaire used in the research.

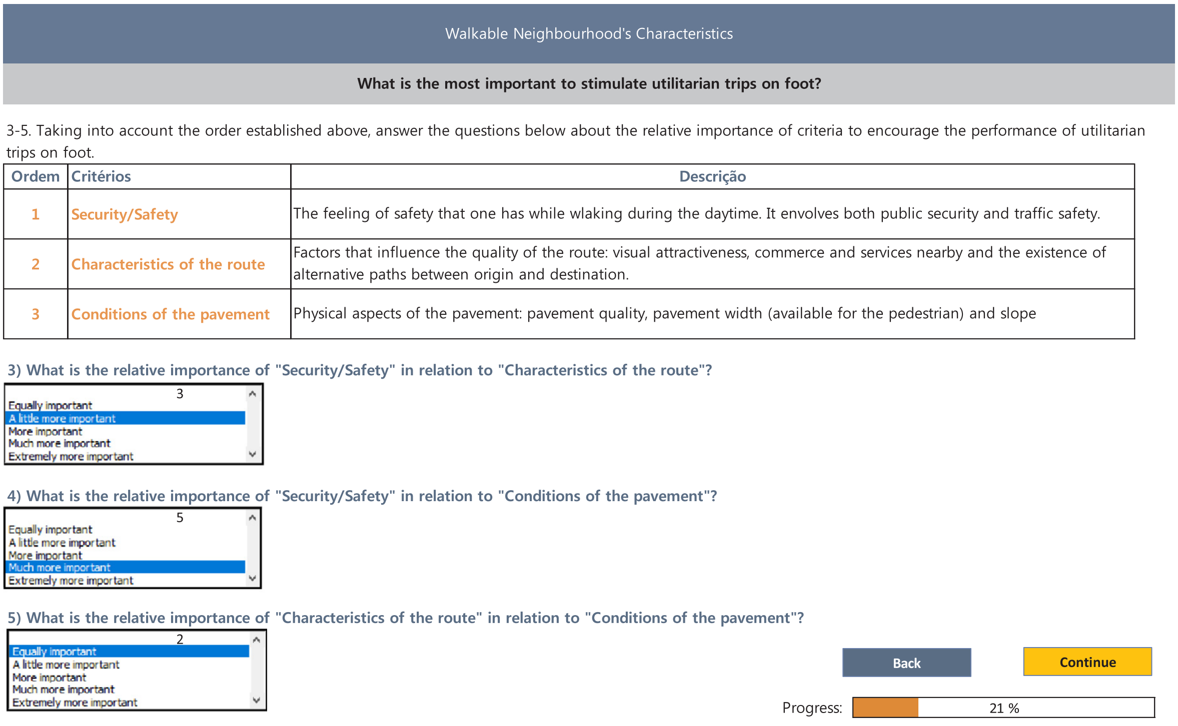

Fig. 4. Example of pairwise comparison questions from the virtual questionnaire used in the research.

The most important aspect is *public security*. This result is not surprising, as urban violence, related mainly to thefts, robberies, and assaults, is one of the principal social problems in Brazil. Specifically in Porto Alegre city, this problem has been growing significantly in the past few years. Although other studies showed public security as a significant factor in relation to walkability (Foster et al., 2010; Halat et al., 2015; Singleton and Wang, 2014), it did not have such an important impact, principally because those studies were done in countries with different social backgrounds. Leslie et al. (2005), in a study conducted in Australia, found that *safety from crime* is related to walkability but has much lower importance than in the present study and less importance than many other aspects. Anyway, the result obtained with the application of these methodologies allows knowing the degree of relative importance that this circumstance presents on the walkability.

Walkable Neighbourhood's Characteristics

What is the most important to stimulate utilitarian trips on foot?

16-24. **Evaluate your neighbourhood in relation to the aspects previously considered from the point of view of the convenience to make utilitarian trip on foot.**

Neighbourhood: **Downtown**

Aspects CONDITIONS OF THE PAVEMENT

Pavement quality
16) Does the quality of the sidewalks in your neighbourhood encourage walking?

○ 1 - Very litte	Unpaved or non-paved sidewalks.
○ 2 - Little	Pavements in bad conditions and without maintenance.
○ 3 - Indifferent	Pavements in medium conditions and with little maintenance.
◉ 4 - Moderately	Good pavements and with acceptable maintenance.
○ 5 - Much	Pavements in excellent condition and with good maintenance.

Pavement width
17) Does pavement width of the sidewalks in your neighbourhood encourage walking?

◉ 1 - Very little	Narrow sidewalks with many obstacles that impede walking.
○ 2 - Little	Reduced sidewalk at some points and with some obstacles that affect the walk.
○ 3 - Indifferent	Sidewalks of acceptable width, but with obstacles that slightly affect pedestrian traffic.
○ 4 - Moderately	Wide sidewalks with few obstacles that represent minor inconveniences for walking.
○ 5 - Much	Wide walkways and practically free of obstacles.

Slope
18) Do the streets in your neighbourhood have many slopes that make walking difficult?

○ 1 - Very little	Flat sidewalks with no slope problems.
○ 2 - Little	Sidewalks with some slopes that do not represent inconveniences to the walk.
◉ 3 - Indifferent	Sidewalks with smooth and continuous slopes that slightly affect walking.
○ 4 - Moderately	Sidewalks with many slopes that disturb the walk.
○ 5 - Much	Sidewalks with steep and continuous slopes that hinder walking.

Fig. 5. Example of questions of evaluation of the subcriteria of the neighbourhood from the virtual questionnaire used in the research.

Table 4
Absolute weights and consistency ratios obtained with the FAHP and Kendall methods (in %).

Criteria	Weight FAHP	Weight Kendall	Subcriteria	Weight FAHP	Weight Kendall
Conditions of the Pavement	16.52%	24.04%	Pavement quality	41.35%	40.01%
			Pavement width	30.16%	30.86%
			Slope	28.40%	29.13%
				CR = 0.13%	
Security/Safety	67.80%	51.33%	Public Security	79.24%	64.67%
			Traffic Safety	20.76%	35.33%
Characteristics of the Route	15.67%	24.64%	Attractiveness	34.90%	34.76%
			Number of shops and services	42.35%	38.44%
			Connectivity	22.76%	26.80%
				CR = 0.06%	
	CR = 0.03%				

Table 5
Comparison of final weights obtained for the FAHP and Kendall methods.

Attributes	FAHP Weight	Kendall Weight	Variation
Public Security	53.73%	33.19%	−20.5%
Traffic Safety	14.08%	18.13%	4.1%
Pavement quality	6.85%	9.62%	2.8%
Number of shops and services	6.64%	8.56%	1.9%
Attractiveness	5.47%	9.47%	4.0%
Pavement width	4.98%	7.42%	2.4%
Slope	4.69%	7.00%	2.3%
Connectivity	3.57%	6.60%	3.0%

Table 6
Ranking positions obtained by applying Social Choice Functions to data.

Criteria/Subcriteria	Plurality	Borda	Copeland	Simpson	Schulze	Raynaud
Conditions of the Pavement	3	3	3	3	3	3
Security/Safety	1	1	1	1	1	1
Characteristics of the Route	2	2	2	2	2	2
Pavement quality	1	1	1	1	1	1
Pavement width	2	2	2	2	2	2
Slope	3	3	3	3	3	3
Public Security	1	1	1	1	1	1
Traffic Safety	2	2	2	2	2	2
Attractiveness	2	2	2	2	2	2
Number of shops and services	1	1	1	1	1	1
Connectivity	3	3	3	3	3	3

The second most important attribute is *traffic safety*, also motivated by the high importance attributed to the *security/safety* criterion, but with a much lover importance than *public security*. Literature shows that traffic safety is a fairly important aspect for walkability (Singleton and Wang, 2014) but is often not among the most important factors (Tribby et al., 2016).

After that, all of the other aspects appear with weights between 3 and 7% for the FAHP and between 6 and 10% for the Kendall method. However, it is possible to determine that the most relevant aspects of this group are *quality of the pavement, number of shops and services*, and *attractiveness*. It is interesting to observe that the respondents give more importance to the concrete characteristics of the walking surface than to the existence of obstacles or narrowing of the pavement. Other studies found that similar factors, such as *pedestrian infrastructure* (Clark et al., 2014), *infrastructure for walking* (Leslie et al., 2005), and *closeness to food shops and other services* (Lindelöw et al., 2017), are slightly associated with an increase in walking, with medium importance, as well as *attractiveness* (Koh and Wong, 2013; Tribby et al., 2016).

The aspects considered less important by the individuals are *slope* and *connectivity*. These criteria present greater influence in other studies (Clark et al., 2014; Ewing and Cervero, 2010; Wei et al., 2016), but citizens of Porto Alegre care much more about their safety and the convenience of the route, again probably due to the local situation of the city, as discussed above.

4.2. Social choice functions

The rankings calculated for each SCF are presented in Table 6. Unlike the other methods, the SCFs do not provide a full ranking of variables but only rankings for each level of the established hierarchy. In this case, they provide four rankings (one for the criteria level and three for each group of subcriteria).

The obtained results for the six SCFs employed are exactly the same, so they show strong consistency. The comparison of these results with the rankings by importance obtained with the other MCDA methods used, also shows a high similarity.

4.3. Stratification of the results

Studies such as Moura et al. (2017) and Sugiyama et al. (2015) proved that socio-economic factors and age groups have an influence on people's walking preferences and thus on their perceptions of walkability.

Therefore, Table 7 presents the stratifications of the results for gender, age, number of walking trips per week, and number of cars owned by the respondent's family (including the number of respondents of each stratum in the first column). The row labelled "All" presents the absolute weights obtained for all the respondents. The other rows present the absolute weights for each group. Firstly, the weights obtained through the application of the FAHP method are presented in each line, and, behind them, the weights obtained from the Kendall method.

It is possible to observe certain similarities in the results, for FAHP as well as for Kendall method. The most important attribute for all groups is *public security*, which always shows a large difference from the other aspects. However, the main difference between genders was not with regard to in the *security/safety* aspects, as found by many similar studies, but with regard to the *slope* and *attractiveness* aspects. Women tend to give more importance to the incline of the streets than men. In addition, men tend to value the *attractiveness* of the streets more than women do.

In the stratifications by age group, it is possible to observe that *public security*, while having similar results for all age groups (Moura et al., 2017), has higher importance for young people (15–29 years old), which was expected, as this is the group that suffers most from thefts. The other age groups (30–59 and, particularly, 60 or more years old) gave less importance to it. The elderly group gave this aspect the lowest value of importance among all analysed groups (probably due to the high values given to the pavement quality), although *public security* remains the most important factor, as for all the groups.

Also, the 15–29 age group gave the smallest values for the aspects *pavement quality* and *slope*, showing that the younger people are much more concerned about having safe streets than having good pavements when compared to the other groups. On the other hand, the elderly group (60 + years old) gave the highest values for these two aspects, as found by Moura et al. (2017). This is explained by physical factors, as older people have more difficulty getting around most of the time and Porto Alegre city has a long way to go in becoming an accessible city for people who are elderly or physically disabled.

Table 7
Stratifications of the FAHP (first line) and Kendall (second line) results by gender, age, number of walking trips, and ownership of cars.

	Public security	Traffic safety	Pavement quality	Number of shops and services	Attractiveness	Pavement width	Slope	Connectivity
All (N = 176)	53.73%	14.08%	6.85%	6.64%	5.47%	4.98%	4.69%	3.57%
	33.19%	18.13%	9.62%	8.56%	9.47%	7.42%	7.00%	6.60%
Men (N = 85)	55.04%	13.54%	6.57%	6.29%	6.48%	4.39%	3.88%	3.80%
	33.34%	18.50%	9.49%	8.84%	9.44%	6.99%	6.56%	6.85%
Women (N = 91)	52.23%	14.60%	7.10%	6.92%	4.54%	5.64%	5.67%	3.30%
	33.01%	17.75%	9.75%	7.69%	7.49%	7.88%	10.15%	6.28%
15–29 years old (N = 76)	55.54%	15.49%	5.43%	5.71%	5.43%	5.50%	3.84%	3.06%
	34.59%	19.06%	7.73%	8.60%	8.90%	8.45%	6.66%	6.01%
30–59 years old (N = 75)	53.61%	13.40%	7.13%	7.42%	5.55%	4.18%	4.64%	4.07%
	32.40%	17.88%	8.93%	9.72%	9.97%	6.83%	7.00%	7.27%
60+ years old (N = 25)	42.99%	10.44%	14.27%	7.31%	4.76%	5.93%	10.69%	3.60%
	30.01%	7.22%	15.01%	9.54%	9.27%	7.68%	15.00%	6.27%
0 walking trips/week (N = 28)	55.94%	14.37%	6.48%	6.43%	4.60%	4.69%	4.55%	2.93%
	36.25%	18.13%	9.23%	7.26%	7.42%	9.62%	6.53%	5.56%
1–4 walking trips/week (N = 73)	51.74%	14.19%	7.64%	6.76%	5.63%	5.04%	5.04%	3.96%
	31.87%	17.28%	10.37%	8.90%	9.75%	7.41%	7.36%	7.06%
5–10 walking trips/week (N = 39)	56.72%	12.92%	5.91%	6.92%	4.57%	4.18%	4.74%	4.05%
	34.43%	18.69%	7.77%	8.75%	6.84%	6.93%	9.58%	7.01%
10 + walking trips/week (N = 36)	53.06%	14.80%	6.46%	6.01%	6.87%	6.05%	3.98%	2.76%
	32.63%	19.47%	9.75%	8.03%	9.18%	8.45%	6.59%	5.90%
0 cars at home (N = 40)	51.71%	15.37%	5.45%	7.16%	6.38%	6.18%	4.31%	3.43%
	30.53%	18.49%	8.43%	8.92%	9.34%	10.56%	7.16%	6.58%
1 car at home (N = 68)	56.44%	14.67%	6.27%	5.61%	4.70%	4.58%	3.95%	3.77%
	35.68%	19.03%	9.21%	7.82%	8.40%	7.04%	6.33%	6.49%
2 cars at home (N = 53)	50.72%	12.62%	8.46%	8.33%	6.23%	4.51%	5.73%	3.39%
	31.43%	16.66%	10.63%	9.42%	10.55%	7.54%	7.03%	6.74%
3 cars at home (N = 7)	57.87%	10.58%	5.12%	6.35%	3.75%	5.02%	6.57%	4.74%
	37.01%	18.51%	8.70%	6.33%	6.33%	7.71%	7.71%	7.71%
4 or more cars at home (N = 5)	51.84%	14.03%	15.05%	2.21%	3.52%	5.73%	5.92%	1.71%
	36.36%	11.69%	18.18%	7.79%	7.79%	6.06%	6.06%	6.06%

There were no major differences between groups according to the number of walking trips made in a week, but it is possible to see that the respondents who are not used to walking (zero walking trips per week) seem to give less importance to *attractiveness* than those who do a lot of walking (10+ walking trips per week). Also, the two groups that are used to realizing an average number of walking trips (1–4 and 5–10) gave higher importance to *connectivity*, unlike the groups that do not walk at all or walk a lot. Sugiyama et al. (2015) found similar but more significant differences among frequent and infrequent walkers in relation to the *pedestrian infrastructure*.

Among the groups differentiated by ownership of cars, the differences are found to be more closely related to the *traffic safety* and *slope* aspects. People who have no car or just one car at home tend to give more or equal importance to *traffic safety* and less importance to *slope*. This question is probably related to the fact that people who do not have a car at home (or have just one, which may be used by other residents of the house) make more trips as a pedestrian than people who have more cars, and pedestrians tend to value more traffic safety and to give less importance to slope than non-pedestrians. Furthermore, car ownership can be related to socioeconomic status, as studied by Sugiyama et al. (2015), who found similar differences between the purchasing power of low- and high-income populations.

5. Characterization of the neighbourhoods in accordance with walkability

5.1. Evaluation of the neighbourhoods with regard to the walkability attributes

The analysed neighbourhoods were evaluated by the questionnaire respondents (responses to the fifth part of the questionnaire described in Section 3.3). Table 8 presents the evaluations of the respondents for each attribute of their residential neighbourhood and a general evaluation of the walkability of the neighbourhood (16 respondents per neighbourhood). The five-point Likert-type scale used offered values of 1 (worst), 2, 3, 4, and 5 (best) for each criterion and the general evaluation of the walkability. The values reported in Table 8 represent the arithmetic mean of the importance assigned by each respondent.

5.2. Categorization of the neighbourhoods and stratification of the weights of the attributes

Table 9 presents the categorization of the researched neighbourhoods based on their walkability. The column headed "General Evaluation" refers to the mean value of walkability for the residential neighbourhood of the respondents (directly from the last column of Table 8). The columns headed "FAHP evaluated variables" and "Kendall evaluated variables" refer to the values obtained

Table 8
Evaluation of the criteria and general walkability of the neighbourhoods.

Neighbourhood	Pavement quality	Pavement width	Slope	Public security	Traffic safety	Attractiveness	Number of shops and services	Connectivity	General
1	2.88	2.96	2.31	1.96	3.50	3.19	2.27	3.27	3.12
2	3.00	3.00	2.14	2.29	3.43	3.36	3.38	3.36	3.21
3	3.53	2.94	1.59	3.00	3.24	3.35	4.12	3.76	3.76
4	2.38	3.00	3.25	1.63	3.63	2.38	1.88	2.13	2.50
5	3.00	2.69	2.77	2.08	3.23	2.69	4.15	3.38	3.23
6	2.69	3.31	3.13	2.69	3.50	4.00	2.56	3.13	3.38
7	3.59	3.59	3.03	2.69	3.59	3.59	3.14	3.55	3.34
8	3.93	3.53	2.60	3.00	3.67	4.20	4.33	3.93	4.13
9	2.69	3.00	3.77	2.08	3.31	2.77	2.85	3.31	2.15
10	3.50	3.70	3.40	3.10	3.40	3.80	3.00	3.30	3.40
11	4.17	3.50	2.50	3.33	3.17	3.67	3.67	4.17	4.33

Table 9
Categorization of the researched neighbourhoods based on walkability.

General Evaluation		FAHP evaluated variables			Kendall evaluated variables		
Neighbourhood	Average evaluation	Neighbourhood	Weighted evaluation	Variation (%)	Neighbourhood	Weighted evaluation	Variation (%)
11	4.33	11	3.41	−21%	8	3.51	−19%
8	4.13	8	3.35	−19%	11	3.45	−16%
3	3.76	10	3.25	−14%	10	3.33	−12%
10	3.40	3	3.12	−8%	7	3.21	−6%
6	3.38	7	3.05	−10%	3	3.17	−6%
7	3.34	6	2.93	−12%	6	3.05	−9%
5	3.23	2	2.69	−17%	2	2.87	−11%
2	3.21	5	2.58	−20%	5	2.79	−13%
1	3.12	9	2.55	−18%	9	2.76	−11%
4	2.50	1	2.44	−2%	1	2.66	+6%
9	2.15	4	2.18	+1%	4	2.40	+11%

for the walkability through the weights obtained by FAHP and Kendall method, respectively (Table 5) and the evaluations of the respondents for each attribute, by applying the weighted sum method (equation (5):

$$A_i = \sum_{j=1}^{m} w_j a_{ij} \tag{5}$$

where A_i is the weighted evaluation of the neighbourhood i (i = 1, … , 11); w_j are the weights obtained for each subcriterion (j = 1, …, 8) (from Table 5); and a_{ij} are the average evaluations of the subcriterion j for the neighbourhood i (from second to ninth columns of Table 8).

The variation values of these weighted evaluations in relation to the average general evaluation for each stratum are also included in Table 9.

The chi-square test for homogeneity was computed to compare between the calculated walkability values (using the weights obtained by FAHP and Kendall methods) with those reported by the respondents for each neighbourhood (General evaluation). On testing equivalence of three populations, the null hypothesis states that all three populations are homogeneous or equal with respect to walkability values. The alternative hypothesis claims that they are not. The test statistic was 0.04 lower than the critical value (chi-square for 0.05 level of significance and 10 degrees of freedom), accepting the null hypothesis that walkability values are equivalent.

The most walkable neighbourhoods are #11 and #8. Due to the high importance value calculated for *public security*, the neighbourhoods with the best walkability coincide with those where the residents feel more secure, while the inverse is true for the less walkable neighbourhoods (#1, #4, and #9).

The most walkable neighbourhoods (#11, #8, #10, and #3) are near to each other at a distance of 2–3 km from the downtown area. Both consist of mixed land use (residential and commercial) and are among the densest neighbourhoods of the city (IBGE, 2010). Both are visually and aesthetically pleasing, with a lot of greenery, besides the fact that two of the biggest parks in the city are located near these neighbourhoods. Socioeconomically speaking, they have some of the highest standards of living and the property values are high. All of these aspects converge toward safe environments, with the lowest crime rates of the city and thus high walkability.

On the other hand, the less walkable neighbourhoods (#1, #4, and #9) are areas with mostly residential land use and low density and are further from the downtown area (IBGE, 2010). The average income is much lower than in the walkable neighbourhoods, with many people living in irregular conditions, and these areas are historically neglected by public policies. This is reflected by the higher crime rates, clearly unsafe environments, and consequent lack of walkability. Thus, the obtained results are logical in relation to the characteristics of the urban environments of the different neighbourhoods, so the calculated index is a useful tool for assessment of neighbourhood walkability.

Analysing the results among neighbourhoods, it is possible to observe great consistency with regard to *public security* being the most important aspect, with *traffic safety* coming second. However, some variations that repeat themselves in more than one case can be noticed.

The residents of neighbourhoods where the *condition of the pavement* is poor tend to give a higher importance to this aspect. This can be observed in the high values obtained by *quality of the pavement* and *pavement width* in neighbourhoods #4 and #9 (briefly described above), which are the two neighbourhoods with the worst pavement conditions (according to their residents). On the other hand, the residents of neighbourhoods that present good pavement conditions (such as neighbourhood #11, already discussed previously) gave these variables lower importance. This probably happens because people only care about a problem when they have to live with it.

An aspect that presented great variation among the neighbourhoods was *number of shops and services.* On analysing the neighbourhoods that received low values for this aspect (#1, #4, #6, and #9), it is possible to see that three of them were considered to have a low presence of commerce and services by their residents and that the neighbourhoods that received high values for this aspect are the ones where the residents see a high presence of commerce and services. This leads us to the conclusion that people only see commerce and services as a benefit for walkability when they have these features around them.

It is also possible to see a relation between higher values of *slope* and the presence of steep streets in the neighbourhoods. Neighbourhoods #7 and #11 are examples of this. Finally, no relation was found between the neighbourhood of residence and giving a higher value to *public security*. This is a problem that has been such a major issue in Porto Alegre lately that people consider it a major problem independently of the region of the city in which they live.

6. Conclusions

This paper quantified the importance of the urban environment characteristics in order to develop a weighted walkability index. The case study was the city of Porto Alegre (Brazil), a regional metropolis for a median size developing-country city with 1.4 million inhabitants. This case study presents important particularities regarding walkability studies. Its application to a Latin American city proposed a varied point of view from the usual North American and European perspective, where safety, security and infrastructure quality issues present different thresholds. On the other hand, the few Latin American walkability studies reported in the literature are usually concerned with very large cities, like Bogota, Santiago, Mexico city, that, due to their size and complex economic activities, do not represent the reality of most urban areas in the region.

Three techniques were used: the Kendall rank correlation method, SCFs, and FAHP. The values obtained by FAHP and Kendall rank correlation method were compared using the chi-squared test of homogeneity and the ranking obtained was contrasted against the ranking obtained using SCFs. SCFs have not been previously used in walkability assessment. Comparing the results obtained with the different MCDA methods, it was proved that there is a high similarity.

The results show that all adopted techniques made it possible to determine the relative importance and to construct a hierarchy for the main urban environment characteristics to improve the walkability of Porto Alegre city, Brazil. The FAHP technique provided a special strength to the values due to its fuzzy treatment of data and the satisfactory consistency of the results obtained. These weightings were similar to the ones calculated with the Kendall method, and the rankings of attributes were very similar to those obtained with the SCFs. The Kendall method is a simpler technique and could be easily apply in other studies and contexts, but it reaches more inaccurate results.

The input data needed for these methods were obtained from an online questionnaire applied to a carefully selected sample of city residents. The two most important attributes identified by residents of Porto Alegre city were *public security*, with a value of 51.00%, and *traffic safety*, with a value of 13.78% (both FAHP values). In decreasing order, the levels of importance of the other attributes calculated with the FAHP method were *pavement quality* (7.52%), *number of shops and services* (7.02%), *attractiveness* (6.03%), *pavement width* (5.59%), *slope* (5.01%), and *connectivity* (4.06%). The result for *public security* was not a surprise, as urban violence has become a major social problem in Brazil, but through the application of the proposed methodology it was possible to quantify the relative importance of the analysed criteria. Security is usually ignored in studies of European and American cities; however it is of fundamental importance in the Latin American context. This result can be extended to other cities. According to the annual report prepared by CCSPJP (2018), 43 of the 50 most insecure cities are located in Latin America. Connectivity was less important than that observed for American cities; however the presence of shops nearby de residence was shown to be an important feature to encourage walking, as observed in American cities.

The characterization of 11 neighbourhoods in Porto Alegre city (Brazil) based on their walkability allowed identifying the most and least walkable neighbourhoods from the residents' point of view. Among the studied neighbourhoods, the ones considered to be most walkable have the highest standards of living and environment attributes that favour safety and pleasing aesthetics. The less walkable ones were away from the downtown area, with clearly unsafe environments, low density and lack of services. Urban and transportation policies that aim to encourage walking trips must pay special attention to these aspects. Promoting walkability in existing neighbourhoods should focus on increasing public security, diminishing the risk of traffic accidents and improving the pavement quality of streets. Initiatives and efforts should be directed toward bringing together key players within the city administration and the community around the topics of crime prevention and traffic safety.

Studied theories and measures applied in other cities to make the environment more physically healthy, such as controlled use of barriers, crime prevention through environmental design, illumination, and vegetation management, should be considered.

Revitalization programs making the streets safer could also be initiated in some areas. Investments and government participation is needed to improve pavement quality in cities like Porto Alegre.

Researches are needed to analyse specifically the impact of security on walking trips and to identify the environmental attributes that influence the sense of security. Future studies could determine the importance of the urban environmental factors in an indirect form, through declared preference or another elicitation technique (best-worst scaling, for example) that reduces the political bias that may exist in the respondent's answers and compare with the values obtained with MCDA methods. The comparison and joint evaluation, with a meta-analysis for example, will contribute to the formulation of a walkability index for different contexts. The comparison against a different method to obtain walkability indexes will contribute to compare with the formulation of a walkability index for the city.

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