AN EVALUATION THERMOMETER FOR ASSESSING CITY SUSTAINABILITY AND LIVABILITY

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HIGHLIGHTS

- An evaluation system is developed to measure city sustainability and livability.
- The understanding of the cause-and-effect relationships is enhanced.
- Cognitive mapping improves the selection of evaluation criteria.
- The use of cognitive maps and AHP enhances city livability evaluations.

ABSTRACT

The real estate industry is an important indicator of national economic growth and development, which is influenced by the environment in which it operates. Various countries have been seriously affected by the most recent international financial crisis. Nevertheless, regardless of the challenges some cities currently face and the impacts on their sustainable livability, urban real estate is still of interest to investors. Given this context, researchers have sought to develop and apply methods of evaluating sustainable livability in cities. However, most practical applications have been hampered by methodological limitations (*e.g.*, how to select and weight criteria in evaluations), which has hampered progress in this area. The present study thus aimed to develop a knowledge-based decision support system to evaluate city sustainability and livability in a transparent and informed way. To achieve its goal, this research combined cognitive mapping techniques and the analytic hierarchy process (AHP). Based on real-world data, the advantages and limitations of this integrative evaluation system are discussed.

KEYWORDS: City Sustainability and Livability; Multiple Criteria Decision Analysis (MCDA); Analytic Hierarchy Process (AHP); Cognitive Mapping.

ARTICLE CLASSIFICATION: Research Paper.

1. INTRODUCTION

The residential real estate industry is most often related to choosing suitable residences or their locations. These choices are considered difficult since they must take into account not only economic issues but also various social factors. According to Uysal and Tosun (2014: 322), real estate decisions are a result of a *"complex function of a wide range of housing and location attributes"*. Currently, some of these attributes are related to searching for livable and sustainable neighborhoods (Faria *et al.*, 2018; Fernandes *et al.*, 2018; Lasarte-Navamuel *et al.*, 2018; Pires *et al.*, 2018). People are looking for a place to live in communities and cities that offer both quality of life indicators and sustainability components.

The need to find sustainable and livable conditions in neighborhoods and/or cities is connected to the challenges cities face on a daily basis. These include, first, the complexity of city housing markets and, second, personal preferences since *"each person has* […] *different* [ideas about] *pleasurable and socio-economic properties"* (Uysal and Tosun, 2014: 393). A third challenge is the positive and negative effects of cities. A fourth is the role of urban planning and management, which contributes to *"better standards of human wellbeing without compromising environmental sustainability in the long-term"* (Zanella *et al.*, 2015: 696). The last challenge is the influence of a strong tourism industry. Given these issues, two questions need to be answered:

(1) How can sustainable livability be measured in cities?

(2) Which methodologies facilitate the consideration of both quantitative and qualitative indicators?

On a methodological level, the techniques used to evaluate sustainable livability should represent the reality being examined as closely as possible. Therefore, the present study focused on an integrated use of cognitive mapping techniques and the multiple criteria decision analysis (MCDA) approach. The latter is particularly appropriate for addressing complex problems that are influenced by human concerns. Roy (1990: 324) observes that MCDA *"enhance*[s] *the degree of conformity and coherence between the evolution of a decision-making process and the value systems and the objectives of those involved in this process"*. The current research's goal was thus to develop a non-parametric system to evaluate city sustainability and livability – based on a constructivist approach – by bringing together a panel of real estate experts in face-to-face work sessions.

Cognitive mapping reveals the structure of decision problems, helping to identify and understand the cause-and-effect relationships between evaluation criteria (Ackermann and

Eden, 2001), while the additional use of the analytic hierarchy process (AHP) enables the calculation of criteria weighting. According to Gonçalves *et al*. (2016) and Ribeiro *et al.* (2017), cognitive mapping is of great importance because it not only improves the understanding of the problems in question but also broadens the range of criteria used in decision-making systems. Cognitive mapping also helps in *"the structuring and clarification of complex decision situations"* (Ferreira *et al*., 2016: 4954). Developed by Saaty (1980), the AHP is one of the most widely used MCDA tools to deal with multiple and complex problems (*cf.* Ishizaka and Siraj, 2018).

Although these two approaches have produced excellent results when dealing with complex real problems due to their simplicity and ease of application, the literature review conducted for the present study revealed no prior report of the combined use of these approaches in the context of city sustainability and livability. This research gap means that the current study's approach contributes significantly to the existing literature on sustainability, real estate, and operational research/management science (OR/MS).

The remainder of this paper is organized as follows. The next section provides an overview of the literature on city sustainability and livability. Section three introduces the relevant methodology and epistemological aspects. Section four describes the processes followed to construct and test the proposed evaluation thermometer (*i.e.*, evaluation system). The final section offers the study's conclusions and presents a roadmap for further research.

2. RELATED LITERATURE

Cities can face challenges that affect their sustainable livability. This makes having methods and measures to evaluate cities essential (Fernandes *et al.*, 2018; Marques *et al.*, 2018). The effectiveness of these measures depends, for example, on assigning rules for assessing residents, environments, or dwellings. The methods used to evaluate city livability have come under scrutiny, which has contributed to the development of new approaches. *Table 1* identifies some of these studies, highlighting their contributions and limitations.

Table 1: Methods of Evaluating City Sustainability and Livability

AUTHORS	METHOD USED	CONTRIBUTIONS	METHODOLOGICAL LIMITATIONS
Marshall (2013)	▪ Transit-oriented development used to evaluate transportation sustainability and livability.	▪ Makes connections between methodology and concepts of sustainability and livability; ▪ Helps city planners to recognize the most efficient cities and places to live in with regard to transportation sustainability and livability.	▪ Fails to consider the variables selected for this assessment as proxy; ▪ Deviates from the stated end goals.
Okulicz-Kozaryn (2013)	▪ Data gathered with the Urban Audit Perception Survey and the Mercer city ranking.	▪ Identifies weak correlations between satisfied residents and livable cities and dissatisfied residents and unlivable cities; ▪ Establishes importance of subjective variables such as trust when evaluating quality of life and city livability.	▪ Establishes only a weak relationship between the Mercer ranking and survey data when measuring perceptions; ▪ Has difficulty assessing subjective measures of quality of life.
Ding *et al.* (2015)	▪ Development of a model of spatial, logical, and time dimensions for the assessment and development of city sustainability (*i.e.*, "Trinity of Cities' Sustainability").	▪ Guides the process of applying sustainable development indicators; ▪ Provides a framework for assessing sustainability in developing countries; ▪ Assists planners to formulate policies in developing countries to ensure sustainable development and growth.	▪ The model is unsustainable when the goal is city development in developing countries; ▪ Fails to meet the need to introduce multiple criteria.
Marsal-Llacuna *et al.* (2015)	▪ Principal component analysis used to determine the performance of cities.	▪ Offers a representation of sustainable livability indicators in the form of a synthetic index combining subjective (*i.e.*, qualitative) life-satisfaction and objective (*i.e.*, quantitative) quality of life indicators; ▪ Reduces the number of variables by combining them into smaller groups, which can be considered the principal components.	▪ Includes low frequency update of real-time indicators.

Norouzian-Maleki *et al.* (2015)	▪ Delphi method used to determine which criteria are most important to define livability in two different countries.	▪ Introduces additional variables, alterations to wording, and the merging of other terms based on the ideas of a panel of experts; ▪ Allows initial ideas to be tested for consensus since the Delphi method is characterized by creating a participatory and interactive environment; ▪ Offers tools useful for building livable neighborhoods and sustainability.	▪ Reports problems in creating a tool to determine and measure physical environments; ▪ Fails to overcome limits of experts' cultural bias; ▪ Bases process on the judgments of the chosen panel, which may not be representative as a whole; ▪ Presents results that are not a final solution.
Silva *et al.* (2015)	▪ Outcomes from the Index of Sustainable Urban Mobility used to compare mobility conditions in five Brazilian macro-regions.	▪ Provides evidence that wealthier cities tend to have better performance; ▪ Confirms that the size of a city affects its performance.	▪ Fails to compensate for how the availability and quality of data are affected by accentuated regional differences between cities; ▪ Develops an unequal number of indicators when comparing cities.
Zanella *et al.* (2015)	▪ Conceptual model used to determine livability of cities in Europe by considering two components: human well-being and environmental impact.	▪ Presents a composite indicator constructed using data envelopment analysis (DEA) specified with a directional distance function; ▪ Offers results that can be used as benchmarks, including that cities with low performance may learn from their peers (*i.e.*, best practices); ▪ Helps decision makers define policies in order to improve their cities' performance.	▪ The way evaluation criteria have been selected is not completely explained.
Zhou *et al.* (2015)	▪ Development of responsibility-based method (*i.e.*, "Strategic goal-Responsibility department-Response" (SRR)) used to select and model sustainability indicators.	▪ Provides empirical evidence that SRR effectively assists the practice of finding and choosing sustainable indicators; ▪ Gives guidelines for implementing sustainable strategies.	▪ Reports that the SRR method is affected by the degree of specification of responsibilities and interdependence between departments; ▪ Tests the method in just one city in China.
Faria *et al.* (2018)	▪ Integrated use of cognitive mapping and measuring attractiveness by a categorical-based evaluation technique (MACBETH).	▪ Provides a holistic perspective of quality of life in urban areas. ▪ The use of cognitive mapping was important to structure the decision problem under study.	▪ Quality of life is just one dimension of city sustainability and livability.

Although the methods presented in *Table 1* facilitate the decision-making process by combining certain indicators, these approaches have shortcomings. First, some studies used data from surveys, such as Okulicz-Kozaryn (2013) and Silva *et al*. (2015). Second, certain variables and criteria were considered depended on the availability and quality of the existing data. Third, according to Silva *et al*. (2015: 155), *"the larger availability of data in the short run does not guarantee the good quality of these data"*. Fourth, other studies have highlighted the need to integrate further multiple criteria and/or to measure efficiently using both objective and subjective criteria in their evaluations, such as Okulicz-Kozaryn (2013) and Ding *et al*. (2015). Last, the reasons are unclear why definitions of criteria weighting differ from study to study.

The present study sought to overcome these limitations by integrating cognitive mapping and the AHP method. This combination was selected to deal with some of the shortcomings noted in *Table 1* above. Each method measures quality of life differently, and methodological choices depend on the particular reality decision makers must deal with, which means that cognitive mapping and MCDA can make a strong contribution in this context.

On the one hand, cognitive mapping can be the starting point for identifying and/or selecting the criteria to be included in an evaluation model. On the other hand, the AHP approach enables decision makers to define the criteria's trade-offs, thereby determining the weighting of the criteria. For these reasons, combining these approaches is essential to dealing with complex problems, integrating multiple criteria and efficiently weighting objective and subjective criteria (Okulicz-Kozaryn, 2013; Faria *et al.*, 2018; Fernandes *et al.*, 2018; Oliveira *et al.*, 2018). The next section presents the methodological background of this study.

3. METHODOLOGICAL BACKGROUND

This research relied on the MCDA approach (for an in-depth theoretical discussion, see Bana e Costa *et al*. (1997) and Belton and Stewart (2002)), which is usually divided into three main phases: (1) structuring; (2) evaluation; and (3) recommendations (*cf.* Bana e Costa *et al*., 1999; Ferreira *et al*., 2015b). The first phase is, perhaps, the most important because it deals with defining the decision problem, including collecting data and/or criteria on the problem. In the present study, the objective was to use cognitive mapping to identify the criteria that are important when deciding whether a neighborhood and/or city is sustainable and livable.

Amine *et al*. (2014) describe the second phase as a chance for decision makers to express their preference for criteria, based on the data collected in the first phase. By applying the AHP method, decision makers can obtain value functions and trade-offs between criteria. The third phase is when decision makers combine the outcomes of the second phase to determine the best alternatives. The multiple criteria used in the model can then be validated, and recommendations can be made.

3.1 Cognitive Mapping

In broad terms, a cognitive map is *"composed of concept nodes of a target problem, signed directed arrows, and causality value between the nodes"* (Xue *et al*., 2010: 228). Cognitive mapping is thus composed of three components. The first is elements that represent objects of interest within the domain of investigation, such as people or activities. For example, these can be system analysts or systems of project development, respectively (Tan and Hunter, 2002). The second component is constructs, which are considered concept nodes and which represent participants' interpretations of the elements (Tan and Hunter, 2002; Nassreddine, 2016). The last component is links, which are represented by directed arrows accompanied by positive or negative signs and used to connect the elements and constructs. For this reason, cognitive maps are also known as causal maps since the arrow's direction indicates *"believed causality"* (Eden, 2004: 673). According to Eden and Ackermann (1992: 310), *"a statement at the tail of an arrow is taken to cause, or influence, the statement at the arrowhead"*.

Eden (2004) states that cognitive maps should be understood to represent a hierarchical structure in the form of means and/or ends, in which goal statements are placed at the top of the hierarchy. When nodes are linked with arrows, cause-and-effect relationships are defined by placing a sign – either positive (+) or negative (–) – next to the arrows' heads (*cf.* Klein and Cooper, 1982; Eden, 2004; Ho, 2015; Oliveira *et al.*, 2017; Fonseca *et al.*, 2018). As pointed out by Ho (2015: 739): *"[A] + sign (e.g., A – [+] → B) means that an increase in variable A leads to an increase of variable B, whereas a – sign (e.g., A – [–] → B) indicates the opposite* […] *That is, an increase of variable A leads to a decrease in variable B". Figure 1* is an example of a cognitive map showing the causality between concept nodes.

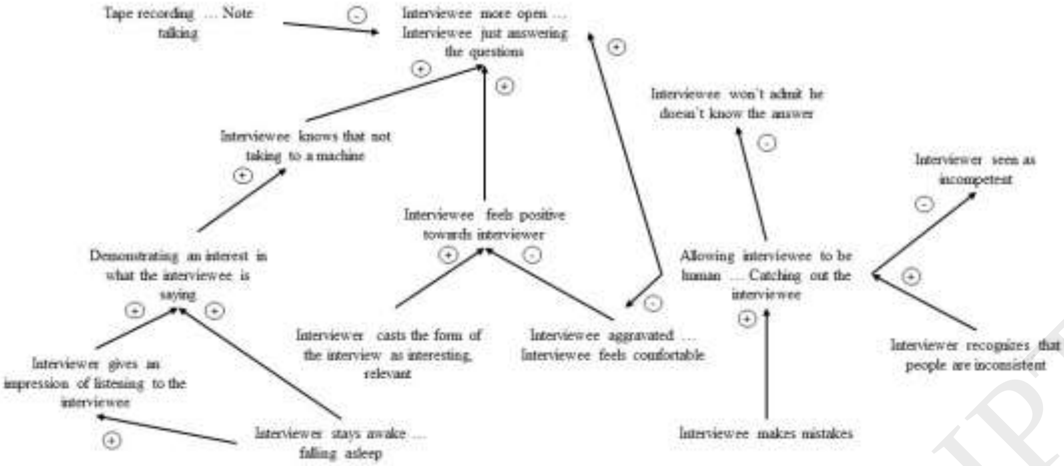

Figure 1: Example of a Cognitive Map

Source: Adapted from Eden and Ackermann (1992: 311)

Cognitive mapping is strongly linked to a constructivist stance. As Ferreira *et al*. (2016: 4954) note, cognitive maps are *"well-established and interactive visual tools, which allow for the structuring and clarification of complex decision situations"*. Ferreira *et al*. (2016) and Nassreddine (2016) also emphasize cognitive mapping's great power to facilitate discussion, communication, and negotiation. While this approach has some methodological limitations (see Ferreira *et al*., 2015b), it has proved to be a useful structuring tool when dealing with complex decision problems.

3.2 Principles of AHP Technique

Russo and Camanho (2015), Dweiri *et al*. (2016), Karanik *et al*. (2016), Singh and Nachtnebel (2016), and Ishizaka and Siraj (2018) report that the AHP is one of the most widely used MCDA methods. It was developed in the early 1970s by Saaty (1980), who wondered how ordinary people decide while bearing in mind all the information needed.

This technique facilitates the resolution of multiple and complex decision problems by getting a group of decision makers to identify not only objective but also subjective factors. According to Jovanovic *et al*. (2015: 226), *"the main purpose of the AHP method* [… is] *to help the decision-makers to, based on the information available, make the best decision possible"*.

In accordance with the procedural steps of the MCDA approach, the AHP has three main functions/principles (*cf*. Saaty and Vargas, 1998; Russo and Camanho, 2015). These are: (1) structuring complexity; (2) measuring preferences; and (3) synthesizing. *Figure 2* presents the conceptual proposal of the AHP method, in which the problem is decomposed into a hierarchical structure during the structuring phase.

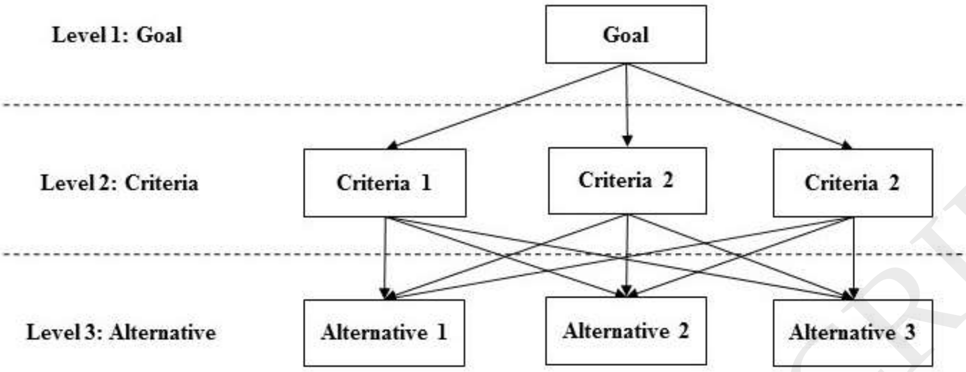

Figure 2: Basic Hierarchical Structure of the AHP Method
Source: Adapted from Dweiri *et al.* (2016: 274)

As shown in *Figure 2*, the AHP uses different hierarchical levels to break down the complexity of decision problems (Jovanovic *et al*., 2015; Dweiri *et al*., 2016; Morano *et al*., 2016). In the AHP hierarchy, factors are distributed as follows: at level one, the objective and/or goal of the decision process; at level two, the criteria and sub-criteria; and, at level three, alternative decisions (*cf.* Singh and Nachtnebel, 2016).

In the evaluation phase, the decision makers' preferences are quantified. The AHP is based on relative measurement, that is, by deriving a scale from pairwise comparisons. According to Dweiri *et al*. (2016: 274), *"this pairwise comparison* [… facilitates] *finding the relative weight of the criteria with respect to the main goal"*. It should be highlighted that the AHP uses ratio scales, and the judgments are given by the quotient of two quantities with the same units. However, as stated by Ishizaka and Labib (2011: 14337), *"the decision maker does not need to provide a numerical judgement; instead, a relative verbal appreciation, more familiar in our daily lives, is sufficient"*. These comparisons are summarized in a positive reciprocal matrix (1), where a_{ij} is the comparison between element *i* and element *j*:

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & \dots & a_{ij} & \dots \\ \dots & a_{ji} = \frac{1}{a_{ij}} & \dots & \dots \\ a_{n1} & \dots & \dots & 1 \end{bmatrix} \quad (1)$$

As noted by Ishizaka and Labib (2011), the following transitivity rule (2) holds for all comparisons under the assumption of a perfectly consistent matrix *A*:

$$a_{ij}=a_{ik}a_{kj} \quad (2)$$

Evaluation of different alternatives is conducted based on the same preference scale. In this work, due to the decision makers' profiles and application characteristics, a verbal scale was used, which allowed verbal judgements to be converted into numerical values. Specifically, Saaty's fundamental scale was used (see *Table 2*), which is perhaps the most used verbal scale in the MCDA literature, and contains integers from one to nine (for a review of different alternative scales, see Ishizaka and Labib (2011)).

Table 2: Importance Scale of Factors in Pairwise Comparison

SCALE	DESCRIPTION
1	Equal importance of "i" and "j"
3	Weak importance of "i" over "j"
5	Strong importance of "i" over "j"
7	Demonstrated importance of "i" over "j"
9	Absolute importance of "i" over "j"

Note: 2, 4, 6, and 8 are intermediate values.

Source: Adapted from Dweiri *et al.* (2016: 53–55)

Derivation of priorities $p_1, \dots, p_n$ is the main objective of the method such that p_i/p_j match the comparisons a_{ij} in a consistent matrix. In this work, the mean of the row method was used, which is a well-established method based on three steps (*cf.* Ishiszaka and Labib, 2011):

(1) Sum the elements of each column *j*: $\sum_{i=1}^{n} a_{ij} \quad \forall i, j$;

(2) Divide each value by its column sum: $a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad \forall i, j$;

(3) Mean of row i: $p_i = \frac{\sum_{j=1}^{n} a'_{ij}}{n}$.

Saaty proposes the principal eigenvector p as the desired priorities vector (3), arguing that slight variations in a consistent matrix imply slight variations of the eigenvector and the eigenvalue (*cf.* Ishizaka and Labib, 2011):

$$A \cdot p = \lambda \cdot p \tag{3}$$

where A is the comparison matrix, p the priorities vector and λ the maximal eigenvalue.

When using the AHP approach, a minimal consistency is required to ensure quality and consistency in the decision makers' judgments (Ishizaka and Labib, 2011; Karanik *et al.*, 2016; Fernandes *et al.*, 2018). Saaty (1977) proposed the following consistency index (CI) (4), based on the eigenvalue method, where n is the dimension of the matrix and λ_{max} is the maximal eigenvalue:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{4}$$

Consistency is checked using the consistency ratio (CR), which results from the ratio between CI and RI, as shown in formulation (5):

$$CR = \frac{CI}{RI} \tag{5}$$

where RI is defined as a random index, constructed by using Saaty's scale values (1980), and obtained from 500 randomly designed positive reciprocal matrices (Karanik *et al.*, 2016). The RI calculated by Saaty (1977) is shown in *Table 3*.

Table 3: Random indices

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty (1977)

According to Saaty (1994), Jovanovic *et al*. (2015), Karanik *et al*. (2016), and Singh and Nachtnebel (2016), when the CR is 10% or less, this means that the pairwise matrix is consistent. However, when the CR is over 10%, other methods should be used to improve this index through revisions and adjustments, although the matrix needs to remain complete.

In the last phase – *i.e.*, recommendations – the AHP process should be synthesized. The goal is to identify actions that can be taken in the future.

4. IMPLEMENTATION

The integrated application of cognitive mapping and AHP in the present study followed the steps discussed in section three, which are presented in greater detail in *Figure 3*. Specifically, the structuring phase focused on defining the evaluation criteria (*i.e.*, the objective was to use cognitive mapping to identify evaluation criteria – also known as fundamental points of view that, from the decision makers' perspective, can be used to measure city sustainability and livability. The evaluation phase sought to define the relative and global weight of each criterion using the AHP method. The recommendations phase involved a critical analysis of the results of the two previous phases to identify possible limitations and formulate recommendations.

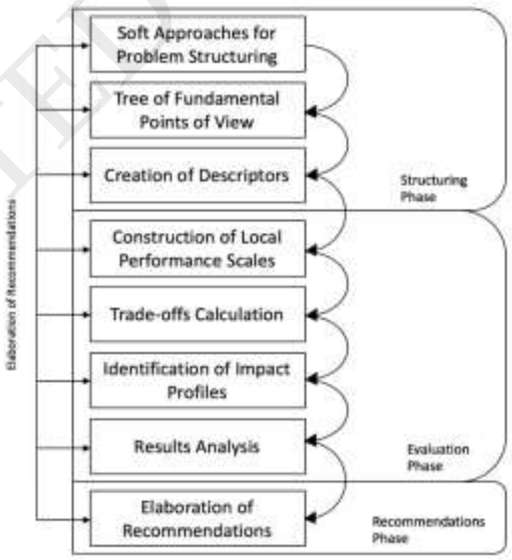

Figure 3. Structure of Methodological Processes

Source: Adapted from Ensslin *et al.* (2000)

The participative component of these techniques implied gathering a panel of decision makers willing to collaborate in defining and analyzing the decision problem in face-to-face group sessions. In this study, the panel was composed of six professionals from the real estate industry (*i.e.*, civil engineers, urban planners, and real estate agents). Even though the existing literature does not stipulate a fixed number of participants required to form a panel, Eden and Ackermann (2004) suggest that a panel ideally should consist of 6 to 10 key individuals.

Notably, the aim of studies using these methods is not to achieve representativeness or to be able to formulate generalizations. As Bell and Morse (2013) note, these methods have a strong focus on process, meaning that they seek to bring together the knowledge and experience of a group of experts in the field, and to create new insights and use these to develop an evaluative framework. Although this means the results are somewhat idiosyncratic, the procedures followed – when correctly adjusted – can work well with different panels or in various contexts (*cf.* Bell and Morse, 2013; Ferreira *et al.*, 2016; Oliveira *et al.*, 2017; Fernandes *et al.*, 2018).

Two experienced facilitators (*i.e.*, researchers) also participated in the sessions to facilitate the negotiation and communication processes for the panelists. Three face-to-face group sessions were held, with an average duration of four hours each. The first session covered the structuring phase.

4.1 Structuring Phase

The first session started with a brief introduction of each panel member and clarification of methodological aspects. The following trigger question was then asked: *"Based on your own values and professional experience, what are the main reasons for – or factors that most influence – city sustainability and livability?"*. This question sought to stimulate the panel to identify the evaluation criteria by sharing and discussing their perspectives.

Next, the "post-its technique" was applied (Ackermann and Eden, 2010). Each member was asked to write on post-its the criteria that they believed were important. Two essential rules were followed: (1) one criterion per post-it; and (2) a negative sign (–) in the upper righthand corner of the post-it note whenever the cause-effect relationship was considered negative (*cf.* Ferreira *et al*., 2015a; Martins *et al*., 2015).

The goal of the second part of this process was to reorganize the post-its into different clusters and/or areas of concern. The results were used to develop a cognitive map using the *Decision Explorer* software (http://www.banxia.com), which supported further discussion of how the decision problem was structured. *Figure 4* represents the final version of the group cognitive map, after it had been collectively validated by the decision makers (size restrictions prevent the inclusion of a clearer version of the map in this paper, but an editable version can be obtained from the corresponding author upon request).

Even though *Figure 4* represents the useful output of a structuring tool, this map was not perceived as the final goal of the structuring process. Given the participative nature of the methodology, the above collective cognitive map shows the criteria that the decision makers considered the most relevant to constructing a knowledge-based decision support system for evaluating city sustainability and livability. In addition, the map shows the cause-and-effect relationships between variables (for more information on the advantages of cognitive mapping, see Eden (1994), Ackermann and Eden (2010), and Ferreira *et al*. (2016)).

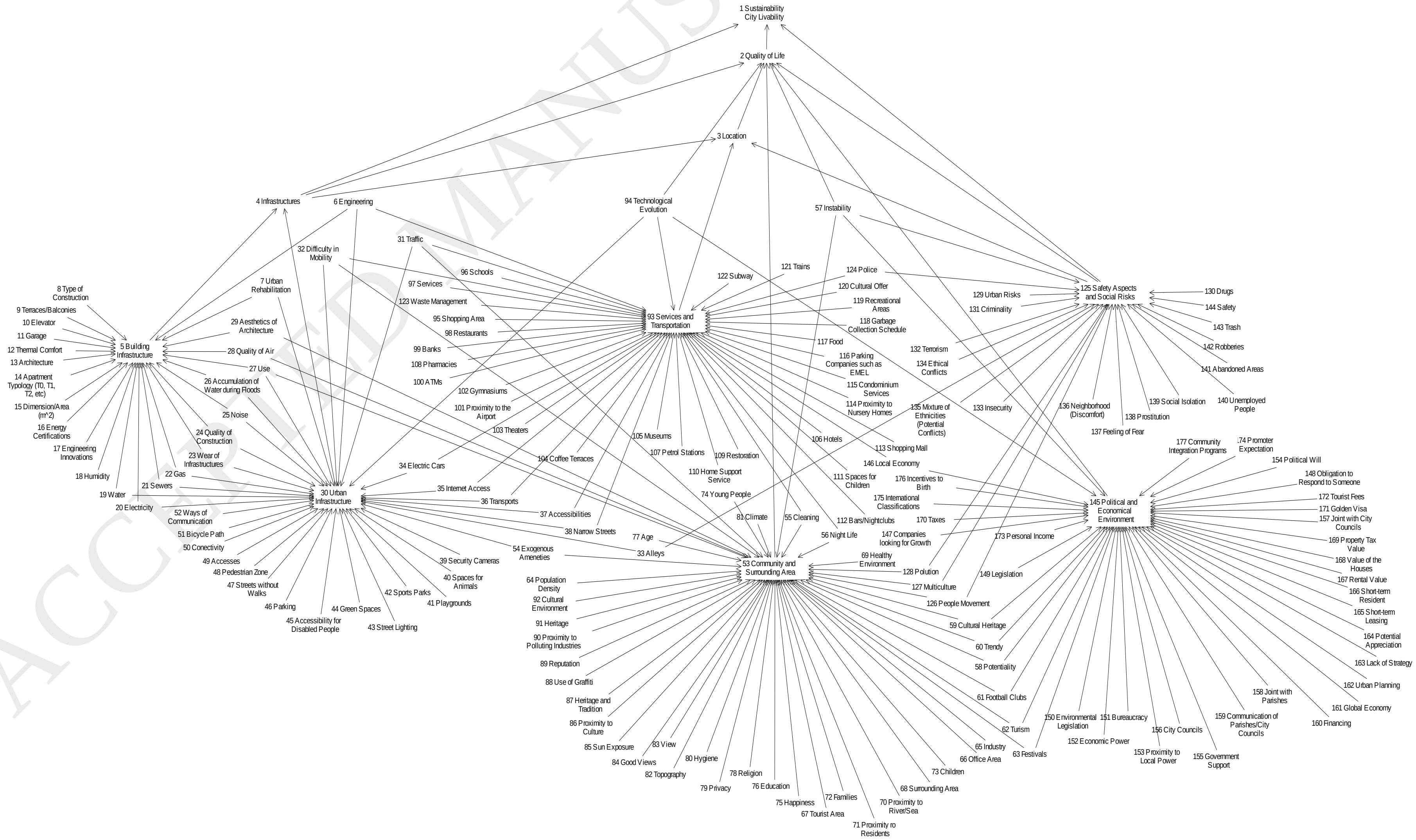

Figure 4: Collective Cognitive Map

By following Keeney's (1992) and Eden's (1994) methodological guidelines, the key areas of concern were defined by the panel of decision makers, which facilitated the selection of key criteria (*i.e.*, CTR01–6). *Figure 5* shows the constructed and validated value tree.

Figure 5: Value Tree

The panel members agreed on the importance of verifying that the following CTRs are met. Building infrastructure (CTR01) includes all the characteristics and factors related to buildings themselves (*e.g.*, existence of water, dimension and/or area, types of building, and quality and types of construction). Services and transportation (CTR02) comprise characteristics in terms of the offer and quality of different services and transportation (*e.g.*, schools, restaurants, coffee terraces, waste management, transportation networks, services, and cultural events). Community and surrounding area (CTR03) integrate characteristics of the community environment of the residential area (*e.g.*, sunshine duration, topography, hygiene, reputation, education, population density, and climate and/or weather). Political and economic environment (CTR04) refers to political and economic aspects that might influence city sustainability and livability (*e.g.*, house market value, legislation, personal income, urban planning, global economy, future prospects, and property taxes). Safety aspects and social risks (CTR05) include a set of factors or situations that affect city livability classifications (*e.g.*, neighborhood, social isolation, trash accumulation, criminality, and insecurity levels). Urban infrastructure (CTR06) comprises a set of characteristics related to the area surrounding buildings and what it offers (*e.g.*, street lighting, parking lots, green spaces, roadways, and accessibility).

During the second session, the decision makers were asked to focus their attention on the cognitive map and the value tree, and define a descriptor and respective levels of partial performance for each CTR (*cf.* Bana e Costa *et al*., 1999). This required a thorough analysis of the cognitive map and of the tree of criteria. For each CTR, the panel members pointed out the sub-criteria they considered most relevant for the assessment of city sustainability and livability; and an adaptation of Fiedler's (1965) scale was used to facilitate cognitive comparisons. "Good" and "Neutral" reference levels were defined for each descriptor. *Figure 6* is an example of a descriptor and its partial performance levels.

Descriptor CTR01 - Building Infrastructure [BI]			Level	Description
Inexistence of Potable Water or Extremely Inadequate Plumbing	1 2 3 4 5 6 7 8	Existence of Potable Water, with Extremely Adequate Plumbing and Excellent Pressure	**L1**	Index BI ∈ [36-40]
Very Poor Distribution of Space	1 2 3 4 5 6 7 8	Excellent Distribution of Space	**Good**	Index BI ∈ [29-35]
Excessively Small Areas	1 2 3 4 5 6 7 8	Excellent Areas	**Neutral**	Index BI ∈ [20-28]
Extremely Inadequate Functional Construction	1 2 3 4 5 6 7 8	Extremely Adequate Functional Construction	**L4**	Index BI ∈ [11-19]
Very Poor Quality of Construction	1 2 3 4 5 6 7 8	Excellent Quality of Construction	**L5**	Index BI ∈ [5-10]

Figure 6: Descriptor and Levels of Local Performance for CTR01

Figure 6 is just an example of the procedure followed for all the CTRs. It represents the descriptor created for CTR01, which produces the Building Infrastructure (BI) index, where L1 represents the best possible performance level, comprising a state where the sum of the values assigned by the panel members to each sub-criterion on the left side of the descriptor, after analysis of the respective poles, belongs to the maximum practicable range of values on the right side of the same descriptor. In contrast, L5 is a clearly inadequate level of performance, indicating a state classified by the minimum range. Because each descriptor can present a different number of impact levels, this procedure was carefully applied to the remaining five clusters. The structuring phase was thus completed when a detailed descriptor had been defined for each CTR. According to Rita *et al.* (2018), it is worth noting that descriptors can be adjusted (or even replaced) every time the decision makers consider it necessary or appropriate to do so. This does not jeopardize our proposal, which is process-oriented and grounded on the combined use of cognitive mapping and AHP; and can be applied using different types of descriptors. The next subsection focuses on the second phase of the process – the evaluation phase.

4.2 Evaluation Phase

The evaluation phase was completed in the last group session with the panel of experts. In the first part, after a brief explanation of the AHP methodology, the panel experts were asked to focus their attention on the identified CTRs and rank them based on their overall preferences. The idea was to assign a value of "1" whenever one CTR was globally preferred over another and a value of "0" otherwise. This exercise was carried out using fictitious alternatives to compare the attractiveness of the "swings" of the CTRs, avoiding the "most common critical mistake" in decision analysis (see Keeney, 1992). The CTR in first place was the one with the highest total score, while the last one corresponded to the CTR with the lowest score obtained (see *Table 4*). Tests were subsequently conducted to guarantee mutual preferential independence between CTRs.

Table 4: Matrix of Overall Preferences

		CTR01	CTR02	CTR03	CTR04	CTR05	CTR06	TOTAL	R
Building Infrastructures	CTR01	–	1	1	1	1	1	5	1
Services and Transportation	CTR02	0	–	1	0	0	1	2	4
Community and Surrounding Areas	CTR03	0	0	–	0	0	1	1	5
Political and Economic Environment	CTR04	0	1	1	–	1	1	4	2
Safety Aspects and Social Risks	CTR05	0	1	1	0	–	1	3	3
Urban Infrastructures	CTR06	0	0	0	0	0	–	0	6

After the CTRs were ranked and the panel approved the results, the next step consisted of constructing a pairwise comparison matrix to obtain the trade-offs. The definition of these priorities and relative rankings was based on Saaty's fundamental scale (see *Table 2* above). As *Table 5* shows, semantic tests were conducted to validate the consistency of the experts' value judgments. In this case, the differences in terms of importance should decrease from top to bottom and increase from left to right in the matrix.

Table 5: Semantic Validations and Value Judgments Consistency

	CTR01	CTR04	CTR05	CTR02	CTR03	CTR06	
CTR01	–	2	2	4	6	7	Positive
CTR04	–	–	2	3	5	7	Positive
CTR05	–	–	–	3	3	7	Positive
CTR02	–	–	–	–	3	4	Positive
CTR03	–	–	–	–	–	4	Positive
CTR06	–	–	–	–	–	–	Positive

The *Super Decision* software (www.superdecisions.com) was used to fill in the matrix of judgments and identify the trade-offs between CTRs (see *Figure 7*). The calculation results were shown to the decision makers for further discussion and validation. The inconsistency index was 0.04773, which is lower than the acceptable threshold value of 0.10.

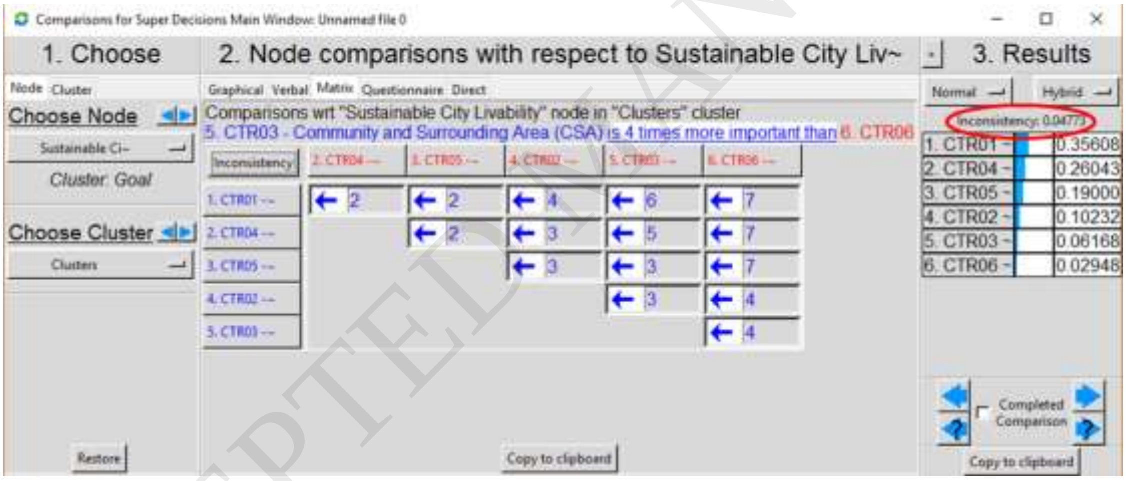

Figure 7: Judgments Matrix and Trade-offs Between Criteria

Once these results were validated, a consensus was reached that the highest weight (*i.e.*, 35.608%) should be assigned to CTR01 (*i.e.*, building infrastructure). At the other end of the spectrum, the lowest weight (*i.e.*, 2.948%) was allocated to CTR06 (*i.e.*, urban infrastructure). In other words, in the panel's opinion, building infrastructure is the most important CTR by which to evaluate city sustainability and livability.

The next step was to fill in a comparison matrix for each of the defined descriptors, which meant that the technical procedure used to calculate the trade-offs between criteria had to be applied in each case. *Figure 8* shows an example of the local scale of CTR01. The same procedure was used for all the descriptors, which showed inconsistency levels of under 10%.

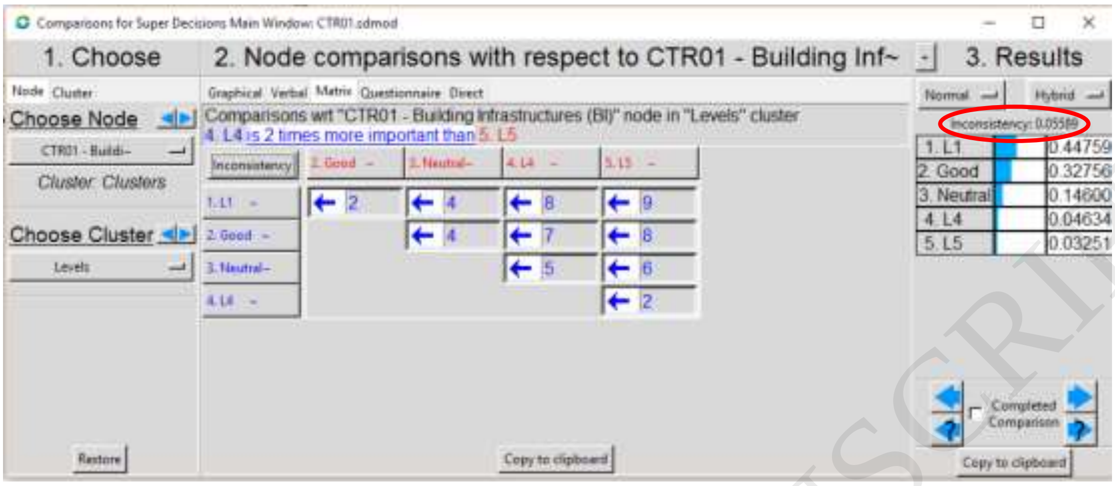

Figure 8: Judgments and Value Scale for CTR01

The evaluation phase was considered complete after the trade-offs between CTRs were obtained, along with the local performance scales for the descriptors identified in the model. This meant that the practical applicability of the proposed evaluation model could be verified.

4.3 Practical Application and Recommendations

In order to analyze the results obtained and assess the applicability of the proposed process, the new evaluation model of city sustainability and livability needed to be tested. The testing procedure started with determining the global performance of four fictitious neighborhoods (hereafter designated as "Alphas"), which was the starting point for cognitive comparisons. *Table 6* shows the partial and global weights of each Alpha.

Table 6: Impact Levels and Overall Performance per Alpha

0,6	OVERALL	CTR01	CTR02	CTR03	CTR04	CTR05	CTR06
Alpha 1/Excellent	**0.45155**	0.44759	0.39887	0.39239	0.42497	0.54445	0.44221
Alpha 2/Good	**0.29679**	0.32756	0.29747	0.32570	0.26083	0.27881	0.29584

Alpha 3/Neutral	**0.12693**	0.14600	0.16824	0.14074	0.09990	0.09653	0.15892
Alpha 4/Terrible	**0.02850**	0.03251	0.02150	0.02318	0.02309	0.03290	0.02948
WEIGHTS		**0.33958**	**0.09066**	**0.05440**	**0.21063**	**0.18101**	**0.02731**

As shown in *Table 6*, Alpha 1 corresponds to a fictitious neighborhood designated as having "Excellent" performance, which includes the best partial levels for all CTRs. Similarly, Alpha 2 is a "Good" neighborhood that represents the good level for all CTRs. Alpha 3 is the "Neutral" neighborhood as it exemplifies the neutral levels for all CTRs. Finally, Alpha 4 is the "Terrible" neighborhood since it combines all the worst partial levels for the criteria identified.

In the second step of the testing procedure, the panel was asked to give actual information about real neighborhoods to examine the impact level for each CTR in each neighborhood. *Table 7* represents the partial and global performance of the sample of eight neighborhoods (hereafter referred to as "Deltas").

Table 7: Partial and Global Performance and Ranking of Deltas 1–8

	OVERALL SCORE	**CTR01**	**CTR02**	**CTR03**	**CTR04**	**CTR05**	**CTR06**	**RANKING**
Delta 5	**0.35402**	0.44759	0.39887	0.39239	0.26083	0.27881	0.29584	**1**
Delta 4	**0.21621**	0.32756	0.29747	0.32570	0.09990	0.09653	0.15892	**2**
Delta 6	**0.19982**	0.14600	0.29747	0.32570	0.15222	0.27881	0.15892	**3**
Delta 3	**0.17478**	0.14600	0.29747	0.14074	0.09990	0.27881	0.15892	**4**
Delta 7	**0.17478**	0.14600	0.29747	0.14074	0.09990	0.27881	0.15892	**4**
Delta 8	**0.14570**	0.14600	0.16824	0.14074	0.03900	0.27881	0.15892	**6**
Delta 1	**0.13794**	0.14600	0.16824	0.14074	0.15222	0.09653	0.07026	**7**
Delta 2	**0.06927**	0.04634	0.16824	0.08084	0.03900	0.09653	0.07026	**8**

As can be seen in *Table 7*, the Deltas were ranked based on their overall scores, which were obtained through the application of a simple additive aggregation model (see Martins *et al.*, 2015). The results support the conclusion that Delta 5 is the neighborhood with the best performance, while Delta 2 is the worst in terms of sustainable livability. *Table 8* shows the relative position of each Delta, which took into account how they compared with the Alphas previously created.

Table 8: Deltas' Positioning Taking into Consideration Alphas

ALPHA/DELTA	GLOBAL INDEX
Excellent	**0.45155**
Delta 5	0.35402
Good	**0.29679**
Delta 4	0.21621
Delta 6	0.19982
Delta 3	0.17478
Delta 7	0.17478
Delta 8	0.14570
Delta 1	0.13794
Neutral	**0.12693**
Delta 2	0.06927
Terrible	**0.02850**

On a practical level, *Table 8* represents an evaluation thermometer for assessing city sustainability and livability. Only Delta 5 falls between "Excellent" and "Good". Six other neighborhoods are in between "Good" and "Neutral" in terms of their sustainable livability. The last neighborhood (*i.e.*, Delta 2) received scores placing it between "Neutral" and "Terrible". In this study, no neighborhoods were evaluated as below the "Terrible" level.

This phase of the process was essential to consolidate the results obtained and generate a feeling of satisfaction among the panel members. Indeed, the outcomes of our testing exercise were provided to the panel members, and deeply discussed and validated by them on a collective basis. This is one of the advantages of the constructivist stance assumed in this paper, which allows for adjustments every time the decision makers consider them necessary and appropriate. Nevertheless, given the inherent subjectivity of this process, sensitivity analyses were also needed. These facilitated the examination of possible variations in the ranking of alternatives. For instance, *Table 9* shows the sensitivity analysis results for CTR01.

Table 9: Sensitivity Analysis for CTR01

CTR 01 WEIGHT	PRIORITIES							
	DELTA 1	DELTA 2	DELTA 3	DELTA 4	DELTA 5	DELTA 6	DELTA 7	DELTA 8
0.050090	0.093444	0.056293	0.131944	0.112196	0.214522	0.158102	0.131944	0.101554
	7	8	3	5	1	2	3	6
0.150070	0.093497	0.054194	0.128938	0.120055	0.220399	0.153018	0.128938	0.100962
	7	8	3	5	1	2	3	6
0.20060	0.09353	0.053154	0.127448	0.123949	0.223310	0.150499	0.127448	0.100669
	7	8	3	5	1	2	3	6
0.250050	0.093548	0.052120	0.125968	0.127820	0.226204	0.147995	0.125968	0.100378
	7	8	4	3	1	2	4	6
0.300040	0.093574	0.051092	0.124496	0.131668	0.229081	0.145506	0.124496	0.100088
	7	8	4	3	1	2	4	6
0.350030	0.093599	0.050071	0.123033	0.135492	0.231940	0.143032	0.123033	0.099513
	7	8	4	3	1	2	4	6
0.400020	0.093625	0.049055	0.121579	0.139294	0.234783	0.140572	0.121579	0.099513
	7	8	4	3	1	2	4	6
0.450010	0.093650	0.048046	0.120133	0.143073	0.237608	0.138128	0.120133	0.099229
	7	8	4	2	1	3	4	6
0.500000	0.093675	0.047042	0.118696	0.146829	0.240417	0.135697	0.118696	0.098946
	7	8	4	2	1	3	4	6
0.549990	0.093720	0.045243	0.116120	0.153566	0.245454	0.131339	0.116120	0.098438
	7	8	4	2	1	3	4	6
0.599980	0.093764	0.043462	0.113570	0.160232	0.250438	0.120727	0.113570	0.097936
	7	8	4	2	1	3	4	6
0.649970	0.093808	0.041701	0.111047	0.166827	0.255369	0.122761	0.111047	0.097440
	7	8	4	2	1	3	4	6
0.699960	0.093852	0.039958	0.108551	0.173353	0.260248	0.115839	0.108551	0.096948
	7	8	4	2	1	3	4	6
0.749950	0.093895	0.038233	0.106081	0.179811	0.265077	0.114361	0.106081	0.096462
	7	8	4	2	1	3	4	6

Table 9 shows that the system created appears to remain stable when the weights are changed. In other words, the higher the weight attributed to the CTR is, the less significant are the changes verified in the Deltas' ranking. This result confirmed the stability of the model created.

Although the sensitivity analyses provided proof that the proposed model can be used to evaluate city sustainability and livability, the system has idiosyncratic characteristics (*i.e.*, the results depend on the context and actors involved). For this reason, any extrapolation of these results cannot be made without taking proper precautions. However, the way the sessions unfolded, the tests of the different CTRs, and the satisfaction expressed by the decision makers offer support for the conclusion that the obtained results are important. The AHP method, in specific, facilitated the calculation of trade-offs among criteria, giving the experts a more accurate, informed, and transparent understanding of the evaluation system developed. Therefore, this evaluation thermometer's successful application reinforces the conviction that the integrated use of cognitive maps and the AHP can make pertinent contributions to the development of real estate evaluation practices.

5. CONCLUSION

Given the nature of the real estate industry and the role of sustainable livability in urban planning projects, this study sought to develop a new approach to constructing knowledge-based decision support systems for assessing city sustainability and livability (*i.e.*, an evaluation thermometer). This was achieved by combining cognitive mapping and a well-established MCDA tool – the AHP. Cognitive mapping techniques were employed as a way to identify the evaluation criteria. The AHP approach was used to obtain the weights for each CTR identified. The integration of these approaches enabled this study to answer the two research questions:

(1) How can city sustainability and livability be measured?

(2) Which methodologies facilitate the consideration of both quantitative and qualitative indicators?

The MCDA approach applied proved to be useful as a way to evaluate city sustainability and livability. This was due mainly to how cognitive mapping organized the ideas and reduced the number of omitted criteria, and the AHP was instrumental to calculating the trade-offs among evaluation criteria. Furthermore, the AHP proved to be an important tool when ranking key evaluation criteria, producing a consensus that the highest weight (*i.e.*, 35.608%) should be assigned to CTR01 (*i.e.*, building infrastructure). The results thus underline the importance of buildings' characteristics when evaluating city sustainability and livability.

Overall, the model creation was a learning process, in the sense that the constructivist approach applied was conducive to reflecting on the evaluations made and suggesting adjustments (Ferreira, 2013; Govindan *et al.*, 2014). This was a valuable process meeting Eden and Ackerman's (2004) panel size recommendations.

In practice, the contributions of our study are both methodological and with regard to the findings. Although the findings presented are idiosyncratic in nature, they can be a starting point for other researchers and practitioners hoping to identify and prioritize determinants of city livability; and should be used to complement previous studies in the field. From a methodological perspective, the contribution comes both from the integration between methodologies, which we believe to be novel in this study context; and from the description of the process followed, which can allow for replications in a new setting or with different participants (*cf.* Bell and Morse, 2013). For this reason, the model should make it easier to measure the sustainable livability of cities, enabling future decisions that are well-thought out and more transparent thus benefiting the real estate industry, city planners, the communities and the overall society.

Nonetheless, the proposed model should be regarded as idiosyncratic. Thus, future research could: (1) compose a panel of experts from different countries and backgrounds to determine the robustness and transparency of the present results; and (2) use different MCDA methods and conduct comparative studies – although not an objective of the present paper, we recognize the importance of methodological comparisons and strongly encourage them. Any potential adjustment in the proposed evaluation model will be another step forward toward more accurate evaluations of city sustainability and livability.

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