A REVIEW OF MULTI-CRITERIA ASSESSMENT OF THE SOCIAL SUSTAINABILITY OF INFRASTRUCTURES

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ABSTRACT

Nowadays multi-criteria methods enable non-monetary aspects to be incorporated into the assessment of infrastructure sustainability. Yet evaluation of the social aspects is still neglected and the multi-criteria assessment of these social aspects is still an emerging topic. Therefore, the aim of this article is to review the current state of multi-criteria infrastructure assessment studies that include social aspects. The review includes an analysis of the social criteria, participation and assessment methods. The results identify mobility and access, safety and local development among the most frequent criteria. The Analytic Hierarchy Process and Simple Additive Weighting methods are the most frequently used. Treatments of equity, uncertainty, learning and consideration of the context, however, are not properly analyzed yet. Anyway, the methods for implementing the evaluation must guarantee the social effect on the result, improvement of the representation of the social context and techniques to facilitate the evaluation in the absence of information.

KEYWORDS: infrastructure; multi-criteria; social sustainability; equity; stakeholders; uncertainty.

1. INTRODUCTION.

The social dimension is one of the pillars of sustainability. However, evaluation of the social aspects is taken less into consideration than the economic and environmental dimensions (Missimer et al. 2017, Díaz-Sarachaga et al. 2016). Indeed, some public projects have not yet integrated the social aspects sufficiently and instead focus their attention on socioeconomic performance (Valdés-Vázquez and Klotz 2013, Torres-Machi et al. 2017). Polese and Stren (2000) define social sustainability as "*development that is compatible with harmonious evolution of civil society, fostering an environment conducive to the compatible cohabitation of culturally and socially diverse groups while at the same time encouraging social integration, with improvements in the quality of life for all segments of the population* (p. 229)."

Specifically, publicly funded civil engineering projects seek out social development that will justify their investment. Civil engineering projects seek to build services and facilities, which are basically needed for transportation and energy supply; they are generally called infrastructures. The development of infrastructures involves the design, construction, operation and dismantlement of the service or facility in order to comply with a public need (Pellicer et al. 2014). In this sense, infrastructures represent an intermediary link that opens opportunities for sustainable social development (van de Walle 2002, Mostafa and El Gohary 2014). By contrast, not considering the social dimension in an infrastructure's development may have detrimental effects on the project and society (Temper et al. 2015, Naderpajouh et al. 2014). In the short term, the dynamics of increasing participation by stakeholders and their interactions imply risks that challenge the fulfillment of the project when a suitable social treatment is not preconceived (Munda 2004, Naderpajouh et al 2014). In addition, the non-reversal of effects that may put the quality of intra-generational life at risk has long-term repercussions on the state of development of future generations (Axelsson et al. 2013, Sierra et al 2017a, 2018).

The social sustainability of infrastructures depends on the evaluation criteria that determine their state of development; however, the definition of the criteria that comprise social sustainability in construction projects is not clearly delineated. Social criteria have more or less prominence according to the application contexts, the participants' perspective and the life cycle stages (Labuschagne et al. 2005; Valdés-Vásquez and Klotz 2013; Sierra et al. 2016). Moreover, identification of social criteria must be associated with the affected parties (Di Cesare et al. 2016). Given this, the decision-makers and the rest of society must establish a mutual interaction to support a sound decision. A technocratic approach where decisions are based solely on the contributions of experts is not recommended. Munda (2004, 2006) holds that from this participation the scientific team can improve their knowledge of the issue and the context to draw reasoned conclusions.

Evaluation methods must also safeguard the effect of each social criterion. That is, methods should avoid full compensations and consider not only the quantifiable but also intangible criteria that are meaningful (Munda et al. 2004; Gervásio and Da Silva 2012). At the feasibility stage, project features have a high degree of uncertainty that must be considered by the evaluation method (Pan 2009, Zavadskas et al. 2018). If it is possible to anticipate the future state of the system, there is a stochastic uncertainty (Gervásio and Da Silva 2012). Another formulation, called fuzzy uncertainty, concentrates on the ambiguity of the information of an event. This situation is very common in human systems with a clear intention but a less clear extension (Umer et al. 2016). Similarly, grey systems theory is characterized as having poor information and small samples. In this case, the definition thresholds of an event are clear, but the intention is not (Delgado and Romero 2016).

In addition, an assessment method of social sustainability must give account of equity in the distribution of the benefits of an infrastructure. In fact, the concept of sustainability implies the safeguarding of the present and the intergenerational conditions (Hyard 2012, Bueno et al. 2015). Multi-criteria studies dealing with social equity are limited. Among them, the SUMINI method has implemented a specific indicator to measure sustainable mobility inequality in cities (Thomopoulos et al. 2009, 2013). In another approach, a participatory and transparent process promotes the use of criteria and weights according to fair social equity standards (Hyard 2012). In this sense, a method must consider the criteria that represent all the sectors of society including minorities and the most vulnerable (Munda 2006, Soltani et al. 2015, Salas and Yepes 2018b).

On the other hand, the social assessment must promote the judgments and agreements on the social impacts through a dynamic learning process (Munda 2004, Pellicer et al. 2016, Missimer et al. 2017). A method that promotes a long-term learning process must be adaptive, flexible and with a high institutional commitment. In addition, the feedback and consultations among the participants are fundamental (Díaz-Sarachaga et al. 2016, Muench et al 2011). In a method with these characteristics, the participants focus their learning on the needs of the context. Thus, understanding the context and adjusting the participants' interest improve the precision in future assessments.

The level of development of a place affects the degree of satisfaction and the needs required there (Missimer et al. 2017, Sierra et al. 2017b, 2018). In fact, Valdés-Vásquez and Klotz (2013) emphasize the consideration of location within the processes of sustainable development of the infrastructure. However, there is also a lack of longitudinal data that can give account of the conditions that determine social development in specific contexts (Labuschagne and Brent 2006, Colantonio 2011, Chow et al. 2014). Furthermore, given the cultural diversity, local experiences are at times more useful than expert opinions for obtaining adequate data (Munda 2004, Soltani et al. 2015). In these cases the use of social tools like interviews or field studies can capture the contextual information (van de Walle 2002, Karami et al. 2017).

Traditional methods present weaknesses when social aspects of sustainability are assessed. The treatment of elements like equity, qualitative variables and democratic considerations are some of the difficulties (Hyard 2012, Mostafa and El-Gohary 2014). Multi-criteria methods are an assessment alternative that can take the social aspects into account (Munda 2004, Gervásio and Da Silva 2012). However, the social aspects still get less attention in the sustainability assessment (Missimer et al. 2017, Diaz-Sarachaga et al. 2016). Some isolated studies have taken the multi-criteria social assessment into account, treating the uncertainty of the social data (Delgado and Romero 2016, Zavadskas et al. 2018), considering social equity in the distribution of the effects of the infrastructure (Hyard 2012, Thomopoulos et al. 2013), promoting a social learning process (Díaz-Sarachaga et al. 2016, Pellicer et al. 2016), or promoting the participation and contextualization the assessment structure according to the time and place of implementation (Valdés-Vásquez and Klotz 2013, Soltaní et al. 2015). The implementation of these treatments has been variable, mixed with others elements of the sustainability and not completely understood in all the development areas of an infrastructure (Vanclay 2002, Valdés-Vásquez and Klotz 2013, Pellicer et al. 2016). In fact, there is no clarity in the specifications of the treatments implemented in the multi-criteria evaluation of the social aspects in infrastructures, nor if these are adequate to address the weaknesses detected in a social assessment of sustainability. Thus, the multi-criteria methods used to deal with the social dimension of infrastructures require a review, and this is the starting point of this study. Accordingly, this study presents a review of the infrastructure assessment methods to answer the question: How are social aspects treated in infrastructures' multi-criteria assessment? A content analysis on a sample of 94 previous contributions is used to respond to the research question.

This article is structured in five additional sections. First, the authors present a state-of-the-art on multi-criteria assessment methods used for infrastructure social decision-making. The following section explains the research method, specifically the sampling, the categorization of information and the content analysis. Next, the results section analyzes the relevant social criteria, the multi-criteria methods applied, as well as the considerations of the context, equity and social learning. These results are discussed and, finally, the conclusions of the article are provided.

2. MULTI-CRITERIA ASSESSMENT METHODS

The multi-criteria assessment methods make possible the decision-making among different alternatives, considering the multidimensionality of the real world. To this end, these methods are also called multi-criteria decision-making methods (MCDM), multi-criteria decision-making analysis (MCDA) or simply multi-criteria analysis (MCA). Specifically, Jato-Espino et al. (2014a), Penades-Pla et al. (2016) and Zamarrón-Mieza et al. (2017) have identified different multi-criteria methods applied to infrastructure projects. MCDM are comprised of multi-attribute (MADM), multi-objective (MODM), and complementary techniques (Zamarrón-Mieza et al. 2017). Multi-attribute techniques are able to decide on the best options from among previously selected infrastructures; in these techniques, the weights of the criteria influence the decision-making (Jato-Espino et al. 2014a). Conversely, multi-objective techniques identify optimal solutions that satisfy different general objectives in conflict (Salas and Yepes 2018a). The complementary techniques facilitate the most representative processing of the data. Thus, the multi-criteria methods are usually hybrid methods to address different realities in the infrastructure assessment.

Generally a multi-criteria evaluation process is comprised of four stages. First, the problem and the assessment structure are defined. Then the weights of the criteria that integrate the assessment structure are determined. After this, the different alternatives are evaluated with respect to each criterion. Finally, the evaluation of the alternatives is weighted against the weight of each criterion (Bueno and Vassallo 2015, Soltani et al. 2015). Table 1 shows a summary of the infrastructure assessment methods that come from the review process. These methods are selected as a result of this in-depth review that identifies multi-criteria assessment studies applied to infrastructures, considering the social facet.

Table 1 Summary of the main multi-criteria assessment methods

Type	Method	Description
MADM	Analytic Hierarchy Process (AHP)	Structured technique for the analysis of multi-criteria decision-making issues according to a pairwise comparison scale. It considers the decision-maker's consistency and weights obtained through the eigenvalues (Saaty 2004).
MADM	Analytic Network Process (ANP)	Generalization of the AHP, it allows interdependence between criteria without a hierarchical pattern (Saaty 2004).
MADM	Integrated Value Model for Sustainability Assessment (MIVES)	Unified methodology that combines the concepts of multi-criteria decision analysis and value engineering to synthesize the types of criteria on a value index. It uses a generic value function that standardizes each indicator. The AHP is used to determine the weights of the hierarchical decision-making structure (de la Cruz et al. 2015a).
MADM	Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)	Belonging to the methods of the outranking family and based on the selection of a preference function for each criterion that is part of the multi-criteria decision-making issue. This method is based on the pairwise comparison between alternatives to establish a relationship of outranking of one over another. The method applies a positive and negative assessment for each alternative and creates a ranking in relation to the decision weights (Gervásio and Da Silva et al 2012).
MADM	Simple Additive Weighting (SAW)	Technique that determines an average weighting for each alternative through the addition of the contribution of each attribute multiplied by its weights (MacCrimon 1968).
MADM	Grey Relational Analysis (GRA)	Method based on Grey systems theory applicable with vague and incomplete information. The GRA determines a correlation index of alternatives through which it is possible to obtain a prioritization (Chen et al. 2014).
MADM	Multi-Attribute/Value Utility Theory (MAUT/MAVT)	The MAUT is a methodology used to make decisions by comparing the utility values of a series of attributes with uncertainty. The MAVT is a technique that converts the attributes that comprise a MCDM problem into a single value through the value functions (Jato-Espino et al. 2014a, Soltani et al. 2015)

Type	Method	Description
MADM	Emergy	This analyzes the contributions to nature and the human economy by means of a conversion factor that reflects the solar energy needed to make a unit of a product or service (Li et al 2012, Reza et al. 2014).
MADM	Life Cycle Assessment (LCA)	Method that evaluates the impact on the environment and society with respect to the infrastructure and its processes of design, construction, use and maintenance and final disposition (Benoit-Norris et al. 2011). This tool needs data and the assessment of the social aspects of infrastructures is still emerging (Di Cesare et al. 2016, Zastrow et al. 2017).
MODM	Complex Proportional Assessment (COPRAS)	Step-by-step method that seeks to prioritize a set of alternatives according to their significance and degree of utility (Zavadskas and Kaklauskas 1996).
MODM	Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)	Technique based on the concept that the best alternative for a multi-criteria decision-making problem is the one closest to a positive ideal solution and farthest from a negative ideal solution. It is a method of compensatory aggregation that compares a set of alternatives through the weights of their criteria and standardized scores (Kucukvar et al. 2014).
MODM	Vlse Kriterijuska Optimizacija Komoromisno Resenje (VIKOR)	Method to determine a list of ranking by compromise between a set of alternatives according to the measurement closest to an ideal solution. The method formulates conditions to guarantee acceptable advantages of one alternative over another (Curiel-Esparza et al. 2016).
MODM	Goal Programming (GP)	Extension of linear programming methods that seeks optimized variables that satisfy multiple goals in the best way according to certain values to be reached. The goals are formulated as restrictions and the objective functions seek to minimize the sum of the absolute deviations of each objective (Wey and Wu 2007, 2008).
Complementary	Grey Systems Theory	Philosophy of data manipulation according to the information they contain, usable with vague and incomplete information. This block groups the methods listed such as Grey *Numbers* that can handle the uncertainty; *Grey Clustering* is to classify objects of observation in defined classes (Delgado and Romero 2016).
Complementary	Fuzzy Sets	A fuzzy number is an extension of a regular number in the sense that it does not refer to a unique value but to a set of possible values that vary with a weight between 0 and 1, called membership function (Pan 2008, 2009)
Complementary	Monte Carlo Simulation	Non-deterministic methods used to find approximate solutions to complex problems experimenting with random numbers (Gervásio and Da Silva 2012, del Cruz et al. 2015a).
Complementary	System Dynamics (SD)	Complementary technique serves to analyze complex, dynamic and nonlinear interactions between variables and generally used to simulate an evaluation process. The SD is a tool that has been used to model sustainable development scenarios (Zhang et al. 2014, Karami et al. 2017).
Complementary	Delphi Method	Iterative and systematic method designed to obtain a consensus from a group of experts who respond to a questionnaire reiteratively (Hallowell and Gambatese 2010)
Complementary	Entropy	Method that measures the weights of the criteria with the purpose of representing the intrinsic information transmitted for the decision-making. For each criterion an entropy function is applied and a determined degree of divergence with respect to the set of evaluated alternatives (Delgado and Romero 2016)

The evaluation process can be approached by one or several methods according to their capacity and the characteristics of the problem. In fact, some weighting methods are often hybridized with other alternative evaluation methods. Thomopoulos et al. (2013), Ugwu et al. (2006a) and Su et al. (2006) employ the AHP-SAW combination to address social criteria through scores and artificial scales. Likewise, the AHP-MIVES method is applied in the evaluation of the sustainability of structures (de la Cruz et al. 2015a, Jato-Espino et al. 2014a). Aghdaie et al. (2012) make use of the AHP-COPRAS method to assign the best location of pedestrian bridges according to social conditions. In addition, Shang et al. (2004) and Wey and Wu (2007) propose an approach based on benefit, opportunities, costs and risks, whereas the ANP assesses the interaction of social criteria, stakeholders and alternatives of mobility in the city, simultaneously. Chen et al. (2014) compares the hybridization of Entropy-TOPSIS and Entropy-GRA to prioritize transport infrastructure through objective weights. Likewise, Balali et al. (2014) selects bridge construction materials and methods through the Entropia-PROMETHEE method.

On the other hand, in the group of complementary techniques, fuzzy sets, gray systems theory or the Monte Carlo method contribute to treating uncertainty (Kucukvar et al. 2014, Delgado and Romero 2016, Jato-Espino et al. 2014b). Other methods, such as the geometric mean, Delphi or probability distributions, group information from multiple evaluators (Su et al.

2006, Ramani et al. 2011, Curiel-Esparza et al. 2016). Some studies focus their evaluation on the impact of a single infrastructure. In this vein, Gervasio and Da Silva (2013) assess the impact of a bridge through the life cycle analysis (LCA) for social cost criteria. Labuschagne and Brent (2006) and Sahely et al. (2005) use an LCA on aqueducts and transport systems with limited application due to lack of social information. Shen et al. (2005), Hong et al. (2011) and Zhang et al. (2014) propose theoretical models based on systems dynamics to evaluate the impact of an infrastructure. In the latter contribution, the results are conditioned to predicted scenarios only being useful in the long term. In this way, multi-criteria methods become hybrid methods in order to address the different realities of the evaluation process.

3. RESEARCH METHOD

The research method employed in this paper includes the procedures for adequate sampling, the description of the selected sample and the in-depth analysis of its contents. This overall process is displayed in Fig. 1 and detailed sequentially in the next subsections.

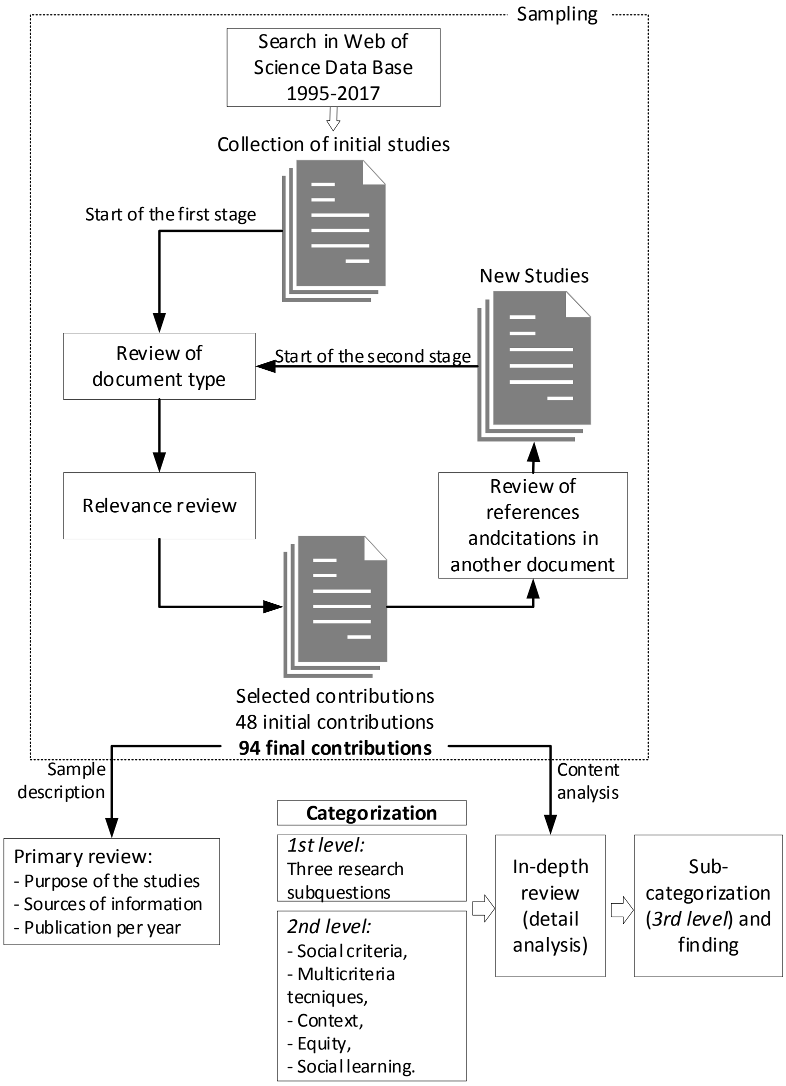

Fig. 1 Overall research process

3.1. Sampling

The sampling process was comprised of two stages according to the Fig. 1. In the first stage, an exploratory search established the selected initial contributions. The second stage was a follow-up of the references and citations of the contributions selected in the first stage. In the first stage, the search strategy was based on the previous study of the literature and the experience of the research team. Fig. 2 represents the scopes, keywords and Boolean operators of the search strategy in the first stage. The search was carried out through the scientific database *Web of Science*. The search period concentrated on 1995 to 2017 (January) since the multi-criteria methods in construction only acquired relevance from the 1990s (Jato-Espino et al. 2014a).

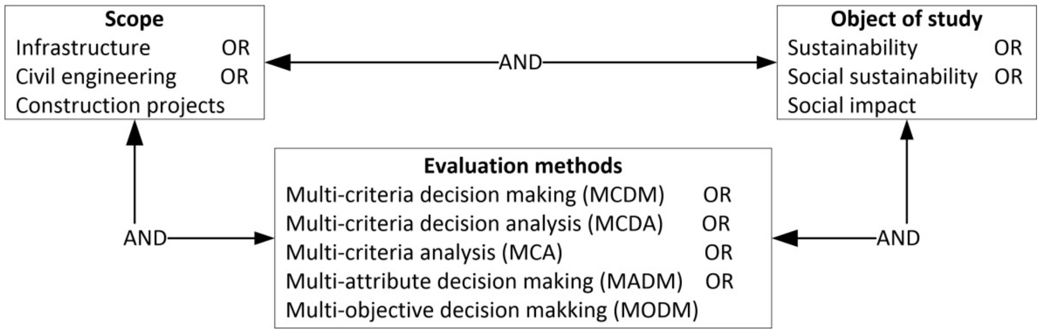

Fig. 2 Initial search strategy

According to Fig. 1, the initial contributions were selected according to the type of document and its relevance from the results of the search strategy. The selected documents were original articles, review articles and conference proceedings. In addition, the fit of each contribution (title, keywords and abstract) to the search strategy (scope, methods and field of study) determined its relevance (Fig. 2). Furthermore, three criteria guided the inclusion or exclusion of each contribution. First, the selection of documents considered only peer-reviewed scientific papers that used a multi-criteria evaluation method or related indicators; conceptual descriptive studies that did not specify an evaluation mechanism were excluded. Second, the sample excluded the studies that were not clear in the identification and treatment of social aspects. Third, the selection process considered contributions implemented at any stage of the life cycle of civil engineering infrastructures; studies conducted on building projects were beyond the scope of this study. Thus, in the first stage, 48 initial contributions were selected.

In the second stage, references of contributions analyzed at the first stage and the documents citing them are both reviewed. Other studies have already used these techniques to complete an adequate sample of papers and compile a body of knowledge (Burnhem 2006, Engert et al. 2016, Zamarron-Mieza et al. 2017). Similarly, the papers were filtered according to the type of document, its relevance and a review of references and citations to identify new contributions. During this phase, some systems of sustainability certification (*Rating Systems*) which comply with the conditions of the search strategy emerge from the initial contributions. Thus, 94 final contributions were selected.

From the selected final sample a primary review identified the purpose of the contributions, the sources of information and the publication years. Three types of studies were detected according to their purpose. The first type included 60 articles that evaluate infrastructure sustainability including the social dimension in the analysis. In the second, seven contributions are based on *Rating Systems* for the assessment of infrastructure sustainability and they include social aspects. Finally, 27 articles were chosen considering multi-purpose infrastructure assessment methods with a social approach. Furthermore, Table 2 shows 55 sources of information: 47 are scientific journals, seven international conferences, and a group of third-party certification institutions (*Rating Systems*). The journals that contribute with more items are: *Journal of Construction Engineering and Management* (8), *Automation in Construction* (6) and *Transport Policy* (5). In other cases the sample is disaggregated. Specifically, the scientific journals in the transportation field are 20% (19/94) of the papers in the sample. In addition, from 2001 on, the publishing trend has slowly increased, not exceeding 14 annual publications (see Fig. 3). This result is not consistent with previous reviews that show an exponential growth of multi-criteria techniques in construction (Jato-Espino et al. 2014a, Zamarron-Mieza et al. 2017). Thus, the unknown treatment in the evaluation of social aspects could be the cause for this slow growth in this research field.

Table 2 Summary of scientific sources

#	**Sources**	**Number of works, authors and year**
1	AMBIO[1]	1 Axelsson et al. 2013
2	Association of State Dam Safety Officials[2]	1 Ferre et al. 2014
3	Automation in Construction[1]	6 Chou et al. 2013; Hong et al. 2011; Kucukvar et al. 2014; Pan 2009; Ugwu et. al 2006 a; b
4	Building and Environment[1]	1 Ugwu and Haupt 2007
5	Canadian Journal of Civil Engineering[1]	3 Dasgupta and Tam 2005; Koo et al. 2009; Sahely et al. 2005
6	Clean Technologies and Environmental Policy[1]	1 Reza et al. 2014
7	Construction Management and Economics[1]	1 Abu Dabous and Alkass 2008
8	Ecological Indicators[1]	1 Fernandez-Sanchez and Rodriguez - Lopez 2010
9	Engineering Structures[1]	1 Sabatino et al. 2015
10	Engineering Sustainability[1]	1 MacAskill and Guthrie 2013
11	Environment and Planning B: Planning and Design[1]	1 Wey and Wu 2008
12	Environmental Impact Assessment Review[1]	2 Matthews et al. 2015; Karami et al. 2017
13	Environmental Modelling and Software[1]	1 Delgado and Romero 2016
14	Environmental Science and Policy[1]	3 Curiel-Esparza et al. 2016; Diaz-Sarachaga et al. 2017a; b
15	European Journal of Operational Research[1]	3 Caliskan 2006; Ferrari 2003; Munda 2004
16	Evaluation and Program Planning[1]	1 Thomopoulos et al. 2009
17	Expert Systems with Applications[1]	3 Gervasio and Simoes da Silva 2012; Jato-Espino et al. 2014; Pan 2008
18	IEEE Transactions on Engineering Management[1]	1 Shang et al. 2004
19	Informes de la Construcción[1]	2 Fernandez-Sanchez and Rodriguez-Lopez 2011; Jeong et al 2014
20	Industrial Engineering and Engineering Management[2]	1 Mousavi et al 2014
21	Information Management, Inn. Management and Industrial Engineering[2]	1 Xinzheng et al. 2009
22	Traffic and Transportation Studies[2]	1 Leng et al. 2012
23	International Journal Life Cycle Assessment [1]	1 Labuschagne and Brent 2006
24	International Journal of Project Management[1]	1 Zhang et al 2014
25	International Journal of Sustainable Built Environment[1]	1 Umer et al. 2016
26	International Journal of Sustainable Transportation[1]	4 Chow et al. 2014; Jeon et al. 2010; Lee et al. 2008; Shiau et al. 2015.
27	International Journal of Transport Economics[1]	2 Macura et al. 2011; Tsamboulas et al. 2007
28	Journal of Civil Engineering and Management [1]	1 Shen et al. 2007
29	Journal of Cleaner Production[1]	1 Labuschagne and Brent 2008
30	Journal of Construction Engineering and Management ASCE[1]	8 Boz and El-adaway 2014; 2015; El-Diraby and O'Connor 2001; Koo et al. 2008; Mostafa and El-Gohary 2014; Shen et al. 2011; Sierra et al. 2016; Su et al. 2006
31	Journal of Construction Research[1]	1 Shen et al. 2002

#	Sources	Number of works, authors and year
32	Journal of Management in Engineering (ASCE)[1]	1 Li et al. 2012
33	Journal of Reliability of Structures and Materials[1]	1 Nishijima et al. 2007
34	Journal of Transportation Engineering[1]	1 Ramani et al 2011
35	Journal of Zhejiang University: Science[1]	1 Shen et al. 2005
36	Mathematical and Computer Modelling[1]	1 Wey and Wu 2007
37	Municipal Engineer[1]	1 Gilmour et al. 2011
38	Procedia - Social and Behavioral Sciences[2]	1 Amiril et al. 2014
39	Procedia Engineering[2]	1 Bitarafan et al. 2013
40	Proceedings of the Water Environment Federation[2]	1 Andreas et al. 2010
41	Rating System User Guide. Third-party certification institutions [3]	4 CEEQUAL 2010; ISCA 2012 ;ISI 2015; Muench et al. 2011
42	Soft Computing Applications for Renewable Energy and Energy Efficiency[1]	2 De la Cruz et al. 2015 a; b
43	Structure and Infrastructure Engineering[1]	2 Gervasio and Simoes da Silva 2013; Yadollahi et al.2015
44	Sustainability[1]	2 Dobrovolskiene et al. 2016; Zavadskas et al. 2015
45	The Baltic Journal of Road and Bridge Engineering[1]	1 Aghdaie et al. 2012
46	The International Journal of Life Cycle Assessment[1]	1 Zhang et al. 2016
47	The international journal of social sustainability in economic, social and cultural context[1]	1 Resendez et al. 2014
48	Transport[1]	1 Bueno and Vassallo 2015
49	Transport Policy[1]	5 Ahern and Anandarajah 2007; Bonsall and Kelly 2005; Jeon et al. 2013; Ivanovic et al. 2013; Tsamboulas 2007
50	Transportation[1]	2 Berechmann and Paaswell 2005; Thomopoulos et al. 2013
51	Transportation Research Part A: Policy and Practice[1]	2 Chen et al. 2014; Tudela et al 2006
52	Transportation Research Part B: Methodological[1]	1 Brocker et al. 2010
53	Transportation Research Record: Journal of the Transportation Research Board[1]	2 Balali et al. 2014; Jeon 2010
54	Tunnelling and Underground Space Technology[1]	1 Gilchrist and Allouche 2005
55	World Development[1]	1 Van de Walle 2002

(1) Scientific journal ; (2) International conference with peer review ; (3) Rating System handbook of the sustainability

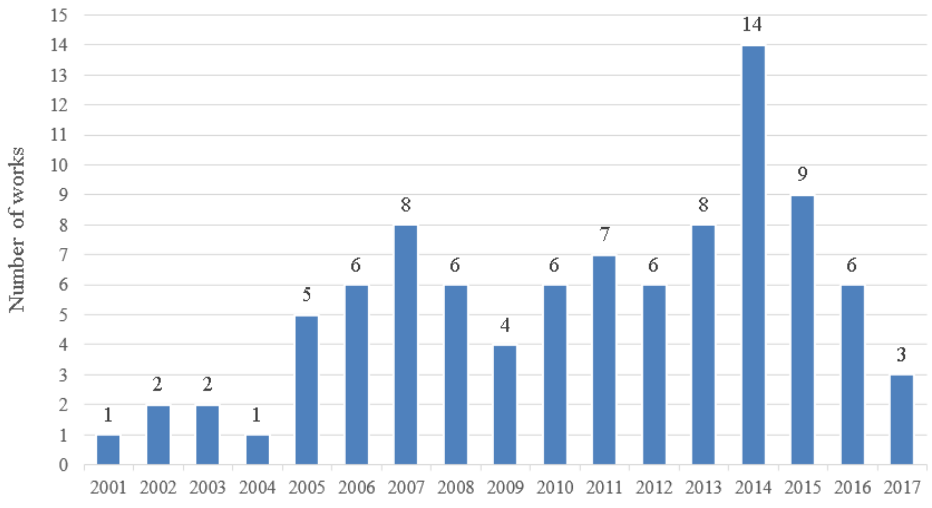

Fig. 3 Distribution of contributions per year (2001-2017)

3.2. Categorization and analysis of the information

In this instance the selected final contributions were subjected to an in-depth review (Fig. 1); i.e., the contributions were reviewed completely to apply a content analysis. Previous states of the art by Soltani et al. (2015), Engenrt et al. (2016) or Zamarron-Mieza et al. (2017) have already used content analysis to define sustainable categories in other areas. For the implementation of a content analysis, a categorization scheme composed of three levels is proposed. Three research questions make up the first level, five conceptual categories make up the second, and clusters of findings obtained from an inductive process and content analysis of 94 contributions make up the third. Thus, according to the research question *How are social aspects treated in infrastructures' multi-criteria assessment?*, the research team determined the following sub-questions: (Q1) *What is valued regarding the social contribution of infrastructures*?; (Q2) *What multi-criteria methods are used to assess the social contribution of infrastructures*?; and (Q3) *What treatments are used in multi-criteria social assessment processes of infrastructures*?.

At the second level, the categories are proposed according to the weaknesses, detected theoretically, in the social evaluation of sustainability. The weaknesses were identified from a previous literature review by the research team and this led to different works published in the field of social sustainability of infrastructure (Sierra et al., 2016, Sierra et al., 2017 a, b, Sierra et al., 2018). The main studies that refer to the weaknesses in the evaluation of social sustainability are presented in Table 3, as well as in the Introduction of this article. Thus, the categorization of the information focused on the following fields: (1) social criteria in the infrastructure life cycle, (2) multi-criteria assessment techniques, (3) context, (4) equity, and (5) social learning in the assessment process. These categories enable a review of the implementation of multi-criteria social assessments of infrastructures and limit the scope of this study.

Table 3 Categorization of qualitative information

Research question	**Sub-question (first level)**	**Category (second level)**	**Reference**
How are social aspects treated in infrastructures' multi-criteria assessment?	*What is valued regarding the social contribution of infrastructures*?	(1) Social criteria in the infrastructures life cycle	Labuschagne et al. 2005 Valdés-Vásquez and Klotz 2013 Sierra et al. 2016
	What multi-criteria methods are used to assess the social contribution of infrastructures?	(2) Multi-criterion assessment techniques	Munda 2004 Gervásio and Da Silva 2012 Zavadskas et al. 2018
	What treatments are used in multi-criteria social assessment of infrastructures?	(3) Consideration of context	Soltani et al. 2015 Valdés-Vásquez and Klotz 2013
		(4) Consideration of equity	Hyard 2012 Bueno et al. 2015
		(5) Consideration of social learning	Diaz-Sarachaga et al. 2016, Pellicer et al. 2016, Missimer et al. 2017

At the third level, the sub-categories emerge as a result of an inductive process in each category in Table 3 from the content analysis of the 94 contributions; i.e., the sub-categories are defined according to the grouping of relevant annotations of each contribution (Carnevalli and Miguel 2008). For instance, the social criteria are the result of the clustering of indicators or principles that value a social aspect. In this case, each social indicator/principle is related to a stage of the life cycle of a type of infrastructure where the impact occurs. In addition, a content analysis involved several readings of each contribution by the main researcher and the confirmation of a second researcher in order to refine the coding process and ensure consistency in the overall research.

4. RESULTS

This section explains the results and asserts the findings obtained by analyzing the sample of 94 contributions that integrate the social aspects in the multi-criteria assessment of infrastructures, considering the categories proposed in Subsection 3.2. Thus, the analyzed fields are: (1) social criteria in the infrastructures life cycle, (2) multi-criteria assessment techniques, (3) context, (4) equity and (5) social learning in the assessment process. These results are presented in the following subsections.

4.1 Social criteria in the infrastructures life cycle

On this point, according to the methods explained in Subsection 3.2, the research team grouped by affinity (Carnevalli and Miguel 2008) the social aspects mentioned in each contributions, until 23 criteria were obtained. Table 4 explains the social criteria identified in the review process and classifies them into seven approaches. These approaches are the result of a new grouping according to an inductive process. The conceptual interpretation of human, community, cultural and productive capital is associated with the social structure proposed by Labuschagne et al. (2005, 2006). In addition, the studies by Spangenberg (2002) and Missimer et al (2017) delve into the concepts of social and institutional capital in social sustainability. Furthermore, Vanclay (2002) presents the relationships between the company and the community and the socioeconomic process as categories that cause social impacts.

Table 4 Social criteria

#	Criterion and Description
Human capital approach:	
1	**Basic needs** that include the conditions of food, housing and shelter necessary to satisfy the human being’s living conditions (Karami et al. 2017).
2	**Education** takes into account the aspects of formal education (Gilmour et al. 2011, Axelsson et al. 2013), training (Fernández-Sánchez and Rodríguez-López, 2010) and civic education, and raising awareness of the local population (Ugwu et al. 2006a, Shaiu et al. 2015)
3	**Health** involves the effects on the human being’s physical and mental state due to accidental causes (Li et al 2012, Resendez et al. 2014), long-term diseases (Ugwu and Haupt 2007, Chow et al. 2014) or exposure to sources of pollution (Jeon 2010, Yadollahi et al. 2015).
Community capital approach:	
4	**Public opinion** includes the perception of the community with respect to the general acceptance of the project, unease or satisfaction with the construction or the operation of the infrastructure (Dasgupta and Edwin 2005, Gilmour et al. 2011, Zavadskas et al. 2015).
5	**Esthetics and degradation** is the extent to which the infrastructure design fits with the harmony of the surroundings and public sensitivity (Pan 2008, Hong et al. 2011, Balali et al. 2014)
6	**Safety of the environmental** corresponds to all those physical risks and implications of criminality for the local population (Bonsall and Kelly 2005, Shen et al. 2011).
7	**Identity and cohesion** consider the displacement or resettlement of families (Koo et al. 2009), the strengthening of the local characteristics (Bueno and Vassallo 2015), integration of physically challenged people (Gilmour et al. 2011) and/or the inclusion or discrimination of social groups (Diaz-Sarachaga et al. 2017, Resendez et al. 2014).
Cultural capital approach:	
8	**The cultural criterion** combines aspects related to the protection of a community’s intangible cultural values (Ugwu et al. 2006b,

#	Criterion and Description
	Axelsson et al. 2013) and/or the tangible cultural values or property (Shen et al. 2011, Jeong et al. 2014).
Productive capital approach:	
9	**Private property** combines aspects related to the protection of the condition of the house (Labuschagne and Brent 2006), acquisitions of rights of way (Koo et al 2009) or changes in the assessment of a community's assets (Boz and El-Adaway 2015).
10	**Mobility and accessibility** integrate suitable coverage of transportation services (Shang et al. 2004, Umer et al. 2016), modes of non-motorized mobility (Shaiu et al. 2015) or access to public services (Gilchrist and Allouche 2005).
11	**Urbanization services** include integration with the existing infrastructure, the type of sanitary, electrical and communication networks (Gilmour et al. 2011, Delgado and Romero 2016), as well as sports infrastructure and public spaces (Labuschagne and Brent 2006, Gilchrist and Allouche 2005).
12	**Research, development and innovation (R+D+i)** promotes technological development in the infrastructure project to generate social contributions (Labuschagne and Brent 2006, ISI 2015).
13	**Land use** makes reference to the efficiency and effects of the changes of ground use in the community for the development of the infrastructure (Wey and Wu 2007, Thomopoulos et al. 2013).
14	**Distribution of production benefits** refers to equity in the distribution of the contributions and costs of the infrastructure among the local and regional population (Van de Walle 2002, Muench et al. 2011).
Social and institutional capital approach:	
15	**Stakeholders participation** groups the aspects related to the contribution of information to the community and involvement of their participation in the decision-making about the project (Labuschagne and Brent. 2006, Gilmour et al. 2011)
16	**Public management skills** take into account the aspects related to the skills of the administration (Labuschagne and Brent 2008) and the transparency and integrity (Karami et al. 2017) of the public agencies involved in the development of the infrastructure.
Socioeconomic system approach:	
17	**Economy and regional development** includes the aspects that enhance the development of the main economic activity or its diversification in the region (Caliskan 2006, Labuschagne and Brent 2008). In addition, effects on the collection of taxes that alter the funds for public expenditure (Gilchrist and Allouche 2005). The maintenance costs assumed by the regional administration are another aspect included in this criterion (Gervásio and Da Silva 2012, Li et al. 2012)
18	**Economy and local development** include the improvement or harm to local business (Kucukvar et al. 2014, Resendez et al. 2014), and the alteration of the operational costs of the users of the infrastructure (Koo et al. 2009, Reza et al. 2014).
19	**Employment** takes into account the aspects related to the number of work opportunities associated directly and indirectly to the development of an infrastructure (Labuschagne and Brent 2008, Hong et al. 2011, Delgado and Romero 2016)
Business-community relations approach:	
20	**User-oriented design** refers to the design of infrastructures being compatible with the needs of a context (Pan 2008, Valdés-Vásquez and Klotz 2013). In addition, the construction and maintenance processes must be compatible with the safety of those performing these functions (Fernández-Sánchez and Rodriguez - Lopez 2010).
21	**Working training** involves all those aspects in which a company promotes the professional development of its employees. Training in matters of safety, health and safety protective equipment, and health and safety plans are some of the aspects included (Labuschagne and Brent 2008, Fernández-Sánchez and Rodriguez-Lopez 2010).
22	**Work health and safety** involves the practices of a company that protect workers' lives. Training in matters of safety, health and safety equipment, and health and safety plans are some of the aspects considered (Shen et al. 2005, Yadollahi et al. 2015)
23	**Ethical labor practices** combines the aspects related to dignity and ethics in the employer-employee contractual relation. Aspects such as a suitable work load, child labor and gender equality are included (Labuschagne and Brent 2006, MacAskill and Guthrie 2013, Axelsson et al. 2013)

In particular, Table 5 shows the number of times that a social criterion is considered in the multi-criteria assessment studies. Since 2006, the contributions have included greater diversification of the social criteria in the assessment process. The criteria of economy and local development, mobility and accessibility, environmental health and safety are the most frequent. This article identifies the life cycle of the infrastructure (planning-design, construction, use-maintenance, end of life) where the impact on each social criterion occurs. Fig. 4 (upper) represents the percentage of times each social criterion has been considered at each stage of the life cycle. Generally, the use-maintenance stage is impacted in more than 50% of the criteria, followed by the construction stage. The end of life stage is less considered because in most cases it is not clearly defined. Fig. 4 (lower) illustrates the proportion of the type of infrastructures linked with each social criterion. Infrastructure types include transportation (road, railway, subway, ports, cycle paths and pedestrian lanes), bridges, tunnels, sewage, water and energy networks (sanitation, gas, or electrical energy distribution system), hygiene treatment plants (managed landfills and waste treatment plants), mining and civil infrastructure in general (contributions that do not specify a type of infrastructure). Thus, the transport infrastructure has the greatest representation in the contributions and includes the greatest diversity of social criteria.

Table 5 Evolution of social criteria by year

Social criteria	**Year of publication**																	
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	**Total**
1. Basic human needs																	1	**1**
2. Education		1				3		1		1	1		1	1	1	2	1	**13**
3. Health		2	1		3	4	4	5	2	3	5	5	5	5	6	5	1	**56**
4. Public opinion			1		3	3	2	2	1	1	3		1	3	3	1	1	**25**
5. Aesthetics			1			4	1	2		2	3	2	2	5	1	2		**25**
6. Security of the environment	1			1	5	5	4	4	2	4	5	4	4	5	3	4		**51**
7. Identity and social cohesion				1	1	3	1	2	2	4	3	1	4	5	4	2	3	**36**
8. Culture and inheritance			1		1	5	4	3	1	2	4	2	3	4	1	2	3	**36**
9. Private property					3	2		2	1		1			3	2	1	3	**18**
10. Mobility and access	1	2	2	1	3	5	6	2	2	4	7	5	6	6	3	3		**58**
11. State of urbanization services					1	1	1	1		1	2	1		1		2		**11**
12. Research & innovation						3	1			2	2	2		1	2	1		**14**
13. Land use		1	2		2	3	5	1	2		3		1	1	3			**24**
14. Distribution of the productive benefit		1					1		1	3	1		3	1	1		2	**14**
15. Stakeholder participation		1	1		2	3	2	3	2	2	2	2	2	1		1	3	**27**
16. Public management capacity						1		1			1			1		2	1	**7**
17. Economy and regional development				1	2	2	4	2		3	2	3	3	3	5	3		**33**
18. Economy and local development	1	1		1	2	6	5	3	1	3	4	4	3	7	8	3	3	**54**
19. Employment		1	1	1	1	3	4	2		2	3		2	4	4	3	3	**34**
20. User-oriented design					1		1	1	1	1	1	1		2				**9**
21. Staff training						1	1	1		1					1	2		**7**
22. Occupational health and safety	1				2	3	2	3	2	1	1		1	4	4	2		**26**
23. Ethical labor practices						1		1					2			2		**6**
Total of contributions	**1**	**2**	**2**	**1**	**5**	**6**	**8**	**6**	**4**	**6**	**7**	**6**	**8**	**14**	**9**	**6**	**3**	**94**

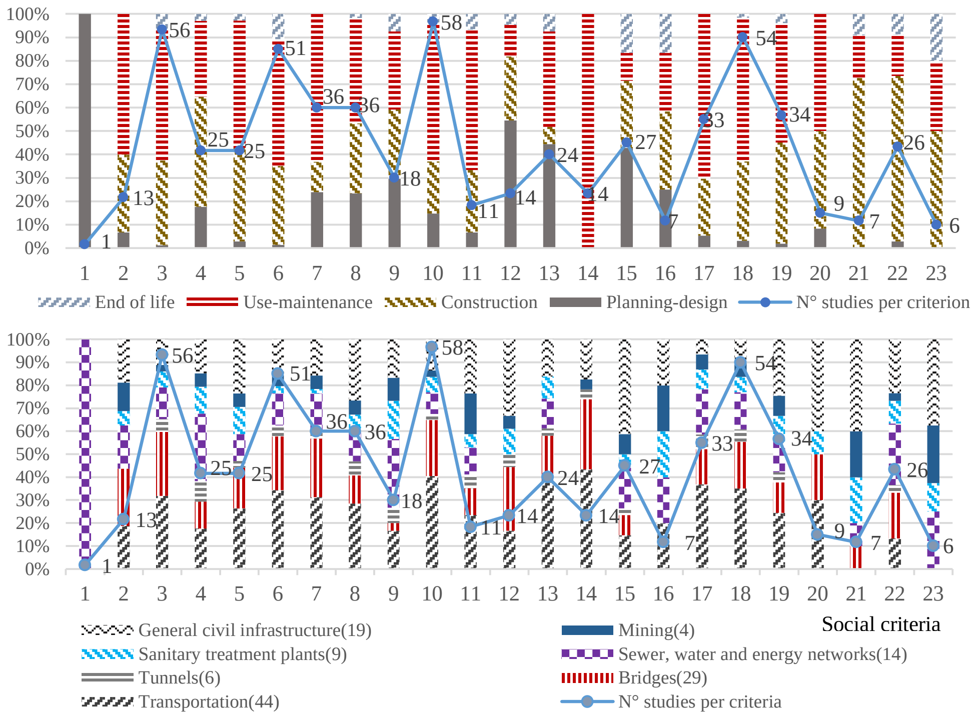

Fig. 4 Social criteria impacted by each stage of the life cycle (upper) and infrastructure type (lower).

Specifically, the distribution criteria for the production benefits (14) and the economy and regional development (17) are more strongly linked to the use-maintenance stage. Aspects such as ground assessment, technological processes and citizen participation (12, 13, and 15 respectively) have a greater presence in planning and design. Aspects like the local inconveniences (4) and labor related criteria (21, 22, and 23) are more represented in the construction stage. Other cases are environmental safety (6) and user-oriented design (20), the impacts of which have been shown in the use-maintenance and construction stages. For their part, transportation infrastructures, bridges and tunnels are strongly related to the criteria of health, environmental safety, identity and cohesion, mobility and access, ground use, distribution of the production benefits and regional and local development (3, 6, 7, 10, 13, 14, 17, and 18). Public participation (15) is applied to civil engineering infrastructures in general.

4.2 Multi-criteria assessment techniques

The analysis of multi-criteria methods focuses on: weighting techniques, assessment of alternatives, treatment of social indicators and the uncertainty treatment that each method uses. They are developed in the following subsections.

4.2.1 Weighting methods: Fig. 5 shows the number of methods that determine the weight of the criteria. The methods that used the multiple evaluators' opinions are clearly differentiated. In this line, the AHP (30), the ANP (5), and the Entropy (6) are methods for determining weights. Other weight methods include direct allocation (10) and order relationship (8). In the direct allocation methods, the evaluator identifies a direct score that represents the importance of each criterion (Shen et al. 2011, Koo et al. 2009, Balali et al. 2014). In the order relation methods, the evaluator organizes the criteria by order of importance, through which weights are obtained (Jeon 2010, 2013, Ramani et al. 2011, Chen et al. 2014). Some contributions consider more than one method for weight determination. Bueno and Vasallo (2015) take into account the opinion of evaluators through the AHP and the contextual conditions through a direct score. Chen et al. (2014) combine objective weights through entropy and subjective weights through the AHP. Furthermore, 11 contributions use the Delphi method to group the participants' weight. Other methods of opinion aggregation include SAW (2) (Thomopoulos et al. 2009, 2013), the geometric mean (3) (Shang et al. 2004, Jato-Espino et al. 2014b, Curiel-Esparza et al. 2016), probability distributions (1) (Su et al. 2006), and fuzzy operators (5) like the determination of the center of gravity (Pan 2008, 2009, Wey and Wu 2007). It should be noted that 23 contributions do not report the method used to group the participants' opinions.

On the other hand, among the single-evaluator methods, direct allocation (6) and the use of credits (7) are more frequent. This is the case of the *Rating Systems* that deal with the importance of each criterion through pre-established credits (CEEQUAL 2010, Muench et al. 2011, ISCA 2012, ISI 2015).

4.2.2 Alternative assessment: Fig. 6 represents the frequency of use of 14 assessment methods of the infrastructure alternatives, called "A". The A methods are AHP, ANP, MIVES, TOPSIS, LCA, COPRAS-G, GRA, VIKOR, PROMETHEE, SAW, GP, SD and Emergy. In addition, in three contributions the arithmetic mean was also used to group the value of the criteria (Dasgupta and Tam 2005, Boz and El-Adaway 2015). These 14 methods act independently or complement others. For example the Emergy method was used together with the LCA to combine the assessment of the criteria into one unit (Li et al. 2012, Reza et al. 2014).

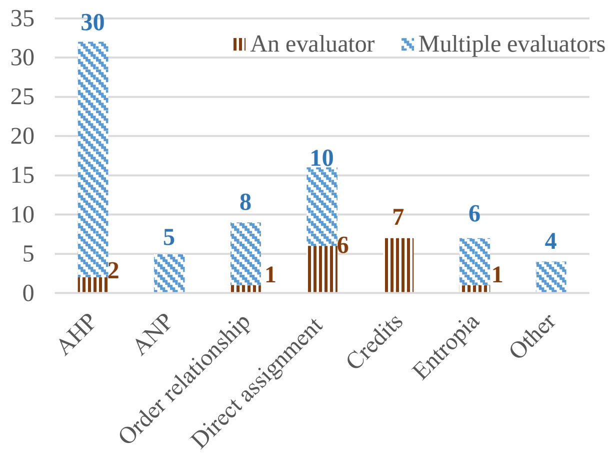

Fig. 5 Methods for determining the weights of social criteria

4.2.3 Treatment of indicators: In 58 contributions, six treatments of the indicators of each criterion made possible the implementation of the A methods. These treatments improve the representation of the value of a criterion with respect to the context or the remaining indicators. In Fig. 6, the treatments of the performance indicators are represented in the B group, which include the use of techniques of social cost, artificial scales, value or utility functions (MAUT), scoring systems, linguistic variables and grey clustering. The social cost quantifies the data of a context through monetary functions for each criterion that represent the cost for the user or society (Gilchrist and Allouche 2005, Koo et al. 2009, Gervásio and Da Silva 2012). The artificial scales standardize different units according to interpolation functions (Dasgupta and Tam 2005, Ramani et al. 2011, Thomopoulos et al. 2013). The utility or value functions (MAUT) identify the degree of satisfaction in the condition of certainty (value function) or uncertainty (utility function) (De la Cruz et al. 2015a,b, Diaz-Sarachaga et al. 2017b). The qualitative criteria have been processed through a scoring system or by linguistic variables. The first corresponds to a scoring system that depends on the degree of compliance of the infrastructure attributes (Boz and El-adaway 2015, Muench et al. 2011, ISI 2015). The linguistic variables link a nondeterministic verbal concept to the performance of an indicator in each alternative (Abu-Dabous and Alkass 2008, Kucukvar et al. 2014, Delgado and Romero 2016). *Grey Clustering* classifies limited and uncertain information from each alternative in defined classes to enable their assessment (Delgado and Romero 2016).

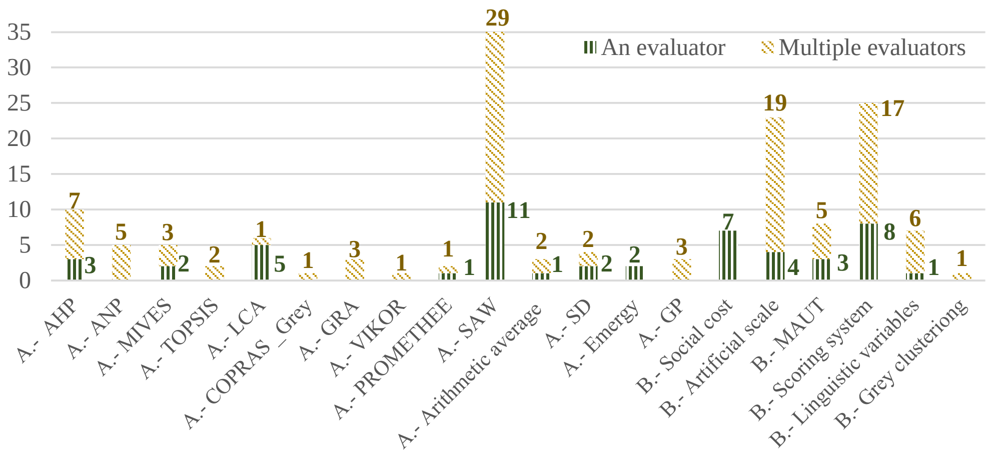

Fig. 6 Methods for the social assessment of infrastructure alternatives

Some treatments are more closely linked to certain methods for assessing alternatives. In particular, the social cost has been used in the LCA and in some cases with PROMETHEE and Emergy. Social cost has been used to assess such aspects as rights of way, loss of productivity and cost of delays or operations. The linguistic variables have dealt with the uncertainty regarding the input variables in the TOPSIS, COPRAS-G and AHP (Abu-Dabous and Alkass 2008, Aghdaie et al. 2012, Umer et al. 2016). On the other hand, the artificial scales and scoring systems treat the quantitative and qualitative variables in SAW, ANP, SD, GP and arithmetic means. The value functions (MAUT) have been used mainly through the MIVES.

4.2.4 Treatment of uncertainty: Of all the selected contributions, 22% (21 contributions) treat the uncertainty of the data input into the model. The three identified methods to deal with uncertainty are the fuzzy sets, Grey System theory and probability distributions. The fuzzy sets complement the weight assessment through the AHP and Entropy (De la Cruz et al.2015b, Kucukvar et al. 2014, Jato-Espino et al. 2014a), and in eight contributions alternatives were assessed through MIVES, AHP, SAW and TOPSIS (Pan 2009, De la Cruz et al. 2015b, Kucukvar et al. 2014). Grey Systems theory deals with uncertainty in two contributions through *grey clustering* and COPRAS-G when assessing infrastructures (Aghdaie et al. 2012, Delgado and Romero 2016). Finally, in 11 contributions probability distributions were constructed for each uncertain criterion. LCA, MIVES and PROMETHEE have used probabilistic systems to deal with uncertainty. Some contributions have required contextual information to establish the probability distributions (Bonsall and Kelly 2005, Gervásio and Da Silva 2012, 2013); in others consensus of the parameters facilitates their implementation (Abu-Dabous and Alkass 2008, De la Cruz et al. 2015a).

4.3 Context

There are no pre-established criteria or relationships applicable to all contexts. Different levels of development affect the degree of satisfaction; furthermore, local needs are not always associated with evaluation criteria of the country (Valdés-Vásquez and Klotz 2013, Munda 2006). On this point, two analytical approaches emerge from the review of these 94 contributions. First, the level of representation of the participants in the assessment process: who they are and which function they have in the process. Second, the mechanisms used to assess the context.

4.3.1 Participants in the assessment process: Sixty seven percent (64 contributions) of the reviewed methods include multiple evaluators at some stage of the process. Fig. 7 represents the number of times each group of actors participates in infrastructure assessment processes. The experts, consultants and contractors, government, academia and nongovernmental organizations (NGOs) have greater participation than the local context. The “experts” are categorized as professionals with experience in engineering with no specification as to their origin. In addition, Fig. 7 represents the work of each participant in the assessment process. In absolute terms, the determination of the weights and the decision-making structure (i.e., the criteria and relations) are the most frequent tasks. According to the number of cases, there is a connection between the determination of the weights and the work done by the experts, consultants-contractors and academia-NGOs. Furthermore, the decision-making structure is linked to the functions of the government.

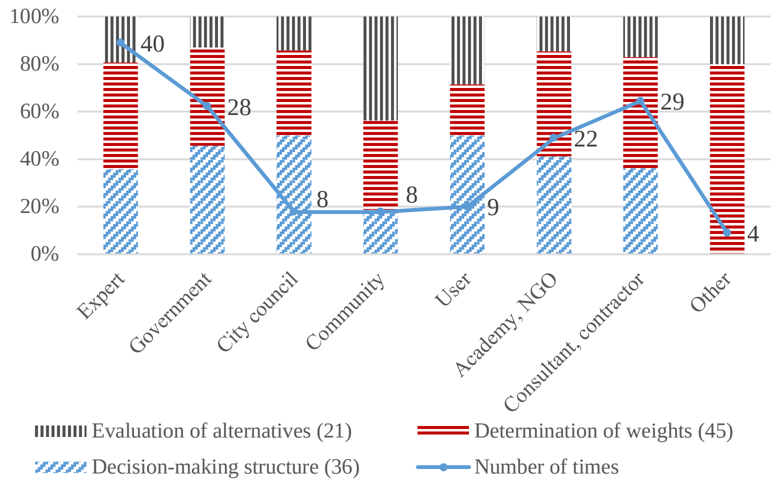

Fig. 7 Participation in the multi-criteria social assessment of infrastructures

4.3.2 Mechanisms that represent the context in the assessment: Eighty-six percent (81 contributions) considered some mechanism to represent to the context. From of an exploratory study is found that the context is represented in the following way: (T1) stakeholders who define the assessment structure; (T2) the personal opinion of the stakeholders who evaluate criteria or alternatives; (T3) a synthesis of the contextual information so that the actor evaluates and makes the decision; (T4) the contextual empirical information processing through an assessment mechanism; or (T5) a mixed system in which part of the process corresponds to the stakeholders' opinions and another to quantitative information processing. Thus, Fig. 8 represents the distribution of the treatments that involve the context in the assessment process.

First, the treatment (T1) is transversal to the rest of the treatments. In this review 36 contributions were detected in which the stakeholders define the assessment structure. Of these, in only 23 (25%) is there participation by representatives of government, municipality, community, users, academia or NGOs. In the remaining cases, the stakeholders are limited to experts, consultants or contractors. This situation is present in all the treatments (Balali et al. 2014, Boz and El-Adaway 2015, Umer et al. 2016). In other cases there is only one evaluator (Resendez et al. 2014, MacAskill and Guthrie 2013, Karami et al. 2017).

Second (T2), the comparison methods (AHP, ANP), the scoring systems and linguistic variables are frequent for processing the stakeholders' personal opinions (Balali et al. 2014, Boz and El-Adaway 2015, Pan 2008).

In the third treatment (T3), participants receive feedback with contextual information (Karami et al. 2017, Resendez et al. 2014, Wey and Wu 2007). The contextual information is compiled from regional databases, territorial development plans or censuses. For the local cases the information was assimilated from approximate secondary sources (Resendez et al. 2014) or specific field studies (Karami et al. 2017). In any case, the way in which the data are presented influences the stakeholder's assessment.

In the fourth treatment (T4), the quantitative social information of the context is processed and stakeholders are not required. The social criteria dealt with under this modality were health and safety, regional economic development, the impact on the user (operational costs, travel times, accidents) and employment. The use of artificial scales and the social cost have been common in this treatment (Gilchrist and Allouche 2005, Koo et al. 2009, Shaiu et al. 2015). Nevertheless, some contributions presented limitations in the availability of data on the social state (Sahely et al 2005, Labuschagne and Brent 2006, Chow et al. 2014). In others, the criteria used correspond to those with availability of information (Gervásio and Da Silva 2012, 2013).

Finally, some methods collect the stakeholders' opinions and also process the quantitative information of the context (T5). The artificial scales frequently involve the scope of a project with respect to the capacity of a context. Similarly to the previous treatments, the exclusive participation of experts and the limitation of the use of criteria with available information were demonstrated (Ugwu and Haupt 2007, Ugwu et al 2006b, Jeon et al. 2013).

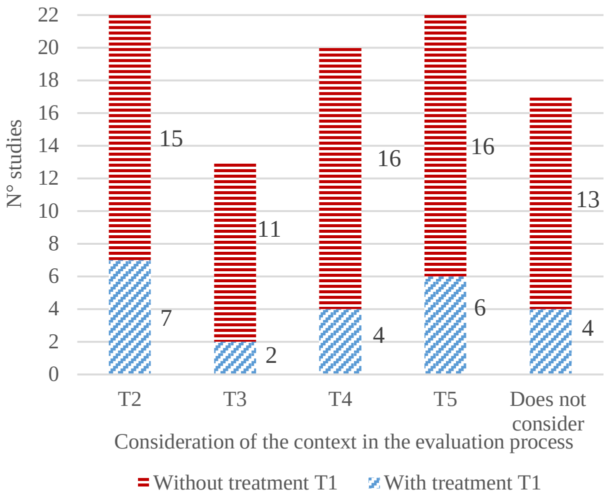

Fig. 8 Distribution of the treatments for consideration of the context

4.4 Equity

From the 94 contributions reviewed, 16% (15 contributions) consider equity in the assessment process. The evaluations of transport infrastructures (11) and bridges (7) were those of greatest integration in this approach. An inductive process helped to define two approaches to the analysis: (1) the level of integration of equity in the assessment model and its influence on the final result, and (2) the techniques used to represent equity in the assessment process. According to these approaches, Fig. 9 represents the distribution of the equity treatments in the 15 contributions analyzed.

4.4.1. The integration of equity in the assessment model: In the methods, equity was considered cross-sectionally to the assessment model or through specific indicators. In the first case, equity is considered a cross-sectional mechanism to the structure of assessment model and intervenes in each indicator and result (Bonsall and Kelly 2005, Thomopoulos et al. 2009). In the second case, equity is a part of the assessment system in which specific indicators are compensated with others without guaranteeing the equity of the system (Jeon 2010, Shaiu et al. 2015).

4.4.2. Techniques for representing equity in the assessment process: The contributions that consider the equity required quantitative information from contextual censuses or databases. At this point, the techniques used to represent equity can group in three categories: (a) econometric models, (b) functions of difference between groups or (c) the measurement of vulnerability.

In the first place, the econometric models focused on the costs and regional economic benefits of large projects and their distribution in the population in the long term; the application of this treatment has been limited to theoretical examples (Brocker et al. 2010, Mostafa y El-Gohary 2014). On the other hand, the difference functions measure the inequality of the costs or benefits of an infrastructure among the affected groups of an area of influence. The criteria dealt with using this technique include impacts on health, mobility and safety, which have implications for all the population groups (Jeon et al. 2010, 2013, Thomopoulos et al. 2009).

Third, the measurement of vulnerability estimates the impact on specific groups or areas with less resilience to the variation in certain social criteria. It is assumed that the contributions generated for more vulnerable zones contribute to equity. The most frequently named vulnerable groups are the population with low income, seniors, indigenous population, families without a car, women and the disabled (Resendez et al 2014, Bonsall and Kelly 2005). Likewise, spatial vulnerability is identified through census data on education, health or poverty (van de Walle 2002, Axelsson et al. 2013).

Most of the works point to intragenerational equity. The inclusion of intergenerational equity was dealt with only through two econometric approaches and with theoretical applications (Nishijima et al. 2007, Mostafa and El-Gohary 2014).

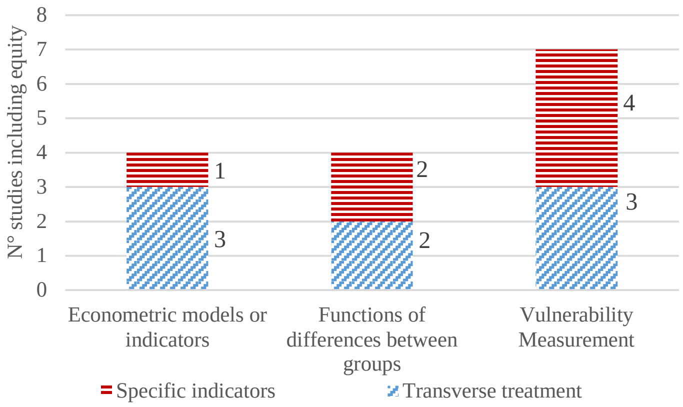

Fig. 9 Distribution of the treatment of equity in multi-criteria social assessment methods

4.5 Social learning

The measurement of sustainability does not necessarily seek a result but rather a process that must promote the social learning of those involved (Munda 2006). Cyclical assessment processes are advisable so that the proposed mechanisms orient society towards better decisions. This approach is relevant in decision-making processes regarding public resources that impact on society. Only 17% (15 contributions) include some system of social learning. Fig. 10 represents the proportion of the contributions that deal with social learning in their assessment methods. Thus, the identified means to carry out learning in the assessment process have been through of a progressive evaluations or the use of cognitive instruments.

4.5.1 Progressive evaluations: This process promotes an assessment of the impact of an infrastructure progressively on its development. In this process, feedback and incentives of certification by third parties are contributed to the project team, including promoters, planners and contractors. This approach is applied in the *Rating Systems* ENVISION (ISI 2015), CEEQUAL (2010), IS (ISCA 2012), SIRSDEC (Diaz-Sarachaga et al. 2017) and Greenroads (Muench et al. 2011).

4.5.2 The cognitive instruments: Certain instruments help the evaluators understand the factors that affect sustainability. Specifically, cognitive maps helped define the evaluation structures (criteria, indicators and their relationship) (Ugwu et al. 2006a, Caliskan 2006, Gilmour et al. 2011). In other cases geographic information systems make it possible to visualize different alternative scenarios to subject them to evaluation (Jeon et al. 2010, 2013). In this light, social learning is more relevant if the evaluators represent society. However, in some cases participation in the assessment process is limited only to experts or a decision-maker.

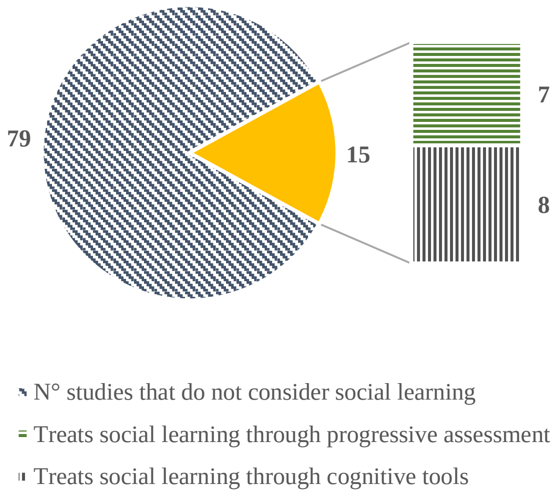

Fig. 10 Distribution of the contributions that deal with social learning

5. DISCUSSION

In this section, the three sub-questions stated at the beginning of the study (see Table 3) are discussed in different subsections. A final subsection discusses issues and limitations that affect the overall research of this article.

5.1 What is valued regarding the social contribution of infrastructures? (Q1)

Recent years have seen an increase in studies that consider the social aspects in multi-criteria assessments of infrastructures. Aspects such as esthetics, cohesion and culture or research and innovation were unusual at the beginning of this century (see Table 5). Ugwu et al. (2006b) correlate the demands of sustainability with the technological changes and preferences of the population. In general, 56% of the contributions are focused on the assessment of five social criteria in different contexts: environmental health and safety (accident rate), identity and cohesion (inclusion or discrimination), mobility and access (travel times or delays or distances), socio-economic and regional development (maintenance costs), and socio-economic and local development (user operational costs). In these cases, the infrastructures (mainly transport) are located in different places; however, the evaluation criteria tend to be the same and insensitive to the need of the context. A greater participation of "non-experts" may be necessary to select and weight criteria according to the problems of each place and not just according to the technical factors of the type of infrastructure.

Studies by Vanclay (2002) and Valdés-Vásquez and Klotz (2013) emphasize that there are no pre-established social criteria that are valid for all contexts, and those that exist can only be used as a reference. Other studies guide the evaluation towards quantifiable social aspects, which limits the representation (Gervásio and Da Silva 2012, 2013, Di Cesare et al., 2016). In addition, in developing countries, Díaz-Sarachaga et al. (2016, 2017) expose the need to pre-establish criteria that look beyond current preferences focused on the socioeconomic. Indeed, if future needs such as education or health are not considered, the scope of social sustainability is limited.

In addition, 13 out of the 23 social criteria are impacted within the use-maintenance stage of infrastructures. Similarly, the impacts on the planning-design and construction stages were of greatest frequency in three and four of the social criteria, respectively. The end of life stage was not predominant in any criteria (see Fig. 4). If the dismantlement activities have an impact on their environment (Vanclay 2002, Sierra et al. 2016), then there is a need for studies that investigate social criteria impacted at the end of the life cycle.

5.2. What multi-criteria methods are used to assess the social contribution of infrastructures? (Q2)

The participatory assessment processes are centered on determining the weights of the social criteria. The AHP is used to determine weights in a participatory way (Caliskan 2006, Curiel-Esparza et al. 2016). Some studies, however, question the application of subjective weights (Munda 2004, 2006). Others prefer a direct allocation of weights based on predefined principles (Chow et al. 2014, Bueno and Vassallo 2015). The Delphi method contributes to determining the weight given to each criterion by experts, adding their opinions through consensus (Ramani et al. 2011, Bueno and Vassallo 2015). A consensus promotes a compromise of positions and learning of the participants. In additions, the Delphi method not only reduces uncertainty, but also legitimates positions on a topic. In some selected contributions, the grouping form is not explicit (23). In this light, we can think about the use of simple methods as an arithmetic mean to reflect representativeness without considering the variability of the results. Otherwise, there is a proximity to the interpretation given by evaluators who have the same profile. In fact, 47% of the time the experts (including consultants and contractors) are the decision-makers. In this way, economic and technical aspects are the most valued, and social aspects are the least valued within the scope of sustainability (Diaz-Sarachaga et al., 2017). Whatever the case, it is important that almost half the techniques employed consider neither the inclusion nor the variability of the participants' judgments.

For its part, the most frequently used method for evaluating infrastructure alternatives was SAW. Normally SAW groups the assessment of an alternative in an indicator that compensates for the criteria considered. Yet some authors suggest that a full compensation of a sustainable assessment process is inadequate (Munda 2006, Gervacio and Da Silva 2012). Considering that social aspects tend to have the least importance in evaluation, there is no guarantee that the proposed solutions will have a social influence. Complementary, the scoring systems and artificial scales are the most frequently used treatments for the qualitative and quantitative variables, respectively. In this sense, the selected scores and the range of the scales must be appropriate to each context. Some contributions adopt values from certification systems that are not necessarily valid in developing countries (Muench et al., 2011, Diaz-Sarachaga et al., 2016). In particular, the social aspects are sensitive to local conditions. Research methods in the field can help confirm or adapt the proposed scales (Delgado and Romero 2016, Karami et al., 2017).

Treatment of the uncertainty of the input data was demonstrated in only 22% of the contributions. The main treatments of uncertainty are the probabilistic methods and fuzzy logic. In the first case, a database analysis is usually required (Gervásio and Da Silva 2012, 2013). Other contributions have been successful with data provided from a participative process (Su et al., 2014, de la Cruz et al., 2015). On the other hand, although fuzzy logic processes linguistic variables, a diffuse operator generates a single deterministic result of participation (Jato-Espino et al., 2014, Sabatino et al. 2015). The latter tends to be unclear in the eyes of the participants and reduces the legitimacy of the result.

5.3. What treatments are used in the multi-criteria social assessment of infrastructures? (Q3)

In 67% of the contributions there is some degree of participation of stakeholders in the assessment process. However, in only 17% of the opportunities is the local context involved. In most cases the experts, consultants and governments determine the evaluation methods and the weight the criteria, which influence the result. Munda (2004) and Soltani et al. (2015) suggest that local participation helps understand the assessment problem beyond a technical approach. However, local participation tends to face a variety of opinions and difficulty in geographical scope on specific projects. Therefore, academia can help interpret appropriate conclusions in a comprehensive participatory context (Munda 2004, 2006). In this way, treatments that involve the opinion of specialists should consider methodological complements to include the participation of the affected local population.

Other studies used databases to determine the objective contribution of the project in the context. However, databases of social aspects are not always available (Sahely et al 2005, Labuschagne and Brent 2006, Chow et al. 2014). Some contributions adapt the information from the macrocontext increasing the uncertainty (Resendez et al. 2014, Diaz-Sarachaga et al. 2017). In other cases, the social criteria have been limited to the information available (Gervásio and Da Silva 2013). In this sense a specific case is the equity treatment. The treatment of equity required geolocation databases and population distribution (Thomopoulos et al. 2013). Thus, the equity approach was considered in only 16% of the contributions. In fact, real implementations of intergenerational equity were not recognized. Some methods of social research can fill the data gap (Munda 2004, Karami et al. 2017). In this way, techniques that allow an adequate social representation with limited quantitative information are still necessary.

The learning approach was included in 17% of the contributions. Indeed, the implementation of cognitive instruments and progressive evaluations involve costly processes to obtain learning results in the short term (CEEQUAL 2010, ISI 2015, Muench et al. 2011, ISCA 2012). Otherwise, planning a cyclical evaluation process with stakeholders that represent the context may be a more viable way to obtain long-term social learning.

5.4. Limitations of the research

Analysis of the research questions revealed gaps in the treatment of social aspects in the multi-criteria assessment of infrastructures. In short, techniques must be promoted that determine the social criteria appropriate to the needs of the present and future context. In addition, it is necessary to clarify the social impacts of the final stage of the life of an infrastructure. Methodologically, there is a need for techniques to consider all stakeholders and the variety of opinions in the evaluation structure. In addition, implementation studies that reduce the compensation of social aspects are also needed. In the absence of social data, the evaluation process requires complementary social techniques to obtain values appropriate to local contexts. Finally, the incidence of cyclical evaluation processes in social learning should be studied.

Despite the contributions of this study, the methodology implemented presents two main limitations. First, an independent review to determine the relevance and selection of each study cannot be enough to eliminate bias. Second, a predefined category layout in consideration of previous studies (Sierra et al. 2017 a, b, 2018, Labuschagne et al. 2005, Valdes-Vasquez and Klotz 2013) can limit the exploratory findings. However, being a recent theme (social sustainability in infrastructure), a theoretical position guides the general search within certain standards. In this sense, the works by Zamarron-Mieza et al. (2017) and Penades-Pla et al. (2017) follow the same guidelines

6. CONCLUSIONS

This research examines the treatment of the social aspects in multi-criteria assessment methods of infrastructures. Multi-criteria assessment methods attempt to integrate the social aspects in the evaluation of infrastructure sustainability. The results identify 23 social criteria used in the assessment methods; mobility and accessibility, safety, identity and cohesion, and local development are the most frequent criteria. In addition, the Analytic Hierarchy Process and Simple Additive Weighting methods are the most frequently used to assess the weights and alternatives, respectively. Complementary, Delphi Method is the main method to center the participants' opinions. Assessment of the social dimension, however, requires certain treatments not always covered in the assessment systems. Improvements are needed that guarantee the social contribution in decision-making with regard to an infrastructure. These improvements correspond to considerations in the processing of information and in the methods for implementing the evaluation. First, the method must guarantee the social effect on the result, improvement of the representation of the social context and techniques to facilitate the evaluation in the absence of information. Second, representative participation and cyclic learning processes should be part of social assessment.

This article establishes a theoretical base to initiate methodological research of the social treatment of infrastructures. The study supports future research to improve the framework for assessing social aspects or engaging in a more detailed analysis of specific variables and interlinkages. This analysis can lead to deeper insights and thus help improve the quality of the implementation. Hence, greater applications must be advanced that include the adequate treatment of social aspects in the multi-criteria assessment systems. In this sense, the specific formulation and integration of methodological improvement is a much needed development.

It is important to establish improvements in the public methodologies on decision-making in infrastructure that best represent social needs. Moreover, such contributions increase the legitimacy in the eyes of the population and delineate better decision-making in the future. The contributions of this article are limited to a general layout of predefined categories and independent reviews by the research team.

In general, future research should focus on incorporating the social dimension into the evaluation of sustainability. In this way, future methods should consider the particularities of the context, the adequate representation of social needs and mechanisms that guarantee the social contribution of the proposed solutions. This involves adjustments in the formulation of the multi-criteria evaluation model, in the processing of information and the participative organization of the evaluation processes.

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