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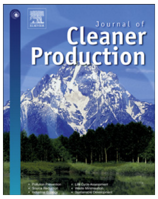

Review

Managing trade-offs in complex scenarios: A decision-making tool for sustainability projects

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ABSTRACT

The inclusion of sustainability factors in projects is considered a challenge for technicians, managers and decision makers. Sustainability projects deal with a large number of criteria from different areas, making the decision-making process more complex and uncertain. Multicriteria methods can guide project choices to reach their objectives; however, they are not able to manage the overlap and conflicting aspects of these objectives, called trade-offs. Trade-offs are considered to be an integral part of any sustainability project, since they address conflicting objectives, taking into account environmental, social and economic aspects. In some studies, trade-offs have been approached from the view of their formation process, or from how they can be identified in projects. However, there is a gap in the literature related to structured procedures to support decision-makers after the identification of trade-offs. Therefore, this paper proposes a tool to support trade-off management in the decision-making process in complex sustainability-focused projects. The Trade-Off Decision-Making tool assists the project planning stage, unfolding into two sequential phases: guidelines to be considered for the management of trade-offs; and trade-offs management operationalization. The guidelines were developed based on literature best practices, while the trade-offs management originated from the operationalization of five comparative analyses carried out between conflicting objectives, using a structured worksheet. The proposed tool contributes to the proper handling of conflicting objectives in sustainability projects not only in managerial but also operational areas. Our guidance structure for handling trade-offs provides greater robustness, objectivity and traceability to the choices made during the planning of sustainability projects.

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1. Introduction

Growing global concerns about the impacts of human activity on the environment have triggered changes in projects and products from different industry sectors. Such changes have occurred because of the organizations' urgency to integrate their strategies into sustainable development factors, reflecting their values of social, economic, and environmental responsibility (Garcia et al., 2016). The achievement of sustainable development goals is seen as fundamental to society as a whole; considering that it seeks to meet the needs of the present without compromising the needs of future generations (United Nations, 1987, 2015).

However, it is not always clear how sustainability can be addressed in the practice of project and product development. This is because the inclusion of sustainability factors in any process demands a complete understanding of the complexities of the scenario analyzed. This understanding should range from terms and specific definitions of the study area (Glavič and Lukman, 2007) and to a critical evaluation of how sustainability can be incorporated into organizations' strategic planning (Sanchéz, 2015). In that sense, considering the multidisciplinary nature of sustainability projects (Elkington, 1999), achieving the right balance between reducing social and environmental impacts and the economic feasibility of those projects is an important challenge for their management (Pearce, 2008; Marcelino-Sábada et al., 2015; Garcia et al., 2016). According to Marcelino-Sábada et al. (2015), uncertainties associated with management processes persist, such as: what the definition of a sustainability project is; how the management of sustainability projects should be conducted to achieve the expected results; and how managers can efficiently include sustainability in their projects. It is important to note that there is no single answer to those questions; given that the meaning of sustainability may be different, depending on each project context. Therefore, sustainability studies in projects should be broad, considering geographic, economic, cultural and organizational strategies.

The studies focusing on the inclusion of sustainability factors in industry have emphasized solutions for product development through the use of approaches such as Ecodesign (Rossi et al., 2016; Lamé et al., 2017; Rousseaux et al., 2017) and Life Cycle Assessment (LCA) (Arushanyan et al., 2014; Häfliger et al., 2017; Iraldo et al., 2017). However, there are gaps associated with methods and tools that support the stages of integrated project management, considering the particularities of complex sustainability scenarios (Brones et al., 2014; Sanchéz, 2015; Marcelino-Sábada et al., 2015). The lack of adequate approaches to support decision-making can lead to inefficient management and policy decisions, and consequently to unreliable outcomes due to choices based on subjective criteria (Plevin et al., 2013; Zhang et al., 2016). This is because sustainability projects involve the consideration of a large number of requirements by necessity. These requirements are of many different natures which may be overlapping, contradictory, and interact strongly with each other (Alberti, 1996; Zhang et al., 2016). Therefore, studies that support decision-making in sustainability projects must be based heavily on structured methods (Chow et al., 2014; Cinelli et al., 2014; Medineckiene et al., 2015), capable of considering multiple requirements and objectives (Munda, 2005; Kang et al., 2016). In this sense, according to Egilmez et al. (2015), multicriteria methods may be considered adequate, since they involve the classification and selection of alternatives, providing greater flexibility to analyze different scenarios. However, Ali-Toudert and Ji (2017) highlight that those methods, although operational, need further refinement and maturity to support projects of high intrinsic complexity, such as sustainability projects. Considering that, multicriteria methods in sustainability projects tend to be focused on the identification of an optimal solution for a specific problem (Ren and Dong, 2018; Vishnupriyan and Manoharan, 2018). Therefore, decision-making based solely on multicriteria methods may neglect the required discussions about overlaps and contradictions of project objectives, due to the hierarchical structure of these methods (Lombardi et al., 2016).

According to Morrison-Saunders and Pope (2013), the methods and tools adopted should lead to adequate balance in meeting different and conflicting requirements of the project (Garcia et al., 2016). In this way, the management of conflicts, known as trade-offs (Da Silveira and Slack, 2001; Byggeth and Hochschorner, 2006), plays a significant role in achieving the stated objectives (Nielsen et al., 2016), mainly when the project management scope addresses the three dimensions of sustainability – economic, social, and environmental. Therefore, this work proposes a tool to support the trade-offs management in the decision-making process of complex sustainability-focused projects. The tool seeks to fill an essential gap in the management of those projects, as a complement to the application of multicriteria methods; conferring greater objectivity and traceability to the decision-making process. There are several tools in the literature which intend to characterize the trade-offs of projects. However, to our knowledge none of the previous tools provide guidance to decision makers after the identification of these trade-offs. The tool developed in this research provides such guidance.

This paper is divided into five sections. Section two gives the contextualization of the theme and the theoretical background. Section three presents the proposed tool, while section four contains discussions about its use potential and its relation to other research. Finally, section five provides some conclusions and the suggestions for future studies.

2. Theoretical background

2.1. Sustainability in project management

Projects are characterized by efforts expended in a temporary period to create a particular product, service or result; thus, their closure occurs when the established objectives are achieved (Project Management Institute, 2008). However, according to the Guide to the Project Management Body of Knowledge (PMBOK Guide), these temporary efforts do not necessarily aspire to obtain temporary results. In contrast, according to the PMI, project objectives must be geared towards lasting results. For those objectives to be achieved, different challenges are faced by managers, emphasizing the importance of monitoring the stages throughout the projects' development. That monitoring usually includes primary factors, such as deadlines and costs (Callistus and Clinton, 2016); nevertheless, the main difficulties tend to arise when considering that project management is dynamic, with the need to re-prioritize objectives as well as track the decisions made (Sánchez, 2015).

When projects focus on sustainability, their management becomes even more complex because sustainability objectives must be sufficiently clear and explicit at each stage (Marcelino-Sábada et al., 2015; Sánchez, 2015). However, Marcelino-Sábada et al. (2015) consider that project management can be a viable way to include sustainability in organizations, taking sustainability aspects into account in all stages and levels of business. This is because sustainability factors can be considered in areas such as strategic planning (Maletič et al., 2014), innovation (Morioka and De Carvalho, 2016), learning, processes, as well as internal and external stakeholders management (Dyllick and Hockerts, 2002; Agudo-Valiente et al., 2015; Garcia et al., 2016).

Thus, the literature emphasizes that, when the insertion of sustainability factors initially occurs at the strategic level, the dissemination of the sustainability objectives to the other levels of the organization is optimized. Therefore, the strategies of the company play a crucial role in the sustainability process, from the adaptation of the organizational culture (Engert et al., 2016; Morioka and De Carvalho, 2016) to the innovation incentive (Calik and Bardudeen, 2016; Przychodzen and Przychodzen, 2017).

Labuschagne and Brent (2005) argue that for project management methods to effectively address sustainability issues, there must be a clear understanding of how project lifecycles and their interactions influence the future impacts of the results generated (Morioka and De Carvalho, 2016). Thus, according to the authors, the management of those projects must be guided by lifecycle thinking, from the scope definition to the review phase. For that purpose, several tools can be used to support lifecycle management in projects, such as Balanced Scorecard – BSC – (De Villiers et al., 2016; Varmazyar et al., 2016; Modak et al., 2017); Stakeholders' Analysis (Sánchez, 2015; Garcia et al., 2016); and LCA, the latter being the most widespread currently (Marcelino-Sábada et al., 2015; Sánchez, 2015). LCA has been used in many industry sectors since it is capable of assessing the environmental impacts of products or services, from raw material extraction to manufacturing, use, and end-of-life disposal (International Organization for Standardization, 1997).

It is important to emphasize that, in some types of projects, there are overlaps between the lifecycle of the project and product, as in the case of the construction industry (Marcelino-Sábada et al., 2015; Khoshnava et al., 2016). When those projects incorporate sustainability as a focus of development, a high level of complexity is also included, especially when applied to the urban environment (Ali-Toudert and Ji, 2017). This is due to the large number of factors considered in urban sustainability projects, from different origins, which may be interdependent and often conflicting (Zhang et al., 2016; Ali-Toudert and Ji, 2017). The management of those projects requires consideration of the multiple dimensions involved, as well as the simultaneous analyses of multicriteria and multi-objectives (Marcelino-Sábada et al., 2015; Engert et al., 2016). For that reason, decision-making on sustainability projects has been addressed using complex systems.

2.2. Decision-making in complex scenarios

Criteria establishment is one of the essential steps in decision-making for projects, as this guides their development from the early stages. Criteria can be defined as measurable standards (Ali-Toudert and Ji, 2017) or as objectives to be meet, according to a ranking (Hallstedt, 2017). For the sustainability function's fulfillment of the criteria, stakeholders should first understand what are the objectives, how can they be achieved, and, above all, how sustainability is measured (Arena et al., 2009).

The definition and incorporation of sustainability criteria in the decision-making process constitute significant challenges for project management (Garcia et al., 2016), especially when considering the risks and uncertainties associated with the desired results (Williams, 1999; Kerzner, 2014). Traditionally, project management is based on time, cost, and quality objectives (Crawford and Pollack, 2004); however, this point of view has been modified with the growing importance of adding sustainability objectives to the project's scope. (Bragança et al., 2010; Kamali and Hewage, 2017; Silvius et al., 2017). According to Hallstedt (2017), one of the major obstacles to include those objectives in projects and products is the complexity of analyses required for the decision-making process. That complexity may emerge from the criteria's different origins and mutual interactions (Snowden and Boone, 2007), beyond the possible interdependence and overlap (Byggeth and Hochschorner, 2006; Zhang et al., 2016; Ali-Toudert and Ji, 2017).

Complex systems are characterized by being difficult to understand (Kiridena and Sense, 2016), highly unpredictable, as well as often uncontrollable; with different actors and individual mechanisms generating collective consequences (Alberti, 2016). Thus, Snowden and Boone (2007) point out that the decision-making process within these systems is duly complex, mainly because both small and significant changes can introduce unpredictability and uncertainty to the analyses. Therefore, sustainable systems management has been approached under new paradigms, such as from the perspective of resilience (Olazabal and Pascual, 2016; Meerow et al., 2016; Dhar and Khirfan, 2017).

The resilience of a system is related to its ability to adapt and transform to unexpected changes, with the maintenance of its functions, being 'safe-to-fail' but not necessarily 'fail-safe' (Snowden and Boone, 2007; Ahern, 2011; Meerow et al., 2016). For Alberti (2016), resilience is related to the amplitude of system stability, the ability to absorb change, and adaptability to varying states, parameters, and factors (Holling, 1973). Given these needs, it is understood that decision-making in complex projects must be able to deal with issues of multidisciplinarity, dynamics, specificity, and constraints (Wideman, 1991). For that reason, the choices should be guided by strong technical and managerial integration

(Williams, 1999), considering multidimensional aspects of planning, management, and strategy (Ahern, 2011; Medineckiene et al., 2015).

In this sense, multicriteria methods have been used to allow simultaneous treatment of a substantial number of criteria in project decision-making, taking into account risks and uncertainties (Khalili and Duecker, 2013; Garcia et al., 2016). Those methods are considered adequate for use in sustainability assessments (Santos et al., 2017) since, for every single scenario, a unique response is generated; while the results are obtained from the participation of different decision-makers (Munda, 2006; Khoshnava et al., 2016). In addition, multicriteria analyses give consistency to the problem structuring, reducing the subjectivity of selection between alternatives through both the explicitness and the quantification of criteria (Egilmez et al., 2015; Fantinatti et al., 2015; Medineckiene et al., 2015).

Several recent studies in the sustainability field have been based on the application of Multicriteria Decision Analysis (MCDA) and its variations for the development of structures to support decision making; mainly by applying the Analytical Hierarchy Process (AHP) and Multi-Attribute Utility Theory (MAUT) methods. In the construction sector, Akadiri et al. (2013) used a variation of AHP to select less environmentally impactful materials. Khoshnava et al. (2016) developed a similar study applied to Green Building Materials (GBM). Indiviata et al. (2018) used AHP for the prioritization of design strategies in sustainable buildings, while Kamali et al. (2018) used the same method to propose a sustainability assessment model for buildings. Energy studies have also applied MCDA methods, such as for the selection of private water-heating systems (Casanovas-Rubio and Armengou, 2018); for planning the integration of renewable energy into the existing grid (Vishnpriyan and Manoharan, 2018); and for the comparison of the sustainability performance of concentrated solar power projects (Simsek et al., 2018). Most of these studies address the identification of the main objective, which has criteria and sub-criteria. In turn, they provide the definition of a range of alternatives to be hierarchically prioritized and selected (Lombardi et al., 2016; Ren and Dong, 2018 and Indiviata et al., 2018).

The application of multicriteria methods is often related to the evaluation of the three dimensions of sustainability (social, economic and environmental) simultaneously, seeking a pairwise comparison of pre-established solutions. That pairwise comparison, however, may not consider conflicts between criteria, hindering the determination of the proper balance between different objectives. Accordingly, the consideration of interrelationships between criteria and sub-criteria may affect the selection between alternatives that have been evaluated individually in each dimension of sustainability (Khoshnava et al., 2016). On the other hand, the conflicting design criteria may inhibit the application of some multicriteria methods, which are related to consistency indices for the validation of results. This is because conflicts inherent in sustainability projects, when separately evaluated, can generate inconsistent decisions and lead to unreliable results.

Since decisions are dependent on preferences in MCDA, Pohekar and Ramachandran (2004) emphasize the need for consensus on a commitment to sustainability, guided by the proper trade-offs management (Morrison-Saunders and Pope, 2013). Trade-offs are characterized as conflicts between the objectives to be meet; in which the gains/benefits in some aspects are obtained from losses/prejudices in the attendance of others (Byggeth and Hochschorner, 2006; Morrison-Saunders and Pope, 2013). Thus, according to Nielsen et al. (2016), trade-offs are inevitable in sustainability assessments, and are an integral part of the decision-making process (Da Silveira and Slack, 2001). Morrison-Saunders and Pope (2013) emphasize that conflicting objectives' importance and constraints need to be explicit, ranked, and prioritized; making the selection of alternatives more accurate for decision-makers (Byggeth and Hochschorner, 2006; Karatas and El-Rayes, 2015; Umer et al., 2017).

However, despite the existence of a complex network of evaluations to be conducted in sustainability projects, some methods seek to obtain an optimal solution for each analysis context (Casanovas-Rubio and Armengou, 2018; Khoshnava et al., 2016; Vishnupriyan and Monoharan, 2018). Optimal solutions, while practical in nature, can disregard essential conflicts; as well as excluding alternatives generated from the proper management of trade-offs from the set of solutions. Therefore, the integration of the multicriteria method with scenario analysis has been highlighted as relevant in sustainability research. In their study, Rohrbach et al. (2018) compared land use planning from the use of MCDA and participatory mapping; emphasizing that the first presented higher spatial resolution and provided results that can be better compared; while the latter was able to suggest more applicable alternatives with better-contextualized information.

Thus, considering the high intrinsic complexity of sustainability projects, Ali-Toudert and Ji (2017) believe that multicriteria methods must be allied with other management tools. Such tools are capable of adding greater maturity of judgment to multicriteria methods by providing a better understanding of the different factors involved in the decision-making process. Therefore, management tools can support multicriteria methods and reinforce the choices from complementary analyses, especially when considering the trade-offs associated with each project.

3. Trade-off decision-making (TODeM) tool for sustainability projects

This section presents the tool developed for trade-off management in the decision-making process of sustainability-focused projects – TODeM. The use of this tool presupposes the use, at an earlier stage, of a multicriteria method for the analysis and treatment of requirements and design criteria. From the multicriteria method's application, potential trade-offs are identified, which will then be managed by the proposed tool. Thus, there is a fundamental premise for the use of TODeM: although it is possible to integrate the tool with different multicriteria methods, it is mandatory that the method employed be able to identify and prioritize both the requirements and the criteria, as well as indicate the correlations between those criteria. Therefore, the outputs of the multicriteria method compose the inputs for the trade-offs management tool.

The TODeM tool was developed to assist the project planning stage, unfolding into two sequential phases: (i) guidelines to be considered for the management of trade-offs; and (ii) analyses of project's trade-offs. The guidelines originated from literature best practices related to the management of trade-offs for the development of projects and more sustainable products. In turn, the trade-off analyses are based on five sequential comparisons, which should be performed for each pair of conflicting objectives. In this way, the more relevant objectives are made explicit for the decision-makers, supporting the analysis of the project sustainability factors. Fig. 1 presents the use context of the proposed management tool and its relation to multicriteria methods. The two phases of the TODeM tool are further detailed, as follows.

3.1. Guidelines for trade-offs management

The tool's first phase proposes a list of 13 guidelines divided into three groups: initial decisions, acceptable and negotiable aspects, and support for the decision-making process. The groups were defined based on a recurrent recommendation in the literature for the trade-offs management in sustainability projects. That

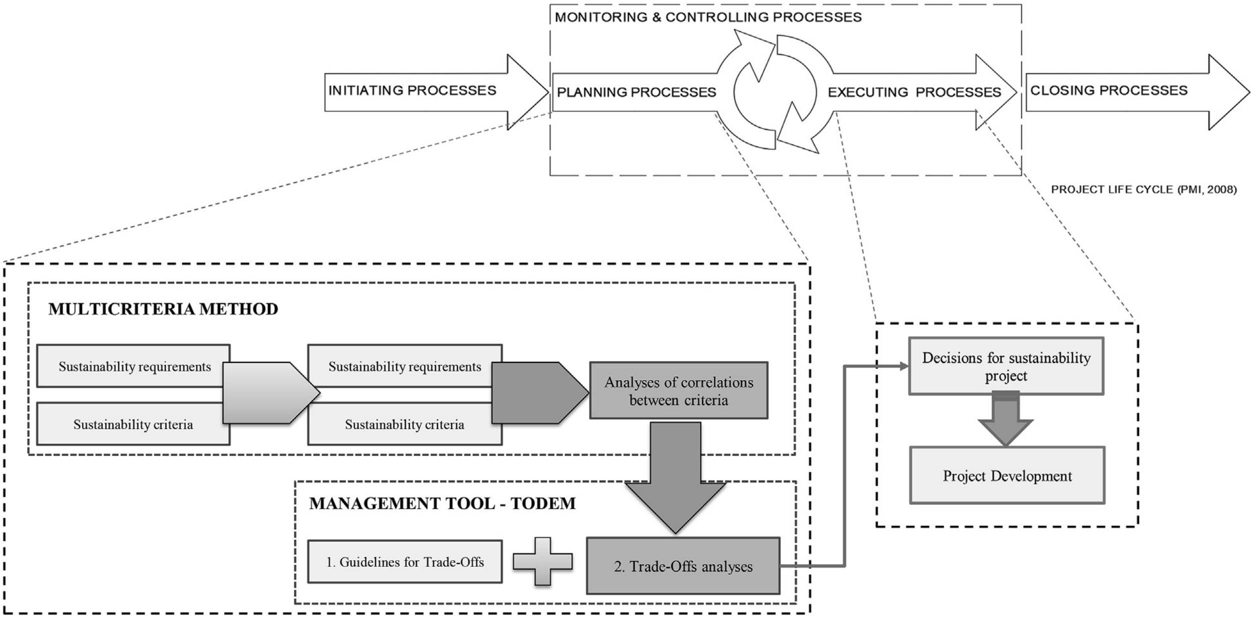

Fig. 1. Trade-off decision-making tool for sustainability projects – TODeM.

recommendation highlights the need to consider three principles for handling conflicts in this project profile: (i) establishment of clear requirements to be attended; (ii) prioritization of requirements by specific methods (multicriteria methods, matrix systems, among others); and (iii) monitoring of their performance through indicators or criteria (Gibson, 2006; Morrison-Saunders and Pope, 2013; Nielsen et al., 2016). The guidelines defined based on those principles are presented in Table 1 and detailed in the following subitems.

3.1.1. *Group 1 – early decisions*

The guidelines that make up the first group are fundamental to the application of TODeM. Those guidelines were selected to highlight the key assumptions that should guide the trade-offs decision-making process in the focus project. Consequently, the definitions of this group will be reflected both in the guideline groups 2 and 3 and in the tool's second phase; since they contain the project essence. Thus, all specific project decisions after the application of the TODeM tool reflect the key assumptions previously defined (Morrison-Saunders and Pope, 2013).

3.1.2. *Group 2 – acceptable and negotiable aspects*

The second set of guidelines addresses a recommendation advocated by Morrison-Saunders and Pope (2013) for sustainability systems analysis regarding the delineation of aspects that will be considered as 'acceptable' in design decisions. Those aspects are

Table 1
Guidelines for trade-offs management.

Group	Guideline	Reference
1. Early Decisions	1.1 In the early decisions, the fundamental objective of project sustainability should be privileged	Morrison-Saunders and Pope (2013)
	1.2 Before any interventions are proposed, the suitability potential of the project in the scenario must be evaluated to minimize the occurrence of complex trade-offs	Bartke and Schwarze (2015)
	1.3 The sustainability trade-offs management of a project must occur systematically and not one by one individually	Morrison-Saunders and Pope (2013)
	1.4 Between two conflicting objectives, the one which does not transfer potential negative impacts to the future should be prioritized	Gibson (2006)
	1.5 The early decisions should consider the views of different actors involved in the process	Gibson (2006)
2. Acceptable and Negotiable Aspects	2.1 Initially, unacceptable aspects of the sustainability project should be defined, and the degree of flexibility to changes for unacceptable aspects should be established	Morrison-Saunders and Pope (2013)
	2.2 The offsets should be defined - project aspects that are considered negotiable, among the unacceptable ones	Morrison-Saunders and Pope (2013)
	2.3 The alternatives selection for the project should be carried out within the established limits for acceptable and negotiable sustainability aspects	Morrison-Saunders and Pope (2013)
3. Decision-making process support	3.1 It is mandatory to comply with the minimum requirements of standards and legislation	Byggeth and Hochschorner (2006); Morrison-Saunders and Pope (2013)
	3.2 All decisions should be aligned with the organization's strategic objectives	Byggeth and Hochschorner (2006)
	3.3 Decisions on project trade-offs should be guided by the expected results defined in the pre-development stages	Morrison-Saunders and Pope (2013)
	3.4 Decisions must be based on minimizing or accommodating process variability, which can scarcely be eliminated	Gibson (2006)
	3.5 The sustainable product's adequate performance should be prioritized, even when it is detrimental to the adoption of solutions with lower environmental impact	Morrison-Saunders and Pope (2013)

contained in different dimensions, such as economic, social, environmental, political, and technological, among others. Once it is not possible to attend the aspects considered acceptable, a negotiation process begins. The negotiation process constitutes the trade-offs management as shown in Fig. 2. It is important to emphasize that trade-offs can occur not only between different dimensions, but also within the same dimension. In that case, acceptable and negotiable aspects should be re-evaluated and redefined when necessary.

For each dimension of decision-making, the aspects considered acceptable are defined and divided into what may or may not be negotiated. For this purpose, the selection of aspects that participate in the trade-offs management is expressly restricted to those established as acceptable and negotiable, excluding the options of aspects considered as 'non-acceptable' and 'non-negotiable.'

3.1.3. Group 3 — decision process support

In group three, topics are covered in support of the decision-making process in different stages, considering both technical and managerial approaches. The guidelines emphasize the importance of the choices being aligned with the organization's strategies, taking into account expectations about its performance. In this sense, when sustainability factors are introduced in projects, the leaders' support is fundamental to the achievement of the established objectives. This is because the inclusion of those factors can impact changes in organizational vision; in the routine tasks of the design process; in cost analysis (shifting the focus from initial costs to lifecycle costs); in the learning process of the project team; and in the organizational culture.

Likewise, the guideline group emphasizes that, while project decisions can be guided by sustainability factors, they cannot negatively interfere with the fulfillment of product performance requirements. Accordingly, it is emphasized that the project will meet its objectives only if it can combine sustainability factors, in their different dimensions, with the minimum expected and required performance of the product.

3.2. Project's trade-offs analyses

Based on the proposed guidelines, TODeM's second phase deals with the operationalization of trade-offs management based on five comparative analyses. Those analyses must consider the three principles for trade-offs management presented in section 3.1: establishment of clear requirements, prioritization of requirements by multicriteria methods, and monitoring performance based on established criteria. Those criteria have their origin in the sustainability requirements which, in turn, align with the project objectives.

Therefore, the multicriteria method should allow the identification of both the positive and negative correlations and the number and intensity of relationships between requirements and criteria. Given that those relationships also reflect the connections between project criteria and objectives, the comparative analyses carried out to seek to explain how much the prioritization of a given criterion can express the meeting the sustainability objectives of the project as a whole.

The analyses proposed by the tool sequentially perform the comparison between characteristics related to the conflicting objectives of each pair of sustainability criteria that make up the trade-off. The comparative analyses, which are the essence of trade-offs managed by the TODeM tool, are presented in Fig. 3 and detailed in the next subitems.

3.2.1. Analysis #1 — design stages related to sustainability criteria

The first analysis aims at mapping the design stages to which every conflicting objective relates. In this way, the area of influence

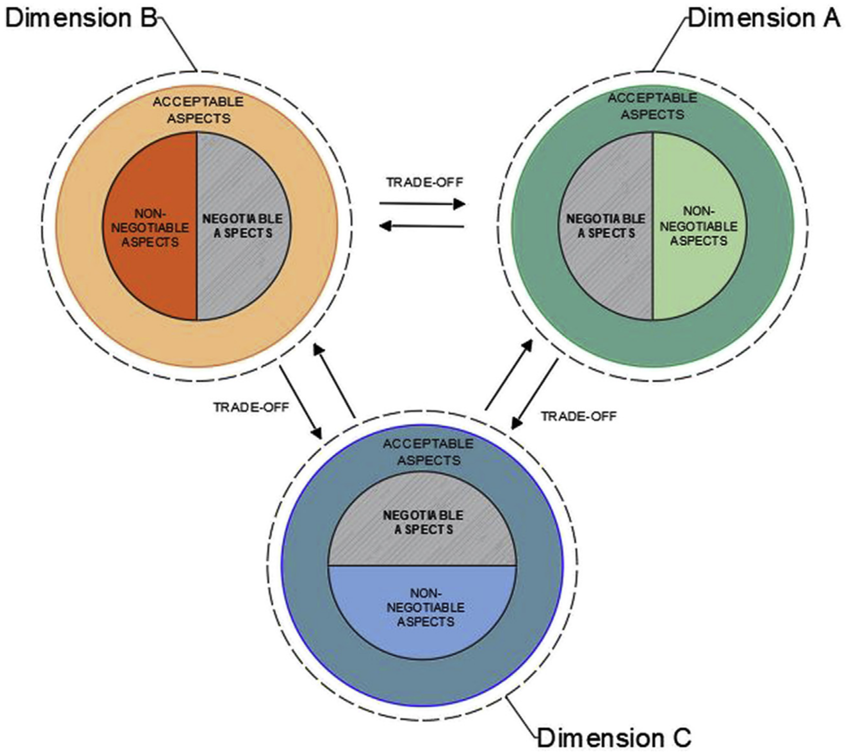

Fig. 2. Acceptable and negotiable aspects in trade-offs management.
Source: adapted from Morrison-Saunders and Pope (2013).

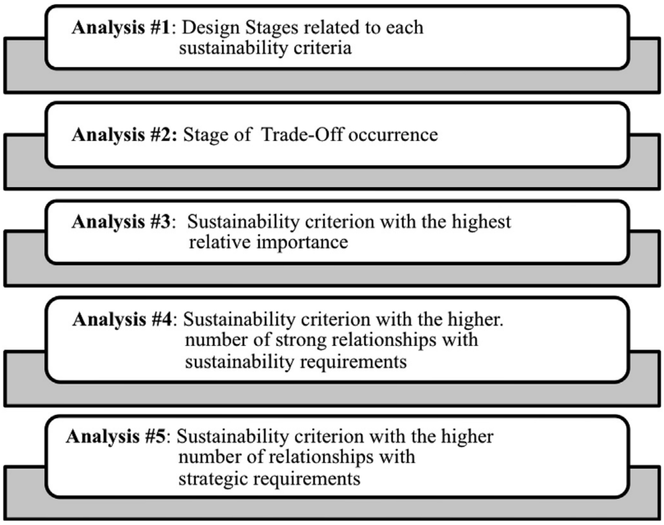

Fig. 3. Sequence of comparative analyses for the sustainability-focused trade-offs management.

of the objective on the development stages of the design is identified. For establishment of the objective's influence area, the relationship between the activities belonging to each project stage and the criteria to be met by those activities should be analyzed (De Magalhães et al., 2017).

3.2.2. Analysis #2 – stage of trade-offs occurrence

Sequentially, the second comparative analysis proceeds with the verification of overlap between the conflicting objectives' influence areas, which were identified in Analysis #1. Therefore, project development planning can be carried out in anticipation of actions that mitigate the effects of identified trade-offs.

The frequency of trade-offs' occurrence can be multiple: located within the same design step, in the transition between two stages, or even in more than one stage. The latter, when it manifests itself, requires replication of the pair of conflicting objectives pair for each stage where they appear, as well as new analyses of the trade-offs that arise at each particular stage. The replicated analyses may lead to diverse project definitions in the decision process resulting in attendance to different objectives, depending on the scenario in which each trade-off presents itself.

3.2.3. Analysis #3 – relative importance of sustainability criteria

From the third analysis, the integration of the tool with the multicriteria method becomes more evident and necessary. That is because Analysis #3 compares the criteria's relative importance to the conflicting objectives, highlighting those that have the higher value associated with a given characteristic.

The relative importance of sustainability criteria, regardless of the method adopted, is a result of the quantity and the intensity of relationships established between those criteria and the design requirements. Therefore, the comparison of relative importance seeks to highlight the criterion that most impacts the attendance of the project objectives.

3.2.4. Analysis #4 – strong relationship between sustainability requirements and sustainability criteria

Similar to Analysis #3, Analysis #4 is based on data obtained from the application of the multicriteria method, performing qualitative and quantitative assessments of the relationships established between sustainability requirements and sustainability criteria. Depending on the method adopted, those relations may be more or less explicit; nonetheless, it is essential that their intensity be well defined.

The fourth analysis identifies, among all the relationships established between requirements and criteria, those relationships that stand out because they are strongly linked. Based on that identification, key criteria for the sustainability of the project are highlighted. The key criteria are capable not only of influencing, but also of determining the fulfillment of specific requirements.

3.2.5. Analysis #5 – relationships between sustainability criteria and strategic requirements

In Analysis #5, the number of relationships between the sustainability criteria and the requirements considered strategic to the project is evaluated. The definition of which requirements will be classified in that way is determined by the organization, according to strategic business objectives.

For the definition of strategic requirements, the following alternatives can be used, taking account the contribution of those requirements with the project scope fulfillment:

- performance improvement of the product or service;
- project's potential increase for innovation;
- design process flexibility improvement
- product lifecycle costs reduction, when applicable;
- project environmental quality increase;
- alternative redundant solutions provision for the same purpose (Ahern, 2011); and
- action in response to risks previously identified for the project.

3.3. Trade-offs management operationalization

Finally, to make analyses more visual and understandable, the use of a worksheet for the trade-offs management operationalization is suggested, performing paired comparisons between the conflicting objectives. For those objectives that comprise trade-offs occurring in more than one design stage, analyses must be performed as often as the overlaps are identified. After the analyses, for each of the trade-offs, the objective to be attended must be selected, and the justification of that choice must be specified.

To provide a better understanding of the trade-offs management operationalization, we executed an illustrative example of the tool application in a sustainability project. The example included the development, by a multidisciplinary team, of a non-residential building project, which aimed for international environmental certification by the Leadership in Energy and Environmental Design (LEED) system. The project considered the minimization of impacts related to economic sustainability in addition to the environmental dimension.

3.3.1. Scope and objectives project

The building project example included its architectural, landscaping, and infrastructure designs (paving of external areas, drainage, water and sewage systems), construction waste management plan, assessment of life cycle costing of the building, as well as environmental management of the area (existing native vegetation). Due to the multiple disciplines and dimensions involved, it was designed using a Building Information Modelling (BIM) tool.

In addition to fulfillment of program requirements, the following were considered as sustainability objectives for the project development: (a) soil permeability improvement; (b) the reduction of the building's life cycle costs; (c) toxic materials minimization; (d) energy efficiency; (e) solid waste minimization; (f) minimal intervention in existing native vegetation; (g) water consumption reduction. These objectives were related to the specific criteria of LEED, in accordance with each credit category.

3.3.2. Trade-offs identification

Initially, for trade-offs identification, the project objectives (whether sustainability-related or not) were associated with the design stages in which they should be defined. For example, the objective of saving existing vegetation was associated with the stages of feasibility studies and basic design; while the objective of waste minimization was related to the stages of executive design and construction. From these relations, the objectives that could result in conflicting decisions were identified, even when related to different stages of the project. These conflicting decisions constitute the project's trade-offs. Accordingly, the TODeM tool provides a comprehensive view of the project strategies, starting with the early decisions, and considering its complex network of evaluations while maintaining a focus on sustainability objectives.

In accordance with the principles for the employment of TODeM, the Fuzzy-AHP method was first used to prioritize the project objectives in the environmental and economic sustainability dimensions. In addition to the relative importance provided by the AHP, Fuzzy logic was used to identify the relationships between objectives and project requirements. The prioritization data and the relationship between requirements and objectives were entered into the appropriate columns in the worksheet for trade-offs management. After the trade-offs identification, the information of higher relevance associated with each conflicting sustainability objective was made explicit, allowing simultaneous evaluations by the decision makers.

3.3.3. Worksheet for operationalization of the trade-offs management

Pairwise comparisons are carried out with the AHP method, considering the prioritization scale of 1-3-5-7-9 (Saaty, 1977). For this purpose, the objectives were used to assemble two matrices, one that considers the probability of its inclusion into the project scope, and another that considers the impact of its execution to achieve the fundamental project objective (obtaining LEED certification). Table 2 presents the definition of the score in the prioritization scale used for the probability and impact matrices.

In the rows and columns of the matrices, the letters a, b, c, d, e, f, and g identify the sustainability objectives discussed in section 3.3.1. Each cell of the matrix indicates the relative priority of the row to the column. For example, row ‘a’, column ‘c’ in the probability matrix indicates that the probability of including objective a, relative to objective c is 3.00 in the scale. Thus, row ‘c’, column ‘a’ has a value of 1/3. The normalized probability and impact matrices were obtained by dividing each component of the original matrix by the sum of its column. Then, the relative importance vectors are composed of the linear averages across rows of the normalized matrices. Figs. 4 and 5 present the probability and impact matrices, respectively, composed from the attribution of importance scores to the objectives. For both matrices, Saaty's consistency index (CI) was 10%.

The relative importance vectors of the probability and impact matrices were then multiplied by each other, resulting in the final relative importance ranking for the sustainability objectives of the project, as shown in Table 3.

Considering that relative importance was composed of two factors (probability of inclusion into the project and impact on the achievement of the fundamental objective), in several trade-offs, the balance between these factors in one of the objectives was highly relevant to selection. In the case of the objective '(b) reduction of the building's life cycle costs', which is first in the prioritization, the value obtained for probability was higher than the objective '(d) energy efficiency'. However, for impact, the score of the second objective was higher than the first one. As objective 'b' has more comprehensive characteristics for the scope of the project, its probability of inclusion was considered higher by the respondents.

For the objectives '(c) toxic materials minimization' and '(a) soil permeability improvement,' there is an inverse relationship. Objective ‘c’ is less likely to be included in the project scope, which may be related to legal (land occupation) issues expressed in objective 'a'. However, the impact of the first objective on the sustainability aspect of the project was higher, leading to its prioritization. In this way, the meeting of sustainability objectives, even if they are not required by environmental legislation, may be relevant to the project's fundamental objective.

Nonetheless it is important to highlight that the importance scores can only be compared in a relative way to each other since they do not represent ordinal values comparable in magnitude. Consequently, it is not possible to say that objective 'a' is 1.4 times more important than objective 'b'; but rather that the first objective is more important than the second, mainly due to its higher probability of inclusion into the project scope.

Considering the project scope objectives as well as those related to LEED certification, the fuzzy logic identified the occurrence of six sustainability trade-offs. Table 4 presents the operationalization worksheet for the management of these conflicts. For the relations between criteria and sustainability requirements, the project considered 52 design requirements of which 20 were strategic ones. The strategic requirements in this example were those directly related to the highest LEED certification criteria score desired for the project. After the trade-offs identification, the first column to be filled numerically in the operationalization worksheet and the first data analyzed in the selection process are the relative importance of the criteria shown in Table 3.

Table 2
Scale for objectives prioritization.

Score	Description	
	Probability Matrix	Impact Matrix
1 Equal importance	Equal likelihood of the objectives being included in the project scope	Equal relative impact on meeting the fundamental project objective
3 Weak importance of one over another	One of the objectives is slightly more likely to be incorporated into the project than the other	One of the objectives has a slightly higher impact than the other on attendance the fundamental project objective
5 Strong importance	One of the objectives has a significantly higher probability of being incorporated into the project than the other	One of the objectives has a stronger impact than the other on the attendance of the fundamental project objective
7 Demonstrated importance	One of the objectives has a predominantly higher probability of being incorporated into the project than the other	One of the objectives has a predominantly highest impact than the other on attendance the fundamental project objective
9 Absolute importance	There is no doubt that one of the objectives is much more likely to be incorporated into the project than the other	There is no doubt that one of the objectives has a much highest impact on attendance the fundamental project objective than the other

	a	b	c	d	e	f	g
a	1.00	1/7	3.00	1/5	1/5	5.00	1/7
b	7.00	1.00	7.00	3.00	5.00	9.00	3.00
c	1/3	1/7	1.00	1/5	1/3	3.00	1/7
d	5.00	1/3	5.00	1.00	3.00	7.00	1/3
e	5.00	1/5	3.00	1/3	1.00	7.00	1/5
f	1/5	1/9	1/3	1/7	1/7	1.00	1/9
g	7.00	1/3	7.00	3.00	5.00	9.00	1.00
	25.53	**2.26**	**26.33**	**7.88**	**14.68**	**41.00**	**4.93**

	a	b	c	d	e	f	g	Vector
a	0.04	0.06	0.11	0.03	0.01	0.12	0.03	0.06
b	0.27	0.44	0.27	0.38	0.34	0.22	0.61	0.36
c	0.01	0.06	0.04	0.03	0.02	0.07	0.03	0.04
d	0.20	0.15	0.19	0.13	0.20	0.17	0.07	0.16
e	0.20	0.09	0.11	0.04	0.07	0.17	0.04	0.10
f	0.01	0.05	0.01	0.02	0.01	0.02	0.02	0.02
g	0.27	0.15	0.27	0.38	0.34	0.22	0.20	0.26

Fig. 4. Probability matrices.

	a	b	c	d	e	f	g
a	1.00	1/7	1/3	1/9	1/5	1/7	3.00
b	7.00	1.00	7.00	1/3	5.00	3.00	9.00
c	3.00	1/7	1.00	1/7	1/3	1/7	5.00
d	9.00	3.00	7.00	1.00	7.00	5.00	9.00
e	5.00	1/5	3.00	1/7	1.00	1/3	7.00
f	7.00	1/3	5.00	1/5	3.00	1.00	7.00
g	1/3	1/9	1/5	1/9	1/7	1/7	1.00
	32.33	**4.93**	**23.53**	**2.04**	**16.68**	**9.76**	**41.00**

	a	b	c	d	e	f	g	Vector
a	0.03	0.03	0.01	0.05	0.01	0.01	0.07	0.03
b	0.22	0.20	0.30	0.16	0.30	0.31	0.22	0.24
c	0.09	0.03	0.04	0.07	0.02	0.01	0.12	0.06
d	0.28	0.61	0.30	0.49	0.42	0.51	0.22	0.40
e	0.15	0.04	0.13	0.07	0.06	0.03	0.17	0.09
f	0.22	0.07	0.21	0.10	0.18	0.10	0.17	0.15
g	0.01	0.02	0.01	0.05	0.01	0.01	0.02	0.02

Fig. 5. Impact matrices.

Table 3
Prioritization of sustainability objectives and criteria.

Objective	Criterion	Relative importance
b.Reduction of the building's life cycle costs	Total costs/construction costs	0.0882
d.Energy efficiency	Real consumption of energy/precast consumption of energy	0.0636
e.Solid waste minimization	Volume of construction waste	0.0097
g.Water consumption reduction	Real consumption of water/precast consumption of water	0.0054
f.Minimal intervention in existing native vegetation	Number of native species suppressed	0.0031
c.Toxic materials minimization	Mean concentration of VOCs in construction materials	0.0021
a.Soil permeability improvement	Permeable area/building area	0.0019

3.3.4. Selection and justification

As shown in Table 4, in several trade-offs, the selection and justification of the objective to be met were directly related to the context of the conflict. Therefore, TODeM supported the decision-making process based on the complementary evaluation of each MCDA result, in a structured but flexible means. When the energy efficiency objective was present, for example, the choice for decision-makers was, for the most part, to prioritize it (except in trade-off 5). This objective did not achieve the highest final prioritization among all the objectives considered. However, it was the one that obtained the highest relative impact, which demonstrates its importance for the achievement of the project results. Using our tool, it is possible to verify that the energy efficiency has several strong relationships with the project requirements (62%), which were identified using the Fuzzy method. Accordingly, the attendance of this objective contributes in a significant way to obtain the required environmental certification. Energy efficiency was also related to all strategic requirements (20 relations with the 20 strategic requirements). Therefore, in different trade-offs, it was the objective chosen by the decision makers, even if it had less relative importance when compared to a conflicting objective.

In the trade-off 1, the selection considered the guidelines of Group 2, which stated that, although the saving of native vegetation was an essential objective, the project team could negotiate the achievement of this objective in favor of other environmental benefits (negotiable aspect). The selection justification also contributed evidence that it would obtain the desired score in the LEED system and the appropriate environmental licenses. As the trade-off occurred from feasibility studies, the selection of design alternatives could be managed from early decisions, minimizing the need for structural changes in the final stages. In the second trade-off, guideline 3.5 supported decision-makers by showing that to achieve the same project performance, materials with fewer toxic substances would be preferable, even at higher acquisition costs. Thus, although all the values associated with the analyses of one of the objectives were higher than the other objectives, in a systemic view, the meeting of the second one was prioritized. Also regarding the importance of a systemic view of the project strategies, trade-off 3 was composed of two conflicting objectives with very similar (or equal) analysis values. The high uncertainties regarding the data associated with the first objective encourage the achievement of the second one, in order to mitigate the risks associated with the choice.

Decision-making in the fourth trade-off was associated with guideline 1.4, which concerns the minimization of transferring potential negative impacts to the future. It is important to note that in this trade-off, all analysis values of the operationalization worksheet also pointed at meeting the objective of solid waste minimization. On the other hand, in trade-off 5, although all values guided the meet of the energy efficiency objective, decision-makers

Table 4
Worksheet for trade-offs management operationalization.

Conflicting Objectives		Trade-off description	Design Stages related to sustainability criteria				Stage of Trade-Off occurrence	Relative importance of sustainability criteria	N. of strong relationships between sustainability requirements and criteria (52 requirements)	N. of relationships between sustainability criteria and strategic requirements (20 requirements)	Selection (insert 'x')	Justification
			Feasibility Studies	Basic Design	Executive Design	Construction						
1	Minimal intervention in native vegetation	The existence of native vegetation in specific areas may cause undesired shading for higher energy efficiency	▨ √	▨ √			Feasibility Studies and Basic Design	0.0031	6	3		The environmental benefits of energy efficiency can be reflected in the long-term, considering the use phase of the building and its infrastructure.
	Energy efficiency		▨ √	▨ √	▨	▨		**0.0636**	**35**	**20**	X	
2	Reduction of life cycle costs	Materials with lower toxic content and the same performance have embedded research and development, which can increase their market costs.			▨ √	▨	Executive Design	**0.0882**	**35**	**20**		Contamination by toxic materials can cause severe environmental damage to the ecosystem as well as the health of staff. Also, the end-of-life treatments of these materials usually have a higher cost.
	Minimization use of toxic materials			▨	▨ √			0.0021	12	4	X	
3	Reduction of life cycle costs	Design solutions that provide higher energy efficiency can increase building construction costs.			▨ √	▨ √	Executive Design and Construction	**0.0882**	**35**	**20**		Due to uncertainties associated with the life-cycle costs of buildings, the benefits of increased energy efficiency can result to lower environmental and economic impacts.
	Energy efficiency		▨	▨	▨ √	▨ √		0.0636	**35**	**20**	X	
4	Minimal intervention in native vegetation	The existence of native vegetation in specific areas may create difficulty in the modulation of infrastructure designs, increasing waste generation construction from construction.	▨	▨ √			Basic Design	0.0031	6	3		Measures that include planting and transplantation can offset vegetation management. However, the impacts of waste generation have complex and long-term environmental mitigation.
	Solid waste minimization			▨ √	▨	▨		**0.0097**	**23**	**12**	X	
5	Reduction of water consumption	The use of equipment that supports control and rations water consumption can cause high energy consumption.	▨ √	▨ √	▨ √	▨ √	Feasibility Studies, Basic Design, Executive Design and Constructon	0.0054	30	18	X	According to design alternatives analyses, the reduction of water consumption can positively impact the improvement of energy efficiency.
	Energy efficiency		▨ √	▨ √	▨ √	▨ √		**0.0636**	**35**	**20**		
6	Improvement of soil permeability	Construction techniques for improving soil permeability may employ lower performance materials due to water infiltration needs, leading to higher system maintenance costs.	▨	▨ ↘			Transition: Basic Design and Executive Design	0.0019	7	10	X	For this trade-off, we apply natural drainage solutions, associated with a conventional drainage system, to improve the soil permeability and the maintenance costs.
	Reduction of life cycle costs				▨ ↘	▨		**0.0882**	**35**	**20**	X	

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▨ Stage to which the criteria relate
▨ √ Stage of Trade-Off occurrence
▨ ↘ ▨ Trade-Off occurrence at transition between stages
n Selected value

chose to prioritize the objective of water consumption reduction. That is because both objectives were related to all design stages, which shows the existence of interdependencies and overlaps between criteria; demanding the adoption of different solutions at different levels of the project. Finally, in trade-off n.6, TODeM seek a balance in meeting both objectives, contrary to the lack of flexibility observed when adopting a unique optimal solution. This trade-off occurred in the transition between two design stages, indicating that the choices were associated with different hierarchical levels in the project. Therefore, the decision-making process considered the compound of two solutions, so that higher performance was obtained for the system with lower associated environmental and economic impacts.

4. Discussions

4.1. Existing trade-off models for decision-making process

Several models to handle trade-offs have been proposed in the literature as mechanisms to support the decision-making process in technical, economic, environmental and social contexts. These models are based on higher or lower complexity approaches in comparison with TODeM; focusing mainly on scenario modelling or in-depth analysis of specific trade-offs, relevant to each area of knowledge.

In economic development studies, the related models seek an optimal solution among capital investment options, considering upstream modelling outcomes and applications of analytical frameworks (Wang and Khan, 2017; Wang and Zhang, 2018). In the chemistry (Wang and Lin, 2018) and energy fields (Frew and Jacobson, 2016; Rosburg et al., 2016; Jin et al., 2018), trade-offs management is addressed using computer simulation of a specific trade-off to find the most efficient technical solutions. These models are applied to agriculture research (Valdivia et al., 2012; Coleman et al., 2017; Tian et al., 2018) and basic sanitation research (Jiang et al., 2018), for example. Some simulation-based models also address the possible influence of the preferences of the decision makers in each process (Franke and Ciccozzi, 2018; Turkelboom et al., 2018). These models can be considered more flexible than those based purely on modelling and simulation since they allow adaptations to different trade-offs.

In this context, Vahidi (2013) concludes that the existing trade-offs management models are of limited practical applicability since they are formed by structures that are either too complex or too simple (Clough et al., 2000), which can restrict the information provided to the decision-makers. Thus, methods based on modelling and parameters sensitivity analysis are limited in their ability to deal with social, political, environmental, and non-normative technical issues.

The tool proposed in this study aims to address the aforementioned restrictions of existent models. The TODeM analyses are based on the decision-makers' preferences for consensus and attaches these preferences to fundamental sustainability objectives of the project. The sustainability objectives, which sometimes have conflicting characteristics, could introduce complex trade-offs to the project. These complex trade-offs cannot be handled by using overly-simplistic solutions, or by using the detailed systems that are characteristic of computer simulation models. TODeM provides a solution that falls in between those that are considered too simple and too detailed to aid in the management of trade-offs for sustainability projects.

4.2. *Handling sustainability trade-offs*

Research that seeks to trace a path to sustainable development, based on the contribution of projects aimed at that purpose, has focused on the influence of those projects' results on society in different contexts. Considering that the study of sustainability from any point of view is highly complex and strongly dependent on the context, there is no consensus in the literature about what defines a project as sustainable. The work of Marcelino-Sábada et al. (2015), however, presents a meaningful consideration that no project is capable of producing sustainable results if it is not contained in a process in which sustainability characteristics are explicit.

For that reason, there are many gaps to be filled in the field of sustainability projects, even though the theme has been widely discussed. Much research has been dedicated to proposing frameworks for evaluating sustainable projects supported in their management process, mainly from the determination of performance indicators (Sánchez, 2015). More broadly, the development of frameworks that support sustainability factors' integration in projects at an organizational level, considering the internal and external context of the relationships established among the stakeholders, also stands out (Morioka and De Carvalho, 2016).

Some authors approach project sustainability from the definition of criteria for product development, as proposed by Hallstedt (2017). Although studies of this type consider other approaches, their results are of high relevance for sustainability project management research. This is because analyses of the development of sustainable products aggregate important conditions in guiding the design process. Those conditions contribute to the process as a whole, given that the product will not have adequate sustainability performance if it has not originated in a project developed and managed based on that objective (Prendeville et al., 2017).

Therefore, due to the complexity and the interdependence of determining factors, project sustainability assessments frequently have broad and poorly defined boundaries; resulting in a highly subjective decision-making process (Zhang et al., 2016). Trade-offs management supports the definition of system limits, especially because it considers the key relationships between the factors that influence the project's sustainability. Accordingly, it is sought to establish both the origin and the potential consequences related to the identified conflicts. Despite the importance of handling sustainability trade-offs, few studies have focused on that aspect of the decision-making process. Among those, we can highlight the framework proposed by Morrison-Saunders and Pope (2013), which is focused on managing trade-offs in sustainability assessments.

In the target projects from that research, different types of trade-offs may arise due to the requirements of each scenario. However, the conflict between the need for costs reduction and the quest for environmental impacts minimization is recurrent in this literature (Karatas and El-Rayes, 2015; Umer et al., 2017). The trade-offs that occur between the product's technical performance improvement and the reduction in related environmental and social damages are also frequent (Byggeth and Hochschorner, 2006). Thus, whenever the decision-making process includes trade-offs with the characteristics mentioned above, particular attention should be given to those, so that the appropriate selection of the objectives to be privileged can be carried out (Table 4).

By applying TODeM, other relevant implications for the trade-offs management in sustainability projects are considered. The sequential analyses performed with TODeM seek to reduce the overlap of the project objectives' influence area without impairing the intended final performance. In this way, the more evident the fundamental objectives are, the more structured the analyses and the more grounded the decisions will be. Another important aspect of the tool application is observing how many stages of design are associated with the same objective, regardless of comparisons with other objectives. Although this analysis is not explicit in the operationalization phase, its observation may justify the choice to attend to a specific objective that composes the trade-off. This is related to the fact that if the objective is present in more than one stage, it may have a significant influence on several design activities, and consequently on a large number of decisions. It is also worth noting that when trade-offs occur in more than one design stage (as exemplified in trade-off 5 of Table 4), higher complexity is aggregated into the decision. For those cases, the operationalization suggests that the trade-offs in each level should be analyzed individually, so that distinct objectives can be privileged, depending on the context of analysis of each design stage. Thus, different conflicting objectives can be selected for each of the overlapping stages (as exemplified in trade-off 6 of Table 4). Finally, it is important to highlight that the operationalization proposed by TODeM intends to contribute merely to the structuring and orientation of the decision-making process in the trade-offs management; and not to provide a ready solution for such conflicts. Therefore, even if all the data analyzed point to the attendance of a certain objective, another may be prioritized, depending on the project characteristics, the decision-makers' risk profile, and the organization's technical and strategic positioning. The choice occurs in this way since the justification for such can be associated as much with the selection as the exclusion of the objectives' attendance. For that reason, the ‘justification’ column was proposed in the operationalization worksheet, allowing adequate documentation and tracking of the reasons that led to the selection or exclusion of the objectives by the decision makers.

4.3. *Contributions of the TODeM*

The existing trade-off models in the literature are based on two main approaches: (i) mapping the formation process and identification of trade-offs in different contexts; and (ii) modelling and simulations development to find optimal solutions in the occurrence of specific trade-offs. These models are considered very limited when applied in sustainability contexts, due to the high levels of complexity and subjectivity of conflicts that could occur between objectives of such projects. For this reason, in sustainability projects, the proposed approaches are more often based on best practices for decision makers after the trade-offs identification, and not on restricted models that are designed to find an optimal solution. Thus, the TODeM tool intends to be a guidance structure applied to sustainability projects management in operational terms. This increases the consistency of the outcomes of such projects with decision-makers' preferences, providing solutions that are conducive to the achievement of the objectives previously established. In this sense, the tool can also support the operationalization of other methods such as Life Cycle Sustainability Assessment (LCSA) which, according to Petit-Boix et al. (2017), finds difficulties for practical application due to the high complexity of the decision-making process involving the three dimensions of sustainability.

On the other hand, the present work contributes, through the proposed tool, a higher robustness of decision-making in these projects by giving greater objectivity and traceability to the choices. The guidelines consideration presented in the first phase of the tool has practical implications for project managers. That is because the guidelines seek to increase understanding of the choices' influence on the technical, environmental, social and economic performance of the project. A greater understanding of the decisions' influence reduces uncertainties in the decision-making process, contributing to the more accurate selection of solutions geared to the project objectives.

The operationalization materialized in the second phase of TODeM directs the decisions to what is considered, effectively, as more important in the context of analysis based on the value vision of the stakeholders. Consequently, with the integration of the two proposed phases – guidelines and operationalization – the TODeM tool presents itself as an objective structure to support multiple factors analyses, necessary for the trade-offs management in sustainability projects.

5. Conclusions

The research developed in this work proposed a tool to aid the decision-making process in complex sustainability projects, with a focus on trade-offs management. TODeM acts in the planning stage of project management. Employment of the tool is predicated on the prior application of a multicriteria method, which will define requirements and criteria to attend. TODeM is structured in two phases, the first of which considers guidelines, previously defined, for the trade-offs management; while the second phase develops in a sequence of comparative analyses between the conflicting objectives identified.

Despite its potential for applicability, the proposed tool can be refined and complemented by other studies. As a continuation of this research, the following opportunities for future studies are suggested: (i) method development to monitor the impacts associated with the decisions implemented based on TODeM's use; (ii) TODeM's application in several sustainability projects; (iii) adjustments in the tool structure to provide refinement for its use in different types of sustainability-focused projects; and (iv) tool adaption to in-depth product and service environmental impact assessment studies, such as those using the LCA approach.

Trade-offs are considered inherent to any sustainability project, especially in complex scenarios, where the paths to meeting the objective depend on multiple factors. Inadequate trade-offs management in projects with this profile may result in lower-than-expected performance or in a project failure. However, the treatment of trade-offs associated with sustainability is still little explored in the literature; and when approached, is not usually considered as a mechanism to support the decision-making process even if it has significant potential for it. In contrast, trade-offs are often analyzed from a risk perspective to be mitigated rather than an opportunity to optimize design solutions.

Therefore, proposed tools for trade-offs management must consider the full sustainability context in which the trade-offs fit. This enables a structured and less restricted decision-making process. In this way, the balance of meeting different objectives without impairing performance, achieved via proper trade-offs management, could be a key aspect of effective sustainability projects.

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