SUSTAINABLE DECISION-MAKING MODULE: APPLICATION TO PUBLIC PROCUREMENT

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ABSTRACT

Universities are preparing future professionals to face real problems. Sustainable development is a challenge that requires particular attention from education programs. In their profession, civil engineers address many decisions that can compromise the sustainability of infrastructure. This paper proposes a sustainable decision-making module to promote student competencies relevant to solving real engineering decision-making problems while meeting sustainability criteria. The module is tested in a Project Management course for a Master in Planning and Management in Civil Engineering program. Students were placed in a procurement process scenario with the objective of designing a sustainable decision-making layout for selecting the best construction company to construct a highway. The assessment of student performance revealed that most students acquired higher-order cognitive skills, and the perception survey showed that this learning method has been widely accepted for developing competencies related to both decision-making and sustainable thinking. This study could serve as an example for engineering education to promote sustainable practices through active exploration of decision-making in real professional situations.

KEYWORDS: sustainability; decision-making; procurement procedure; problem-based learning

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1. INTRODUCTION

Engineers have an important role in the pursuit of sustainable development. Construction is responsible for the majority of greenhouse gas generation (Liu et al. 2013) and natural resource use (Lippiatt 1999). Specifically, in developed countries, 50% of the total energy cost is closely related to or a consequence of the construction industry (González and García Navarro 2006), with its concomitant production of greenhouse gas. Buildings construction consumes 40% of the raw stone, gravel, and sand used globally each year, and 25% of the raw timber (Lippiatt 1999). Across different areas of activity within the construction industry, such as project management (Molenaar et al. 2010; Molenaar and Johnson 2003; Xia et al. 2015) and project design (García-Segura et al. 2017; de Medeiros and Kripka 2014; Penadés-Plà et al. 2017), developing new approaches to adopt sustainable practices has been a research focus. However, numerous researchers have highlighted that the mechanism best suited to integrating sustainability initiatives into the construction industry is public procurement (Loosemore 2016; Ruparathna and Hewage 2015). In public procurement of infrastructure, social and environmental criteria should be included in the decision-making process to guarantee a sustainable performance during the infrastructure's life cycle (Montalbán-Domingo et al. 2018).

In response to these challenges, universities are preparing future engineers to shoulder professional responsibilities in an exemplary manner. Higher education institutions from around the world are involved in promoting sustainability in various ways (Shephard 2008). Tilbury et al. (2005) point out that universities should integrate environmental knowledge into existing courses and Valdes-Vasquez (2013) emphasized the importance of increasing the awareness about social sustainability. These authors also claim that sustainability education involves training individuals in making informed decisions and creating ways to work towards a more sustainable world. Similarly, Dancz et al. (2018) point out that sustainability education requires the integration of practical, hands-on activities within courses. Therefore, this training should aim not only for knowledge acquisition, but also for skill and competence development in sustainable behavior and actions.

As Dancz et al. (2018) showed, one way to integrate sustainability into engineering curricula is to include modules that improve student cognition and perceptions of sustainability. Additionally, it is important to use the principles of active learning to achieve stronger learning outcomes and development for students (El-Adaway et al. 2015). In this sense, active learning in which students generate rules, procedures, and guiding principles by solving a problem or case is a preferable alternative for engineering education (Prince and Felder 2006). The problem-based learning (PBL) model has been used to improve student skills since its original development (Barrows and Tamblyn 1980). This active learning induces students to analyze and confront real, ill-structured and complex problems (Prince and Felder 2006; Thomas 2000). Students gain confidence in their own learning abilities by solving problems similar to those encountered by engineers in their professional life (El-Adaway et al. 2015).

The five themes of problem-based learning highlighted by Steinemann (2003)—applicability, problem solving, active learning, motivation, and professional skills—are in line with the objective of teaching sustainable decision-making, as it aims to encourage students to apply sustainable criteria for solving real professional problems. This has encouraged an increasing number of engineering programs to incorporate PBL into their traditional courses. Lehmann et al. (2008) point out that problem-oriented learning facilitates the handling of sustainability-related problems by engineers. Steinemann (2003) proposed a course based on PBL to acquire critical cognitive and professional skills related to sustainable urban development. Pellicer et al. (2016) applied an active-learning method to teach students how to take infrastructure sustainability into account in decision-making. Brundiers and Wiek (2013) also agreed that PBL courses are powerful educational settings for building students' sustainability expertise.

This paper proposes a module of PBL activities in which students solve an ill-structured problem integrating sustainability and decision-making concepts. Even sustainability concepts have been implemented in engineering studies (Dancz et al. 2018; Pellicer et al. 2016; Shephard 2008; Steinemann 2003; Tilbury et al. 2005), multi-criteria decision-making methods are necessary to allow individuals to select a more precise rational solution, taking into account the trade-offs that inevitably exist between the various candidate solutions regarding sustainability goals (García-Segura et al., 2018; Zavadskas et al., 2018). This module contributes to advance knowledge in sustainability and decision-making education, as students use the last decision-making techniques to formulate a decision-making problem and decide the importance of sustainability criteria according to the context. This approach also involves students in a real workplace context to develop a better capacity for reflecting and creating knowledge while at the same time raising awareness about the importance of sustainability. The module is intended to be employed in engineering education as training in determining the most sustainable solution to a real problem. As an example, this proposal is applied in a project management course to simulate a public procurement process in which students are asked to select the best construction company to carry out a highway construction project based on sustainability criteria.

The features and the activities of the proposed module are described in Section 2. Then, Section 3 presents the module's practical implementation, divided into presentation, problem formulation, student grouping, group decision-making and final discussion. The module is assessed by evaluating student performance and perception (Section 4). Finally, the main conclusions and recommendations are respectively presented in Sections 5 and 6.

2. Module description

This module aims to develop students' skills in decision-making and sustainable practices. The learning objectives are four: (1) to design a decision-making layout, (2) to decide the importance of sustainability criteria in the tendering procedure according to the context and consequences, (3) to defend the sustainable priorities, and (4) to reflect about the consequences of their opinions. The first two objectives are evaluated through the rubric using a report as evidence. The report summarizes the results of the activities. The third and fourth objectives are assessed by observing the discussion activity.

For this purpose, five groups of activities are proposed (Fig. 1): presentation, problem formulation, student grouping, group decision-making and final discussion. With the exception of student grouping, these activities correspond to those of a standard decision-making process. In real-world problems, differences in willingness and perception among people affect their capability to reach consensus (Bañuelas and Antony 2007; García-Segura et al. 2018). In this sense, random grouping can make the decision-making process more difficult and lead to deviations from the objective. This module proposes an intermediate activity to create homogenous groups according to their opinions. Therefore, this activity allows students to identify their sustainability priorities and analyze the consequences of their opinions. A final activity is proposed to discuss the decision-making results and the effects of their judgments. In addition, a sensitivity study is proposed to examine the importance of the context.

The module includes activity instructions, lecture slides, class discussion, individual and group analysis, surveys, homework, and instructor analysis. The PBL activities are designed to promote the advantages and address the limitations identified by Wood (2004). The decision-making resolution and the description and valuation of sustainability criteria are carried out in several activities, as re-using knowledge reinforces the processes of remembering (Wood 2004). The final discussion is proposed as an independent activity to encourage the reflection needed to conclude the learning process. Regarding the limitations (Wood 2004), some slides presenting activity concepts, such as sustainability criteria and decision-making techniques, are used to avoid student rejection for being in a system they are not familiar with (Forcael et al. 2015). In addition, the module is applied to a course with a reduced number of students to keep the PBL activities manageable for the instructor. It is worth noting that, during all of the activities, the instructor acts as a facilitator and coordinator of activities and the students become the active agents in the learning process.

1) **Presentation.** The first activity consists of presenting the activity instructions. The objectives and the problem that students must solve during the module are explained. Next, the instructor explains some activity concepts needed to solve the problem through slides. Then, students brainstorm economic, environmental and social criteria that could be applied for the decision-making problem and propose a list. Afterwards, the instructor suggests diverse decision-making techniques, like Analytical Hierarchy Process (AHP) (Saaty 1987), Vlse VlseKriterijuska Optimizacija I Komoromisno Resenje) (VIKOR) (Opricovic 1998), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Hwang and Yoon 1981) and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) (Brans et al. 1986). The instructor explains the drawbacks of the

decision-making techniques, and the students discuss the convenience of each technique. Information regarding the use of each technique can be obtained in the study of Penadés-Plà et al (2016) and Jato-Espino et al. (2014).

2) Problem formulation. The decision-making problem is formed by the criteria, the indicators and the metrics with which to assess a group of alternatives (Fig. S1). Sustainability indicators show how each sustainability criterion is evaluated, and the metrics indicate the unit of measure of each indicator. Once the problem is defined, the alternatives are evaluated according to the metrics associated with each indicator. To formulate the problem, students are asked to select social, environmental and economic criteria from the list generated in the previous step and propose associated indicators and metrics. They should analyze and discuss the importance of the criteria. If no consensus is reached, the students are asked to fill out a survey to select the three most important criteria. Then, they must propose a well-defined indicator and a metric for each indicator in order to evaluate the criteria objectively. The survey is analyzed by the students to form the decision-making scheme. Finally, the alternatives must have a value for each indicator. These values can be provided by the instructor or decided by the students in groups.

3) Student grouping. This activity consists in grouping students according to their sustainability priorities. Students evaluate the weights of the criteria individually according to the chosen decision-making technique. Afterwards, a cluster analysis is performed to create affine groups. Cluster analysis is a widely used methodology to partition a set of individuals into homogenous clusters based on similarity of priorities (Kamis et al. 2018). This analysis identifies the points of view according to the distances between their priorities (Lee et al. 2014; Pellicer et al. 2016). Their opinions are examined using a cluster analysis based on Ward's (1963) method. This method is used to produce groups by minimizing within-group dispersion. Ward's (1963) method evaluates the intra-group variation using the sum of squared errors as the criterion. The cluster analysis is drawn both to inform students about their sustainability priorities and to create homogenous groups to carry out the next steps.

4) **Group decision-making.** Each group is asked to select the best alternative through the decision-making scheme. The affine groups are expected to reach consensus regarding the importance of the criteria to achieve the sustainability goal. First, the affine groups evaluate the weights of the criteria by providing consensus opinions. Second, they use the weights and the values of each alternative to prioritize the alternatives and select the best one.

5) **Final discussion**. A final round of discussion is planned to debate the importance of the context, the perceptions of sustainability and the consequences of decision-making. For the debate on the context, a sensitivity analysis is conducted, and students are asked to reconsider their prioritization in a particular situation.

3. Practical implementation

The module was implemented in a Project Management course for the Master in Planning and Management in Civil Engineering at Universitat Politècnica de València (Spain). In this course, students learned about the planning, organization, direction and control of projects. One of the goals of this course was to acquire decision-making competencies to manage civil engineering projects. Many of the students may work as public agency staff, private promoters, consulting engineers or constructors. Within their professional functions, one task may be to plan or participate in a procurement process. Thus, the proposed problem focused on engaging students to integrate sustainability award criteria into the construction industry through a more effective public procurement process. Students must assume a public role to design a sustainable decision layout for selecting the most sustainable construction company.

During the 2017–2018 academic year, 39 students were enrolled in this course. All of the students were graduates in Civil Engineering. Their ages varied between 22 and 35 years, while most were less than 28 years old. Apart from Spain, students came from 12 different countries of Europe and Central and South America. The highest percentage of students came from Ecuador (11 students), followed by equal percentages from Spain, France and Peru (5 students), Norway (3 students), and Colombia and Mexico (2 students). As the students had similar backgrounds but came from different countries and universities, it was expected that they may have similar knowledge but different skills. Note that these students worked individually and in groups through the development of the activities.

3.1. Problem presentation.

The problem proposed corresponds to the tender process for construction of a highway in which sustainable development was a priority. The highway connected the Northern neighborhoods with the historic city center of Alcoy (Spain) (see Fig. S2). Students were asked to design a decision-making layout for a procurement process to select the best construction company with the goal of achieving the most sustainable performance. Students analyzed the problem and proposed sustainability criteria that were included in the decision-making layout. Social (Table 1), environmental (Table 2) and economic criteria (Table 3), as well as their definitions, were proposed.

Finally, the instructor explained diverse decision-making techniques and the advantages of each technique. Students considered that the most convenient technique is AHP (Saaty 1987). AHP is a simple decision-making tool for addressing complex and multi-attributed problems (Güngör et al. 2009). The main characteristic of this technique is the hierarchical structure of the problem formulation. Sustainable decision-making problems follow a hierarchical structure (e.g., sustainable goal, criteria, sub-criteria and indicators), which makes this technique suitable for this type of problem (Gervásio and Simões da Silva 2012). A pairwise comparison matrix is obtained for each comparison level (Table S1). The bottom layer (indicators) is compared in pairs according to their importance to achieve the higher level (sub-criteria). The verbal scale of each judgment has a numerical equivalent on a scale of 1-9. These values form a pairwise comparison matrix of ($m_x m$), where m is the number of elements compared. This matrix is accepted after validating the consistency of the judgments. The local weights (w_j) are obtained by the eigenvector method. The indicator weights are calculated by combining the local weights with respect to all hierarchical levels.

3.2. Problem formulation

During this phase, students selected the criteria, indicators with metrics and the alternatives. In this case, students agreed that the most important economic criteria were the cost and the duration. However, they did not reach consensus about the social and environmental criteria to be included in the tender process. Therefore, students were asked to select the three most important social and environmental criteria through a survey. Additionally, they proposed a well-defined indicator and a metric associated with each criterion in order to evaluate the criteria objectively. Afterwards, the survey was analyzed by the students to select the environmental and social criteria that form the decision-making model.

The results of the survey are presented in Figs. 2 and 3. From the list of social and environmental criteria, the three social criteria and five environmental criteria with the largest percentages were retained for the model. Employment, local participation, and health and safety were the three most-selected social criteria. Employment was chosen by 70.27% of the students, while local participation and safety and health were selected by 54.04% and 45.95% of students, respectively. Comparing these results with the literature, health and safety and employment are frequently included in tender processes. However, local participation is omitted from most tenders, especially when the contract size is over 10M€ (Montalbán-Domingo et al. 2018). Regarding environmental criteria, water and waste were selected by more than 50% of the students. Materials (43.24%), energy (40.54%) and flora and fauna (37.84%), were all selected as they only differed by one vote. Therefore, these five environmental criteria were selected as the most representative to achieve environmental sustainability. Ruparathna and Hewage (2015) also observed that water and waste were among the environmental criteria most frequently considered in a procurement process. In contrast, Testa et al. (2016) noted that tenders focused primarily on energy consumption and recycled material. Concerning the economic indicators, the students selected the price and duration criteria as important by consensus. These criteria are commonly used for the selection process of design-builders (Xia et al. 2013; Molenaar and Gransberg 2001).

Students provided an indicator for each criterion. Fig. 4 shows the most popular indicators and metrics associated with each criterion. Concerning the social criteria, a greater number of indicators were assigned to employment and local participation. The indicators associated with employment evaluate the number of new contracts due to the construction, the percentage of people with disabilities, and the percentage of workers with age under 30 years. Surprisingly, the students' perception coincides with the current demand to include the employment of vulnerable groups in social goals (Montalbán-Domingo et al. 2018). For local participation, the indicators measure the percentage of contracted companies that are local during the execution of the project and the percentage of local workers. With regard to environmental criteria, health and safety is evaluated as the percentage of the budget allocated to protection measures. Most of the students agreed that the environmental criteria must be measured by indicators that evaluate the percentage of the reduction of the environmental impact, except for the water and flora and fauna criteria, which considered respectively the level of pollution control for the hydrological system and the percentage of the budget assigned to environmental management and protection. For the economic criteria, the lowest price and the shortest construction duration were selected for the price and duration criteria.

During this last phase, the alternative companies were proposed, having different propositions regarding the sustainability criteria. In this case, it was decided that students would provide different alternatives in order to gather different company profiles. The objective of this practical application was to promote sustainable practices in a public procurement process. Therefore, the instructor asked groups of four to propose a value for each indicator assuming a sustainable role for a specific company. They analyzed each indicator and provided a value depending on their role: social sustainability promotion, environmental sustainability promotion, economic sustainability promotion or three-pillar balance. Table 4 shows the ten companies proposed by the students to participate in the tendering process.

3.3. Student grouping

Once the decision-making scheme was established, students evaluated the relative importance of the indicators individually through the AHP technique. The multicriteria decision was represented by the hierarchical model of goal, criteria, sub-criteria and indicators, as Fig. 4 depicts. Then, the cluster analysis provided a dendrogram (Fig. 5) that divided the students into clusters according to the correlation of their opinions. Groups were formed by joining students according to common nodes. Then, large groups were divided and individual cluster members were joined to the most affined groups to create groups between 3 and 5 members. Fig. 5 shows that eight general profiles were determined. While 56% of the students prioritized the economic criteria, 21% and 23%, respectively, gave greater importance to the social and environmental pillars. These findings are in line with previous research, as the majority of studies focused on the environmental aspects rather than the social ones (Abdel-Raheem and Ramsbottom 2016; Ruparathna and Hewage 2015). Three profiles prioritized social sustainability, although with differences in the sub-criteria. These three profiles formed two groups. Just one student gave greater importance to social criteria, especially local participation. This student decided to join group 2 by affinity. Two groups underlined the importance of the environmental pillar with either an economic or a social trend. Finally, five groups were formed that prioritized the economic criteria, but they did not agree on the relative importance of project cost and duration.

3.4. Group decision-making

Each affine group selected the best construction company to carry out a sustainable highway construction project. The members were expected to reach consensus regarding the importance of the criteria. As a group, they valued the importance of the indicators following the AHP method. The weights obtained were applied to each indicator to rank the construction companies and select the best one. Table 5 shows the results of the decision-making. Group 1 selected company G, which was very good at employment and had a good balance of meeting environmental and economic criteria. Group 2 determined that the best company was J, which especially promotes social criteria, particularly health and safety, but without disregarding the environmental and economic aspects. Group 3 chose company H, which had a very good environmental and economic proposal, but scored weakly for the social criteria. Group 4, on the other hand, selected company E, which, as mentioned previously, opted to promote environmental measures without overlooking the other two pillars. Groups 5-10 considered the economic criteria to be most important, and they chose companies D and H. Company D (chosen by groups 5, 8 and 9) had the best proposal based on the economic criteria, but presented bad social and environmental conditions. Company H (chosen by groups 6, 7 and 10) did not score as well with respect to price and time as company D, but it presented a good environmental proposal. Comparing the results with the cluster analysis, it is worth noting that minor changes between individual and group opinions were detected. Despite the individual students in groups 5-9 apparently disagreeing about the relative importance of price and duration, when they decided in groups, the major differences among groups were observed with respect to the environmental criteria.

3.5. Final discussion

During the class discussion, students argued their opinions. They realized that after carrying out the module activities, they were better able to express their priorities. The activities assisted them in understanding their point of view with respect to sustainability. Therefore, as Pellicer et al. (2016) pointed out, the cluster analysis was suitable for identifying the profiles of students with respect to their prioritization of the sustainability criteria. They also reflected on the consequences of their opinions and the sustainable performance of each company. Thus, the instructor concluded that third and fourth learning objectives (Section 2) were achieved.

Regarding the sensitivity analysis, the added context was that the decision-making is carried out for infrastructure that is located close to a unique natural place. The results of this particular case are shown in Table 5. In this case, just companies E and H, which had the best environmental proposal, were selected. However, company E opted to balance social and economic aspects, while company H weakened the social criteria at the expense of improving the economic ones. Groups 1 and 2 selected company E, as they prioritized the social pillar. Interestingly, groups 3 and 4 exchanged the companies. Group 3 gave more weight to the social criteria because they considered that as the work would be developed in a rural area, job creation and local participation needed further consideration. Conversely, group 4 reduced the importance of social aspects in favor of the economic criteria because they accorded greater importance to the price and duration. Finally, as might be expected, groups 5-10 selected company H, as they gave more importance to economic aspects.

As a conclusion, it is highlighted that the decision-making was strongly influenced by the sustainable profile of the students. However, it was observed that opinions can be slightly changed after group creation. It is also very important to highlight the drastic reduction of the variability in the decision results when the highway is located in a particular place, such as near a natural area.

4. Module assessment

The module assessment was evaluated based on the students' performance and perceptions. These techniques were also used by other authors (Dancz et al. 2018; El-Adaway et al. 2015; Li and Daher 2017) to verify learning outcomes. Student performance was assessed using a rubric, based on a report presented by each group of students. The report summarized the results of the activities. The rubric assessed the first two learning objectives (Section 2): decision-making implementation and sustainability analysis. Table 6 summarizes the rubric. It is worth noting that the learning outcomes corresponded to high cognitive levels. Results were expressed as the percentage of groups that achieved each grade. Fig. 6 shows that most of the groups achieved a B grade in both learning outcomes. Mistakes committed in the decision-making resolution were minor. Note that most of the students had never used a decision-making technique before. Regarding sustainability analysis, all students discussed the context and consequences. However, just 30% of the groups reached a high level of debate. As El-Adaway et al. (2015) noted, students perform better with more structure and guidance from the instructor.

Student perception was evaluated through a survey. Students were asked to provide their opinion about the usefulness of the activity for acquiring competencies in decision-making and implementing a sustainable procurement process. The Likert scale questionnaire contained three questions:

- Q1: These activities have helped me to acquire competence in decision-making
- Q2: These activities have helped me to increase my awareness about the importance of sustainable practices in a public procurement process
- Q3: In general, I consider that these activities have favored my learning outcomes

Table 7 summarizes the answers to these questions. Most of the students agreed that the activity helped them to acquire competence in decision-making (average = 4.33, standard deviation = 0.53). Regarding sustainability awareness, while "agree" was the most-selected answer, 22.2% of the students were neutral and 8.3% disagreed. These outcomes reveal that these activities are helpful for acquiring competence in decision-making and for increasing awareness about the importance of sustainable practices in a public procurement process. However, some students think that they need more activities to develop their thinking related to sustainability. The Q3 answers showed that 94.5% of students agree or strongly agree that this activity favored their learning outcomes. This confirms that PBL provides a motivating context for acquiring practical problem-solving skills (Steinemann 2003). This approach is conducive to discussing, understanding and making decisions about sustainable development (Lehmann et al. 2008). Therefore, it could be said that this learning method has been widely accepted as a good methodology for achieving competencies related to both decision-making and sustainable thinking.

5. Conclusions

This paper presents a module to promote decision-making and sustainability skills in engineering education. The proposed framework describes the PBL activities and the learning methodologies to reinforce the development of skills. The module was implemented in a Project Management course to simulate a procurement process in which students assume a public role to design a sustainable decision scheme. Students selected the best construction company by analyzing the case, discussing the sustainability criteria and solving the decision-making scheme. A cluster analysis grouped the students according to their priorities for further analysis of their sustainability priorities and the consequences of their opinions. While most of the students assigned greater importance to the economic criteria, 21% and 23% of the students underlined, respectively, the importance of the social and environmental pillars. These findings are in line with most of the research that prioritizes environmental aspects rather than the social ones.

The results indicated that the activities promoted reflection and awareness about the sustainability priorities of the students. Although the decision-making was strongly influenced by the sustainability profiles of the students, the entire group decided to focus on the environmental aspects of construction when a particular case of a nearby natural area was suggested. The module was assessed based on student performance, using a rubric, and student perception, using a survey. The outcomes obtained showed that most of the students developed higher-order cognitive skills in decision-making and sustainability. In addition, the survey revealed that 94.5% of the students agree or strongly agree that the activities favored their learning outcomes. Therefore, this study demonstrates that incorporating active strategies in engineering education can motivate students to construct new strategies supporting efficient decisions that contribute towards the sustainable performance of infrastructure.

6. Recommendations

This module could be applied in other engineering programs to prepare future decision-makers in formulating and developing new sustainability challenges. Both decision-making and sustainability skills have a multidisciplinary nature as well as the potential to be useful when facing real engineering problems. It is recommended to follow the order of the activities: presentation, problem formulation, student grouping, group decision-making, and final discussion. Regarding presentation, although the instructor can modify the module's configuration according to their needs, the activity instructions and lecture slides are recommended to improve student comprehension. For problem formulation, the criteria and indicators must be defined according to the particular sustainable decision-making objective. That is, they must evaluate the economic, environmental, and social characteristics of the alternatives to achieve the final goal of selecting the most sustainable alternative. Finally, discussion is also important to foster student reflection. A heterogeneous group discussion could be added to develop consensus skills. It is worth noting that activities can be adapted to develop other specific skills for the course.

7. Limitations and challenges

The authors have established some limitations related to the implementation of the module to the case study. The module has been integrated into one class of a Project Management course for a Master's in Planning and Management in Civil Engineering program. As results could be conditioned by the level of knowledge and background of students, future research aims to implement the module into undergraduate studies in civil engineering to improve student skills and awareness in sustainable practices and decision-making from early stages of engineering education and to evaluate the cognitive level of the outcomes. Regarding the scope, this study is limited to one case study. Increasing the duration of the module, several cases studies could be carried out to foster the critical thinking of sustainable decision-making in different contexts.

On the other hand, some challenges can be highlighted. When students came from different countries, there is a risk that sustainability concepts differ from one country to another. In this sense, an explanation of the sustainability concepts and the objective of the sustainable decision-making is essential during the presentation. Furthermore, the case study should be selected to offer a range of possible opinions regarding the sustainability priorities. Results showed a reduction in the decision-making variability when the context changed to a particular case of a nearby natural area. Finally, the discussion activity must be planned to ensure that all the students have the opportunity to express their perceptions of sustainability and the consequences of their opinions on the sustainable performance.

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Supplemental Materials

Figs. S1 and S2 and Table S1 are available online in the ASCE Library (ascelibrary.org).

Data Availability Statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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Table 1. Social criteria

Cultural heritage	Considers actions that favor the protection of cultural heritage in the area where the project will be developed.
Employment	Focuses on aspects related to job creation, also considering persons who are vulnerable or under conditions of social exclusion.
Health and Safety	Seeks to incorporate measures and activities necessary for the prevention of work-related risks and guaranteeing the safety of workers and indirect persons
Training	Aims to increase the level of knowledge of workers in technical and/or sustainability-related issues
Impact on Users	Includes those actions aimed at minimizing the possible inconvenience that the population may experience due to the development of the project (mobility, services, etc.)
Local participation	Seeks to promote local entities and entrepreneurial initiatives that favor local development
Public participation	Focuses on the inclusion of public opinion in decision making
Professional ethics	Concentrates on anti-corruption policies, practices of non-discrimination in hiring processes, fair working conditions, etc.

Table 2. Environmental criteria

Energy	Favors the responsible consumption of energy by controlling its use and/or reducing its environmental impact
Emissions	Favors the control and minimization of pollutant emissions
Waste	Aims to minimize and properly manage waste
Water	Focuses on the protection of the hydrological system and water quality
Flora and fauna	Seeks to protect the vegetation and faunal species
Management	Considers the implementation of environmental management and monitoring systems to control the project's performance
Materials	Concentrates on minimizing the consumption of raw materials and increasing the use of recycled or environmentally friendly materials
Landscape	Seeks minimization of the project’s impact on its surroundings and its integration into the landscape
Noise and vibration	Focuses on the control and minimization of noise and vibrations

Table 3. Economic criteria

Cost	Evaluates the cost of construction
Duration	Focuses on the duration of construction

Table 4. Indicators of the construction companies

	CONSTRUCTION COMPANIES									
INDICATORS	A	B	C	D	E	F	G	H	I	J
Number of new contracts (n)	0	10	10	0	8	10	10	0	8	10
Percentage of people with disabilities (%)	0	5	5	0	4	5	5	0	4	5
Percentage of workers with an age under 30 years (%)	0	0	5	0	3	5	5	0	2	5
Percentage of local contracted companies during the execution of the project (%)	0	50	50	0	25	50	50	0	20	50
Percentage of local workers (%)	0	0	20	0	15	20	20	0	10	20
Protection measures related to health and safety (% of the budget)	20	20	20	0	15	10	10	5	5	20
Maximum level of the hydrological pollution control system (maximum level)[a]	L	L	L	L	H	H	H	H	M	M
Percentage of waste reused (%)	0	50	0	0	50	50	40	50	25	20
Proposals for energy consumption reduction (% of reduction)	0	0	0	0	40	40	20	40	20	15
Plans for the management and protection of vegetation and animal species (% of the budget)	0	0	0	0	20	20	10	20	10	5
Percentage of resources from recycled materials (%)	0	20	0	0	50	50	25	50	20	10
Lowest price (millions of €)	4.7	5.5	5.5	4.0	6.9	8.1	6.0	4.9	6.0	5.5
Reduction in project duration (days)	90	90	90	110	50	0	80	90	60	45

[a]L=low, M=medium, H=high

Table 5. Results of the decision-making

Group	1	2	3	4	5	6	7	8	9	10
Case study	G	J	H	E	D	H	H	D	D	H
Natural area	E	E	E	H	H	H	H	H	H	H

Table 6. Rubric for student performance evaluation

Grade	Decision-making implementation	Sustainability analysis
A	Construct a decision layout, solve the problem and verify the results	Define the importance of sustainability criteria in the tendering procedure according to the context and consequences
B	Construct a decision layout, solve the problem with minor mistakes and verify the results	Define the importance of sustainability criteria in the tendering procedure but do not reach a high level of debate on the context and consequences
C	Construct a decision layout, solve the problem with minor mistakes, but do not verify the results	Define the importance of sustainability criteria in the tendering procedure but do not discuss the context and consequences
D	Do not properly construct a decision layout or do not correctly solve the problem and do not verify the results	Do not define the importance of sustainability criteria in the tendering procedure

Table 7. Student perception. Answers to the survey questions

Question	Strongly agree (5)	Agree (4)	Neither agree or disagree (3)	Disagree (2)	Strongly disagree (1)	Mean	Standard deviation
Q1	36.1%	61.1%	2.8%	0	0	4.33	0.54
Q2	22.3%	47.2%	22.2%	8.3%	0	3.83	0.89
Q3	63.9%	30.6%	5.5%	0	0	4.58	0.6

Note: Q1: These activities have helped me to acquire competence in decision-making.
Q2: These activities have helped me to increase my awareness about the importance of sustainable practices in a public procurement process.
Q3: In general, I consider that these activities have favored my learning outcomes