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Evaluation of Higher Education Students' Critical Thinking Skills on Sustainability*

IGNACIO J. NAVARRO
Department of Construction Engineering, Universitat Politècnica de València, 46022 València, Spain.
E-mail: ignamar1@upvnet.upv.es

JOSÉ V. MARTÍ
Institute of Concrete Science and Technology (ICITECH), Universitat Politècnica de València,46022 València, Spain.
E-mail: jvmartia@cst.upv.es

VÍCTOR YEPES**
Institute of Concrete Science and Technology (ICITECH), Universitat Politècnica de València,46022 València, Spain.
E-mail: vyepesp@cst.upv.es

Construction-related enterprises are acknowledged as one of the key actors responsible for shifting society toward the sustainable future claimed by the recently established Sustainable Development Goals. However, university curricula need to emphasize guaranteeing the acquisition of transversal competencies that are essential for the future management professionals required by this new challenge. Consistent and critical thinking is considered a fundamental skill for education in sustainability. To date, no studies have presented an objective measure of the level of acquisition of such transverse skills in university curricula. This study provides an analytical tool to that end, based on the multi-criteria decision-making technique Analytic Hierarchy Process (AHP). Through sustainability-oriented case studies, students are faced with real managerial decision-making problems. The proposed method allows for the analytic quantification of the consistency of their responses. Such consistency is representative of their critical thinking skills. The proposed tool allows teachers not only to find the consistency of their students' responses but also to understand in which areas of sustainability students lack a clear vision of the problem. This tool is therefore useful for teachers to effectively adapt their syllabi according to their students' knowledge.

Keywords: sustainable education; transversal competence; critical thinking; management; consistency

1. Introduction

In 2015, the United Nations unanimously adopted the document "Transforming our World: The 2030 Agenda for Sustainable Development" [1], an agreement that aims to lay the foundations for the development of a global society oriented towards achieving a better future by 2030. One of the key elements of this Agenda is the establishment of the 17 Sustainable Development Goals (SDGs), a set of objectives focused on addressing the most urgent global problems: protecting the environment and the degradation resulting from climate change, eradicating hunger and poverty in all its forms, ensuring a state of social well-being and prosperity, or promoting just and free societies, among others. These SDGs aim to maintain the momentum generated by the Millennium Development Goals and to shape a new sustainability-oriented framework beyond 2030. Although not legally binding, SDGs are expected to have a major impact on governments' strategic decisions in the coming years.

It is widely recognized that universities have a key role in achieving the sustainable future we all aspire to through the SDGs [2]. On the one hand, universities concentrate an extensive portion of the research capacity of the countries. They can provide the knowledge, innovations, and solutions needed to solve the challenges posed by the 2030 Agenda [3]. On the other hand, and because of the above, universities are expected to transmit the results of their research to their students [4]. Universities should provide students with an education that goes beyond the traditional curricula [5–7]. These institutions are, therefore, responsible for training future professionals with the capacity to adequately address the recent and complex economic, environmental, and social challenges posed by the 2030 Agenda [8].

To formulate the appropriate solutions, the challenges to be solved need to be properly understood. This requires, in the context of achieving the SDGs, a strong focus on the development of transversal competencies in university curricula [9, 10]. The development of this type of competencies is particularly relevant for management and technical profiles related to the construction sector. The 2030 Agenda has emphasized the role of infrastructures in the sustainable development of our society, as the construction sector is responsible for a

** Corresponding author.

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significant amount of economic expenditures and environmental impacts [11]. The mitigation of those impacts could extraordinarily contribute to achieving the sustainable future for which we all aim.

However, the transformation of a sector with such momentum can only occur through a sincere and profound transformation of the businesses leading it [12]. The management of construction enterprises focused on sustainable practices and results shall be the central actor that shifts our society towards achieving the recently established SDGs [13]. Consequently, students who aspire to manage enterprises in the construction sector, in addition to being required to acquire transversal skills such as critical thinking, systemic thinking, self-awareness, social responsibility, and normative competencies, are now explicitly required through SDG #9 to build sustainable infrastructures through responsible and conscious management of construction-related companies.

In line with the above, sustainability requires present and future managers to be aware of the economic, environmental, and social consequences that their infrastructures have on the environment along their life cycle, as well as to understand the complex relations existing between these impacts and to quantify them in a substantiated basis. Although the design of sustainable infrastructures has been in the spotlight for many researchers in recent years [14–16], the university education system still requires a major transformation to acquire the necessary transversal competencies oriented towards this end.

The 2030 Agenda calls for the urgent training of future professionals involved in sustainable development, capable of understanding and consistently managing the impacts their decisions have on the environment, society, and the economy. Consistent thinking, besides reflecting a deep understanding of a problem, is one of the essential skills needed to develop critical thinking [17], which, in turn, is one of the transversal competencies considered fundamental to be taught in education for sustainable development [18]. Coherence of thought is also a fundamental pillar for other essential transversal competencies for the development of SDG-aligned professionals: decision-making, the ability to foresee alternative future scenarios, as well as the ability to identify the complex connections that exist between the environmental, social, and economic dimensions of sustainability [19, 20].

Over the last few years, and as a consequence of the above, evaluating the degree of acquisition of the abovementioned transversal competencies has become a strategic objective for many universities [21]. The assessment of competencies is, however, a complex task since there is no consensus on what skills comprise them and, therefore, what skills need to be assessed [22]. On the other hand, teachers are usually assumed to be able to correctly assess certain competencies, although this is not always evident at all. In this sense, some authors recommend having students as evaluators of their own or their peers' skills, thus increasing their critical thinking ability, as well as fostering autonomous learning through metacognition and reflection [23]. However, the reliability of such type of assessments depends to a large extent on the objectivity and reliability of the learner's own judgments [24], thus leaving the exposed gap in the evaluation of transversal competencies still unresolved.

In the absence of objective criteria for the evaluation of the transversal competencies that lead to these SDG-driving profiles, this paper proposes a case study-based methodology for objectively assessing students' ability to make consistent judgments in the field of sustainable design, providing a powerful tool to bridge the existing knowledge gaps in the assessment of the abovementioned transversal competencies. This evaluation technique takes advantage of the well-known problem-based learning pedagogies, thus being simultaneously a learning tool to integrate sustainable development in education through active debate and analysis [25]. In addition, the proposed technique allows teachers to identify the specific areas of sustainability that individual students lack understanding, thus providing an interesting tool to help teachers understand which aspects of their syllabus to emphasize.

The rest of the paper is structured as follows. First, the fundaments of the suggested evaluation technique are presented. Then, a particular case study is presented, which will serve as the basis to show the advantages and applications of the proposed methodology. Then, the specific consistency results are described and discussed. At last, conclusions are drawn on the applicability of the methodology for assessing students' critical thinking competence. The main limitations of this study, as well as the future lines of research, are outlined there.

2. Materials and Methods

The construction of sustainable infrastructures demanded by the ninth SDG can be addressed as a decision-making problem, where several economic, social, and environmental criteria will affect the final design decision. The proposed innovation assesses students' transversal competencies linked to achieving the SDGs through case studies related to sustainable decision-making. In these exercises, students are encouraged to make a comparative paired analysis of the criteria involved in the proposed decision-making problems, which is the basis of the so-called Analytic Hierarchy Process (AHP). This paper proposes its application to mathematically determine objectively the consistency of their judgments and, consequently, the clarity with which they can confront and perceive the problem. Although the case study presented here is oriented to sustainability, the methodology applies to any matter where a student's critical thinking ability needs to be evaluated.

2.1 Assessment of Critical Thinking Through Paired Comparison

When making managerial decisions in a sustainability-oriented construction company, the decision maker needs to understand and bear in mind properly the life cycle economic, environmental, and social consequences of constructing and maintaining infrastructures [26]. In general, when making a decision where a decision maker has to choose between different alternatives which one better satisfies his/her needs, the first step consists in defining clearly the criteria on which he/she will base the decision.

The so-called Multi-criteria Decision-making methods are intended to assist in making complex decisions based on more than one criterion. Such methods allow finding, between different alternatives, the one that best fits the criteria that define the decision problem. A common step in almost all of these methods is the assignment of weights to each criterion. The Analytical Hierarchical Process is a methodology developed by Saaty [27] and applicable to complex multi-criteria decision problems. This process determines the subjective and relative importance of each criterion involved in the decision process to resolve a particular problem [28].

To do this, the method requires the decision maker to compare pairwise the criteria considered influential in the decision-making process, indicating how important he/she considers each criterion to be concerning each of the remaining criteria. This comparison of priorities is made using a numerical scale consisting of 18 values, the so-called Saaty's extended fundamental scale (Table 1), according to which a semantic value is matched to a mathematically manageable numerical value.

Using the fundamental scale, a square matrix A_{nxn} can be constructed, called the decision matrix, in which each element a_{ij} is assigned the numerical value that reflects the decision-maker's judgment in his comparison of criteria *i* and *j*. This matrix must be reciprocal, i.e., if $a_{ij} = x$, then $a_{ij} = 1/x$. From this matrix, the method allows obtaining the relevance of each criterion as the values of the eigenvector that correspond to the largest eigenvalue of the matrix (λ_{max}) [27].

For the weights to be valid, Saaty's method requires the decision matrix to be consistent, i.e., the judgments that the decision-maker has made when constructing the decision matrix must be consistent with each other. A direct mathematical consequence of such consistency is that $a_{ij} \text{ x } a_{jk} = a_{ik}$ $\forall$ *i*, *j*, *k*. The decision-making procedure used here establishes a procedure for calculating the Consistency Index *CI* of the decision matrix as $CI = (\lambda_{max} - n)/(n - 1)$, where *n* is the number of criteria considered.

The weights obtained will be considered valid as long as the so-called Consistency Ratio *CR* does not exceed the limit values shown in Table 2. The Consistency Ratio is calculated as $CR = CI/RI$, where *RI* indicates the consistency of a completely random *n* x *n* square matrix (Table 2).

If the Consistency Ratio *CR* is close to unity, this means that the judgments made by the decision-maker, and therefore the attribution of values to the elements a_{ij} of the decision matrix, have been completely random, reflecting zero knowledge of the problem to be solved. On the contrary, a low value for the Consistency Ratio indicates that the decision-maker has a clear view of the problem to be solved. Consequently, low values of *CR* reflect

Table 1. Saaty's extended fundamental scale [27]

Intensity of importance	Definition
1	Criterion *i* is as important as criterion *j*
3	Criterion *i* is slightly more important than criterion *j*
5	Criterion *i* is more important than criterion *j*
7	Criterion *i* is much more important than criterion *j*
9	Criterion *i* is extremely more important than criterion *j*
2, 4, 6, 8	Intermediate values to be used when compromise is needed
Reciprocal	Reciprocal values are used when criterion *i* is less important than criterion *j*

Table 2. *RI* values and limits for *CR* [27].

Number of criteria	Random index (RI)	Maximum allowable Consistency Ratio (CR_{lim})
2	0.00	0%
3	0.58	5%
4	0.90	9%
5	1.12	10%
6	1.24	10%
7	1.32	10%
8	1.41	10%
9	1.45	10%
10	1.49	10%

that the decision-maker has sufficiently developed critical thinking skills to be able to understand the complexity of the problem at hand and make coherent judgments about it. Thus, it is precisely the value obtained for *CR* and not the weights that could finally result after the application of the presented method, the mathematical concept capable of synthesizing the competence of the decision-maker solving the specific problem in question.

2.2 Consistency Evaluation through Sustainability-Based Case Studies

To find out the degree to which students acquire critical thinking skills throughout their sustainability training, we propose the use of case studies in which students are asked to face a real problem. A case-based approach has been previously followed in the recent literature to evaluate the students' critical thinking skills [29, 30]. By doing so, profit is taken from the active and participative learning through case study activities, as reported by Emblen-Perry [31]. In this case, 23 students of the master's degree in Planning and Management in Civil Engineering taught at Polytechnic University of Valencia (the academic year 2019/2020) were asked to participate in a sustainability-related case study. Given that the student profile of this master's degree is that of a Civil Engineer or Architect, they are faced with a problem directly related to the fulfillment of SDG #9: Design of Sustainable Infrastructures.

The case study is based on the research conducted by Navarro et al. [32], which formulates and analyses the criteria to be considered to assess the sustainability in the design of a transport infrastructure.

A simplified diagram of the consistency evaluation process presented here is shown in Fig. 1.

Specifically, the survey includes the comparison of nine criteria that are meant to measure the performance of an infrastructure design in terms of the three dimensions of sustainability, namely economy, environment, and society. Of the above-mentioned nine criteria, two are related to the economic dimension of sustainability. In this particular case, these criteria are the costs derived from the construction of the infrastructure on the one hand and the maintenance costs along the service life of the structure on the other. The effects that infrastructure might have on the environment along its life cycle can be measured in terms of three types of impacts. On the one hand, the consumption of construction materials directly impacts the scarcity of natural resources. On the other hand, the production processes of such materials generate emissions to the environment that can negatively affect the ecosystems and the health of humans. These are the three environmental criteria included in this case study: scarcity of resources, damage to ecosystems, and damage to human health.

At last, four criteria are chosen to reflect the impacts that the choice of particular construction material for infrastructure can have on society. First, the production of construction materials, as well as their installation and maintenance, will generate different amounts of employment, measured in terms of working hours, depending on the chosen material. In addition, the acquisition of different materials will imply economic benefits for different regions, depending on the location of the corresponding production centers. These two impacts measure positive effects on society. On the other hand, depending on the durability of each material that might be chosen for the construction of the infrastructure, the maintenance activities will take place with varying frequency,

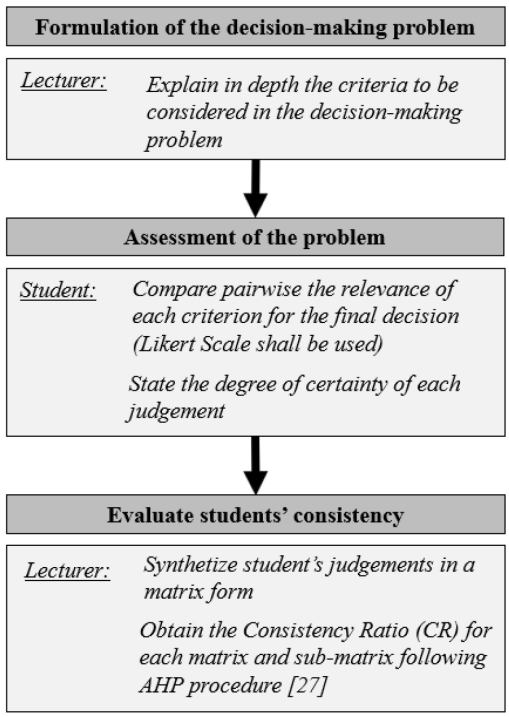

Fig. 1. Simplified overview of the procedure for the evaluation of consistency through case studies. First, the problem to be solved is clearly described to the students. It consists of choosing a construction material to design a concrete bridge in a marine environment so that its response over time is as sustainable as possible. After that, a detailed explanation is given regarding each of the criteria to be considered in the final decision-making, as well as the implications of each of them. Finally, through an online survey, students are asked to compare in a paired way the importance that, according to their experience, each criterion should have, concerning the rest in determining the sustainability of infrastructure. In addition, the respondent is asked to explicitly state the degree of certainty with which he/she has made each comparison paired comparison. For this particular purpose, the respondent is given the possibility to choose from the following five certainty degrees: None, Some, Moderate, Fair, or Total certainty.

Table 3. Relationship between Likert's scale chosen for the survey and Saaty's fundamental scale

Semantic term	Likert's scale values	Corresponding values from Saaty's fundamental scale
Criterion *i* is extremely less important than criterion *j*	1	1/8
Criterion *i* is much less important than criterion *j*	2	1/5
Criterion *i* is less important than criterion *j*	3	1/3
Criteria *i* and *j* are equally important	4	1
Criterion *i* is more important than criterion *j*	5	3
Criterion *i* is much more important than criterion *j*	6	5
Criterion *i* is extremely more important than criterion *j*	7	8

affecting negatively both the users of the infrastructure as well as the local communities. These two criteria, the affection for the users and the affection for public opinion, are the last two criteria for choosing a construction material considering sustainability.

It should be noted that, in the survey carried out, the student is not given the option of working directly with Saaty's fundamental scale when making the comparisons, given the complexity of the problem. For this study, it is sufficient to work with a reduced Likert scale of seven possible answers, as shown in Table 3. To apply the decision-making methodology presented above for determining the consistency of the students, the values of this reduced Likert scale are matched with particular values from Saaty's extended fundamental scale.

Once the comparison matrix is filled by each student using the online survey prepared for that purpose, the overall consistency can be obtained following the methodology described above. If the consistency is below the allowable consistency ratio presented in Table 2 for the corresponding number of criteria, the student is considered to have a clear vision of the problem, and their ability to think critically is out of any doubt. However, if the value of the *CR* is higher than the limiting *CR*, it is possible to evaluate the partial consistencies in his/her comparison matrix to identify where the student is missing clarity.

In a comparison matrix where sustainability criteria are involved, these can be sorted depending on which dimension of sustainability they refer to (Fig. 2). So, different dimension-related submatrices can be extracted from the original comparison matrix. In this case, where two economic, three environmental, and four social criteria were defined, submatrices can be extracted to evaluate the connections assigned by the student between criteria associated with two dimensions: a 5x5 economic-environmental submatrix, a 7x7 environmental-social submatrix, and a 6x6 socio-economic submatrix. Given that the original matrix is square and reciprocal, these submatrices will also retain these properties. Their respective *CR* values can be

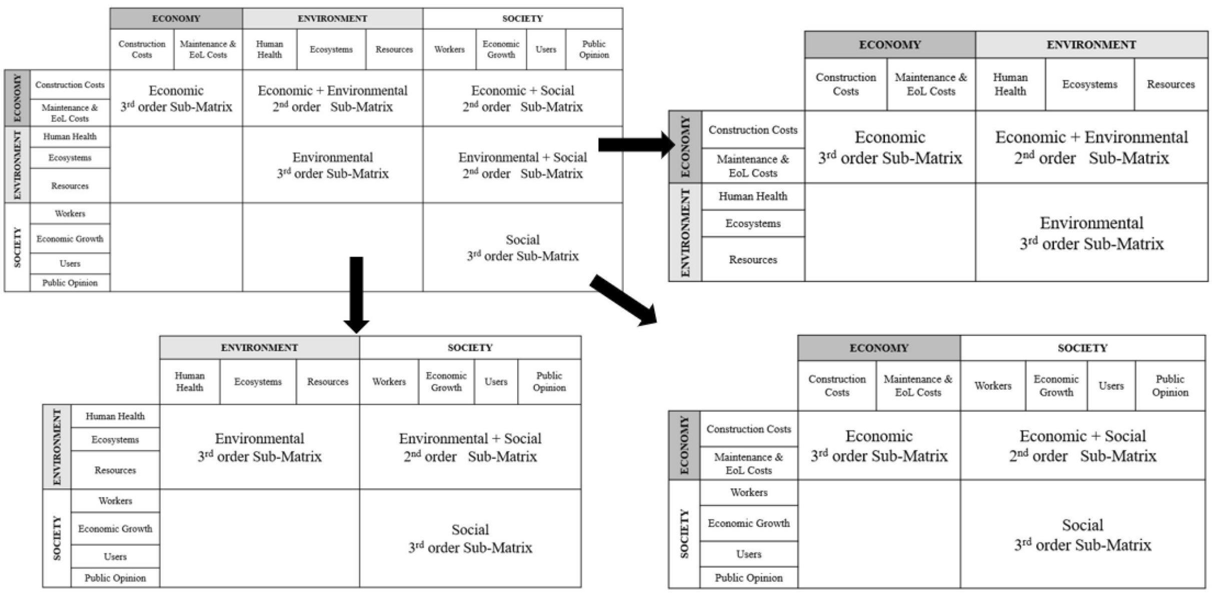

Fig. 2. Sorted comparison matrix and the different n-order submatrices.

Table 4. Statistical characterization of the students' responses when comparing each possible pair of criteria

Criterion *i*	Criterion j	Mean	Standard deviation	5th percentile	95th percentile
Construction costs	Maintenance costs	1.7	1.2	0.4	3.0
	Damage to human health	0.8	1.9	0.1	4.6
	Damage to ecosystems	1.0	1.8	0.1	3.0
	Resource scarcity	1.4	1.4	0.2	3.0
	Employment generation	1.9	1.6	0.2	5.0
	Economic development	1.6	1.8	0.2	5.0
	Negative impacts on users	1.1	1.2	0.1	3.0
	Externalities	2.6	2.2	0.2	5.0
Maintenance costs	Damage to human health	0.9	1.9	0.1	4.8
	Damage to ecosystems	1.3	2.3	0.1	7.5
	Resource scarcity	1.0	1.3	0.2	3.0
	Employment generation	1.7	2.0	0.2	5.0
	Economic development	1.1	1.2	0.1	3.0
	Negative impacts on users	1.8	2.7	0.1	8.0
	Externalities	2.5	2.6	0.2	7.7
Damage to human health	Damage to ecosystems	3.1	2.4	1.0	7.7
	Resource scarcity	3.7	3.0	0.1	8.0
	Employment generation	3.7	2.8	0.2	8.0
	Economic development	3.6	2.7	0.2	8.0
	Negative impacts on users	2.5	2.3	0.3	7.7
	Externalities	4.8	3.3	0.1	8.0
Damage to ecosystems	Resource scarcity	2.7	2.1	1.0	7.7
	Employment generation	3.0	2.7	0.3	8.0
	Economic development	3.0	2.7	0.3	8.0
	Negative impacts on users	2.6	2.4	0.3	7.7
	Externalities	4.8	3.2	0.3	8.0
Resource scarcity	Employment generation	2.4	2.4	0.3	7.7
	Economic development	2.3	2.0	0.3	5.0
	Negative impacts on users	1.7	2.3	0.2	7.7
	Externalities	3.4	3.2	0.1	8.0
Employment generation	Economic development	1.6	1.4	0.2	4.8
	Negative impacts on users	1.6	1.4	0.2	3.0
	Externalities	2.4	2.5	0.1	7.7
Economic development	Negative impacts on users	1.8	1.9	0.3	5.0
	Externalities	3.4	2.7	0.1	8.0
Negative impacts on users	Externalities	4.0	2.6	0.3	8.0

obtained to evaluate consistency between each pair of sustainability dimensions. These matrices will be called 2nd order submatrices.

Following the same principle, it is possible to construct so-called 3rd order submatrices to evaluate the consistencies of students connecting criteria for each dimension individually. In this case, one of those submatrices can be extracted for each dimension, namely a 2x2 economic submatrix, a 3x3 environmental submatrix, and a 4x4 social submatrix. Analyzing the resulting *CR* values for those submatrices can reveal more profound weaknesses in the students' perception of sustainability. The analysis of the consistencies described can strongly assist teachers and educators in strengthening course syllabuses related to education for sustainability in those areas where students are implicitly expressing less coherence of thought.

3. Results

Table 4 shows the results of the survey conducted. In particular, Table 4 shows the statistical characterization of the responses given by the students. It provides the mean value, the standard deviation, and the 5th and 95th percentile of the judgments, measured in terms of Saaty's extended fundamental scale (defined from 1/9 to 9), which were obtained from the equivalences shown in Table 3.

Table 5 shows the average relevance assigned to

Table 5. Mean criteria weights obtained from the survey

Criterion	Sustainability dimension	Resulting AHP weight
Construction costs	Economy	8.3%
Maintenance costs	Economy	8.0%
Damage to human health	Environment	23.3%
Damage to ecosystems	Environment	15.2%
Resource scarcity	Environment	10.0%
Employment generation	Society	8.7%
Economic development	Society	8.8%
Negative impacts on users	Society	11.8%
Externalities	Society	5.9%

each criterion due to this survey. These relevance values are obtained from the decision-making methodology described above. It can be seen that the students surveyed, which are considered a representative sample of recently graduated civil engineering and architecture students, consider environmental aspects to be far more relevant for the sustainable design of infrastructures in comparison to the social and economic criteria.

On average, 57% of the students surveyed expressed a moderate degree of certainty in completing the questionnaire, 22% expressed a fair degree of certainty in their answers, and 13% expressed complete certainty. The remaining 8% of students expressed a low degree of certainty.

4. Analysis and Discussion of the Obtained Results

4.1 Consistency Analysis for the Complete Comparison Matrix

From the results of each survey, it was possible to obtain the overall consistency ratio for the set of responses given by each student (Table 6). On average, the mean consistency ratio is $CR = 0.263$. It can be seen that only 2 of the 23 students have reached a consistency ratio lower than 10%, which is the maximum value of CR allowed by Saaty to consider the judgments of a decision matrix to be valid.

4.2 Consistency Analysis for the 2nd Order Submatrices

Fig. 3 presents the consistency ratios obtained by each student for the 2nd order submatrices that can be derived from their comparison matrices. The results are presented in ascending order for ease of interpretation. It can be observed that the consistencies follow approximately the same trend, irrespective of the submatrix analyzed. However, it is noteworthy that the consistencies associated with the economic-environmental submatrix fall almost in every case below the CR results for the other two matrices. It can be observed that 12 students have achieved consistencies in the economic-environmental assessments below 10%, while for the other two cases, only five students have reached such good results.

It shall be noted that only two students have achieved an overall consistency ratio below 10% in their complete comparison matrices. On average, the mean consistency obtained for the assessment of the economic-social criteria is 0.263, while for the environmental-economic and environmental-social, the average consistency ratios are 0.208 and 0.224, respectively. The analysis of the different field-related 2nd submatrices allows identifying those sustainability-related knowledge fields where the students lack a clear vision of the problem.

4.3 Consistency Analysis for the 3rd Order Submatrices

Fig. 4 shows the consistency ratios obtained by each student for the 3rd order comparison submatrices. The results from the economic field have been excluded from the graph, as no consistency shall be quantified from a 2x2 matrix. It is observed that, again, both curves present a similar trend. However, it is in the environmental dimension that there is the highest number of perfect consistency values ($CR = 0$). In particular, 6 students reached a perfect consistency when assessing the environmental dimension, while only one reached a perfect consistency when assessing the social dimension. This reflects that students are somehow more familiar

Table 6. Consistency Ratios obtained from the students' judgments

CR value	Interpretation	Number of students
$CR < 10\%$	Reveals an excellent capacity for critical thinking and a clear vision of sustainable design and its consequences	2 (8.7%)
$10\% \leq CR < 15\%$	The student shows an acceptable overview of the problem, and this results in sufficient consistency in his/her judgments	5 (21.7%)
$15\% \leq CR < 25\%$	The student does not completely understand the connections between factors involved in sustainable design, resulting in poor consistency in his/her judgments	6 (26.1%)
$25\% \leq CR$	The student has failed in understanding the relations existing between the criteria involved in the case study presented, thus not being capable of emitting consistent and critical judgments	10 (43.5%)

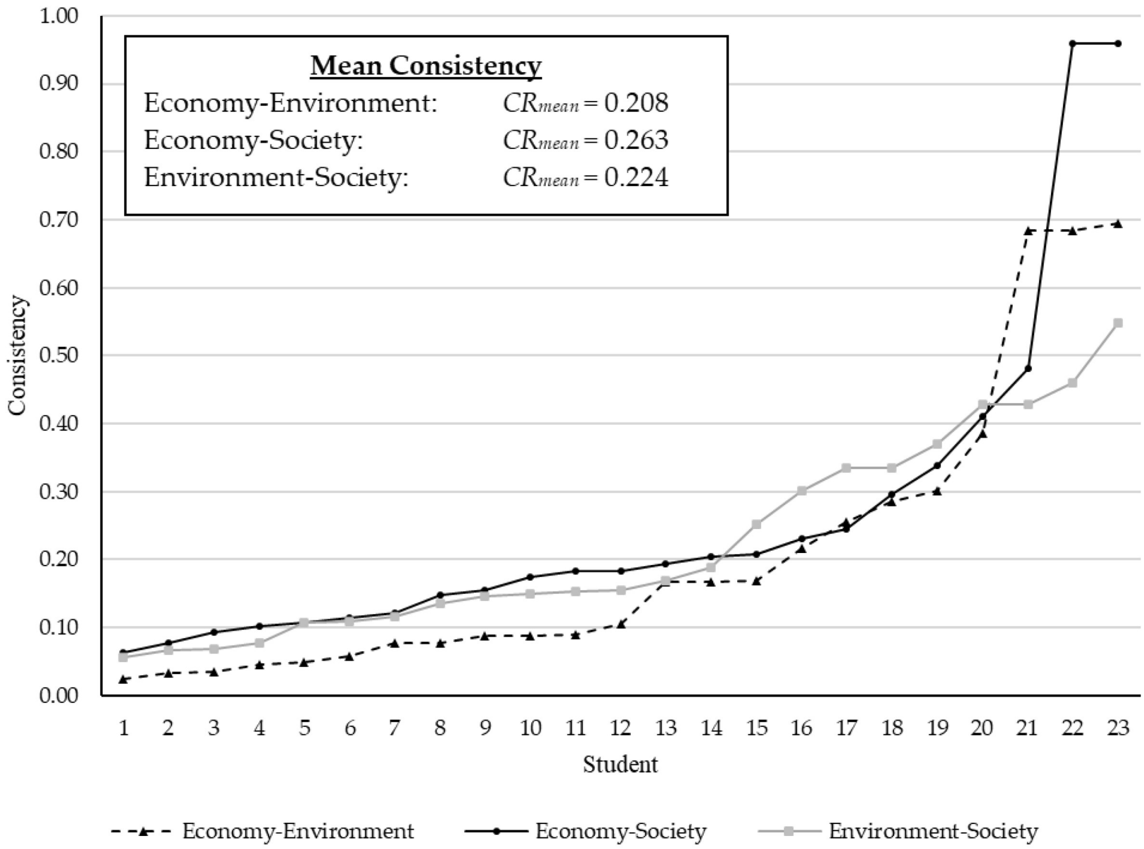

Fig. 3. 2nd order consistency ratios.

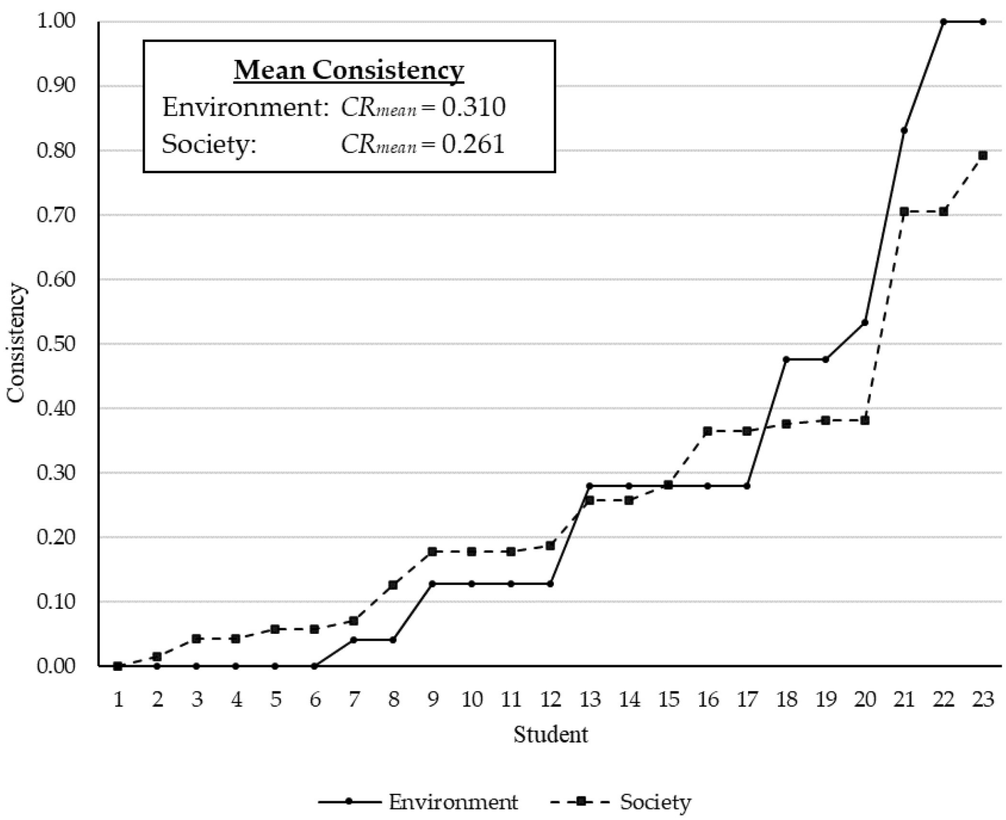

Fig. 4. 3rd order consistency ratios.

with environmental issues [33], while the more abstract aspects of the social dimension of sustainability remain still unknown to most of them. Similar conclusions have been observed in previous research, where it was stated that the assessment of social impacts is far less developed than the assessment of the economic or environmental dimension of sustainability [34, 35].

It shall be noted that, despite the above, the average consistency ratio *CR* obtained for the environmental dimension is greater than that for the social dimension. This is, however, attributable to the bad consistencies obtained by three students, who have obtained consistency ratios greater than 0.80.

4.4 Consistency Correlation Analysis

Spearman's correlation is investigated between the consistencies obtained for the different order submatrices. This correlation allows us to discover if there exists a monotonic relationship between the elements that are evaluated. A correlation factor ρ that is close to one means that there is a clear relationship between them (linear or non-linear). Also, the sign of such correlation provides information regarding the relationship between the two variables: a positive factor means that if one of the variables increases, the other also increases. In contrast, a negative factor represents the case where one of the variables increases when the other decreases.

Fig. 5 presents the correlation factor between 2nd and 3rd order submatrices. It can be observed that a good correlation exists between the 3rd order social submatrix and the 2nd order environmental-social assessments. A high correlation is also found between the assessment consistencies of 2nd order socio-economic and 2nd order environmental-social submatrices. This provides a useful tool to discover how to increase the consistencies in some assessments by strengthening the students' knowledge in other fields that might be more understandable.

Fig. 6 presents Spearman's correlation between the consistencies of the different order submatrices and the overall consistency of the students' assessments.

Although the correlation factors are all positive, it is observed that three of them are significantly high (greater than 0.70). This reveals that, for this particular case, putting greater efforts into increasing the consistency of those three submatrices (social impacts, socio-economic impacts, and environmental-social impacts) will be more effective in increasing the overall consistency of the students rather than focusing on the environmental or the economic-environmental dimensions, for which students have already shown acceptably consistent assessments.

For the case of this particular group of students,

	3rd order Environmental	3rd order Social	2nd order Environ.-Econ.	2nd order Socio-Econ.	2nd order Environ.-Social
3rd order Environmental		0.36	0.52	0.25	0.39
3rd order Social	0.36		0.39	0.65	0.83
2nd order Environ.-Econ.	0.52	0.39		0.22	0.58
2nd order Socio-Econ.	0.25	0.65	0.22		0.77
2nd order Environ.-Social	0.39	0.83	0.58	0.77	

Fig. 5. Spearman's correlation between 3rd and 2nd order submatrices.

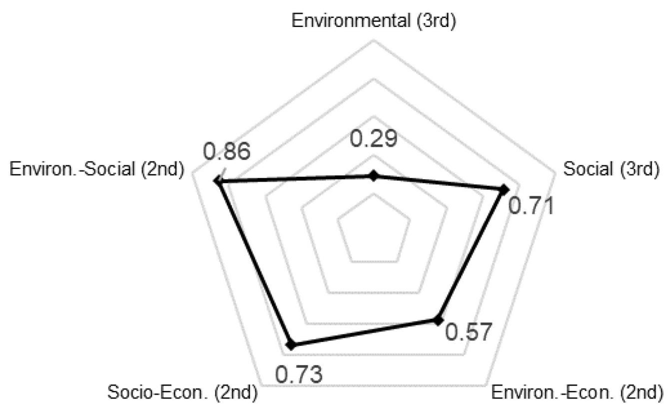

Fig. 6. Spearman's correlation between the overall consistency and the 3rd and 2nd order submatrices.

results show a lack of clear and consistent vision of the social consequences that can derive from adequate/inadequate management practices. Consequently, an evident action to take in this case to improve their overall vision of sustainability-oriented management could be to emphasize the consequences that their future professional practices can have on society, such as employment generation or destruction, bridging or widening the existing gender gap, or the generation or destruction of local economic wealth in poor regions, to cite some examples. The results reveal that doing so will increase the overall consistency of the students, thus improving their perception of sustainability.

5. Conclusions

5.1 Concluding Remarks

The recent establishment of the 2030 Agenda raises the need for management professionals trained shortly to acquire a set of transversal competencies that will enable them to lead their professional practice towards the sustainable development demanded by our society. This paper proposes a novel methodology to detect the degree of acquisition of the transversal competence of critical thinking at any stage of the students' learning.

To this end, an indirect but objective assessment system is proposed based on practical case studies. These, customized for each university discipline, aim to motivate students through real case studies, as well as to encourage critical thinking and analytical skills, all from the point of view of sustainability. The proposed tool makes it possible to know, through the coherence of the students' answers, to what extent the student has developed his/her capacity for critical thinking to face sustainable design problems. The presented evaluation tool is based on the AHP multi-criteria decision-making technique, one of whose intermediate calculation steps consists in quantifying the consistency of a multi-criteria assessment.

The proposed evaluation system provides an objective vision of how students perceive the problem of sustainable infrastructure design. It allows us to know if it is necessary to modify the teaching strategy to bridge the gaps that may be detected in their training after analyzing the obtained results. In addition, the proposed technique allows discovering, through the analysis of Spearman's correlation between the students' assessment submatrices, on which curricula topics to focus to effectively increase the students' consistency when assessing sustainability-related design problems. Consequently, the methodology proposed here can be understood as an evaluation tool of the students' ability to think critically and as a useful tool to help teachers effectively and consistently plan or eventually correct their curricula, irrespective of their teaching field. In this concrete case, this tool has been used in a sustainability-related syllabus, but it is equally valid for any teaching field.

5.2 Limitations and Future Lines of Research

One of the main limitations of the present article relies on the fact that the obtained results are based on a small-scale survey. Consequently, conclusions shall not be drawn on the specific consistency scores obtained by the students but rather on the applicability and advantages of the proposed technique. In addition, it shall be noted that the complexity of the survey or the number of questions included might affect the students' responses. The noise induced by a poorly designed survey will increase students' inconsistencies, which may be more related to the noise than their lack of critical thinking skills. Future studies will be driven on how reducing the number of survey questions might reduce the noise associated to the survey itself, thus revealing higher consistencies.

To further investigate on the results obtained, as a future line of research, the conclusions obtained in the present paper shall be confirmed in a larger-scale survey. Additional data shall be collected on the particular profile of each student in order to establish possible causal relations between their specific backgrounds and the consistency and certainty degree of their assessments.

Future research shall also investigate on the particular reasons that lay beneath each judgement, asking student to justify their comparison values. This will result in an interesting source of information for the lecturers when planning course curricula. In addition, this reflection exercise will be a very effective way for students to strengthen their coherence in making sustainable decisions and will reinforce their critical thinking skills.

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Ignacio J. Navarro serves as associate lecturer at the Department of Construction Engineering, Universitat Politècnica de València (Spain). He received his PhD degree in civil engineering from the Polytechnic University of Valencia. He has specialized in the sustainability-oriented life-cycle design of bridge structures in aggressive environments, paying special attention to the best-performing maintenance strategies for concrete bridges in coastal regions. He authored 12 JCR-indexed journal papers and ten conference papers. Throughout his professional career, he has participated actively in the design of steel and concrete structures, with particular emphasis on highway bridges and port structures.

José V. Martí holds a PhD in civil engineering from the Polytechnic University of Valencia (Spain). He has worked in private companies in the construction sector, business consulting, and financial entities. Currently a Professor at the Polytechnic University of Valencia, he has served for 26 years teaching construction procedures, quality, organization of works, and civil engineering machinery in the Master of Civil Engineering, Geodetic Engineering, and Topography, and the degrees in Civil Engineering and Public Works, all of them in the Polytechnic University of Valencia. He has directed 68 Final Degree Projects and Theses. He has participated in 9 educational books, 23 notebooks, 32 articles in education congresses, and a teaching innovation project. Within his research activity, he has authored a book, a book chapter, 33 articles in JCR-indexed journals, 38 conference papers, and has led nine research projects. His lines of research are mainly focused on the optimization of structures through the application of metaheuristic techniques and on the life cycles and sustainability of structures.

Víctor Yepes holds a PhD degree in civil engineering. He serves as Full Professor with tenure at the Department of Construction Engineering, Universitat Politecnica de Valencia, Valencia, Spain. He has been the Academic Director of the M.S. studies in concrete materials and structures since 2007 and a Member of the Concrete Science and Technology Institute (ICITECH). Furthermore, he is currently involved in several projects related to the optimization and life-cycle assessment of concrete structures and optimization models for infrastructure asset management. In addition, he is teaching construction methods, innovation, and quality management courses. He authored more than 300 journals and conference papers, including more than 140 published journals quoted in JCR. He acted as an Expert for project proposal evaluation for the Spanish Ministry of Technology and Science, and he is the Main Researcher on many projects. Likewise, he serves as a member of the editorial board of 12 international journals (Structure & Infrastructure Engineering, Structural Engineering and Mechanics, Mathematics, Sustainability, Revista de la Construcción, Advances in Civil Engineering, Advances in Concrete Construction, among others).