ENGINEERING AND ARCHITECTURE POSTGRADUATE STUDENT'S PERCEPTIONS ON SUSTAINABLE DESIGN

Ignacio J. Navarro[1], Antonio J. Sánchez-Garrido[1], Víctor Yepes[2]

[1]Dept. of Construction Engineering, Universitat Politècnica de València (SPAIN)
[2]Institute of Concrete Science and Technology (ICITECH), Universitat Politècnica de València (SPAIN)

Abstract

The construction sector is one of the principal contributors to the actual levels of environmental stress, but is also recognised as an essential sector to promote human well-being, access to education or poverty eradication through the development of infrastructures and services. Therefore, since the recent establishment of the Sustainable Development Goals in 2015, architects and civil engineers have emerged as key actors for the sustainable future to which we all aspire. However, the complexity of sustainability claim for fundamental changes in current university curricula to educate professionals who can meet such challenge. Conventional university courses in engineering and architecture fall usually short in providing a holistic education where the students adequately perceive the relevance of considering not only the functional requirements of their designs, but also their social and environmental consequences. The present communication aims to provide an assessment tool to detect the main gaps in the education of engineers and architects based on the post-graduate students' perceptions of sustainable design. A survey is conducted on the students from the postgraduate courses "Models of prediction and optimization of concrete structures" from the Master's degree in Concrete Engineering, and "Innovation Management in the Construction Sector" from the Master's Degree in Planning and Management in Civil Engineering, both taught at the Polytechnic University of Valencia. The consistency of the responses is evaluated objectively based on the Analytical Hierarchy Process method, thus bringing to light the educational fields where special efforts shall be put when adapting university curricula towards the education on sustainability.

Keywords: Education for sustainability, Analytical Hierarchy Process, survey, sustainable design, student's perceptions.

1 INTRODUCTION

The United Nations recognise education as an essential vehicle for meeting the challenges posed by the Sustainable Development Goals (SDG) established in 2015. Many of the target actions defined to achieve a variety of SDG's, such as Climate Change Mitigation, Responsible Consumption and Production, or Gender Equality, among others, are based on improving education to increase both awareness and human capacity on solving such problems. The role of higher education in this context is particularly relevant for several reasons. On the one hand, universities are responsible for generating a great portion of sustainability-related knowledge through research [1]. On the other hand, universities are also responsible for transferring such knowledge to students, thus educating future professionals not only with relevant technical capacities, but also with values and transversal competencies [2] so that they can contribute to a sustainable future. Education for sustainability is becoming therefore over the last recent years a key aspect of universities' curricula.

Particular emphasis is placed on sustainability in the education of future construction-related professionals, engineering and architectural courses. This results from the fact that the construction sector is responsible for a vast amount of environmental impacts and economic expenditures, the mitigation of which would substantially contribute to a more sustainable future. In addition, infrastructures are key elements to achieve great social benefits, which are in line with the SDGs, such as access to services, economic growth of regions, or employment generation, among others. Consequently, sustainable design of infrastructures and buildings are currently in the focus of the scientific community. Efforts have been made to reduce life cycle environmental and economic impacts of a variety of structures, such as bridges [3–6], earth-retaining walls [7, 8], buildings [9, 10] and other infrastructure elements, such as road pavements [11] or floor slabs [12], just to cite some examples. Particular interest is also arising recently on the social impacts and benefits associated to construction and maintenance of infrastructures [13-15].

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Although the technical knowledge exists, at least to some extent, on how to design infrastructures considering a life cycle perspective, sustainable design is a complex and challenging task, which is highly case-specific. The design of a sustainable infrastructure is at the end of the day a decision-making problem, where the engineer or architect has to find a balance over time between the environmental, economic and social impacts resulting from her/his solution. The designer is required to address the problem from a holistic perspective, taking simultaneously into account different criteria that are usually conflicting, and considering the particular social or environmental context of the location where the construction and maintenance activities take place [16]. A number of tools are available for multi-criteria decision-making that shall aid the designer to find the solution that best suits her/his criteria. However, the practical application of such methodologies must always be subject to her/his ability to think critically and holistically [17-19].

At present, engineering and architecture curricula are being adapted to include the necessary knowledge to face the sustainability challenge. However, there is a real risk that these changes will be limited to teaching students how to use the particular tools and methodologies available to evaluate life cycle impacts, leaving aside their education in the recognition of the complex relations and issues existing between the different dimensions of sustainability. Such awareness is the basis of the development of a holistic thinking when it comes to sustainable design, although there is no consensus on how to measure it. Navarro et al. [20] propose a methodology to assess students' ability to address sustainable design problems based on the consistency of their responses to a case study. The suggested approach provides teachers a valuable tool to evaluate the overall perception of students when it comes to a real problem. However, it falls short in providing understanding on what particular aspects and issues of sustainability are beyond the student's awareness.

The present communication aims to analyse more in depth the perception of engineering and architecture postgraduate students on sustainable design problems. The Analytic Hierarchy Process is used to evaluate the consistency of the student's responses to a construction-related case study. Here, the coherency implicit in the different comparison submatrices are evaluated, thus providing teachers a clear mapping of the student's perception of the problem.

2 METHODOLOGY

2.1 The Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a widely used Multi-Criteria Decision-Making tool developed by Thomas L. Saaty in 1980 [21]. This method is intended to help the decision maker in determining the relative importance of each criterion involved in a decision-making problem.

2.1.1 The AHP comparison matrix

As a first step, the decision maker shall compare the relative relevance of every pair of criteria based on the so-called Saaty's Fundamental Scale. This scale consists of nine integers ranging from 1 to 9 that are assigned 9 linguistic terms describing how much one criterion is with respect to the other in each pairwise comparison (Table 1).

So, if n criteria are considered essential when making a decision on a particular problem, a square nxn comparison matrix shall be constructed. Each position a_{ij} in the matrix contains the numerical value from the Saaty's Fundamental Scale representing the relative relevance of criterion i versus criterion j. Constructed this way, the resulting comparison matrix has two relevant properties. Firstly, every element a_{ii} must be equal to 1. On the other hand, the resulting comparison matrix must be reciprocal, i.e. for every element a_{ij} in the matrix it shall be satisfied that $a_{ij} = 1/a_{ji}$, This is obvious considering the fact that if A is assumed to be, for example, much more important than B, then B should be assumed less important than A to the same extent. Once the comparison matrix is constructed, the relative weight of each criterion shall be derived from the elements of the eigenvector that corresponds to the highest eigenvalue λ_{max} of the matrix.

Table 1. Saaty's Fundamental Scale [21].

Numeric Value	Semantic Term
1	A and B are equally important
3	A is slightly more important than B
5	A is moderately more important than B
7	A is much more important than B
9	A is extremely more important than B
2, 4, 6, 8	Intermediate judgements

2.1.2 Evaluation of consistency

Saaty's method provides procedure of evaluating if the obtained weights are based on a consistent comparison matrix. The evaluation of such coherency is based on the calculation of the matrix Consistency Index (*CI*), which is defined as:

$$CI = (\lambda_{max} - n)/(n - 1) \quad (1)$$

Here, n stands for the number of criteria, and λ_{max} for the highest eigenvalue of the comparison matrix. The consistency of the decision maker's judgements shall be then calculated through the so-called Consistency Ratio (CR) as:

$$CR = CI / RI \quad (2)$$

Where *RI* is a random index expressing the coherency of a comparison matrix filled with random values, thus reflecting absolute inconsistency in the judgements emitted. Consequently, the closer *CR* gets to 1, the more inconsistent is the comparison matrix under analysis. The values of *RI* solely depend on the dimension of the matrix, and are given in Table 2.

Table 2. RI values [16].

Number of criteria n	2	3	4	5	6	7	8	9
Random Index (RI)	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45
CR_{lim}	0.00	0.05	0.09	0.10	0.10	0.10	0.10	0.10

According to Saaty's procedure, some degree of inconsistency in the response is allowed depending on the number of criteria involved. As far as the resulting *CR* falls below a limiting value CR_{lim}, the matrix is said to be sufficiently consistent.

2.2 Case study and evaluation of students' perception

To address students' perception on sustainable design, an engineering-related case study is proposed. The case study consists of designing a concrete bridge deck in a coastal region. In such environments, concrete deteriorates rapidly given the presence of chlorides that penetrate the concrete cover and trigger the corrosion of the embedded steel reinforcements. There exist several design strategies based on durable materials meant to enhance the performance of the deck, thus reducing the maintenance needs along the life cycle of the structure. Students are encouraged to take into consideration the economic, environmental and social impacts of using these different materials, keeping in mind not only the impacts derived from their production, but also those related to the construction and maintenance activities required.

According to Navarro et al. [14], the sustainable design of a concrete bridge shall be based on the assessment of nine criteria covering all three dimensions of sustainability. With regard to the economic dimension of sustainability, two categories of impact are considered relevant. The first one is related to the costs associated to the construction of the bridge, which will be different depending on the construction materials used. The second impact refers to the maintenance and End of Life (EoL) costs. Again, the resulting costs will vary depending on the materials used and the maintenance needs along a service life of 100 years.

Three impact categories shall summarise the environmental consequences of the construction and maintenance of an infrastructure. Those are in accordance with the ReCiPe methodology for environmental impact assessment. The first category includes damages to human health derived from emissions of pollutants and other toxic substances to the environment. The second category refers to the damage to the ecosystems derived from land occupation and emission of harmful agents that can hinder the existence of species. At last, the third impact is associated to the depletion of natural resources derived from the extraction activities required to produce materials.

The social dimension involves more complex relationships, as it often involves many stakeholders with different interests. For the case study proposed, four impacts are considered relevant. The first is the generation of employment. Students shall bear in mind that, depending on the social circumstances of the respective production centres involved, the quality of such employment can differ. Aspects such as gender equity, fair salary, unemployment or working safety shall affect the quality of every working hour generated. The second social impact is related to the regional stimulus of economic growth: investing less money in poor regions may have a greater social impact than greater investments in wealthier regions. The third stakeholder that can be affected by the construction and maintenance of a bridge are the users themselves, as excessive maintenance will negatively affect their driving safety and their travel speed, limiting the accessibility of the region. At last, the public opinion shall also be kept under consideration: maintenance activities will alter the aesthetics of the bridge location, generate dust, noise and other undesirable impacts on non-users of the infrastructure.

Considering all these nine criteria that might affect the final designer decision, students are encouraged to fulfill a comparison matrix. If criteria are properly sorted depending on the dimension they are related with, from the complete comparison matrix several relevant submatrices shall be obtained (Figure 1). Here, three submatrices are revealed where only criteria belonging to the same dimension of sustainability are compared with each other. They correspond to the *2x2* economic quadrant, the *3x3* environmental quadrant and the *4x4* social quadrant of the complete AHP comparison matrix represented in Figure 1. The consistency analysis of these so-called third order matrices will reveal the awareness level of the student regarding each sustainability dimension separately. This is the basic level of awareness required for future professionals responsible for the sustainable design of products.

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<tr><th colspan="2"></th><th colspan="2">ECONOMIC CRITERIA</th><th colspan="3">ENVIRONMENTAL CRITERIA</th><th colspan="4">SOCIAL CRITERIA</th></tr>
<tr><th colspan="2"></th><th>Construction Costs</th><th>Maintenance & EoL Costs</th><th>Human Health</th><th>Ecosystems</th><th>Resources</th><th>Workers</th><th>Economic Growth</th><th>Users</th><th>Public Opinion</th></tr>
<tr><td rowspan="2">ECONOMY</td><td>Construction Costs</td><td rowspan="2" colspan="2">Economic Quadrant</td><td rowspan="2" colspan="3">Economic + Environmental Quadrant</td><td rowspan="2" colspan="4">Economic + Social Quadrant</td></tr>
<tr><td>Maintenance & EoL Costs</td></tr>
<tr><td rowspan="3">ENVIRONMENT</td><td>Human Health</td><td rowspan="3" colspan="2"></td><td rowspan="3" colspan="3">Environmental Quadrant</td><td rowspan="3" colspan="4">Environmental + Social Quadrant</td></tr>
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<tr><td rowspan="4">SOCIETY</td><td>Workers</td><td rowspan="4" colspan="2"></td><td rowspan="4" colspan="3"></td><td rowspan="4" colspan="4">Social Quadrant</td></tr>
<tr><td>Economic Growth</td></tr>
<tr><td>Users</td></tr>
<tr><td>Public Opinion</td></tr>
</table>

Figure 1. Complete AHP comparison matrix.

Third order matrices keep aside the complex relations existing between sustainability dimensions. Consequently, the additional analysis of the so-called second order submatrices is suggested. Those three submatrices relate impacts between two dimensions each, namely economy and environment, economy and society, and environment and society. They can be constructed based on the corresponding quadrants of the complete AHP matrix, keeping in mind that the resulting submatrices have to be reciprocal to be able to evaluate consistencies. Figure 2 shows an example where the socio-economical second order submatrix is constructed. Here, the economic, the social and the socio-economic quadrants are combined to form a *6x6* socio-economic submatrix.

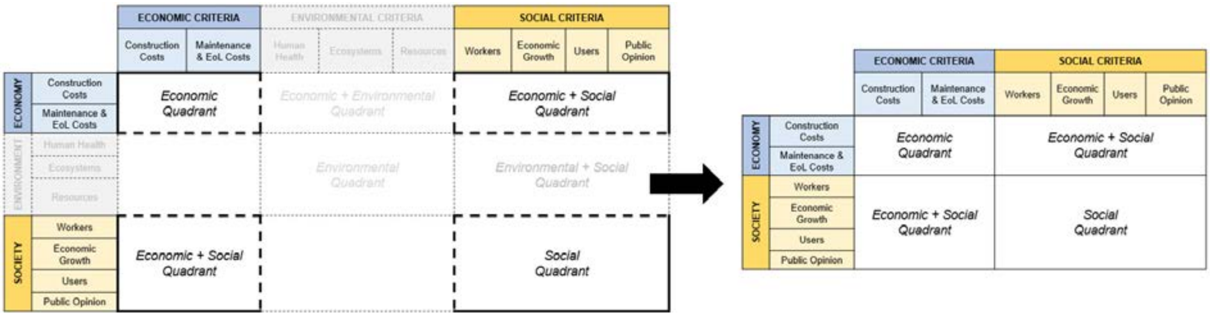

Figure 2. Construction example of a second order submatrix.

The analysis of the consistency of those matrices will help us discover amore advance level of awareness, revealing if the student has a clear vision of the connections existing between dimensions: economy and environment, economy and society, and environment and society. The analysis of those second order coherencies will help us discover the weaknesses in the students' perceptions of sustainability, and shall provide a useful tool to strengthen sustainability-oriented course syllabuses accordingly.

The last and more advance level of awareness is revealed when analysing the consistency of the first level submatrix, which is the complete matrix itself. Here, all three dimensions are related with each other simultaneously.

3 RESULTS

The case study is proposed as an online survey to the students from the postgraduate courses "Models of prediction and optimization of concrete structures" from the Master's degree in Concrete Engineering, and "Innovation Management in the Construction Sector" from the Master's Degree in Planning and Management in Civil Engineering, both taught at the Polytechnic University of Valencia (Spain). 23 students completed the survey.

3.1 Overall results

Table 3 presents the criteria weights obtained from the survey, where *C.C.* stands for construction costs, *S.C.* for service life costs (maintenance and decommissioning), *H.H.* for human health, *Ec.* for ecosystems, *Res.* for resources depletion, *E.G.* for regional economic growth, and *P.O.* for public opinion. The results follow an asymmetric inverse Gaussian distribution, which is defined by two parameters, namely the mean and a scale factor. Table 3 presents the resulting values for both parameters, as well as the 5th and 95th distribution percentiles.

Table 3. Sustainability criteria weights obtained after the survey.

	C.C.	***S.C.***	***H.H.***	***Ec.***	***Res.***	***Workers***	***E.G.***	***Users***	***P.O.***
Mean	0.083	0.080	0.233	0.152	0.100	0.087	0.089	0.117	0.060
Scale	1.617	1.197	1.947	3.258	3.284	3.320	8.729	2.926	1.774
5th Percentile	0.021	0.017	0.066	0.057	0.038	0.033	0.049	0.042	0.016
95th Percentile	0.210	0.221	0.557	0.314	0.206	0.179	0.144	0.250	0.149

It is observed that, in general, students consider the damage to human health the most relevant impact (23.3%) to be avoided when designing for sustainability, followed by the damage to ecosystems (15.2%). On the contrary, the least important impact results to be the effect on the public opinion, with a resulting weight of 6%.

Figure 3 shows the consistency of the students when conducting the survey. Results have been classified depending on the obtained consistency ratios in relation with CRl_{lim}. It can be observed that only two students have emitted consistent judgements ($CR < CR_{lim}$). The remaining 21 students have constructed comparison matrices whose coherency would be unacceptable when applying Saaty's procedure ($CR > CR_{lim}$). 30.4% of the students have provided very poor judgement matrices, with a resulting consistency ratio greater than four times the limiting value ($CR > 4{\cdot}CR_{lim}$).

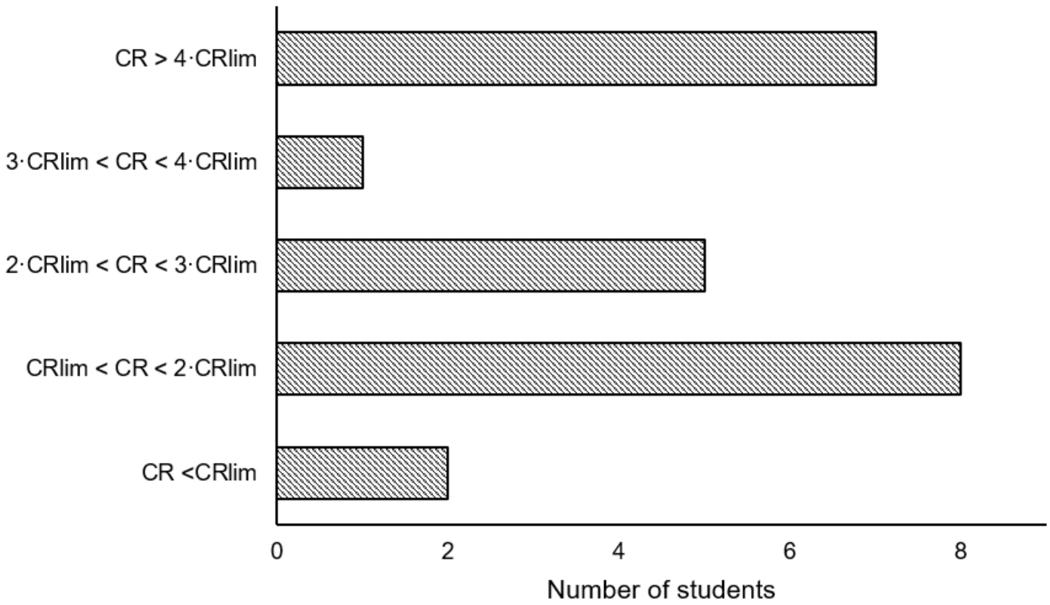

Figure 3. Consistency Ratios for the complete comparison matrix.

3.2 Analysis of second order consistencies

Figure 4 presents the consistency ratios obtained for the three second order submatrices extracted from the students' complete comparison matrices. It is observed that the surveys of over 50% of students have resulted in consistency ratios below CR_{lim} or $2{\cdot}CR_{lim}$. In particular, 11 students have been acceptably coherent when comparing the relevance between environmental and economic criteria ($CR < CR_{lim}$). On the contrary, when the social dimension is involved, only 3 to 4 students achieve such level of consistency.

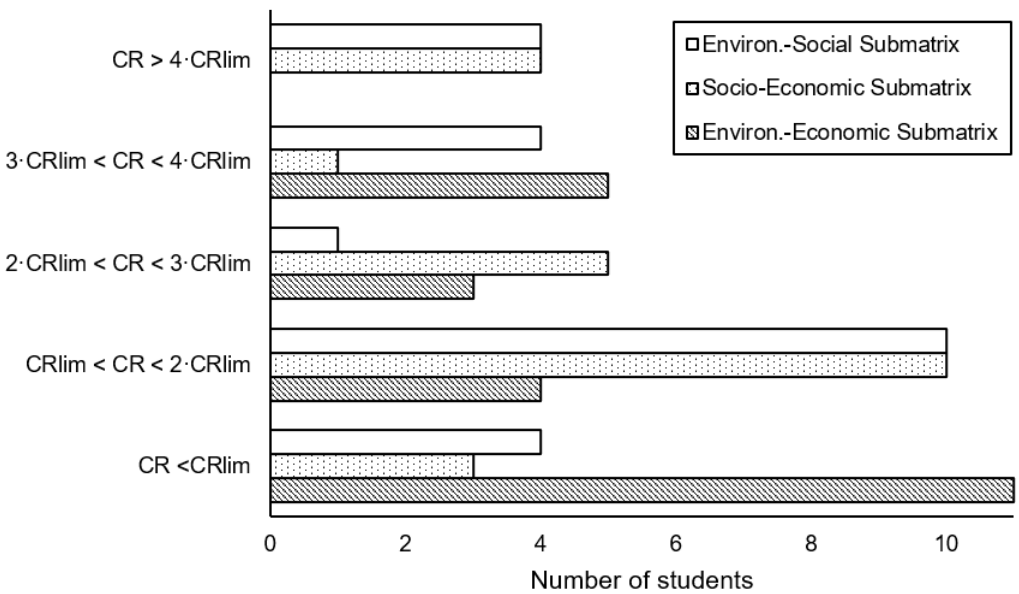

Figure 4. Consistency Ratios for the second order submatrices.

3.3 Analysis of third order consistencies

Figure 5 shows the consistency ratios obtained for the third order submatrices involving environment and society. It shall be noted that the *2x2* economic submatrix results in fully consistent values no matter the judgement emitted, as only two economic criteria are considered for this case study. From the results, it is observed 12 students have obtained consistency ratios greater than $2 \cdot CR_{lim}$ when it comes to comparing social criteria. Such result increases up to 15 students in the environmental field.

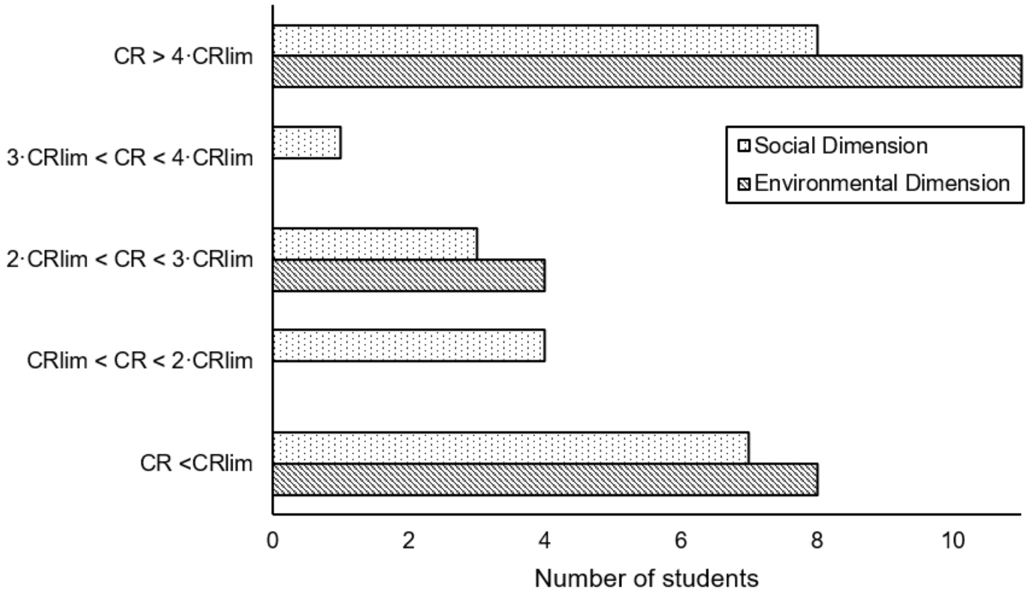

Figure 5. Consistency Ratios for the third order submatrices.

If we compare results with those obtained for the complete comparison matrix, it is observed that the number of students providing fully consistent judgements ($CR < CR_{lim}$) is 4 times greater. Although the coherency results are far better than those obtained for the analysis of the 1st order matrix, they reveal profound inconsistencies by a majority of students ($CR > 4 \cdot CR_{lim}$).

3.4 Analysis of the results

Here, the relation is investigated between the consistencies of the different submatrices analysed. Figure 6 presents the Box-Whisker plot for the consistency ratios derived for every of the six submatrices analysed. The plot represents the 25th, the 50th and the 75th percentiles, as well as the maximum and minimum obtained consistency ratios. It is observed that both the mean consistencies and the lower box bound for the second and third order submatrices are below the corresponding values for the complete comparison matrix. However, the results for the third order submatrices are much more spread than the rest. It can be derived that, in general, it is easier for students to compare criteria belonging to different dimensions of sustainability than comparing the criteria relevancies within one single dimension. The dispersion of results is particularly relevant for the case of the environmental dimension, where a great portion of the students have found it difficult to achieve consistent judgements.

Figure 7 shows the Sperman's correlation existing between the consistencies obtained by students for the different order submatrices. The Spearman correlation factor ρ between two variables addresses if there exists a monotonic relationship between them, linear or not. Spearman's coefficient ranges between 1 and -1, 1 meaning a perfect correlation between both variables. The sign stands for the direction of the relationship between variables. When a variable tends to increase when the other increases, the relation is positive. On the contrary, if one variable increases when the other decreases, the relation is negative. Consequently, for the hypothetical case of a perfect coherency in the first order matrix, the Spearman's correlation coefficients between the first order matrix and the remaining five submatrices would be 1.

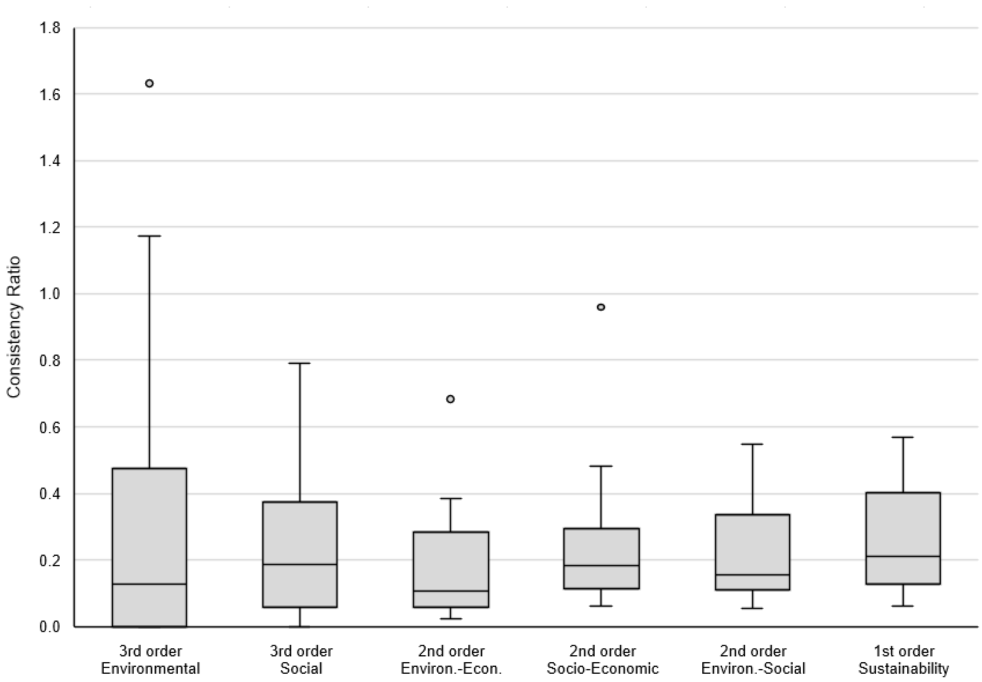

Figure 6. Box-Whisker plot for the 1st, 2nd, and 3rd order Consistency Ratios.

	3rd order Environmental	3rd order Social	2nd order Environ.-Econ.	2nd order Socio-Econ.	2nd order Environ.-Social	1st order Sustainability
3rd order Environmental		0.357	0.518	0.251	0.389	0.290
3rd order Social	0.357		0.392	0.654	0.830	0.713
2nd order Environ.-Econ.	0.518	0.392		0.223	0.576	0.569
2nd order Socio-Econ.	0.251	0.654	0.223		0.767	0.734
2nd order Environ.-Social	0.389	0.830	0.576	0.767		0.855
1st order Sustainability	0.290	0.713	0.569	0.734	0.855	

Figure 7. Spearman's correlation factors between different consistency orders.

Almost a perfect correlation is observed between the first order consistency and the consistency extracted from the environmental-social second order submatrix (ρ = 0.86). Similarly high correlation results are observed between the first order consistency and the submatrices related to the social dimension (ρ = 0.71) and the economic-social interactions (ρ = 0.73). On the contrary, an almost non-existing relationship exists between the students' final coherency and their consistency when addressing the environmental criteria (ρ = 0.29). This implies that the students' total coherencies rely on the socio-economic aspects rather than on the environmental ones, thus revealing a poor awareness level of the connections existing between the environmental dimension and the rest.

4 CONCLUSIONS

The present communication analyses engineering and architecture students' perception of sustainability and sustainable design of infrastructures based on a case study. An in-depth analysis of the coherency of the students' responses and judgements has been conducted. The coherency has been evaluated mathematically by means of the consistency ratio proposed by Saaty to validate the comparison matrices of the AHP method. To reveal the educational fields where more efforts have to be put in order to enhance the actual sustainability-oriented higher education curricula, the intrinsic consistencies derived from the analysis of the submatrices than can be extracted from the complete comparison matrix are assessed.

The obtained results reveal that education in the environmental dimension is the field in which most work needs to be done. Regarding the environmental dimension, an almost null correlation has been found between the third order consistency ratios and the final consistencies that were derived from the analysis of the first order comparison matrices. Additionally, it is the third order consistencies related to environment that include the greatest results dispersion and outliers. On the contrary, although the technical assessment of the social dimension of sustainability is by far the most difficult and controversial, students seem more comfortable when addressing social impacts. However, in spite of lacking the technical knowledge to assess these impacts, students are more aware of social problems, which they experience in one way or another in their daily lives. In contrast with the environmental issues, students are able to identify the connections existing between society and economy. Although the presented results are case specific and cannot be generalised, the application of the suggested methodology has proven to be effective for identifying weaknesses in the education for sustainability conducted in higher institutions.

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