MULTI-CRITERIA DECISION TECHNIQUES IN CIVIL ENGINEERING EDUCATION.

COMPARATIVE STUDY APPLIED TO THE SUSTAINABILITY OF STRUCTURES

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INTRODUCTION

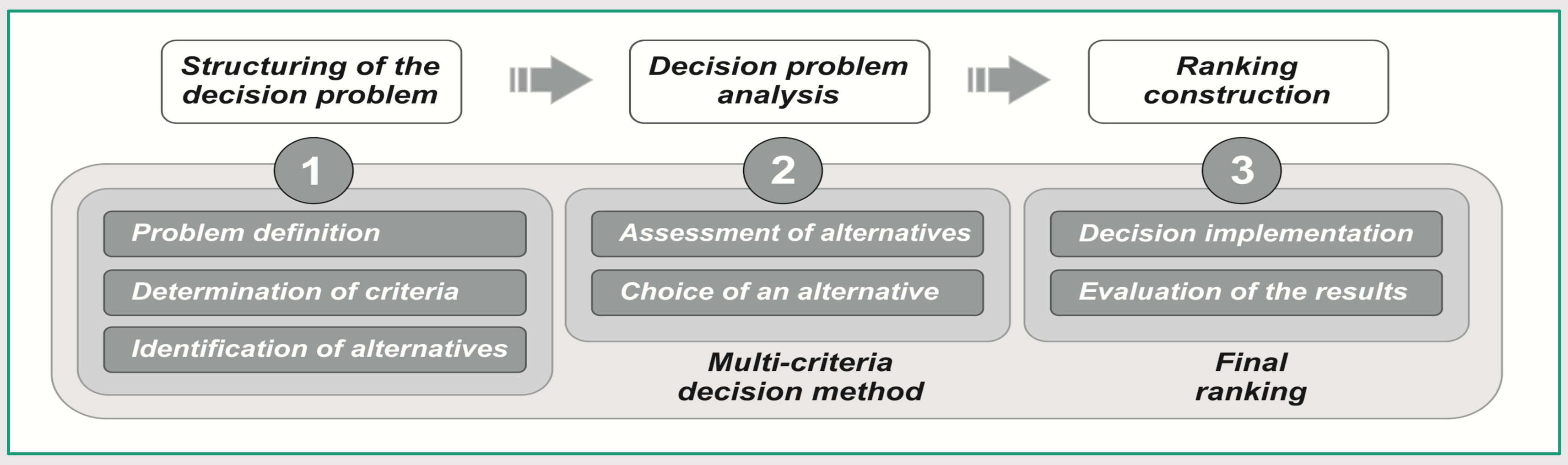
According to UNESCO, "Education for Sustainable Development promotes competencies like critical thinking, and making decisions in a collaborative way". In terms of sustainable design, sustainability implies ensuring that present needs are met without compromising the capability of future generations to meet their own needs. Sustainable design problems require engineers to adopt a transversal thinking to find the solution that best suits the three pillars on which sustainability is based: the economy, the environment and society. The decision is almost never simple, since the criteria that condition the decision are usually in conflict (economy, time, aesthetics, environment, society, durability, among other). Tools are needed to evaluate this decision process.

In the postgraduate course "Prediction and optimization models of concrete structures", taught in the Master of Concrete Engineering at the Polytechnic University of Valencia, Students are taught to employ the different techniques of MCDM, even using them to obtain objective weights of criteria that can be subjective, or for the selection of the best option within a Pareto limit after a multi-objective optimization .

OBJETIVE

This paper aims to make a comparative study of several multi-attribute decision methods, in environments with uncertainty, applied to three different constructive alternatives based on modern constructive methods (MMC). The objective is to define the sustainable alternative that best meets the different perspectives, whatever the interests of the DMs. For this purpose, a set of criteria was used to reach all the building's sustainability perspectives, considering its entire life cycle.

METHODOLOGY



The process of making decisions according to different objectives is usually supported by the use of different methods designed for this purpose. The multi-criteria decision making (MCDM) processes can be classified into multi-attribute decision making (MADM), and multi-objective decision making (MODM). More specifically, MADMs allow the solution of discrete problems when the alternatives are predetermined and the experts evaluate each criterion beforehand, indicating the importance of each one. In this case, the DMs act at the beginning of the process, either by giving weights to the different existing criteria for the evaluation of each of the solutions, or by evaluating these solutions according to subjective criteria. Finally, a prioritization of the alternatives studied is obtained.

- MULTI-CRITERIA ASSESSMENT TECHNIQUES

Direct scoring methods are the most straightforward, being based on the evaluation of the different alternatives through basic arithmetic operations. ***SAW*** and ***COPRAS*** assess the alternatives by aggregating the standardized value of each criterion by its corresponding weight.

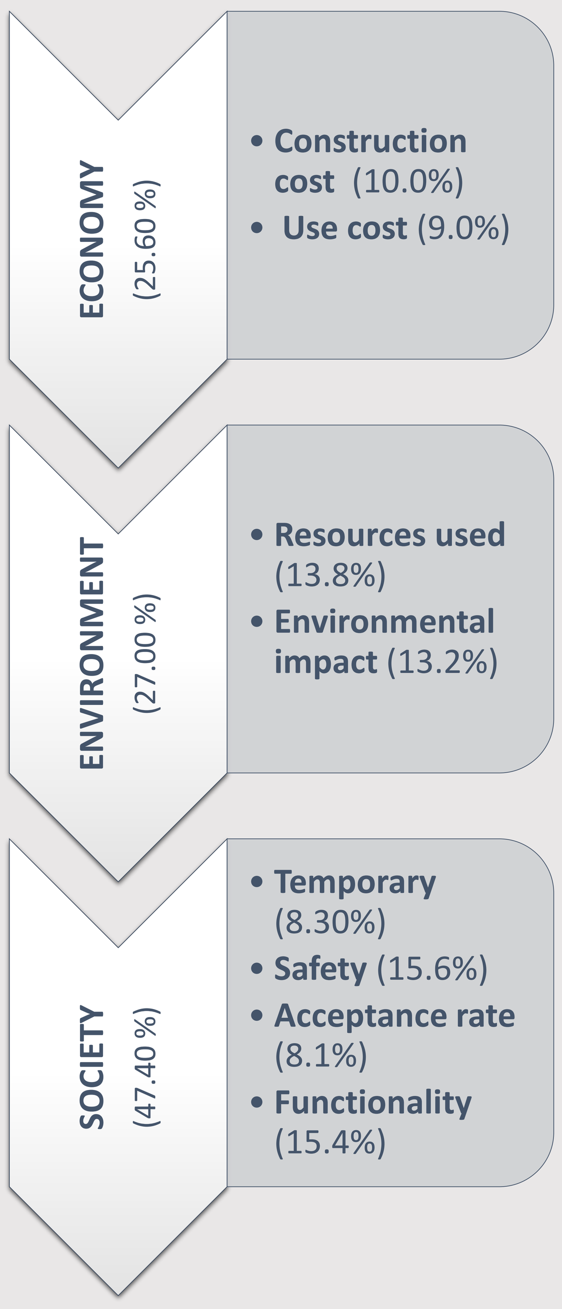
Distance-based methods calculate the distance between each alternative and a specific point. CP, **TOPSIS and VIKOR** are based on obtaining the alternative that satisfies a set of goals, that is, the point is not the optimal one, but the one that fulfills a series of conditions, differing in the normalization of the criteria.

Paired comparison methods, such as ***AHP***, **ANP** and ***MACBETH***, are useful to obtain the weights of the different criteria and to evaluate subjective criteria by comparing the alternatives with each other.

Outranking methods establish a relationship of preference between a set of solutions where each one of them shows a degree of dominance over the others with respect to a criterion. Within this group are ***PROMETHEE*** and ***ELECTRE***.

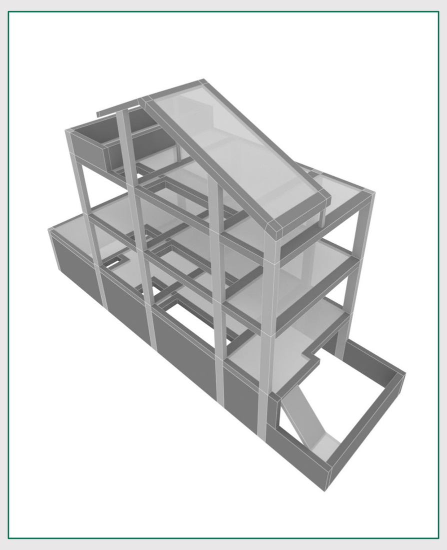
Utility/value methods define functions that determine the degree of satisfaction of an alternative with respect to a criterion. These functions convert the evaluations of the alternatives into a degree of satisfaction for each criterion. ***MAUT, MAVT*** and ***MIVES*** are examples of the above.

-CRITERIA AND WEIGHTING



CASE STUDY

This paper aims to analyze sustainability in residential building, comparing different options for the design of the structure and the enveloping walls from a life cycle perspective. The plot, which is located in Jaén (Spain), has a rectangular shape of 6.20 m x 20.00 m and access from street level. Its elongated and narrow geometry has been the result of the maximum adjustment of the parameters of building density, surface area and occupation, distributed in three floors above ground and a basement. In order to decide the sustainable alternative that best represents the different interests of DMs, it is proposed to compare a traditional reference solution with two construction options based on modern methods of construction (MMC).



Alt.	Components	Design option description
1	*Foundation*	Ø35cm CPI-7 piles with HA-35/F/12/IIa+Qc up to 8.80 m deep and foundation beams with HA-30/B/20/IIa+Qb
	Floor slabs	Reinforced concrete slab with HA-25/B/20/IIa (floor type 24 cm; 26 cm in solarium) and HA-30/B/20/IV in pool
	Sloping floor slab	Reinforced concrete slab HA-25/B/20/IIa (22 cm) and 10 cm PUR
	Supports	Concrete columns and metal profiles (only in roof). Reinforced concrete basement perimeter wall (25 cm)
	Building enclosure	Brick outer wall (11.5 cm); with 9 cm MW and interior brick partition wall (7 cm)
2	*Foundation*	Same to alternative "1"
	Floor slabs	Reinforced plates (floor type 30 cm and 12.5 cm in the turret); Density 600 kg/m³. Passable deck not ventilated, fixed floor with 8 cm XPS. Pool basin with 30 cm plates (live load 1,100 Kg/m²) and reinforced concrete block wall
	Sloping floor slab	Reinforced plates (12 cm); 12 cm XPS (0.032 m²K/W).
	Supports	There are no columns. Reinforced concrete basement wall is maintained.
	Building enclosure	Structural load-bearing walls with tongue and groove aerated concrete blocks with densities (400-350 Kg/m³)
3	*Foundation*	Mat foundation 7/46/7 on 1.00 m deep compacted soil improvement. HRA-30/B/12/IIa+Qb; 46 cm gravel filling
	Floor slabs	Sprayed reinforced concrete lightened slab HRA-25/B/12/IIa (floor type 6+18+6 cm; 7+26+7 cm solarium) and concrete HRA-30/B/12/IV in pool. Passable deck not ventilated, fixed flooring; 26 cm XPS
	Sloping floor slab	Sprayed reinforced concrete lightened slab (5+5+5 cm); 5 cm XPS
	Supports	Reinforced concrete basement wall is maintained
	Building enclosure	Structural walls in façade and dividing walls (6+13+6 cm); interior air chamber formed with 13 cm EPS

[1] **Reference**: Conventional on-site reinforced concrete structure and brick enclosure walls.
[2] **Ytong**: Prefabricated blocks and industrialized slabs, autoclaving aerated concrete manufactured with densities 350-700 kg/m³.
[3] **ELESDOPA©**: Double Wall Structural Element, of Projected Reinforced Concrete.

RESULTS

The summary of the results obtained with the different methods is shown in the following table. In general, alternative 3 is the best evaluated, followed by alternative 2, except for MIVES and VIKOR (v=1). In no case alternative 1, which has been used as a reference, obtains the best score.

MADM	Summary score		Alternative 1 "Reference"	Alternative 2 "Ytong"	Alternative 3 "Elesdopa"
SAW	Final score		0.77	0.87	**0.89**
COPRAS	Final score		0.77	0.86	**0.88**
TOPSIS	Final score		0.43	0.50	**0.62**
VIKOR	Score	v=0	1	0.97	**0**
		v=0.5	1	0.49	**0.02**
		v=1	1	**0**	0.04
ELECTRE	Ranking		3º	2ª	**1ª**
MIVES	Economic rating		0.15	0.16	**0.20**
	Environmental rating		0.04	**0.17**	0.11
	Social rating		0.25	**0.26**	**0.26**
	Final score		0.43	**0.59**	0.57

The direct scoring methods (SAW and COPRAS) offer practically the same final score. Being the simplest for quantitative variables, in the case of the assessment of the sustainability of building structures, they are not the most appropriate as there are also qualitative variables. In the case of TOPSIS, although the distances to the PIS and NIS are calculated, normalization is made at the end. This is why a higher score is obtained for the best alternative. On the other hand, VIKOR is different, obtaining as a result the distance of each alternative to the ideal. The shorter the distance, the better. With the VIKOR method we have taken advantage of the opportunity to carry out a sensitivity study by modifying the variable v. The results show that as the value of v increases, alternative 3 loses importance in favor of alternative 2. This is due to the fact that the distance from Manhattan (S_j) benefits alternative 2 (S_1=0.77; S_2=0.30; S_3=0.32), to the extent that for v=1 the latter becomes the preferred one. Among the methods of outranking, ELECTRE offers both a global ranking of the alternatives, and a comparison between them. It is very suitable for the classification of alternatives according to degree of dominance by pairs, being very useful for discrete problems of multi-attribute decision making. Finally, the MIVES method offers different results to the tendency of the ranking until now., explained by the subjective load introduced by each DM_k. It can be observed that although alternative 3 has the best score in the economic (0.20) and social (0.26) dimensions, the global evaluation is favorable to alternative 2 since it presents the most balanced indexes.

CONCLUSIONS

In this document a study of the decision-making process has been carried out to evaluate the sustainability of the structure of a row house, applying the most important methods of MADM. This learning object belongs to the postgraduate course "Prediction and optimization models of concrete structures" integrated in the curriculum of the Master of Concrete Engineering of the UPV. In these courses it is taught how to apply MCDM techniques in the selection of the best structural typology for the resolution of complex engineering problems. The assessment of the sustainability of structures relies on numerous variables that can make the solution opt for one or another alternative: the criteria considered, the weights assigned and the multi-attribute decision methods employed. All this makes the MCDM process a very complicated process that involves a great deal of uncertainty, which can be taken into account by means of support tools for the decision-making process, such as fuzzy theory or neutrosophic logic, although at the cost of increasing complexity. The process of decision making by multiple attributes always has the same steps, although the way to carry them out is what differentiates one methodology from another. All of them have their advantages and disadvantages, although their choice or preference remains subjective. However, these methods can be modified and adapted to fit the objective of the decision maker. From the analysis of the selected criteria, with any of the methods, it is concluded that only the concurrent consideration of the three pillars of sustainability in a building structure will lead to appropriate sustainable designs.

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