A COMPARATIVE ANALYSIS OF DECISION MAKING METHODS FOR THE SEISMIC RETROFIT OF RC BUILDINGS

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ABSTRACT :

Several different technical options are nowadays available to seismically upgrade an existing building. Selecting the best one with reference to a given structure generally represents a complex problem. In fact many and generally conflicting are also the points of view by which each alternative has to be judged. Decision support systems like the so called Multi Criteria Decision Making (MCDM) methods may be very useful in order to make an as much as possible objective and rational choice.
The paper investigates the applicability and effectiveness of different MCDM methods for the focused decision problem. Some of the most widely adopted and consolidated methods are considered and compared one each other, first in terms of suitability for the particular decision task, then in terms of simplicity of use, reliability of the results, degree of human (subjective) intervention in the process and other significant criteria. The comparison is also quantitatively made with reference to a case-study consisting of an underdesigned RC structure.

KEYWORDS: Seismic retrofit, decision making, MCDM methods, existing buildings

1. INTRODUCTION

In the last years, significant amount of resources have been invested to support the research regarding the application of innovative materials and technologies for the structural upgrading and control of existing buildings in seismic areas. Therefore several are nowadays the retrofit options available to practitioners. Starting from the likely assumption that it is not possible to identify, among those applicable, a retrofit technique better than the others in all cases, authors investigate herein the possibility of supporting who has to upgrade an existing structure (or, more precisely, who has to decide how make it) in selecting the more suitable retrofit strategy for the specific case of interest.
As both the number of criteria and the number of alternatives generally do not allow the decision maker to directly operate a rational choice that takes into account simultaneously all the several variables involved, the guided careful selection of the retrofit technique can be particularly important especially when the structure has an important role from the social-economic point of view. It has been shown that, to this aim, Multi-Criteria Decision Making (MCDM) methods can give a significant help (Caterino et al., 2008).
The main objective of the present work consists in investigating the applicability and effectiveness of different state-of-the-art MCDM methods (ELECTRE, TOPSIS, PROMETHEE and VIKOR) for the seismic retrofit decision problem. These methods are compared one each other in terms of suitability for the particular considered decision task and according to some significant criteria like ease of applicability, reliability and robustness of the choice, degree of decision maker's influence on the results. The following step-wise procedure proposed by Caterino et al. (2007, 2008), independent from the particular MCDM method used, is adopted herein to solve the fixed decision problem:

1. seismic evaluation of the given building, in its original state;
2. definition and design of the set of alternative retrofit solutions to choose among;
3. definition of the criteria in respect of which each solution has to be evaluated;
4. definition of criteria weights of importance;
5. evaluation of each alternative solution according to each criterion (decision matrix);
6. selection of the best solution through the application of a MCDM method.

A case-study developed in a previous work by the same authors is used to apply and compare each method, also allowing to highlight the specific features of the considered procedures. It is a three-storey reinforced concrete building designed to be representative of pre-seismic code constructions in southern Europe (Fardis et al., 2005). The standard (irregular) floor plan is presented in Figure 1. The interstorey height is 3.0 m. The building is assumed to be located in Pomigliano d'Arco (Naples, Italy). This site was classified as a seismic zone in 2003. The code's peak ground acceleration is 0.25*g* (OPCM 3431, 2005), where *g* is the gravitational acceleration. In Caterino et al. (2007, 2008) a detailed description of the structure can be found. The reader should refer to those papers also for details about steps 1 to 5 of the above decision procedure.

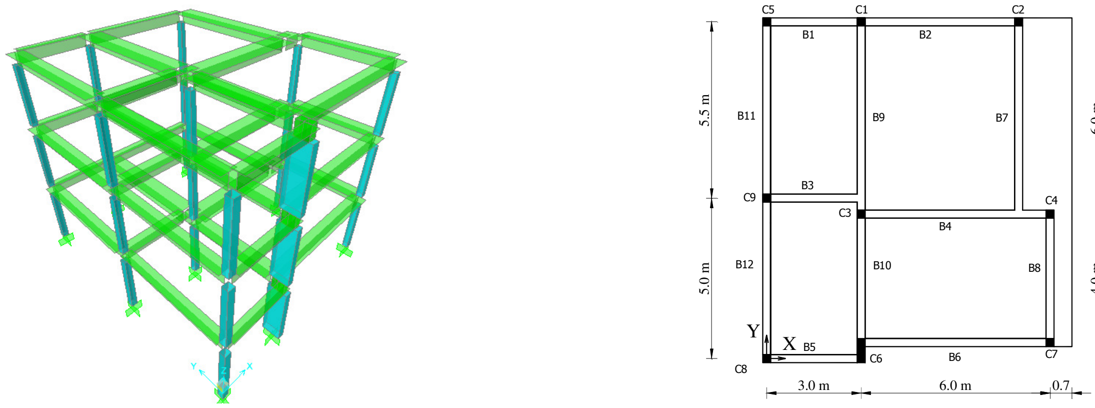

Figure 1. 3D view and floor plan of the case-study structure

Five different upgrade options (A_1, A_2, …, A_5) are considered, three of those aiming at a seismic capacity enhancement, the last two providing a seismic demand reduction. A_1 consists of confinement by Glass Fiber Reinforced Plastics (GFRP) of columns and joints and results in an increase of the building displacement capacity; A_2 provides a global strength (and stiffness) enhancement by adding steel braces; A_3 is the concrete jacketing of selected columns, which provides a partial but simultaneous enhancement of strength and ductility; the base isolation of the structure is referred to as alternative A_4 and results in the reduction of the seismic forces through lengthening the fundamental period of vibration of the structure; finally A_5 consists in installing four viscous dampers at the first story of the building and produces the attenuation of the seismic demand through a drastic increasing of the dissipation capacity of the structural system.
Eight criteria (C_1, C_2,…, C_8) are considered to compare the alternatives. They are reported in Table 1, together with the weight of importance (w_j, j=1, 2, …,8; $\Sigma_j w_j$=1) assigned to each of them. The weights' assignment procedure suggested by Saaty (1980) and based on eigenvalue's theory is used. Refer to Caterino et al. (2008) for details on the rationales of weights.

Table 1 Evaluation criteria

Group	Symbol	Criteria description	Weight w_j
Economical/Social	C_1	Installation cost	0.073
	C_2	Maintenance cost	0.172
	C_3	Duration of works/disruption of use	0.073
	C_4	Functional compatibility	0.280
Technical	C_5	Skilled labor requirement/needed technology level	0.026
	C_6	Significance of the needed intervention at foundations	0.201
	C_7	Significant Damage risk	0.035
	C_8	Damage Limitation risk	0.141

Table 2 reports the so called decision matrix that collects the quantitative evaluation of each alternative according to each criterion (its generic element a_{ij} measures the performance of the alternative A_i in respect of criterion C_j). It is to underline that two criteria (C_4 and C_5) are qualitative and allows only linguistic judgments when alternatives are evaluated according to them; so these criteria required the additional operation consisting in the conversion of these linguistic variable into crisp numbers, which, again, may be found in the referenced work. It is also to be noted that all considered criteria are "cost" type, since the DM is interested to minimize the corresponding variables (time, cost, etc.), except for C_4 (functional compatibility) that represents a "benefit" type criterion.

Table 2 Decision matrix

	C_1 (€)	C_2 (€)	C_3 (days)	C_4	C_5	C_6	C_7	C_8
A_1	23 096	23 206	33	0.482	0.374	2.90	0.022	0.281
A_2	53 979	115 037	122	0.063	0.104	15.18	0.024	0.002
A_3	11 175	40 353	34	0.255	0.044	2.97	0.040	0.171
A_4	74 675	97 884	119	0.100	0.374	2.65	0.020	0.000
A_5	32 309	36 472	19	0.100	0.104	2.87	0.040	0.263

The decision matrix clearly shows that a rational tool to support the selection of the best alternative is needed as it is not evident which one is the optimal. In fact, for example, A_3 (concrete jacketing) requires the minimum cost of installation (criterion C_1), but corresponds to the highest risk of the Significant Damage limit state attainment (criterion C_7); A_1 (GFRP wrapping of columns and joints) guarantees the minimum maintenance costs (criterion C_2), but barely ensures the code's requirement about the non-structural elements protection required by the seismic code (criterion C_8); A_4 (base isolation) leads to the minimum intervention at foundation (criterion C_6) and the minimum risk of non-structural damage (criterion C_8), but needs many days to be realized (criterion C_3) and corresponds to the maximum cost for the installation (criterion C_1).

2. MCDM METHODS FOR THE SEISMIC RETROFIT DECISION PROBLEM

Each of the four aforementioned MCDM methods (ELECTRE, TOPSIS, PROMETHEE and VIKOR) is here briefly presented. After highlighting the critical issues of them in respect to the specific decision problem, they are applied to the case-study structure, allowing (in the following section) a more practical and effective comparison among them. Let n indicate, in general, the number of alternatives A_i and m that of criteria C_j.

2.1. ELECTRE method

The ELECTRE method (ELimination Et Choix Traduisant la REalité, Roy 1968) is based on the definition of outranking relations between alternatives, taken two at a time. According to the method, an alternative A_k outranks another one A_p ($A_k \rightarrow A_p$) if it shows performance values better or at least equal than those offered by A_p in respect of the majority of criteria and responds in a not so bad manner to the remaining criteria.
Firstly the decision matrix has to be normalized (substituting each a_{ij} element by the ratio between a_{ij} and the square root of the sum of the squared elements a_{kj} belonging to the same column) and weighted (by multiplying each value in the j-th column, with j=1, 2, …, m, by the weight w_j of the j-th criterion). After that, four sub-steps have to be carried out. Considering two alternatives A_k and A_p, the so called concordance set C_{kp} is defined as the one that groups all the criteria for which A_k results to be preferred to A_p or, at least, indifferent to it. The discordance set D_{kp}, conversely, includes all the remaining criteria. Then the concordance and discordance indices have to be defined. The generic concordance index c_{kp} between alternatives A_k and A_p is the sum of the weights of all criteria included in the concordance set defined above ($0 \leq c_{kp} \leq 1$) and represents how much A_k is to be preferred to A_p. The generic discordance index d_{kp}, instead, measures the maximum gap between performances of A_k and A_p in respect of criteria included in the discordance set D_{kp}. In order to know if the outranking relation $A_k \rightarrow A_p$ is true or false, it is needed the decision maker sets two threshold values $\underline{c}$ and $\underline{d}$ for the concordance indices and discordance indices respectively. Sometimes $\underline{c}$ and $\underline{d}$ are simply set equal to the mean value of the above-computed concordance and discordance indices respectively. The relation $A_k \rightarrow A_p$ is defined true if simultaneously results $c_{kp} \geq \underline{c}$ and $d_{kp} \leq \underline{d}$. For the case-study application, it is assumed for $\underline{c}$ and $\underline{d}$ the mean value of the concordance and discordance indexes ($\underline{c}$=0.478; $\underline{d}$=0.689). The retrofit option consisting in the GFRP wrapping (A_1) results to be the best one among the considered ones. Vice versa, the solution involving the steel bracing of the building (A_2) results to be "dominated" by each other.
The ELECTRE method often does not lead to the definition of only one solution emerging among the others (except for the cases, like the numerical example done, in which an alternative clearly outclasses the others, even according to concordance and discordance tests separately considered), individuating a subset of solutions

to be preferred in the initial set of available options. For this reason, the method is generally considered more suitable for decision problems characterized by not many criteria and several alternatives allowing to individuate a small subgroup of preferable options. The problem regarding the selection of the best seismic upgrade intervention of a given structure, generally does not have these characteristics. Designing and evaluating a very large number of retrofit alternatives would be too much expensive from the time and cost points of view. Moreover, in such a problem, the decision maker is interested only to know which alternative is better to implement, not to reduce the initial set of alternatives in a smallest one.
However, it is worth to note that the number of selected alternatives strongly depends on the threshold values $\underline{c}$ e $\underline{d}$ fixed by the decision maker. For the example under exam, it has been found that when $\underline{c}$ belongs to the interval [0, 0.5] and $\underline{d}$ to [0.5, 0.9], only one alternative (A_1) is selected. For values of $\underline{c}$ and $\underline{d}$ far from this intervals, instead, the number of selected alternatives quickly increase. On the other hand, may be not correct to consider all the possible couple of values $\underline{c}$ and $\underline{d}$ up to find the one that allows to select only one non-dominated solution, especially if this does not lead to fix more severe threshold values for the concordance and discordance tests.

2.2. TOPSIS method
The Technique for Order Preference by Similarity to Ideal Solution or TOPSIS method (Hwang and Yoon, 1981) consists in identifying the best alternative among those in exam as the one having the shortest distance from a so called ideal solution A^* and the farthest distance from a so called negative-ideal solution A^-. Once the decision matrix has been normalized and weighted (as according to the ELECTRE method), A^* is obtained by taking for each criterion the best performance value among all the alternatives whereas the negative-ideal solution A^- is composed by the worst performances. Each alternative A_i (i=1, 2, …, n), A^*, A^- can be geometrically represented as a point in a m-dimensional space where the generic j-th axes measures the weighted normalized performance of that alternative according to criterion C_j (j=1, 2, …, m). Therefore it is possible to calculate the Euclidean distances S_{i*} and S_{i-} of alternative A_i from the ideal and negative-ideal solutions A^* and A^- respectively. Then the method defines relative closeness of alternative A_i to the ideal solution the following ratio $C_i^*=S_i^-/(S_i^-+S_i^*)$, the value of which is included in the interval [0, 1]. For $A_i=A^-$, results $S_{i-}=0$ and then $C_i^*=0$. For $A_i = A^*$, vice versa, $S_{i*}=0$ and then $C_i^*=1$. The final ranking of the alternatives is made by considering the C_i^* value for each one. The best solution is that having the maximum C_i^* value.
In respect to the case-study, the relative closeness of the five alternatives to the ideal one results to be $C_1^*=0.74$, $C_2^*=0.25$, $C_3^*=0.62$, $C_4^*=0.46$, $C_5^*=0.47$, leading to the following final ranking: $A_1 > A_3 > A_5 > A_4 > A_2$ (the symbol ">" stands for "better than").
Although deferring more comments to a final section where all the methods will be evaluated and compared one each other, it is important to observe that TOPSIS seems to be a procedure suitable to the decision problem about the seismic upgrade of under-designed structures since it allows to select only one solution as the "best" one and it is able to manage each kind of variables and each type of criteria.

2.3. PROMETHEE method
The Preference Ranking Organization Methods for Enrichment Evaluations (PROMETHEE, Brans and Vincke, 1985) is based on the comparison of each alternative with each other considering the deviations that alternatives show according to each criterion. Given its structure, the method allows to operate directly on the variables included in the decision matrix, without requiring any normalization. On the other hand, it is needed that each criterion is of the benefit type. This condition is always easily attainable by multiplying to -1 the variable measured according to cost criteria. This has been done for the case-study switching the sign of the elements of the decision matrix corresponding to the cost criteria (all of them except for C_4).
For each criterion C_j (j=1, 2, …, m) a preference function $P_j(A_k, A_p)$ of alternative A_k to A_p has to be defined giving a value between 0 and 1, increasing with the deviation $x=a_{kj}-a_{pj}$ between the performances of A_k and A_p in respect of C_j. A preference function is such that it results $P_j(A_k, A_p)=0$ if $x\leq 0$, whereas $P_j(A_k, A_p)=p(x)$ if $x>0$, given that $p(x)$ is a monotonically increasing function defined in the positive real domain and having values between 0 and 1. A null value of $p(x)=p(a_{kj}-a_{pj})$ means indifference between A_k and A_p from the point of view of criterion C_j. Values of $p(x)$ slightly greater than zero, closer than one or just equal to one mean a weak, strong or strict preference of A_k to A_p respectively. Standard $p(x)$ functions exist, they may be chosen depending on the particular criterion. Each type of function requires a different degree of involvement of the decision maker (DM)

The function type I ($p(x)$=1 for each value of x>0) is the simplest one and does not require any intervention of the DM. The function II, instead, requires the DM fixes the parameter l (such that $p(x)$=0 for $x \le l$ and $p(x)$=1 for $x>l$) that defines the magnitude of the interval of x in which the two alternatives under consideration have to be considered indifferent. The function type III ($p(x)=x/m$ for $x \le m$ and $p(x)$=1 for $x>m$), through the definition of the parameter m, allows the DM expresses a preference of A_k to A_p linearly increasing with the deviation $x=a_{kj}-a_{pj}$, as far as x is smaller than m. For further details about the other, more complex, function types, please refer to Brans and Vincke (1985). Here it is only important to remark that types IV, V and VI require the definition of two (p and q), two (s and r) parameters and one parameter (σ) respectively.
The method was applied seven times to the case-study in order to investigate about the influence on the final result of all the involved parameters and choices. The first three preference function types are considered. For each application the same type of preference function is assumed for all the criteria. The threshold parameters l and m, needed to use preference functions II and III respectively, are fixed here in percentage terms (10%, 25% or 50%) with reference to the maximum gap among the performances of the five alternatives according to the particular criterion under exam.
After alternatives A_k and A_p has been evaluated in respect of each criterion, it is possible to evaluate the so called "preference index" $\pi(A_k, A_p)= \Sigma_j w_j P_j(A_k, A_p)$ where w_j is the weight of the j-th criterion. This index gives a measure of the global preference of A_k to A_p. After doing this for all couples of alternatives, the degree of "strength" (called "positive outranking flow") $\Phi^+(A_k)=\Sigma_p \pi(A_k , A_p)$ of each alternative A_k in respect to the others has to be evaluated whereas its degree of "weakness" is $\Phi^-(A_k)=\Sigma_p \pi(A_p, A_k)$ ("negative outranking flow"). The version of the method generally referred to as PROMETHEE I allows ranking the alternatives according to these rules: A_k is to be preferred to A_p if $\Phi^+(A_k)> \Phi^+(A_p)$ and $\Phi^-(A_k)< \Phi^-(A_p)$; it is indifferent to A_p if $\Phi^+(A_k)= \Phi^+(A_p)$ and $\Phi^-(A_k)= \Phi^-(A_p)$; otherwise A_k and A_p are incomparable.
Only the first application (carried out using the simplest preference function, type I) to the case-study leads to select one solution (A_1) dominating all the others. In all the other cases, at least two are the alternatives that result to be non-dominated by the others and non-comparable one each other. No application leads, instead, to a complete ranking of the alternatives. The influence of the chosen value for the threshold parameters l (for function type II) and m (for function type III) results to be significant. As could be logically forecasted, larger threshold values correspond to a greater indifference field in the comparison between two alternatives and a poorly defined classification.
Very often the PROMETHEE I method leads only to a partial classification of the alternatives. A modified version of the method, referred to as PROMETHEE II, defines a net outranking flow $\Phi(A_k)$ for each alternative as the difference $\Phi^+(A_k)$-$\Phi^-(A_k)$ and ranks the options assuming that A_k is to be preferred to A_p if $\Phi(A_k)> \Phi(A_p)$, indifferent if $\Phi(A_k)= \Phi(A_p)$. In this way, the method always allows ranking the alternatives in a complete manner. Obviously, the best alternative is the one having the greatest value of $\Phi(A_k)$. For the numerical case under exam, the resulting Φ values lead to the same final ranking for each of the seven applications done ($A_1 \rightarrow A_3 \rightarrow A_5 \rightarrow A_4 \rightarrow A_2$), not highlighting any significant influence of the particular chosen preference function and fixed parameters value.

2.4. VIKOR method

This method (*VlseKriterijumska Optimizacija I Kompromisno Resenje*, VIKOR, by Opricovic, 1998) ranks the alternatives A_i (i=1, 2, …, n) according to the value of three scalar quantities (S_i, R_i e Q_i) that have to be calculated for each option. For each criterion C_j (j=1, 2, …, m), the best a_j^* and worst a_j^- performances among all the alternatives firstly have to be determined. Then S_i, R_i and Q_i values have to be assessed as follows:

$$S_i = \sum_{j=1}^{m} \frac{w_j (a_j^* - a_{ij})}{a_j^* - a_j^-} \quad ; \quad R_i = \max_j \left[\frac{w_j (a_j^* - a_{ij})}{a_j^* - a_j^-} \right] \quad ; \quad Q_i = \upsilon \frac{S_i - S^*}{S^- - S^*} + (1-\upsilon) \frac{R_i - R^*}{R^- - R^*} \tag{2.1}$$

where is S^*=min(S_i), S^-=max(S_i), R^*=min(R_i), R^-=max(R_i). The parameter υ is fixed by the decision maker in the interval [0,1] giving a different weight of importance to each addend into the Q_i expression. Practically υ>0.5 is assumed when the decision maker wants to give more importance to the first term and hence to the global performance of the alternative in respect to the whole of the criteria. Using a υ value smaller than 0.5, instead,

gives more weight to the second term that is related to the magnitude of the worst performances exhibit by alternatives in respect of each single criterion. When the two aspects are considered equally relevant, υ=0.5 should be used.
For the case-study, starting from the decision matrix in Table 2, the S_i and R_i values are evaluated (Table 3). It results: S^*=0.198, S^-=0.788, R^*=0.141, R^-=0.280. The Q_i value is determined for each option, assuming υ=0.5.

Table 3 S_i, R_i and Q_i values (υ=0,5) for each alternative

	S_i	R_i	Q_i
A_1	0.198	0.141	0.000
A_2	0.788	0.280	1.000
A_3	0.320	0.152	0.143
A_4	0.565	0.255	0.720
A_5	0.479	0.255	0.648

The method ranks the alternatives according to the Q_i values. The best option (*A'*) is that with the smallest Q_i value, but only if the following two acceptance criteria are both satisfied:
1. "Acceptable advantage"**:** it should be $Q(A'')$-$Q(A')\geq DQ$, where *A''* is the alternative having the second best Q_i value and *DQ* is taken equal to the ratio 1/(*n*-1) depending on the number *n* of alternatives.
2. "Acceptable stability in decision making": *A'* should be the best also in terms of S_i value and/or R_i value.
If one of these conditions is not satisfied, it is not possible select directly the best solution of the set but a subset of preferable options can be defined, including in it *A'* and *A''*, if only the second condition is not satisfied, or *A'*, *A''*, …, $A^{(N)}$ if the first condition is not satisfied, being $A^{(N)}$ the last option, in the ranking done by Q_i, for which it still results $Q(A^{(N)})$-$Q(A') < DQ$.
According to the Q_i values in Table 3 relative to the numerical example, the following classification is obtained: $A_1 > A_3 > A_5 > A_4 > A_2$. The evaluation of Q_i values is done again each time assuming a different υ value in the interval [0, 1] in order to investigate the actual influence of such a parameter on the results. The final ranking resulted to be independent from the chosen υ. This is due to the fact that the classifications obtained considering only the term $(S_i-S^*)/(S^- -S^*)$, accounting for the global satisfaction of criteria, and only the term $(R_i-R^*)/(R^- -R^*)$, accounting for the worst performance of each alternative in respect to the single criterion, are the same.
Since, for υ=0.5, it results $Q(A_3)$-$Q(A_1)$=0.143 less than *DQ*=1/(5-1)=0.250, the first criterion of acceptability is not satisfied. In other words, considering the relatively small number of alternatives, the final score of solutions A_1 and A_3 are judged to be too much close and it is not possible to distinguish the best one between the two. Therefore, even if the second criterion is satisfied (A_1 is the best one also in terms of S_i only and R_i only), the final result of the VIKOR method consists in indicating the subset A_1, A_3 as a group of compromise solutions. Applying again the method excluding the A_2 alternative from the group leads to the ranking $A_1 > A_3 > A_5 > A_4$ with both the acceptability criteria satisfied, finally individuating A_1 as the best solution.

3. RESULTS AND DISCUSSION

Informations about the applicability of each above examined MCDM method to the seismic retrofit decision problem are resumed in Table 4. All the four methods result to be usable for the peculiar decision problem. With reference to the case-study considered herein, the results in terms of ranking of alternatives each method leads to are also indicated.

Table 4 Applicability of the examined MCDM methods to the seismic retrofit decision problem. Case-study results.

Method	Applicable?	Classification				
TOPSIS	Yes	A_1	A_3	A_5	A_4	A_2
ELECTRE	Yes	A_1 to be preferred				
VIKOR	Yes	A_1 and A_3 to be preferred				
VIKOR (w/o A_2)	Yes	A_1	A_3	A_5	A_4	-
PROMETHEE I	Yes	Partial ranking				
PROMETHEE II	Yes	A_1	A_3	A_5	A_4	A_2

In the following, useful comments about the examined MCDM methods are reported, addressing to understand which one is more suitable to solve the decision task under exam. Starting from ELECTRE, it has been seen that a positive feature of the method consists in the capability to manage non-homogeneous variables and different types of criteria, like the ones occurring in a problem about the selection of the upgrade strategy for a given structure. However, it often does not lead to the definition of only one solution emerging among the others, individuating a subset of solutions to be preferred. Moreover, applying again the method with reference to this subset does not lead to better results. For this reason, the method is considered generally more suitable for decision problems characterized by not many criteria and several alternatives allowing to individuate a small subgroup of preferable options. The problem inherent the seismic retrofit is unlikely one of these. Furthermore, the results given by ELECTRE are generally strongly dependent on the threshold $\underline{c}$ and $\underline{d}$ values fixed by the decision maker. Therefore, in the final step of the procedure a decisive influence of the DM's personal choices occurs. It is also not ensured that using bigger value of $\underline{c}$ and lower value for $\underline{d}$ leads to select a small number of non-dominated solutions, as one logically could expect. For the above reasons, authors do not suggest the ELECTRE method as a preferable tool to solve the decision task under exam.
The structure of PROMETHEE I and II methods allows a direct application to the seismic retrofit decision problem, not requiring the normalization of the variables in the decision matrix. It only requires that all the criteria are benefit type. When this condition is not satisfied (as in the considered case-study), the methods allow to equally satisfy it simply by changing the sign of all the performance values relative to the cost type criteria, without affecting the results. These methods are easily adaptable to each kind of conditions. They allow to associate a different preference model to each criterion, suggesting to use one of six preference functions, different for their degree of complexity and involvement of parameters to be fixed by the DM. As far these parameters are concerned, it is important to underline that they are always easily understandable and have clear practical effects so that the DM may fix them according to logical considerations. On the other hand, as the numerical example confirms, it is worth remembering that PROMETHEE I is essentially addressed to give only a partial ranking of the alternatives. Actually often two or more options result to be non-comparable one each other. This fact discourages the actual use of PROMETHEE I for the specific problem under exam, which has the only purpose of individuating the best retrofit solution among a predefined set. The version II of the method was ideated just as an evolution of the version I aimed at giving a complete ranking of the alternatives. It always allows to compare each pair of alternatives, independently from the particular operating conditions. Conversely, by taking the difference of the positive and negative outranking flows, it leads to less a significant piece of information.
The TOPSIS and VIKOR methods, among those considered, seem to be the most suitable for the decision problem regarding the seismic retrofit of structures. They allow to use variables with different units of measure and criteria of different type. If applied starting from previously evaluated decision matrix and criteria weights, these methods lead to the final result almost without requiring the DM's intervention (except for the definition of the υ parameter of the VIKOR method). They approach to the decision problem in a similar manner: both define, explicitly or not, an ideal solution ad-hoc combining the best performances of the alternatives according to each criterion. They both assume the "distance" of the generic alternative to the ideal one as a partial measure of the desirability of that option, but the VIKOR method leads to the ranking also considering the degree of satisfaction of each single criterion and, by adopting the coefficient υ, it allows to give a different weight to the global performance to the whole of criteria and the individual response to the single criterion. The TOPSIS method, instead, considers, together with the distance from the ideal alternative, also the distance from a so called negative-ideal option obtained combining the worst performances of alternatives in respect to the single criterion. The VIKOR method checks whether the first ranked alternative can be considered "better enough" than the others by checking if the second alternative is far enough from the first, and if the best alternative in terms of Q_i results to be the best also in terms of global performance in respect to the whole of criteria only (S_i) and/or in terms of the performance offered to each single criterion (R_i). If these tests are not passed, the first ranked alternative cannot be defined the best in absolute terms but, together with some of the following ones, composes a subgroup of options to be considered preferable to the remaining ones. TOPSIS, instead, does not include such checks of acceptability for the obtained results, but, since the simplicity and flexibility of use, the easily understandable procedure based on the geometric representation, it has to be considered one of the most recommended MCDM methods for solving a complex decision problem like that under exam.

4. CONCLUSIONS

In the case of managing an existing building to be upgraded to resist seismic actions, the problem of selecting the best way to do it occurs. The achieved structural performance actually may not be adopted as the sole criterion to choose the best retrofit solution. Several other technical, social, and economical aspects the practitioner has to deal with. MCDM methods clearly may help in the matter, although the large literature on the topic does not allow to determine easily which procedure is the more appropriate. The presented study compares four well-known decision methods to a specific case-study. In particular, the paper investigated the actual applicability and effectiveness of them for the focused task. The study pointed out limits, advantages and disadvantages related to the application for the specific particular decision problem of the selected methods.
PROMETHEE I method has a clear approach to the decision problem and a degree of complexity depending on how the decision maker wants to model the preference function according to each criterion, but the method very often does not lead to a complete ranking of alternatives, actually not solving the given problem. The version II of the same method, instead, always allow a complete ranking of options, but it requires a manipulation of the available informations that not always has a logical meaning.
Given their flexibility of use and the general validity of the principles governing their procedures, the ELECTRE, TOPSIS and VIKOR methods can easily applied to solve the considered problem. Nevertheless ELECTRE often is not able to give a complete ranking of the alternatives rather selecting a subset of options to be considered preferable to the remaining ones. The strong and often decisive influence of some parameters to be fixed by the decision maker and the scarcity of rational criteria useful to set them represent further aspects of the ELECTRE method that discourage to use it for the seismic retrofit decision problem. The other two methods, TOPSIS and VIKOR have many common aspects in their general approach, also being different for the possibility that the second one gives to explicitly account for the degree of satisfaction of a single criterion besides the global performance to the whole of criteria and for the double check of acceptability for the final solution VIKOR imposes. These two methods are the most suitable to the decision task involving the selection of a retrofit solution for a given structure, since their capability to deal with each kind of judgement criteria and variables, the clarity of their results and the reduced effect of the decision maker's subjective point of view.

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REFERENCES

Brans, J. P. & Vincke, P. (1985), A Preference Ranking Organization Method (The PROMETHEE Method for Multiple Criteria Decision Making), *Management Science* **31**(6): 647 – 656.

Caterino N., Iervolino I., Occhiuzzi, A., Manfredi G. & Cosenza E. (2007), Dissipazione passiva nella selezione dell'intervento di adeguamento sismico di un edificio in c.a. mediante analisi decisionale, *L'Ingegneria Sismica in Italia – XII Convegno Nazionale dell'ANIDIS*, Pisa, Italy.

Caterino, N., Iervolino, I., Manfredi, G. & Cosenza, E. (2008), Multi-Criteria Decision Making for Seismic Retrofitting of RC Structure, *Journal of Earthquake Engineering*, 12: 1-29.

Fardis, M.N. & Negro P. (2005), Seismic Performance Assessment and Rehabilitation of Existing Buildings, *Proceedings of the SPEAR International Workshop*, Ispra, Varese, Italy.

Hwang, C.L. & Yoon, K. (1981), Multiple Attribute Decision Making, *Lecture Notes in Economics and Mathematical Systems 186*, Springer-Verlag: Berlin, Germany.

OPCM 3431 (2005), Ordinanza del Presidente del Consiglio dei Ministri, *Ultime modifiche ed integrazioni all'Ordinanza n. 3274 del 20 marzo 2003*, Roma, Italy.

Opricovic, S. & Tzeng, G.-H. (2004), Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS, *European Journal of Operational Research*, 156(2): 445-455.

Opricovic, S. (1998), *Multicriteria Optimization of Civil Engineering Systems*, Faculty of Civil Engineering, Belgrade, Serbia.

Roy, B. (1968), Classement et choix en présence de points de vue multiples (la méthode ELECTRE), *Revue Francaise d'Informatique e de Recherche Opérationelle* 8, 57-75.

Saaty, T.L. (1980), *The Analytic Hierarchy Process*, McGraw-Hill, New York, NY, USA.