MULTI-CRITERIA APPROACH FOR SEISMIC RISK MITIGATION ANALYSES

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ABSTRACT

Recent developments of viable and low-cost seismic retrofit solutions within a performance-based approach, suggest the possibility to implement "standardized" solutions at a regional scale. However, different and complex criteria should be considered in order to define the most effective retrofit strategy able to minimize the overall risk. First of all, the feasibility of the intervention should be investigated accounting for the actual limits of the available resources, e.g. financial, physical or human, which could represent a critical constraint for a large scale intervention. Secondly, it should be taken into account that the benefits and costs associated with seismic risk mitigation strategies might have different impacts onto the local and regional economy, while affecting a wider variety of stakeholders, if not a substantial portion of the society as a whole. In this contribution, a multi-criteria approach is proposed as a valuable tool to select an effective retrofit strategy while accounting for both monetary and non-monetary-based criteria. The effectiveness of alternative retrofit options is assessed on a case study area using a multi-criteria approach and compared with the results from a more standard cost-benefit approach.

Keywords: Seismic Risk, Retrofit, Territorial Scale, multi-criteria approach

INTRODUCTION

Valuable and efficient seismic strengthening/upgrading techniques have been developed in the recent past and implemented on real buildings. Latest developments of viable and low-cost retrofit solutions for existing buildings within a multi-level retrofit strategy approach, suggest the possibility to implement "standardized" solutions at a urban or territorial scale.

Nevertheless, the decision to set a large scale retrofit strategy is still neither straightforward nor obvious. When in fact expanding the scale of the intervention (and analysis) to a territorial level (city, region, country), more complex criteria and intervention strategies should be considered and evaluated in order to define the most effective action plan to minimize the overall risk. In particular, the actual limits of available resources, including budget, material, human and technical resources, logistics and supporting infrastructures, can represent the critical constraints for a large scale intervention.

Mitigation analyses, although not yet codified, are expected to become in the near future a fundamental decision making tool for the allocation of funds by local authorities. A typical outcome of such analysis are : a) Prioritizing mitigation actions; b) evaluation of cost-effectiveness of the overall mitigation strategy.
Traditional cost-benefit analyses, balancing the structural requirements and associated benefits versus the costs, can be successfully implemented to support decision-makers when dealing with seismic retrofit of single structures. However, difficulties for the implementation of such analyses may arise when dealing with an intervention at urban or territorial scale, due to: 1) the fact that a unique solution can hardly satisfy at the same time multiple criteria which combine technical and social aspects; 2) the difficulties in reliably quantifying social and societal criteria.

In this contribution, after a brief introduction to the basic concept of Multi-Criteria Decision Analysis, MCDA, the feasibility of adopting a multi-criteria approach is investigated and proposed as a valuable tool to account for both monetary and non-monetary aspects when planning the implementation of retrofit strategies at territorial scale for the mitigation of the seismic risk. The enhanced capability of a multi-criteria approach in identifying the most suitable seismic mitigation strategy, based on strengthening/retrofit, is discussed and compared to a more standard cost-benefit analysis. A practical example will be provided via the implementation of both a GIS-based cost-benefit analysis and of a MCDA to a case study region in Western Liguria Region, Italy.

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ALTERNATIVE RISK MITIGATION ANALYSIS AND DECISION CRITERIA

Benefit-Cost Analyses (BCA) are a viable tool to support the decision making related to seismic mitigation intervention. It is worth noting that BCA are themself a broader group with several subcategory depending on the selection of the output parameters adopted to present the results, i.e benefit/cost ratio, benefit minus cost, deterministic net present value (maximization of net revenues).

Whitin a PSHA (Probabilistic Seismic Hazard Analysis), a stochastic Benefit-Cost Analysis (SBCA) can be implemented. In this case, the results are typically presented in ther form of exceedance probability curves, commonly summarised in terms of Expected Annualised Losses, EAL, measuring the average yearly amount of loss (a measure widely adopted by insurance company). However, it has been noted (Smith and Vignaux 2006) that in spite of being widely adopted by insurance companies, EAL is a very limited measure, not always applicable in some areas of risk management, as annualised risks may appear small and give the wrong impression of risk due to a single event.

Life-cycle cost analyses (LCCA), also commonly used in the evaluation of seismic mitigation strategies, can be properly seen as a subcategory of the broader group of BCAs, with simply a different way of presenting the results. Similarly, a cost-effectiveness analysis can be seen as a further subcategory of the BCAs. In this latter case it is assumed that a policy decision regarding the main goals/objectives driving the implementation of action-plan has already been made (i.e. targeted budget, maximum acceptable downtime) and that the only matter to resolve is the best way of meeting the specific targets. As an example of a cost-effectiveness approach, the PBEE (Performance-Based Earthquake Engineering) methodology, developed at PEER by Cornell and Krawinkler (2000) has been implemented targeting either the minimisation of the expected annual loss, EAL (Hamburger 2004), or ensuring that the probability of exceeding structural limit states, or other socio-economical parameters, is lower than a specific acceptable value (Krawinkler et al. 2004).

When multiple performance targets are defined within a mathematical model, a reliability-based optimization process can be implemented to evaluate the optimum value of a vector-based parameter, for which the retrofit intervention is financially feasible. This approach would rely upon the use of a general objective functional, written in the form of the expected losses, or ultimately of the global seismic risk to be mitigated and an optimation process to obtain the solution.

As highlighted by Zerbe and Falit-Baiamonte (2001), BCAs and cost-effectiveness approaches in general should be implemented within a national perspective, taking into account that the benefits and the costs associated with performance-based earthquake engineering decisions will affect to differnt extent a wide variety of parties, or stakeholders: such as the owner(s) of the buildings, the user(s)/tenant(s) of the buildings, the local economy, the regional economy, and the "society". For this reason, societal indicators of damage should be added to the analysis, (such as the liability resulting from injuries and casualties), and should be quantified in monetary terms (translating, if necessary, qualitative terms into crisp numbers). Being such an approach often criticized on moral grounds, an alternative approach typically consist of separately evaluating and accounting for such societal indicators, without expressing them in monetary terms. The benefits associated to the mitigation strategies would thus comprise of "monetary" figures as well as non-monetary translated social indicators.

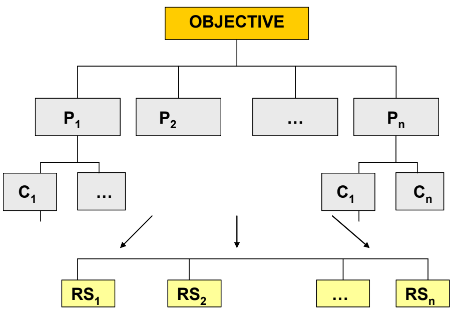
A MULTI-CRITERIA DECISION ANALYSIS APPROACH

When operating at a territorial scale, the evaluation of the overall (city council, region, country as well as inter-country) economical impact of an earthquake event and associated benefits, if a pre-damage strengthening intervention is carried out, become a much more complex task. The reconstruction/repairing costs and time, for example, of the single building after a major event shall be evaluated considering the whole picture. The limited amount of operational funds, lack of material, human and technical resources to implement the repairing/strengthening operations, as well as the delay due to production and transportation difficulties (due to damage to critical infrastructures), will play a major role either in the case of a pre-event retrofit intervention and/or in the case of a post-disaster reconstruction. In the latter scenario, the overall resilience of the society will determine the capacity and speed of recovery.

When multipe decision criteria, mixing technical and social aspects, (costs, time, structural performances, architectural impact, occupancy disruption, etc.) need to be addressed, the identification of the most suitable mitigation strategy is not straightforward due to: 1) the fact that maybe no solution satisfying all criteria simultaneously can be achieved; 2) the difficulty in numerically quantifying social and societal criteria.

Multi-criteria decision analysis (MCDA), is a dynamic process in which both management and engineering levels can be distinguished. The management level defines the goals and chooses the final ''optimal'' solution amongst several technically-sound alternative options proposed by engineers.

The basic steps for the implementation of MCDA include the identification of the decision-makers DM (or group of Decision-Makers, here referred to as DMs) involved in the decision-making process, along with their preferences, and the statement of the objective or a set of objectives the decision makers attempts to achieve. Secondly, the main objectives are decomposed into a hierarchy of evaluation criteria, Cj and decision alternatives, Ai, (herein referred to as alternative retrofit solution RSi), and the relationships between the main criteria Cj, and the alternatives RSi are clarified (Fig. 1a). Pairwise comparisons among the decision elements (criteria and sub-criteria) are judged by the DMs and an evaluation function is assumed in order to estimate the relative weight of the decision elements. Finally the set of outcomes or consequences associated with each alternative-criterion pair, namely the performance measure RSiCj of the i-th retrofit alternative, is evaluated and arranged in terms of the so- called Decision Matrix D=[RSiCj] (Fig. 1b).



		Retrofit Cost (€)	Downtime (days)	Life losses (N)	……
		C_1	C_2	C_3	C_n
No intervention (As Built, AB)	RS_1	RS_1C_1	RS_2C_1	RS_3C_1	…
Partial Retrofit (PR)	RS_2	RS_1C_2	RS_2C_2	…	…
Total Retrofit (TR)	RS_3	…	…	…	…
……	RS_n	…	…	…	RS_nC_n

Figure 1. Features of a MCDA: a) decision criteria Cj and alternatives RSi represented in term of a decision tree; b) decision matrix D=[RSiCj]

In this paper, the aforementioned steps have been implemented according to one of the more widely adopted MCDA process, the Analytic Hierarchy Process, AHP, proposed by Saaty (1980).

The TOPSIS technique (Technique for Order Preference by Similarity to Ideal Solution) proposed by Hwang and Yoon (1981), has been adopted as a decision rule (or combination rules) for selecting the most appropriate alternative from the decision matrix.

It is worth noting that a fuzzy set theory (Ross 1995) can be implemented within a MCDA to represent the fuzziness and vagueness inherently associated to any human decision-making process. However, for the sake of an easier understanding of the overall procedure, crisp numbers will be adopted in this paper, while the implementation of a fuzzy multi-criteria approach for multi-level performance-based retrofit will be proposed in future publications.

Evaluation Criteria

A set of eleven evaluation criteria is herein suggested. They are organised under three major perspectives of the seismic risk reduction, namely to guarantee: 1) a sustainable retrofit intervention, 2) an effective emergency management and 3) a resilient post-earthquake reconstruction. An attempt has been made to propose comprehensive, non redundant (avoiding double-counting of decision consequences), measurable (both qualitative and quantitative) and operational criteria trying to cover the main aims of a seismic retrofit intervention at territorial scale.

It is worth underlying that the evaluation criteria herein proposed are not intended to be exhaustive and are mainly proposed to facilitate a scientific discussion of the problem. Refinements could, for example, be achieved by liaising with local decision makers confronted with a simulated earthquake scenario exercise.
A summary of the assumed criteria is given below. More details on the quantitative evaluation process can be found in Giovinazzi and Pampanin (2007).

<u>Sustainable Retrofit Intervention (SRI) Perspective</u>
C1 = installation cost (fuzzy or crisp number, in □/m2). This criterion represents the total cost for the practical implementation of each alternative, including the required materials and labour.

C2 = disruption of use (qualitative relative parameter). This criterion represents the total duration of the retrofit intervention from the required demolition to the completion, considering all phases of the intervention.
C3 = incremental rehabilitation (qualitative relative parameter). This criterion represents the feasibility of reaching the targeted goal (e.g. the correction of the priority deficiencies as soft-storey, etc.) through an incremental rehabilitation, which phases the interventions over a period of several years, and, whenever feasible, timed to coincide with regularly scheduled repairs, maintenance, or capital improvements.

Effective Emergency Management (EEM) Perspective
The quantification of all the following emergency management criteria have to be evaluated via the implementation of either deterministic or stochastic GIS-based damage scenario analysis.
C4 = amount of debris (damage scenario-based quantitative parameter [tons x 103]). This criterion represents the amount of debris due to structural and non structural damage of buildings
C5 = trapped people (damage scenario-based quantitative parameter, number). This criterion represents the number of people requiring the intervention of SAR (Search and Rescue) teams. It can be evaluated as a function of the number of people living in collapsed building
C6 = injured people (damage scenario-based quantitative parameter, number). This criterion represents the number of people requiring healthcare assistance. It can be evaluated as a function of the number of people living in building that have sustained heavy damage and collapse according to the statistical correlation avaliable for the given region on the basis of data from recent earthquakes.
C7 = homeless people (damage scenario-based quantitative parameter, number). This criterion represents the number of people requiring temporary shelter. It can be evaluated as a function of the number of people living in building that have sustained severe damage to collapse.

Resilient Reconstruction (RR) Perspective
C8 = Earthquake costs (damage scenario-based quantitative parameter, number in M□). This criterion represents the earthquake costs limited to the building reconstruction costs, and the costs sustained for the injuries, the casualties (and the relocation of homeless people. A regional economic impact in terms of direct and indirect economic effects should also be accounted for.
C9 = Reconstruction feasibility (damage scenario-based quantitative parameter, crisp number). This criterion represents the estimated duration (in number of day) of the physical restoration. Material availability, skilled labour required should be as well included.
C10 = Acceptability by the local public (damage scenario-based quantitative parameter, number). This criterion tries to quantify the expected social aspects connected with the permanent relocation, the loss of memorabilia and properties. Reference should be made to the research in the field of social-science for the quantification of this criterion.

Weighting the retrofit perspectives and the evaluation criteria

Importance weights w_k are introduced to measure the relative importance when considering the perspectives and the (qualitative and quantitative) criteria Cj, described above. The importance weights w_k are key factors in the process of multi-criteria decision making, as are the ones reflecting the decision maker's experience, judgment and preference in the framework of the MCDA approach.

The fundamental input to the AHP is the DMs informed judgment to pairwise comparisons. DMs responses to the set of questions "How important is criterion A relative to criterion B?" are gathered in verbal form and subsequently codified according to a nine-point scale (Tab. 1) and finally organised in terms of a pairwise comparison matrix C=[aij].

The number in the ith row and jth column, corresponding to the element aij of the pairwise comparison matrix C=[aij] represents the relative importance of the criterion ci as compared with the criterion cj. as follows: aij=1 if the two objectives are equal in importance; aij=3 if ci is weakly more important than cj; aij=5 if Ci is strongly more important than cj; aij=7 if ci is very strongly more important than cj; aij=9 if ci is absolutely more important than cj. As aij=1/aji and aii=1, decision makers are requested to assign n(n-1)/2 judgements being n the number of criteria accounted for in the decision process.

Table 1. Rating scale assumed for the hierarchy process AHP pairwise comparison.

Less important									Equally Important	More important								
Extremely		Very Strongly		Strongly		Moderately					Moderately		Strongly		Very Strongly		Extremely	
..	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9	..

Within the AHP approach the importance weight w_k are evaluated according to (Saaty, 1980) applying the eigenvalue theory to the pairwise comparison matrix $C=[a_{ij}]$. The weights are evaluated as the element in the eigenvector associated with the maximum eigenvalue on the matrix:

$$C\left[a_{ij}\right]W = \lambda_{max} W \quad (1)$$

where W is the eigenvector, referred to as the weight vector, of the matrix C=[aij] and λmax is the largest eigenvalue of C=[aij].

In order to ensure the consistency of judgments in the pairwise comparison, the consistency ratio CR is evaluated, defined by Saaty (1980) as:

$$CR = \frac{1}{RI}\left(\frac{\lambda_{max} - n}{n - 1}\right) \quad (2)$$

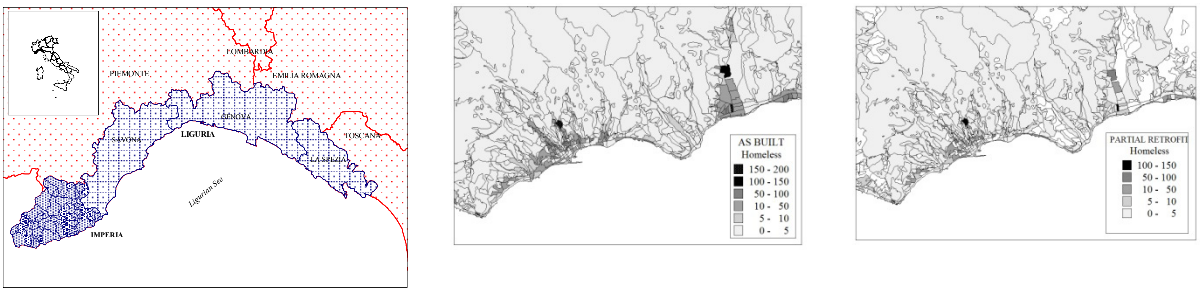
where n is the number of items being compared in the matrix and RI is a random index, the average consistency index of randomly generated pairwise comparison matrix of similar size. The upper threshold values consistency index CR have been evaluated by Saaty (1994) as follow: CR=0.05 for matrices C3x3, CR=0.08 for matrices C4x4, CR=0.1 for matrices larger than C4x4. If CR overcome the upper threshold, the preference assignment need to be revised.

IMPLEMENTATION OF ALTERNATIVE MITIGATION ANALYSES TO A CASE-STUDY AREA

The efficiency of alternative retrofit interventions at territorial scale is investigated and evaluated by means of the aforementioned mitigation analysis (either BCA or MDCA) on a case study area, identified with Western Liguria, Italy (Fig. 2a).

The building vulnerability and the expected consequences of an earthquake in this area have been examined as part of an Italian National research project for the definition of Earthquake scenario and strategies for the preservation of historic centres funded by the INGV-GNDT (2004).

The majority of population lives in RC buildings (60% out of the total 211,349 inhabitants living in RC buildings), mostly designed prior to 1971 (56%). Focusing on the characteristics of pre'71 buildings, the majority are low-rise buildings (59% 1÷2 floors, 33% 3÷5 floors, only 9% >5 floors) and a not negligible part is prone to soft-storey mechanisms (18%) having infills present only in the upper storeys. The highest concentration of pre'71 buildings is in the costal area where soil amplification effects can be expected. More details on the inventorying of the bulding stock can be found in INGV-GNDT (2004).



a) *b)* *c)*

Figure 2. Loss estimation on the study case region Western Liguria, Italy: a) study area (Imperia County); b) homeless people expected for as built conditions before retrofitting; c) homeless people expected after a partial retrofit intervention.

A capacity spectrum-based developed for European building typologies and calibrated on the basis of a macroseismic vulnerability method and observed damage data (Lagomarsino and Giovinazzi 2006) within the Risk-EU project (2004) has been adopted for the representation of the seismic behaviour of pre-1971 RC buildings.

According to a multi-level performance-based retrofit strategy, two levels of upgrading plus a "do nothing" option are considered in this contribution: 0) No Action–As Built condition (AB); 1) Partial Retrofit (PR); 2) Total Retrofit (TR).

Partial (PR) and total (TR) retrofit intervention have been represented within the same capacity spectrum-based vulnerability method by properly specifying the upgrading factors for the capacity-curves (Giovinazzi et al. 2006), based on results from recent numerical and experimental investigations.

In the deterministic damage scenario analysis, the maximum historical event in the region has been assumed, corresponding to the Western Liguria Feb 23, 1887 earthquake (M=6.3) which caused over 509 victims, severe destruction in costal towns and villages. The expected consequences to buildings and people (Fig. 2b,c) and the relative costs have been evaluated for alternative retrofit strategies.

Table 2 summarises the expected outcomes in terms of net Present Value, NPV, assuming alternative retrofit strategies for the study case, as resulting from a previous implementation (Giovinazzi and Pampanin 2007). The Net Present Value, NPV,has been evaluated at different periods (1-50 years) assuming a discount rate of 4%.

It can be highlighted that the hypothesis to retrofit the total stock of the pre'71 buildings would be economically inconvenient either in the case of a partial or a total retrofit intervention regardless of the time frame considered. On the other hand, retrofit interventions restricted to the most vulnerable pre'71 R.C. building typologies (i.e. pilotis buildings) are shown to be effective from a cost-benefit point of view. Similarly as partial retrofit solution localized within targeted areas seems to be a valuable solution even in a medium term plan. A partial retrofit together with an adequate selection of the spatial distribution of the retrofit intervention can thus result into an attractive cost-effective intervention when initial constraints due to limited budget/resources have to be accounted for.

Furthermore, as expected, in all cases, the longer the period prior to the occurrence of the earthquake event, the more negligible are the direct benefits (until they becoming negative) of a retrofit intervention as highlighted by a basic cost-benefit analyses.

It is clear, from all the above considerations, how additional socio-political criteria have to be considered when analysing the validity of territorial scale mitigation strategies.

Table 2. Cost-benefit analyses of alternative retrofit solutions (Giovinazzi and Pampanin 2007)

Retrofit interventions		<'71 all			<'71 pilotis only			localized <'71 pilotis only		
		AB	PR	TR	AB	PR	TR	AB	PR	TR
Benefits minus Costs (NPV)	1 year	-	-436	-1296	-	75	61		27	26
	10 years	-	-571	-1313	-	4	-32		17	15
	20 years	-	-662	-1324	-	-43	-95		9	7
	50 years	-	-793	-1340	-	-112	-186		-1	-4

Acknowledging the limitation of a BCA, a practical implementation of the proposed MCDA has been carried out on the case study area.

A pairwise comparison matrix P has been first of all generated in order to assess the priority weight of the three different seismic retrofit perspectives considered (as defined above), namely: Sustainable Retrofit Intervention, SI, Effective Emergency Management, EEM, and Resilient Reconstruction, RR.

The maximum eigenvalue $\lambda max = 3.033$ has been calculated according to Eq. 1 and the consistency property of the matrix has been checked by evaluating the Consistency Ratio (as per Eq. 2) resulting in CR= 0.028. The perspectives eigenvector W_P of P results in the sought weight w_{SI}, w_{EEM}, w_{RR} (Eq. 3), referring to the aforementioned perspectives SI, EEM and RR, respectively:

$$W_P = \{w_{SI}, w_{EEM}, w_{RR}\} = \{0.11, 0.31, 0.58\} \quad (3)$$

Following the same procedure adopted for the evaluation of the perspective weights, the relative importance weights w_k for both qualitative and quantitative criteria Cj assumed as performance indicators of the three seismic retrofit perspectives have then been evaluated considering a sample area within the study region (Fig. 3).

Figure 4 shows the values of the importance weights w_i resulting from three pairwise comparisons matrixes built for: sustainable retrofit intervention criteria C_{SI}[3x3]; effective emergency management, C_{EEM}[4x4] and resilient reconstruction C_{RR}[3x3]. The resulting consistency ratios for the three matrices result respectively in CR_{SI}= 0.028, CR_{EEM}= 0.072, CR_{RR}= 0.01. In the simulated case study, the Resilient Reconstruction, RR with a priority weight of 0.59, is the most important perspective for a seismic retrofit intervention at a territorial scale, following by Effective Emergency Management, EEM, with a priority weight of 0.33.

P =

	SI	EEM	RR
SI	1	1/3	1/5
EEM	3	1	1/3
RR	5	3	1

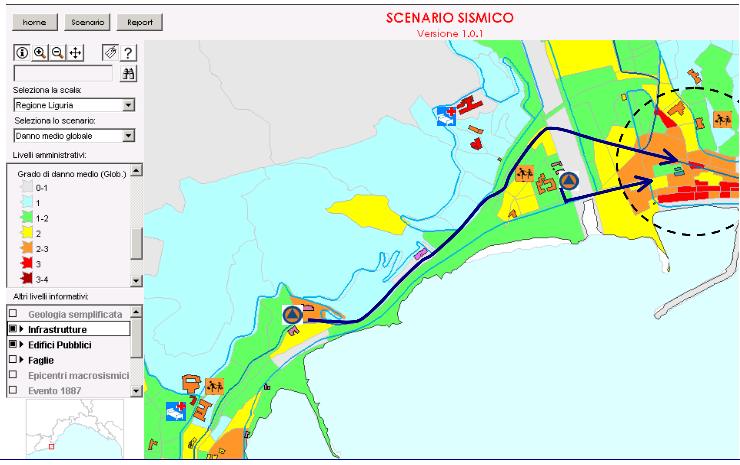


Figure 3. Implementation of MCDA to the study case: a) pairwise comparison matrix for the assessment of the perspectives priority weights; b) GIS-based assessment of the criteria in the sample area

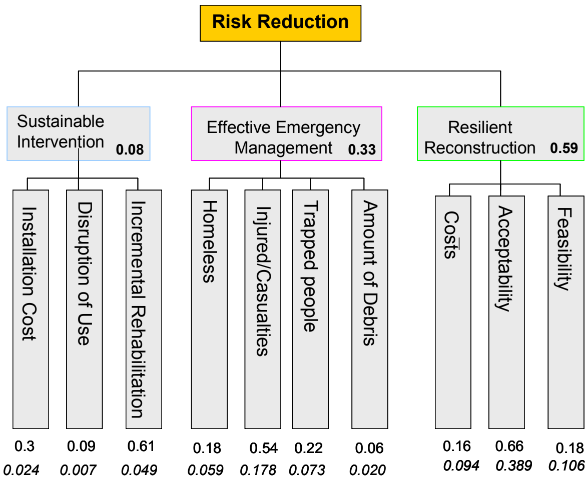


Figure 4. Hierarchical structure in terms of perspectives and criteria for a seismic retrofit intervention at territorial scale and values of: a) priority weights for the perspectives; b) priority weights of the criteria under the same perspective; c) relative priority weights of the criteria among all the criteria (in italic).

According to this analysis, the ''acceptability of the reconstruction'' appears as the most important criterion overall (0.389), with a weight of 0.66 within the Resilient Reconstruction perspective. This means that, according to this analysis, a crucial feature of the seismic retrofit intervention at a territorial scale would be to speed up the reconstruction process. 'Limitation of injuries and casualties'' results as the most important criterion within the Effective Emergency Management, EEM perspective with a priority weight of 0.54 and ranks the second position overall (0.178). The third most important criterion is the ''reconstruction feasibility'' with an overall score of 0.106, followed by the ''reconstruction costs' (0.094). It is worth noting that although the financial issues, namely the retrofit installation costs, are usually emphasized as the discriminating parameter while planning for a retrofit intervention, according to this MCDA implementation they appear in a relative low rank among all indicators (0.024).

It is also worth observing that, according to the hierarchical structures assumed in terms of three main perspectives and performance criteria, a cost-benefit analysis would be an extreme case of a MCDA, corresponding to the following perspectives eigenvector WP={1, 0, 1}. The performance criteria eigenvector for the sustainable intervention, SI and for the resilient reconstruction, RR would therefore be WSI={1,0,0}, and WRR={1,0,0} representing, respectively, the cost of the retrofit intervention and the benefits due to the reduction of the earthquake costs.

Ranking the alternative retrofit solutions

The set of outcomes or consequences associated with each ith retrofit solution and jth criterion pair (with i=1÷3 and j=1÷10), namely the performance measure RSiCj have been evaluated and arranged within a decision matrix D=[RSiCj] as shown in Table 3.

Table 3. Decision matrix $D=[R_{SiCj}]$

		SI			EEM				RR		
		Installation Cost [M□]	Disruption of use [Q]	Incremental rehabilitation [Q]	Debris [thousand Ton]	Trapped [N. people]	Injured [N. people]	Homeless [N. people]	Reconstruction Costs [M□]	Reconstruction Feasibility [N day]	Reconstruction Acceptability [N buildings]
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Retrofit Alternative	A1=AB	0	0	0	18	53	79	6129	592	1102	174
	A2=PR	815	0.17	0.87	10	13	20	2999	386	592	67
	A3=TR	4095	0.83	0.13	8	7	10	2182	1426	452	44

The performance measures RSiCj have been evaluated with to the damage scenario, with the exception of the qualitative criteria under the reduction category, namely the "disruption of use" and the "incremental rehabilitation" (criteria C2 and C3 in Table 3) that have been translated in terms of crisp number on the basis of expert judgments. After normalising the RSiCj values, the decision matrix D=[RSiCj] has been weighted by multiplying the original matrix by the relative priority weight vector {wk}, obtaining the matrix D*=[RSiCj]·{wk} shown in Table 4.

Table 4. Normalised and weighted decision matrix $D^*=[R_{SiCj}]\cdot\{wk\}$: anti-ideal and ideal solution according to the TOPIS method (Hwang and Yoon, 1981)

	Intervention Sustainability			Effective Emergency Managent				Resilient Recostruction		
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1=AB	0.000	0.000	0.000	0.030	0.121	0.049	0.010	0.023	0.197	0.06
A2=PR	0.012	0.005	0.010	0.046	0.030	0.012	0.005	0.015	0.106	0.02
A3=TR	0.059	0.024	0.001	0.014	0.016	0.006	0.003	0.055	0.081	0.02
Anti-ideal	0.059	0.024	0.000	0.046	0.121	0.049	0.010	0.055	0.197	0.064
Ideal	0.000	0.000	0.010	0.014	0.016	0.006	0.003	0.015	0.081	0.016

The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) proposed by (Hwang and Yoon, 1981) has been then used to identify the most appropriate alternative, by evaluating the shortest distance from an ideal solution and the longest distance from the worst possible (anti-ideal) solutions (corresponding to the best and the worst performance value in Table 4, respectively, according to each criteria). Each criterion would thus reach its minimum or maximum possible value, for the ideal and anti-ideal solution, respectively. The only exception occurs for the criterion C3 (incremental rehabilitation) where the maximum value represents the ideal solution whilst the minimum value corresponds to the anti-ideal one. The Euclidean distance for each ith alternative retrofit solution RSi from the ideal and anti-ideal solution are shown in Table 5 and indicated as Di and Di-, respectively. Shown in the same Table 5 is also the closeness coefficient CCi (known also as relative closeness), evaluated as the distance to anti-ideal solution divided by the sum of the ideal and anti-ideal solutions (Table 5). According to the TOPIS method, the best alternative is the one with the largest value WHICH ONE and then with the shortest distance from the ideal solution.

Table 5. Euclidean distances from the alternative i-th to the ideal Di and to the anti-ideal Di- solution and closeness coefficient CCi.

	Di	Di-	CCi
A1=AB	0.073	0.170	0.300
A2=PR	0.154	0.034	0.818
A3=TR	0.172	0.081	0.679

As a result, for the implementation presented in this contribution, the best solution for a retrofit intervention at a territorial scale appears to be a partial retrofit RP intervention while the worst solution, as rationally expected, would be the "no-action" approach , thus maintaining the as-built condition AB).

It is worth nothing that these results have been obtained in the hypothesis of retrofitting the total stock of the pre'71 buildings. When implementing a simple cost-benefit analysis for the same case (shown in Table 1), any retrofit option (either partial or total) would have instead resulted economically inconvenient and not justifiable.

CONCLUSIONS

The advantages of implementing a Multi-Criteria Decision Analysis, MCDA, to support decision makers in the selection of an effective seismic retrofit strategy at a territorial scale have been discussed and demonstrated. The proposed multi-criteria approach is able to account for both monetary and non-monetary aspects related to technical (e.g. structural performance) or social issues (e.g. occupancy disruption, reconstruction acceptability, etc.), while accommodating the wishes, sometime controversial, of several decision makers.

Focus in the analysis has been given to three main targeted perspectives as part of the risk reduction strategy, namely a) maximising the sustainability of the retrofit strategy, b) minimizing the consequences of the event aiming to guarantee an effective emergency management, c) minimizing the expected losses after an earthquake scenario in order to guarantee the maximum resilience of the community during the reconstruction process.

The effectiveness of alternative retrofit solutions has been assessed according to the MCDA with reference to a case study area subjected to a deterministic earthquake scenario within a GIS environment. When comparing the results with those obtained by a more traditional and simplistic cost-benefit approach, it appeared clear that a multi-decision criteria, which naturally tends to reproduce our rational approach within a decision making process, can more properly appreciate the benefit of a retrofit intervention, particularly when targeting an intermediate performance upgrade and limited to selected typologies and number of buildings due to budget constraint (e.g. Partial Retrofit vs. Full Retrofit).

It is also worth noting that, although a deterministic damage scenario analysis has been adopted in this contribution, focused on the conceptual proof of the method, a probabilistic seismic analysis approach can be alternatively implemented within the same framework. Comparative results of a deterministic vs. a probabilistic MCDA will be given in future contributions.

ACKNOWLEDGMENTS

The financial support provided by the NZ Foundation of Science, Research and Technology, FRST, through the Research Project "Retrofit Solutions for NZ MuoltiStorey Buildings" (contract UOAX0411) is acknowledged.

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