# AN INNOVATIVE METHODOLOGY FOR THE SEISMIC RISK MITIGATION ON LARGE TERRITORIAL SCALE

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## *Abstract*

Seismic risk reduction of student populations in highly seismic areas is crucial. A considerable intervention on urban scale in the system of public schools is a challenge for governments due to limited economic availability and the remarkable amount of school buildings that are extremely vulnerable. A prioritization strategy of intervention is required.

Decision makers need modern and efficient methods that allow a multidisciplinary approach. Several studies have proposed prioritization ranking but it is necessary to go beyond the simple reduction of vulnerability aspects and provide rational and valid operational tools on the technical-scientific level.

In this paper, we propose to define a prioritization methodology for seismic risk reduction in public schools. The case of schools in the city of Lima was analyzed. Data of the previous studies were used, elaborated, and integrated in order to provide the proposed methodology.

Through the concept of resilient city, we defined qualitative and quantitative evaluation criteria. They consider the factors that determine the seismic risk of the buildings (i.e. hazard, vulnerability and exposure), how to manage and recover the emergency as well as integration and social cohesion aspects. Based on each criterion, the schools were analyzed separately also using Geographic Information Systems (GIS) in order to identify their spatial and territorial relationships with the surroundings. Subsequently, the processed data were directly integrated using appropriate Multi-Criteria Decision-Making (MCDM) methods. For each criterion was assigned a weight, and through their assignment, numerous political scenarios were considered. These scenarios want to simulate some likely behaviors of the decision maker in order to consider the possible uncertainties involved in planning.

The proposed work could represent a real seismic risk mitigation policy on a large territorial scale. In fact, through the MCDM methods and using the concept of city resilience, it could provide a simplified and multi-disciplinary approach, with solid technical and scientific bases and a holistic view of the problem.

*Keywords: City Resilience, School Buildings, Prioritization methodology, GIS, MCDM methods.*

## 1. Introduction

In many cities of the world, due to the limited availability of economic resources and the remarkable amount of extremely vulnerable strategic buildings, it is necessary to prioritize the interventions on a large territorial scale. In this manner, it is possible to prepare interventions that represent the best solution in order to optimize the allocation of available economic resources, to provide clear and transparent guidelines, and to maximize the resilience of cities.

Decision makers need modern and efficient methods that allow them to face these problems with a multidisciplinary approach. Various studies have proposed prioritization rankings based on the simple reduction of vulnerability aspects, but it is necessary to have a holistic view of the problem and use easy operational tools with solid technical and scientific bases.

In this context, the present work proposes to develop a rational methodology for the mitigation of seismic risk on a large territorial scale. In the paper, the case of schools in the city of Lima was analyzed. For the development of the proposed methodology, recent works [1] were improved and data of previous studies were used, elaborated, and integrated [2] [3].

In order to achieve the set goals, appropriate Multi-Criteria Decision-Making (MCDM) methods were applied and the concept of seismic resilience of the city was adopted. In this way, a new seismic risk mitigation policy with a multidisciplinary approach, and a holistic view of the problem has been developed.

Conflicting several aspects were considered. For the definition of intervention priority on urban scale, fourteen evaluation criteria were used. These judgment criteria were determined according to the concept of city resilience. Based on each criterion, the schools have been analyzed separately also using Geographic Information Systems (GIS) in order to identify their spatial and territorial relationships with the surroundings.

The resilience of the communities has played a key role in the definition of the seismic risk mitigation strategies. Based on resilience aspects, through the assignment of criteria weights, different scenarios were defined in order to investigate about the variability dependence on the will of the decision maker.

In order to support the decision-making process and define the priorities, in this study the authors applied two MCDM methods. These methods are commonly used in most scientific, economic, and industrial fields when decision makers should solve a problem with multiple conflicting criteria.

In the paper, in order to disseminate the proposed methodology and devise a new integrated framework to political strategies in planning of resilient cities, only partial results are shown. These results are a first partial development of the work that has been developed by the authors.

## 2. Concept of city resilience

Resilience concept (a “hot topic” of the scientific research in the last years) is quite fuzzy, but the entrance of the term resilience into disaster discourse could be seen as the birth of a new culture of disaster response [4]. Its significance can vary substantially depending on the specific application or field of study. In fact, in an analysis of the various definitions for resilience especially in the context of disaster recovery, Plodinec [5] lists over forty definitions of the term. For example, according to Bruneau [6], the definition of resilience relating to communities is the ability of social units to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption, and mitigate the effects of future earthquakes. According to Brown [7], it is the ability to recover from or adjust easily to misfortune or sustained life stress, while according to Chenoweth [8], it is the ability to respond to crises in ways that strengthen community bonds, resources, and the community's capacity to cope.

In accordance with some authors [9], in the present work the city resilience will be assumed as the ability of an urban system to absorb, adapt, and respond to adverse changes. In order to achieve these goals, appropriate resilience aspects should be guaranteed. These aspects are defined as follows:

1) to prepare for the emergency (improving the classic factors that determine the seismic risk of the buildings, in other words vulnerability, seismic hazard, and exposure);

2) to manage and recover the emergency;

3) to ensure integration and social cohesion.

Using the concept of city resilience, the authors believe that it is possible to accomplish seismic risk mitigation policy with a multidisciplinary approach, and a holistic view of the problem.

## 3. Seismic risk mitigation through Multi-Criteria Decision-Making methods

In issues concerning seismic risk mitigation on large territorial scale, multiple conflicting criteria should be analyzed and easy operational tools with solid technical and scientific bases should be used. In this context, the Multi criteria decision-making (MCDM) methods can be inserted and they can provide a valuable support in rational and multidisciplinary analysis.

MCDM methods are commonly used in most scientific, economic, and industrial fields. These methods are applied when decision makers would like to establish a ranking of the alternatives in the presence of conflicting criteria. Some interesting applications have been carried out in order to select the seismic retrofitting strategy of single buildings [10], [11], [12] and compare different strategies of natural risks mitigation [13], [14].

There are several methods and models for various MCDM problems defined with respect to different perspectives and theories. However, in some cases they can provide different results. For this reason, in this study, two methods were selected and applied. They are the TOPSIS [15] and VIKOR [16] methods. These methods allow the use of variables with different units of measure and criteria of different types.

TOPSIS method is based on the distance of the alternatives from the ideal solutions, namely the ideal solution and the negative ideal solution. They are defined by the best and worst conditions, respectively.

VIKOR method determines the solution named compromise, based on the best and worst performance of the alternatives with respect to each criterion analyzed. According to this method, in order to establish a ranking of the alternatives, two conditions - acceptable advantage and acceptable stability in decision making - must both be respected. If one of these conditions is not satisfied, it is not possible to directly select the preferred solution of the set, but a subset of preferable options can be defined.

## 4. Case study: public schools buildings in Lima

In the paper, the case of public schools buildings in the city of Lima was investigated. Based on the available data of previous studies [2], [3], 1825 schools were analyzed. The available data were opportunely used, elaborated, and integrated in order to apply the proposed methodology.

According to various authors [17] the school buildings in Lima suffer from poor construction practices arising from a lack of regulated procedures, and quality supervision. With no regular budget for investment in schools, parents frequently build schools themselves after pooling their own financial resources. Most of the schools in Lima were built in a staged construction process and additional capacity has been added when there is money from either families or the government [18].

In school buildings, the presence of unsupervised alcoves, dead ends, and narrow corridors are prevalent due to a lack of planning. In addition, some evacuation routes include staircases with low parapets and are likely to become overcrowded. Safety areas are located near elevated water tanks, which probably do not meet structural safety standards. The lack of technical inspections, along with insufficient training of people involved in construction and those responsible for use of the space and furniture, hinder the correct definition and maintenance of safety areas and emergency exits.

Most of the schools have been built in accordance with obsolete earthquake-resistant criteria and poor quality-control processes. For typical modules built before 1997, a shear failure in columns (called a short-column failure) is likely to occur, causing the structures to collapse if the event scores higher than a VII on the Modified Mercalli Intensity (MMI) scale. More than 50% of the school buildings in Lima require total replacement to bring them into conformance with the Peruvian building code [19].

Schoolchildren in Lima have been targets of previous campaigns to raise risk awareness and build capacity for emergency preparedness. Elementary and high-school students have achieved basic level of risk awareness after community training and monitoring activities involving teachers, parents, and the students themselves [20]. However, government entities, academic staff, teachers, and healthcare workers lack the proper training required to provide information or humanitarian aid to students affected by seismic events [21].

## 5. Definition of criteria and political scenarios

In order to apply the proposed methodology, according to the resilience aspects and the available data, fourteen evaluation criteria were selected. Based on each criterion, the schools were analyzed in order to construct a decision matrix (1825x14).

The Table 1 shows the relationship between the criteria and the resilience aspects. Four of the considered criteria – building type, subsoil category, lifelines, and historical and cultural significance – are qualitative, while the remaining ones are quantitative.

Table 1- Resilience aspects and relative criteria

| RESILIENCE ASPECTS | EVALUATION CRITERIA | |
|---|---|---|
| VULNERABILITY, SEISMIC HAZARD AND EXPOSURE OF THE BUILDINGS | $C_1$ | Damage level in occasional earthquake |
| | $C_2$ | Damage level in frequent earthquake |
| | $C_3$ | Probable annual loss |
| | $C_4$ | Building type |
| | $C_5$ | Subsoil category |
| | $C_6$ | Density of school population |
| MANAGE AND RECOVER THE EMERGENCY | $C_7$ | Lifelines |
| | $C_8$ | Free usable area |
| | $C_9$ | Quantity of roads in a radius of 500m from the school |
| | $C_{10}$ | Distance from the nearest main road |
| | $C_{11}$ | Density of population in the surroundings |
| INTEGRATION AND SOCIAL COHESION | $C_{12}$ | Historical and cultural significance |
| | $C_{13}$ | Social economic condition |
| | $C_{14}$ | Community organization |

The first two criteria represent the damage percentage of the structure relative to an occasional seismic event, and a frequent seismic event, respectively. These percentages are a function of their construction cost

Probable annual loss represents the expected annual loss for a single structure according to the seismicity of the area. It has also been expressed as a percentage of the construction cost. This information was determined with a probabilistic analysis of seismic risk considering several occasional earthquakes.

Through the building type for each school building, the type of structural material (reinforced concrete, masonry, adobe, wood, etc...) and its architectural and structural types were analyzed in order to consider the collapse modes of the structures and their age.

In some zones of the metropolitan area of Lima and Callao, the presence of water in some layers of the soil may generate problems of liquefaction, and instability in the structures. Therefore, in the analyses of the subsoil category of each school, these issues were taken into account.

The criterion $C_6$ indicates the pupils' number per square meter of the school. This information has been quantified by census data.

With the criterion "lifelines", the amount of available basic services (water, sewer, electricity, phone) in each school was evaluated.

The criterion "free usable area" indicates the square meters of available free area for each school building during the recovery, and reconstruction phase. This information was quantified directly or indirectly from design drawings, available data, direct measurement, or from census data.

The criterion $C_9$ expresses the number of roads located within 500 meters from the location of the school. This quantity also evaluates the importance of the single street.

Through the criterion "distance from the nearest main road", the distance in meters shorter than the school from the nearest main road (expressway, arterial or collector road) was assessed. This criterion refers to the ease of access to the school, as a complement to the previous criterion $C_9$.

Density of population in the surroundings expresses the number of inhabitants per square meter. This value, for each school, was calculated assuming an influence area of the same shape and size. The indicator was obtained by dividing the number of inhabitants belonging to the limits of each area surveyed by its corresponding area.

With the criterion $C_{12}$, the cultural and historical importance of the school building was expressed. This indicator was characterized through a study of the cultural, historical, and artistic aspects of the individual districts and how these last ones are related with the city.

The socio-economic condition expresses the average monthly income per capita in soles (S.\ per person) of the adjacent population to the school building. This value, for each school, was calculated assuming an influence area of the same shape and size. Using economic data of the Censo Nacional 2007 and considering the average income of the entire population included in the census area, the indicator was determined.

The last criterion $C_{14}$ indicates the number of rooms or external environments built with the aid of the parents association (APAFA), according to the number of total rooms at the school. This information was obtained from the scholastic information center.

Based on each criterion, the schools (alternatives) were analyzed separately, also using Geographic Information Systems (GIS), in order to identify the spatial and territorial relationships of the schools with their surroundings. Moreover, for each criterion was assigned a weight.

In order to evaluate quantitatively the qualitative criteria and determine the weights of the criteria is necessary a conversion of the qualitative variables of judgment, in quantitative terms. The method used for the transformation was the Analytic Hierarchy Process (AHP) of Saaty [22], [23].

For each qualitative criterion and weight vector of the criteria a matrix of preferences was defined. These matrices were built through simple binary comparisons. For each comparison was attributed a corresponding judgment of relative importance between two alternatives (for the qualitative criteria) or between two criteria (for the weight vectors). These judgments were expressed numerically using the procedure proposed by Saaty (Table 2). The sought numerical values were evaluated through the principal eigenvectors of the matrix of preferences so that their sum is equal to 1. While through the use of principal eigenvalues is possible to do a consistency check in order to exclude unacceptable conflicts. In this way, the final solution is a logical solution and not a random order. Particularly, let it be noted that for each qualitative criterion, a square matrix 1825x1825 (equal to the number of the schools) was defined in order to calculate its principal eigenvalue and the corresponding eigenvector through MATLAB software. The calculated eigenvectors and the data of the qualitative criteria were inserted directly into the decision matrix.

Table 2- Saaty's scale

| Intensity of Importance | Definition |
|---|---|
| 1 | Equal importance |
| 3 | Moderate importance |
| 5 | Strong importance |
| 7 | Very strong importance |
| 9 | Extreme importance |
| 2,4,6,8 | Intermediate judgements |
| Reciprocal (1/2, 1/3, …) | If criterion/alternative i compared to j gives one of the above, then j, when compared to i, gives its reciprocal |

The criteria weights play a fundamental role in the decision-making processes. Based on the value that they assume, in fact, some estimates of the alternatives will be amplified, others will be overturned for substantial changes of the weights value. Therefore, through their assignment, thirty-eight political scenarios were considered. These scenarios want to simulate some likely behaviors of the decision maker in order to consider the possible uncertainties involved in planning.

For each scenario, a preference matrix based on the resilience aspects was defined. In this way, for each factor a weight between 0 and 1 was assigned. This weight was subsequently distributed between the relevant criteria through the definition of a new preference matrix in order to determine the concerning weight vector of the criteria.

All scenarios are being developed, but in order to disseminate the proposed methodology, below just a political scenario has been analyzed. In this scenario, the decision maker gives equal importance to the various aspects of resilience. For each aspect, in order to simplify the proposed procedure, the same relative importance for the relevant criteria was assigned. In this simple case, all terms of the preference matrices are equal to one and are perfectly consistent.

The criteria weight vector $\mathbf{W}^T = \{w_1,\ldots, w_{14}\}^T$ of this scenario is shown in the following Eq. (1):

$$\mathbf{W}^T = \{0.056,0.056,0.056,0.056,0.056,0.056,0.067,0.067,0.067,0.067,0.067,0.111,0.111,0.111\}^T \qquad (1)$$

The pie chart of Fig.1 can be an efficient representation of the weight of each resilience factor, while Fig.2 shows the values of criteria weights regarding to the considered scenario.

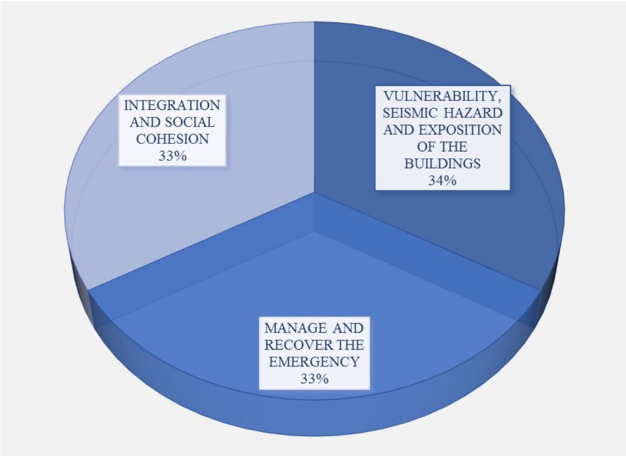


Fig. 1- Weights of the resilience aspects

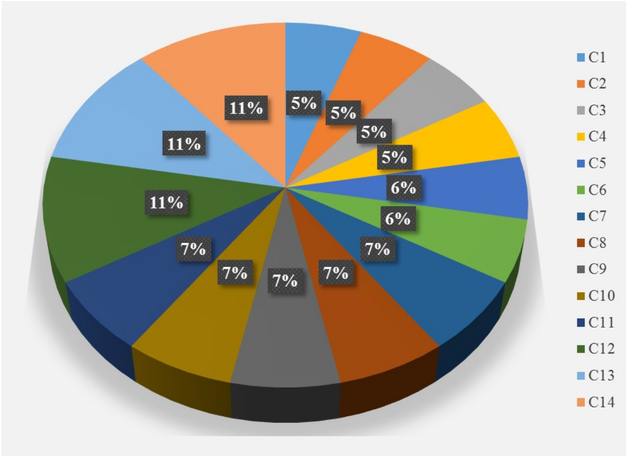


Fig. 2- Weights of the criteria

## 6. Results

After the construction of the decision matrix and criteria weight vector, the considered MCDM methods were applied. In this section, their results are reported and analyzed.

Through the application of TOPSIS and VIKOR methods, a ranking of the alternatives was defined. Moreover, a comparison between the pertinent rankings was carried out in order to compare the two MCDM methods used.

Due to the large number of school buildings (1825), for the sake of brevity only the top twenty schools are reported in Table 3 and Table 4, respectively for TOPSIS and VIKOR method. Based on the $C_i$* values (TOPSIS method) and $Q_i$ (VIKOR method) a ranking was determined. The $Q_i$ values were determined assuming $\upsilon = 0.5$.

According to TOPSIS method, the preferred solution is the one having the maximum $C_i$* value. While, according to VIKOR method, the preferred option is the one having the smallest $Q_i$ value.

Through TOPSIS method, it is possible to directly select the preferred solution. In the examined political scenario, one of the acceptability conditions of the VIKOR method is not satisfied. Therefore, according to this method, it is not possible to directly define the preferred solution of the set, but a subset of preferable options can be identified.

Anyway, the alternatives are ranked in a different manner depending on the considered method. As it can be seen, in the first twenty positions only schools with ID 166, 1485 and 1785 (respectively in eighteenth, seventeenth, and nineteenth place for TOPSIS method and in fourteenth, second, and first place for VIKOR method) are repeated. These differences could be due to the different normalization techniques of the two methods and the parameters $\upsilon$ that the decision maker has to fix in the VIKOR method. In fact, this parameter $\upsilon$ is fixed in the {0, 1} interval according to different weight of importance of each addend into the $Q_i$ expression. For $\upsilon$ >0.5, the decision maker gives more importance to the global performance of the alternative in respect to all the criteria. Instead, for $\upsilon$ <0.5 the decision maker gives more weight to the magnitude of the worst performances exhibited by the alternatives in respect to each single criterion. Assuming $\upsilon$ =0.5, the two aforementioned aspects are considered equally relevant.

Table 3- Ranking according to TOPSIS method

| Position | School ID | $C_i$* |
|---|---|---|
| 1 | 1594 | 0.6360 |
| 2 | 1754 | 0.5021 |
| 3 | 1743 | 0.4836 |
| 4 | 1270 | 0.4234 |
| 5 | 1210 | 0.4173 |
| 6 | 1390 | 0.4171 |
| 7 | 1825 | 0.4085 |
| 8 | 1314 | 0.4055 |
| 9 | 1513 | 0.4045 |
| 10 | 799 | 0.3961 |
| 11 | 1689 | 0.3939 |
| 12 | 405 | 0.3909 |
| 13 | 152 | 0.3903 |
| 14 | 401 | 0.3893 |
| 15 | 479 | 0.3882 |
| 16 | 1670 | 0.3876 |
| 17 | 1485 | 0.3851 |
| 18 | 166 | 0.3813 |
| 19 | 1785 | 0.3807 |
| 20 | 1378 | 0.3802 |

Table 4- Ranking according to VIKOR method

| Position | School ID | $Q_i$ |
|---|---|---|
| 1 | 1785 | 0.0408 |
| 2 | 1485 | 0.0761 |
| 3 | 124 | 0.0813 |
| 4 | 148 | 0.0826 |
| 5 | 122 | 0.0990 |
| 6 | 119 | 0.1025 |
| 7 | 133 | 0.1090 |
| 8 | 1489 | 0.1143 |
| 9 | 1473 | 0.1193 |
| 10 | 153 | 0.1239 |
| 11 | 1482 | 0.1244 |
| 12 | 1701 | 0.1318 |
| 13 | 1789 | 0.1360 |
| 14 | 166 | 0.1389 |
| 15 | 141 | 0.1485 |
| 16 | 128 | 0.1538 |
| 17 | 144 | 0.1594 |
| 18 | 160 | 0.1617 |
| 19 | 1787 | 0.1681 |
| 20 | 142 | 0.1719 |

## 7. Conclusions and work in progress

Nowadays many public buildings, such as schools and hospitals, need retrofitting against seismic actions. This problem is a challenge for many governments due to the limited economic availability and the considerable amount of strategic buildings that are extremely vulnerable. In these contexts, decision makers have to select prioritization strategies of intervention on a large territorial scale in order to optimize the allocation of available economic resources. They need modern and efficient methods that allow a multidisciplinary approach, using easy operational tools with solid technical and scientific bases.

The proposed methodology was applied to the case of public schools of Lima. Concerning the studied buildings, according to the resilience aspects, fourteen evaluation criteria were selected. Based on each criterion, the schools were analyzed separately also using Geographic Information Systems (GIS) in order to carry out efficient territorial analysis. Through the assignment of criteria weights, thirty-eight political scenarios were defined. They consider the possible uncertainties involved in planning, but in order to disseminate the proposed methodology and devise a new integrated framework to political strategies in planning of resilient cities, only partial results concerning a single scenario are shown. This study is not exhaustive, but illustrates only a first partial development of the work that the authors are performing.

Through the MCDM methods and using the concept of city resilience, the authors just want to prove that it is possible to supply a simplified and rational methodology for seismic risk mitigation with a multidisciplinary approach and a holistic view of the problem. These last aspects could provide all the possible variables or disciplines that are not directly integrated and/or are not generally integrated in studies of risk (not only seismic) on large territorial scale.

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## 10. References

[1] Vona M & Murgante B (2014): “Seismic retrofitting of strategic buildings based on multi-criteria decision-making analysis”. IALCCE 2014 Symposium, Tokyo, Japan, Volume: Life-Cycle of Structural Systemsi: tsuyoshi Akiyama, Editors: H. Furuta, D. M. Frangopol, and M. Akiyama TAYLOR and FRANCIS GROUP, ISBN: 978-1-138-00120-6.

[2] Santa-Cruz S, Fernandez De Córdova G, Rivera Holguin M, Vilela M, Arana V, Palomino J (2016): “Social sustainability dimensions in the seismic risk reduction of public schools: a case study of Lima, Peru”. Sustainability: Science, Practice & Policy, 12 (1), pp. 1-13.

[3] Arana V, Palomino J (2016): “Priorización del reforzamiento de los colegios públicos de Lima para la mitigación del riesgo sísmico”. Master's thesis in civil engineering, Pontifical Catholic University of Peru, Lima, April 2016.

[4] Manyena S B (2006): “The concept of resilience revisited”. Disaster, 30(4): 433-450.

[5] Plodinec, M J (2009): “Definitions of resilience: An analysis”. Community and Regional Resilience Institute. <http://www.resilientus.org/about-us/definition-ofcommunity-resilience.html>.

[6] Bruneau M, Chang S E, Eguchi R T, et al. (2003): “A framework to quantitatively assess and enhance the seismic resilience of Communities”. Earthquake Spectra19(4): 733–752.

[7] Brown D & Kulig J (1996): “The concept of resiliency: Theoretical lessons from community research”. Health and Canadian Society, 4,29–52.

[8] Chenoweth L & Stehlik D (2001): “Building resilient communities: Social work practice and rural Queensland”. Australian Social Work, 54(2):47–54.

[9] Vona M, Harabaglia P, Murgante B (2015): “Thinking about resilience cities studying Italian earthquakes”. Proceedings of the Institution of Civil Engineers, URBAN DESIGN AND PLANNING.

[10] Anelli A, Laterza M, Vona M (2016): “Selection of optimal seismic retrofitting strategy for existing RC building”. XII International Conference on Structural Repair and Rehabilitation (CINPAR 2016), Porto, Portugal, 26-29 October 2016.

[11] Caterino N, Iervolino I, Manfredi G, Cosenza E (2008): “Multi-Criteria Decision Making for Seismic Retrofitting of RC Structures“. Journal of Earthquake Engineering. Vol. 12 (4): 555-583.

[12] Caterino N, Iervolino I, Manfredi G, Cosenza E (2009): “Comparative Analysis of Multi-Criteria Decision-Making Methods for Seismic Structural Retrofitting”. Computer-Aided Civil and Infrastructure Engineering, Vol. 24: 432–445.

[13] Opricovic S & Tzeng G H (2004): “Compromise Solution by MCDM Methods: A Comparative Analysis of VIKOR and TOPSIS”. European Journal of Operational Research 156: 445–455.

[14] Shohet I M & Perelstein E (2004): “Decision support model for the allocation of resources in rehabilitation projects”. Journal of Construction Engineering and Management Vol. 130(2): 249-257.

[15] Hwang CL & Yoon K (1981): “Multiple Attribute Decision Making”. Lecture Notes in Economics and Mathematical Systems 186, Berlin. Springer-Verlag.

[16] Opricovic S (1998): “Multicriteria Optimization of Civil Engineering Systems”. Faculty of Pennsylvania.

[17] Blondet M, Dueñas M, Loaiza C, Flores R (2004): “Seismic Vulnerability of Informal Construction Dwellings in Lima, Peru: Preliminary Diagnosis”. Vancouver: 13th World Conference on Earthquake Engineering.

[18] Santa Cruz S (2013). Informe Interno TAP 2. “Evaluación probabilista del riesgo sísmico de escuelas y hospitales de la ciudad de Lima”. Componente 2: Evaluación probabilista del riesgo sísmico de locales escolares en la ciudad de Lima. Lima: PUCP.

[19] MINEDU (2015). Strategy Presentation (in Spanish). Lima: Ministry of Education of Peru

[20] Roca L (2011): “Perceptions of Social Support Among organized Women in Emergency Community Kitchen’s During the Earthquake of 2007”. Unpublished Master’s Thesis (in Spanish). Lima: Pyschology Department, Pontificia Universidad Católica del Perú.

[21] Rivera M, Velazquez T, Morote R (2014): “Participación y fortalecimiento comunitario en un contexto posterremoto en Chincha, Perú”. Psicoperspectivas, 13(2), 144-155.

[22] Saaty TL 1980. The Analytic Hierarchy Process. New York, NY, USA, McGraw-Hill.

[23] Saaty TL (1999): “Decision making for leaders: the Analytic Hierarchy Process for decision in a complex world”. Pittsburgh, PA., USA, RWS Publications.