ISSN: 2227-7994

FORUM A+P

INTERDISCIPLINARY JOURNAL OF ARCHITECTURE AND BUILT ENVIRONMENT

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Source: *Forum A+P 26 | Crafting 'Scientific' Research in Architecture*

ISSN: *2227-7994*

DOI: *10.37199/f40002607*

Publisher: *POLIS University Press*

A Multi-Criteria Methodology For The Integration Of Risk Assessment Into Spatial Planning As A Basis For Territorial Resilience. The Case Of Seismic Risk

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Abstract

Rapid urban development and continuous demands for space have increased the pressure on the territory. The need for this "usable" space, no matter the purpose, leads to an excess of capacities of existing areas and the creation of new areas, both significantly increasing the level of exposure to natural disasters. Statistics show that within a period of almost two decades from 1994 to 2013, 218 million people were affected by natural disasters annually (CRED, 2015). In the situation where the demand for growth is accompanied by an increasing potentiality of damages in economic, social, environmental or cultural terms, disaster risk management (DRM) is having an important focus in terms of research. The way communities and urban systems react to a natural distress is tightly related to the economic and technological development as well as data availability. Developed countries have the capacities to consider mitigation strategies in pre-event situations, which is not always feasible for developing and poor countries. Also, as emphasized by (Gaillard & Mercer, 2012), the issue is related to the fact that disasters affect those who are marginalized and have partial or no access to resources and means of protection. Such paradigm imposes the need to develop preventive strategies focusing on the community, which is directly affected by aftermath of these natural events. The purpose of this research is the analysis of a possible way to integrate disaster risk information within planning instruments aiming towards an inclusive disaster risk reduction (DRR) process through the proposal of a risk assessment methodology at a local scale for the case of seismic events. The main objective is that the proposed methodology will serve as a preliminary tool for several decision-making processes in terms of strategic risk reduction measures, policies, prioritization, fund allocation etc. The methodology is also aimed to serve as an important node that connects the community, the experts and responsible authorities with one another towards an inclusive disaster risk reduction approach.

Keywords

earthquake, resilience, risk assessment, urban system, vulnerability

Introduction / Motivation and problem statement

One of the greatest challenges of human society over the years has always been adapting and living in the constant presence of natural hazards. A detailed study by (Ritchie & Roser, 2014) showed that only in the last decade natural disasters have affected a total of 186.5 million of people (injured, affected and homeless), with an average of 47000 fatalities, making such disasters responsible for 0.1% of deaths. The historical data show that losses to natural hazards tend to be centered in low-to-middle income countries that lack of appropriate infrastructure to cope with such events (Ritchie & Roser, 2014). In the last decades the losses from such events have decreased considerably, with earthquakes being the main event causing losses and fatalities due to the low-frequency but high-impact nature.

One of the latest events that reflects such situation is the earthquake that struck Albania on 26 November 2019 at 02:54:12 (UTC) with a magnitude Mw 6.4 and an epicenter close to the Adriatic coastline 30 km west of Tirana and a focal depth of 22 km due to the thrust faulting near the convergent boundary of the Africa and Eurasian plates (USGS, 2019). The event caused 51 fatalities, injured around 3000 people, left up to 14,000 people homeless and caused serious damages to over two thousand buildings of different typologies (Charleson et al., 2020). Considered as the strongest earthquake to hit Albania in 40 years after the Mw 6.9 Montenegro earthquake of 1979 which was highly felt in the northwestern part of the country near to the epicenter. In engineering terms, taking into account the magnitude of the event, it is considered as an earthquake which even though may be classified as strong, was definitely not in the levels of what is known as the design earthquake used to design seismic-resistant structures. Nevertheless, the damages and the aftermath were quite severe.

The aforementioned summary in terms of statistical data and events, puts forward two key issues related to natural hazards and the behaviour of humans and systems; that of exposure and vulnerability. Not every hazard can lead to a disaster, the combination of the hazard with specific poor conditions of the built environment leads to disasters which is defined as:

"*A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impact, which exceeds the ability of the affected community or society to cope using its own resources*." (UNISDR, 2009, p.9)

The disaster represents the impact and the consequences and to talk about consequences in addition to the hazard, the exposure and vulnerability introduced above must be analyzed and combined. Both exposure and vulnerability are components whose aim is that of answering the following questions:

- Which are the affected elements?;
- What levels of damages can potentially happen in these affected elements?;
- Would these levels of damages lead to a disaster or to a slight disruption?;
- How long would it take to recover?

The approach towards these events and the ability of the system to absorb the stresses from the events in the past was focused in the phase of emergency response and the eventual reconstruction phase, while nowadays there is a shifting paradigm toward prevention strategies before the disaster strike (Sutanta et al., 2010).

Being able to prevent the damages from an event before it even happens implies the need to try and predict the damages that this event might cause in a certain area, so it might be considered as an ex-ante analysis. This analysis is widely known as risk analysis and assessment. The entire process of the risk assessment and eventually the reduction of this risk involves many disciplines and is seen from different perspectives, as such there is an essential need for an integrated approach and a cooperation between different actors in different levels. Based on the large number of studies on disaster-related issues, (Gaillard & Mercer, 2012) emphasize the emerging of two major paradigms; hazard and vulnerability paradigm. The former asserts that disasters occur due to the insufficient perception of risk of the affected people which consequently fail to adapt and adjust to reduce such disasters, therefore can be considered as a generalized approach. On the other hand, the latter paradigm asserts that disasters affect mainly those who are marginalized and lack access to resources and means of protection. Within the second paradigm it is believed and supported that Disaster Risk Reduction should be inclusive in terms of:

- the form of knowledge (scientific and local knowledge);
- combination of top-down and bottom-up actions;
- collaboration and operation of large array of stakeholders.

The lack of this inclusive process together with increasing vulnerabilization levels is believed to be one of the main reasons of why disasters are on rise worldwide. Spatial and urban planning is one of the disciplines that is involved in the matters of risk assessment since its function is to regulate utilization of land, therefore can be considered as an important link in the entire process and can be very useful to reduce the exposure and vulnerability of the entire components affected by the hazard. It is also believed that planning instruments represent a fundamental link in bridging the aforementioned gaps that hinder an inclusive process. As stated by (Suri, Johnson, Lipietz & Brennan, 2020) to be able to create resilient cities planners need to approach disaster risk reduction (DRR) as an issue at the center of a good urban development, whose integration however is often limited.

Purpose of the study

A vast amount of research has been conducted in the last decades with the aim of assessing the risk of a hazardous event. The approaches vary from a specific level, where the risk is analyzed only for a certain hazard, to a multi- approach where several hazards are analyzed simultaneously taking into consideration their common effect in a certain area. Another way of choosing the right approach is by taking into consideration the level of detail required and data availability, based on which the risk is estimated in qualitative or quantitative terms. Despite these approaches the entire process must be seen as a holistic one. Therefore, the integrated variables having a different nature have to be unified to produce an output that is targeted to decision- making structures and actors The holistic perspective of the problem at hand raises a number of issues, mainly related to the way the information is transmitted and understood by different experts. Among these experts are the spatial planners which as mentioned in the previous section are easily considered as a fundamental link in matters of risk assessment in an applied context since the information provided by them is more tangible and understandable from a decision- making point of view. Within this perspective the main issue would be that of integrating the information from this assessment into spatial planning in such way to be understandable, reliable and translatable into planning policies and land- use restrictions together with an analysis of the impacts it might have in planning systems and instruments.

The general objective of the research is the focus on assessing seismic risk at a local territorial scale. The state of the art gives a number of methodologies to assess the risk, so a realistic objective would be that of focusing on existing methodologies and theories with the aim of interpreting them in such a way to be easily integrated in different levels among different stakeholders. The specific objective of the research is directed towards the integration of a semi- quantitative risk assessment model in planning instruments by using inclusive information and variables in a multi-scale approach. A multi-scale approach is believed to facilitate the integration of Disaster Risk Reduction in urban planning processes. Such integration can foster the collaboration between stakeholders, help in bridging the gap between scientific and local knowledge and also improve communication and risk perception.

Based on the general and specific objective the main research question may be elaborated as follows:

How to effectively integrate risk knowledge within planning instruments towards an inclusive Disaster Risk Reduction (DRR) *process*?

In order to answer the main question of this research, it is necessary to put forward other complementary questions, that will serve as important nodes in creating a path towards the fulfillment of the final objective of the research.

a.How to combine multi-scale information to define the levels of risk?

b.Which are the most inclusive and context-adaptable parameters that can be used to define seismic risk?

c.What is the best way to produce and communicate the risk information for decision-making purposes and to increase risk perception within the community?

Proposed Methodology

The methodology proposed for assessing and integrating seismic risk information into spatial planning can be summarized in

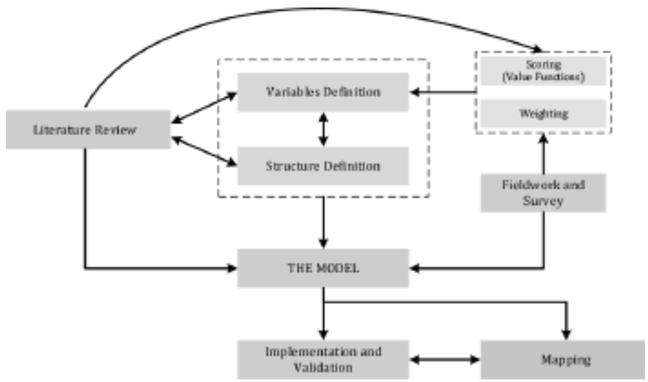

Figure 1. An overview of the methodology

the following scheme: The proposed methodology, is based on the risk-index approach. Risk Index is an approach in which the risk and its constituting elements are derived through a scoring process using ordinal scales. Such approach is more rigorous than a qualitative approach, but is not considered as a purely quantitative approach since the risk is categorized by comparative scores rather than explicit probabilistic terms. Therefore, such approach is categorized as a semi- quantitative. Risk Indices are used in situations where the lack of data makes it difficult to quantify the components of the risk and also when the assessment is carried out in large areas. The input is derived from a detailed analysis of the system thus, the assessment of risk in terms of indices should be preceded by a detailed analysis and a good understanding of the sources of risk. In this stage of the process additional tools such as fault tree or event tree analysis can be used to structure the problem and represent the relationship between each component of risk and each of the indicators selected to represent such components at different levels.

In the field of disaster risk reduction and natural hazards, the information is often given in a spatial way through maps. In cases where the input is a number of geographical data that can be used for choosing alternatives and making decisions the process is known as Spatial Multi- Criteria Evaluation (SMCE). Spatial Multi- Criteria Evaluation is considered as a complementary method to the already existing approaches for qualitative and quantitative risk analysis and zoning. For instance, as it is the case of this research, indices at a local scale are combined with the SMCE to provide a single risk value that can be used for decision- making purposes or preliminary evaluations.

Based on the relevant literature (Eastman, J.R, 2005; Sinha, Priyanka & Joshi, 2014 and Patel, M. R. et al., 2017) the procedure for converting various parameters into a single risk index that can be later used for decision-making processes goes through four general steps as given below:

Step 1- The structure of the decision problem
Step 2- Standardization
Step 3- Weighting Process (Prioritization)
Step 4- Aggregation

Structure Definition

For the purpose of this research the structure is divided into four levels, with an addition of a fifth level as shown in Figure 2. Each variable is selected to better represent all the constituting elements of seismic risk.

Literature provides a considerable number of studies dealing with seismic risk, from qualitative to advanced quantitative methodologies, each one of which having its own indicators. Many indicators, are undoubtedly common no matter the approach, but others differ. One of the reasons for such change is the scale of the problem at hand.

From a structural point of view, assessing the risk means focusing on the building scale and predicting possible consequences to the specific building. Such assessment, requires a high amount of data in this scale, for instance (Kassem, Mohamed Nazri and Noroozinejad Farsangi, 2020) in their work investigate the indices and methodologies in seismic risk to quantify the level of damages to structural elements or to the entire structural system. Parameters like the organization of structural system, configuration of plan layout, configuration in heights, elements of low ductility, non-structural elements etc. are analyzed and quantified to evaluate seismic risk.

Figure 2. Proposed hierarchical structure for the assessment of seismic risk

Instead, from an urban planning point of view the focus is in integrating such building scale into a larger urban scale to help decision makers in defining prevention strategies. Therefore, the indicators have a more inclusive nature with the aim of connecting these two scales. In addition, for planning purposes beside physical indicators other non-physical indicators are quantified to evaluate economic or social vulnerability like population density, social disparity, development level etc. In the proposed hierarchy such interrelationship between scales is given by combining into the vulnerability and exposure indicators that are related to building scale (building characteristic, structural characteristics) with external indicators (physical density, street network and open space). In addition, indicators related to functionality (function and utilization) are also introduced to take into account the level of people exposure and critical structures.

Standardization

Decision-making processes require the integration of a number of variables of different nature, the combination of which provides alternatives. Based on the alternatives, decisions are made to choose the most acceptable one in terms of objectives and feasibility. The integration of numerous variables in such processes to define the worst and/or the best scenarios requires an analysis in which these variables are compared and combined to one another. Making two or more variables comparable requires a scaling or standardization of them, thus resulting at the same unitless scale. The process of switching from a variable of a certain nature to unified variables is defined as standardization process. Such standardization can be achieved using mathematical equations that are represented in the form of the graphs, known as value functions, which are defined by (Beinat, 2012) as:

"…*mathematical representation of human judgements.*"

Explaining that this function translates performances of the alternatives into value score, which on the other hand represents the degree to which several decisions are matched. After the application of such functions all the variables used for decision are analyzed for their meaning and impact in the decision rather than analyzed as explicit numerical values or qualitative measures. A key component in the decision-making process is the accurate determination of value functions. Once a value function has been defined, the results for a given set of choices can be calculated directly. Since value functions represent a preference there is a need of proper and clear evaluation instead of just the graphical representation of such functions. For each of the selected parameters in the proposed structure the following elements are defined:

a. Tendency

Depending on the nature of the indicator (criterion) the value function can have either an increasing or a decreasing tendency. An increasing function shows that as the level of the indicator increases so does the level of satisfaction of the decision maker. In contrast a decreasing value function shows that an increase in the indicator results in a decrease in the level of satisfaction. In addition, there might be value functions that have a mixed tendency; thus, the functions have an increasing/ decreasing tendency up to a certain level of the criterion after which the relationship is inverse.

b. Range

The range consists in defining the points which have the minimum and maximum level of satisfaction from the decision-maker's point of view. If using a scale from 0 to 1, the point of minimum satisfaction would give a value of 0, while the maximum would give a value of 1 or vice versa. It is important to notice that this range represent limits in the satisfaction level only, not in the entire range of values for the considered criterion. Thus, there might be values of the criterion which are not considered because they are outside the defined satisfaction limits.

c. Shape

The next step in the generation of value functions is the definition of the shape that will connect the points within the defined range. Literature suggests several types of functions that can be used for decision-making. For the purpose of this research based on (Alarcon, et al., 2011) and (Rezaei, 2018) the value functions are classified into two groups linear and exponen-

tial. Both linear and exponential value functions following the tendency (Step 1) might be classified as monotonic when the tendency is always increasing or decreasing or non- monotonic when it has a different shape (mixed).
A linear function reflects a constant increase or decrease in the level of satisfaction generated by the alternatives. Throughout the range, there is a proportionate relationship meaning that the rate of change is constant. The exponential functions reflect change rates that are not constant, thus the rate of change near a certain value might be higher than that near another value, emphasizing that the influence of a variable (criterion) changes within the same value function. As with linear functions, the

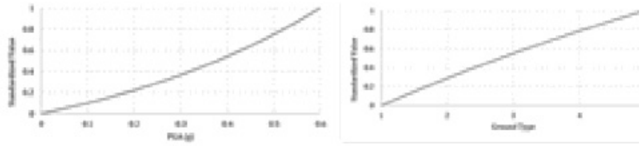

Figure 3. Proposed hierarchical structure for the assessment of seismic risk

exponential functions also have monotonic and non-monotonic nature.

d. mathematical expression.
Each of the value functions are represented by a mathematical expression based on their shape and range.
For the proposed methodology, each variable is standardized using appropriate value function, two of which are given in the following graphs:

Prioritization
In the same way decision making involves many criteria and sub criteria to evaluate alternatives, so does the process of assessing a risk. The inclusion of several criteria into the analysis, as mentioned before, requires their comparison so that decisions are made in a proper way. In a certain analysis, decision-maker might consider that some aspects or criteria are more relevant and important than others, thus their impact in the alternative is greater. The relative importance of different criteria is otherwise known as weight. One of the most used techniques to assign weights is the Analytical Hierarchy Process (AHP) which is developed by (Saaty, 1980). The essence of such method is the development of what are known as pairwise comparison matrices at each level of the hierarchy. As stated by (Saaty, 2008), making a decision to organize priorities requires the decomposition of the general problem and the decision into the following steps:

- Problem definition and determination of the knowledge sought;
- Structure of the decision from top with the main goal up to the lowest level;
- Development of a set of pairwise comparison matrices for each level;
- Use the results of the matrices to weight the alternatives in the same level and to obtain the overall priority.

One of the main advantages of such method, is the fact that the results can be verified by the means of the Consistency Index and Consistency Ratio, based on the n-order of the developed matrix. To verify the coherence in the values attributed to the pair-wise matrix a consistency check ought to be done. A matrix and subsequently the weights assigned are consistent if they are transitive. This condition indicates that the order of

	Building Age	Nr. Storeys
Building Age	1.00	3.00
Nr. Storeys	0.33	1.00
Total	1.33	4.00

	Building Age	Nr. Storeys	Total	Weights
Building Age	0.75	0.75	1.50	0.75
Nr. Storeys	0.25	0.25	0.50	0.25
Total	1.00	1.00		
			CI	0

Table 1. Pairwise comparison matrix and assigned weights of the "Building Characteristics" elements

the different elements is respected. The matrix with the defined attributes can either be absolutely consistent when decision-makers give perfect judgements or not absolutely consistent (Alonso and Lamata, 2006). The weights are assigned starting from the lower level of the hierarchy by comparing elements at the same level. The determination of the relative importance of each variable is done taking into consideration previous studies and extensive literature review combined with expert opinions using a simplified survey which includes a total of 13 questions. The following, is the developed matrix for the comparison of the weight of building age compared to the number of storeys.
Aggregation and Risk Categorization
The procedure of standardization and weighting at each level of the defined hierarchy is followed by the aggregation process. In the aggregation process the entire information is combined to give a final decision model, which in the context of decision-making is known as the alternative while for the purpose of the dissertation it represents the risk level.

One of the most used aggregation methods is the weighted linear combination, in which each standardized factor is multiplied by the relative weight and the results being summed to give the final goal. The following equation might be used to evaluate alternatives (Malczewski, 2000):

(Eq. 1) $$V(x_i) = \sum_j w_j v_j(x_i)$$

where wj is a normalized weight such that ∑wj=1, vj(xi) is the value function for the j-th parameter (attribute) while V(xi) represents the value of the alternative or main objective based on the value of the j-th attribute.

The interpretation of the risk results obtained in the form of indices according to the aforementioned analysis can be carried out by going through a process of categorization. This process corresponds to the division and grouping of the obtained

Risk level	Range	Description
R1	R ≤ 0.2	LOW
R2	0.2 < R ≤ 0.4	MODERATE
R3	0.4 < R ≤ 0.7	HIGH
R4	R > 0.7	EXTREME

Table 2. Risk categorization based on four classes

information and results in different predetermined categories. Each category has its own ranges (in terms of standardized values) and based on the position where the actual result falls into, the corresponding category is selected. Many recommendations suggest that a good approach to categorize consequences and severity is by using a scale from three to five points (ISO 31010). It is believed that the larger the number of points used, the better is the judgment regarding the actual situation in terms of vulnerability levels and risk. Based on literature review and expert opinions it was decided that four classes are to be used to categorize the level of risk

Implementation

The proposed methodology is implemented in two case studies, the first one in the historical city center of Guimaraes, Portugal and the second one in the city of Lezhë in Albania. Each selected case study for implementation represents different situations. The first one is a UNESCO protected area with old buildings, while the second one is a modern representation of chaotic development characterized by high-rise buildings and a complex street network. The output of the implementation of the methodology shows that such approach is feasible and easy applicable no matter the context. In this way, one of the main issues of holistic risk assessment approaches, which is the context-specific nature, is successfully tackled making the methodology easily transferable no matter the specific site.

Figure 4. Risk Map for the city center of Guimaraes, Portugal

The results for both cases are given in the form of risk map and as expected Guimaraes has a combination of low hazard with high vulnerability, while Lezhë has a combination of high hazard and medium to high vulnerability, reflecting in most of the buildings high level of risk

Figure 5. Risk Map for the city center of Lezhë, Albania

Conclusions & recommendations

As concluded by (Gaillard & Mercer, 2012) the main problematics are related to the low levels of perception from the local community and authorities, together with lack of proper integration of a comprehensive risk information aiming to foster the collaboration between stakeholders. The inability for such communication among other factors represented gaps that needed to be analyzed in order to improve the efficiency of Disaster Risk Reduction (DRR) intervention and strategies. This research focused on the possible ways to bridge the gaps in the form of knowledge, top-down and bottom-up approaches and the collaboration and operation of large array of stakeholders

Taking into considerations the demands and needs for an inclusive DRR, the research was oriented towards the proposal of an updated methodology that could integrate specific variables aimed at combining firstly the information at different scales (building and zone), and secondly information from different perspectives: engineering and planning. The main objective was that of generating an effective and essential information which is depicted spatially and would serve as an input for preliminary decision-making processes. Since there were numerous variables that could be integrated in the proposed methodology a selection procedure was necessary. The variables were selected based on three main criteria; complexity, information and importance.

The research showed that a multi-disciplinary approach imposes a multi-scale approach from the operational scale (the building) to the strategic scale (zone scale). A detailed analysis on a building scale would definitely give a complete information regarding the expected level of damages from a possible seismic event, but would lack in giving the relationship between the object itself and the surrounding urban environment. Such aspect is of a greater importance not only during the emergency phase of a disaster, but also during a later recovery phase, since the analysis at such scale generates possible alternatives accelerating such process.

In terms of the main research question regarding the effectiveness of integrating risk knowledge within planning instruments, it can be concluded that a multi-scale approach is necessary in switching towards inclusive DRR processes since it gives the possibility of combining different form of knowledge context specific with generalized scientific data. It also fosters a top-down and bottom-up approach because the data collection and elaboration is context specific giving an output to local and national authorities, while on the other hand such approaches require an understanding of the event at a regional and national scale, implying the need for coordination and information in these levels. Such approach imposes also a vast majority of stakeholders. On one hand there is the local community, which is directly affected from such events and on the other hand there are local and national institutions. In addition, social and physical scientists are the other important actors. It is recommended that the output of the research after "filtering" in the national and local institutions can be used to target local community with the aforementioned dissemination objective. By creating a clear, open-source and easy structure the community is not marginalized in terms of information and means of protection

XFuture improvements might imply the integration of new variables to take into account other aspects of risk assessment, for instance social components or environmental impacts to switch into a holistic approach. From this point of view, the proposed model is flexible allowing for integration of new variables or new hierarchical levels. The tool in the form of an application and software can be used by specialists to assess and map the risk based on appropriate research, by the local institutions to define interventions and by local communities to raise awareness and risk perception.

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