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## RESEARCH ARTICLE

# Proactive Actions Based on a Resilient Approach to Urban Seismic Risk Mitigation

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### Abstract:

#### Background:

Seismic risk mitigation is an important issue in earthquake-prone countries, and needs to be solved in those complex communities governed by complex processes, where urban planning, socioeconomic dynamics, and, often, the need to preserve cultural assets are present simultaneously. In recent years, due to limited financial resources, mitigation activities have often been limited to post-earthquake events, and only a few in periods of inactivity, particularly in urban planning. At this point, a significant change in point of view is necessary.

#### Methods:

The seismic risk mitigation (and more generally, natural risk mitigation) must be considered as the main topic in urban planning and in the governance of communities. In fact, in several recent earthquakes, significant socioeconomic losses have been caused by the low or lack of resilience of the communities. This is mainly due to the high vulnerability of private buildings, in particular, housing units.

#### Results:

Therefore, in recent years, several studies have been conducted on the seismic resilience of communities. However, significant improvements are still needed for the resilience assessment of the housing stock, both qualitatively and quantitatively. In this study, which is applied to the housing system, a proposal regarding a change in urban planning and emergency management tools based on the concept of resilience is reported. As a first application, a case study in Italy is considered.

#### Conclusion:

The proposal is focused on defining and quantifying the improvement of the resilience of the communities and this must be obtained by modifying the current Civil Protection plan. New tools are based on a new resilience community plan by encompassing urban planning tools, resilient mitigation strategies, and consequently, emergency management planning.

**Keywords:** Seismic risk mitigation, Residential building stock, Seismic losses, Resilient quantitative approach, Civil protection, Resilience plan.

### Article History

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## 1. INTRODUCTION

It has been ascertained that earthquake prediction for civil activities is not possible, and in any case, it would be of little use for the mitigation objectives in short to medium term. Consequently, from an engineering point of view, the best way to improve community performance is to improve mitigation and prevention strategies. To this end, the decision makers, population, and tools play key roles. The decision makers should define the tools, and the population should be encouraged to apply such tools. The new trend for the manage-

ment of communities (which are highly complex systems) is based on the resilience concept, and is expected to be the most common approach for future developments.

In recent years, in both scientific projects and literature on disaster management, the concept of resilience has often been integrated with classic risk analysis statements. Consequently, resilience has increasingly become the key to defining risk reduction and management strategies [1 - 3]. This is because an approach focused on the concept of resilience can significantly highlight the critical issues and endogenous resources of a community.

Consequently, an approach based on resilience is

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particularly advantageous when compared with the need to define mitigation activities. It strengthens the ability of social systems to limit negative impacts and reduce the consequences after a negative event. For this reason, the development of resilient communities can now be considered the main goal of risk prevention and mitigation programs.

As a matter of fact, the recovery process generally depends on the economic, technical, and human resources available, as well as the awareness of the community, and public policies. Quantitatively, the recovery process can be defined in several ways, and generally, as a convolution of several functions (*i.e.*, fragility, costs and work time functions, among others) based on different and complex organisational and socioeconomic models.

As reported in previous studies [4 - 7], the resilience of communities plays a key role in seismic risk mitigation strategy and its quantification can be considered a primary goal of every seismic risk mitigation strategy. The resilience of communities mainly depends on the performance of the buildings (in particular, residential buildings), infrastructures, and service networks [8 - 11]. In the recovery phases, social, economic, and public support are essential to guaranteeing an immediate response and acceptable levels of service in a reasonable time.

Four fundamental properties are generally considered in the resilience concept. Robustness is the ability to withstand an assigned level of effort (reduced loss of functionality). Redundancy is a measure of the ability of a system to create alternatives that meet the functional requirements. Speed (rapidity) is the ability to meet priorities and achieve goals in a timely manner. Resourcefulness is the ability to use resources (monetary, physical, technological, or informative) to meet certain priorities and achieve the selected goals. Based on the principles and definitions briefly described above, several methods have been developed in recent years to quantify resilience to disastrous phenomena.

For example [12], community resilience is based on the activities leading up to the event. To obtain a really resilient community, preparation activities are more important than the operational strategies for post-event management. Furthermore, to define resilience, four interdependent dimensions of the resilience of a community have been identified: technical, organisational, social, and economic (TOSE).

In more recent years, a new method for the improvement of community resilience has been studied and a new framework has been developed. Community resilience must include normal mitigation procedures and emergency management activities. More specifically, a community is considered resilient if it has

- Low probability of damage;
- Low consequences due to damage;
- Low recovery times.

A multidimensional representation of resilience was introduced in a study [13]. The concepts of resilience were developed on the basis of control time and recovery time [14];

therefore, starting from the four resilience dimensions (robustness, resourcefulness, redundancy, and speed) and their clarification, the functionality curve was defined, thereby enabling the evaluation of the resilience. On this basis, an interesting framework was proposed for the quantification of disaster resilience of health care facilities [15].

More recently, based on previous studies [16], the interesting PEOPLES resilience framework was developed. In a study [17], an analytical formulation was proposed to evaluate the resilience of the communities, based on an index that combines resilience, exposure, and danger. In another paper [18], a probabilistic and numerical approach to evaluate seismic resilience was proposed, based on the deterioration process during structural life, residual functionality, and post-event recovery. In a previous study [19], a framework was proposed, based on the disaggregation of resilience objectives, with minimum performance targets for each subsystem. Minimum performances need to be identified for each subsystem, and the key issue is to provide the design goals that are the basis of community resilience planning.

Based on this short literature review, it is common knowledge in the scientific community that qualitative approaches are not useful for mitigation strategies. On the contrary, interesting quantitative approaches have been proposed and several applications are available. Similarly, to apply a quantitative approach, an integrated methodology plays a key role. Several approaches have been developed considering different territorial scales (for example, the urban scale) and different topics (such as networks, buildings, and infrastructures).

Resilience is a combination of several factors. Conceptually, it should be considered as the global effects of mitigation measures in periods of seismic inactivity and the quality of management in emergency times. Nevertheless, the real improvement of community resilience must be based on mitigation measures in periods of inactivity. Quality, quantity, and effects of management in emergency times must be considered as the consequences of mitigation measures. Emergency procedures, tools, and materials are defined (or should be defined) based on mitigation measures. For this reason and in the first instance, in this study, emergency management is not considered.

It needs to be highlighted that the next step is the quantification of the resilience of each subsystem of the community. Considering medium and strong seismic events and the key role of residential buildings, the study of community resilience is extremely difficult, particularly its quantification. Some studies have been conducted on the basis of the data observed in post-earthquake management [20]. Lastly, it is known that after disasters, assets are lost and many businesses cease activity. However, after the restoration of some fundamental networks, some economic activities can be resumed. Nevertheless, after a catastrophe, the economy cannot start again.

The occurrence of a subsequent economic catastrophe cannot be considered to be solely dependent on the intensity of the disaster (*i.e.*, in this study, the seismic intensity); however,

it also depends on the initial socioeconomic conditions. To investigate and mitigate the long-term impacts of strong events, it is necessary to define significant additional actions for mitigation based on the best practices of the new Civil Protection, strongly integrated with urban planning tools.

The concept of changing from an emergency plan to a resilience plan should be considered as a natural evolution of the emergency plan itself. Obviously, in this study, the increase of resilience based exclusively on vulnerability reduction is considered.

In this study, a new proposal is described for Civil Protection tools based on resilience, in which the resilience is clearly quantified. This proposal can effectively analyse specific areas (on an urban scale) and their resilience and is based on a de-aggregation process of the resilience of the community and its sub-sections. The de-aggregation process must be considered in order to define the resilience plan based on specific seismic retrofitting objectives for different types of buildings. A resilience assessment framework is proposed and applied to a small city, where several problems play a key role in community resilience, such as cultural heritage buildings, low level of gross domestic product (GDP), and high demographic drop.

The main goal is to move from an emergency plan to a resilience plan. It is considered a natural evolution of the emergency plan itself. In the proposed study, the base concepts of resilience have been considered; on these bases, the proposed approach develops a new resilience plan for the housing system. The resilience of the community is evaluated in a quantitative way for individual buildings and building types. This is a new proposed tool for quantitative resilience evaluation.

## 2. MATERIALS AND METHODS

The strong relationship between Civil Protection goals and resilience concepts is well known. An example of an in-practice application is the current implementation of these concepts in the state of California, in particular in the cities of Los Angeles and San Francisco, where resilience has been considered in the mitigation strategies based on existing studies from the United States Geological Survey (USGS) [20]. A resilient community is realised based on objectives, such as protection of the inhabitants, improvements in performance and recovery time of the city, and protection of the economic activities of the city and Southern California. Consequently, some operational actions and some provisions are defined, in particular, for the existing buildings (designed with the old seismic code) and the structures and infrastructures [21, 22].

However, the aforementioned cases can be considered exceptions. In actual fact, a significant number of studies and consequent applications have been carried out. However, these

works are often related to single entities, such as critical facilities and service networks (hospitals, lifelines). The proposed resilience frameworks can investigate single types of treated objects, but they cannot be applied to cities. To evaluate the possible strategies to improve resilience, the relationship between the standard performance level defined for the technical, organisational, social, and economic aspects and the resilience of a community should be considered in different countries. For example, in Italy and other Mediterranean earthquake-prone countries, resilience is strongly related to their socioeconomic, structural, and infrastructural conditions, historical buildings, and the additional need to protect and preserve the cultural heritage.

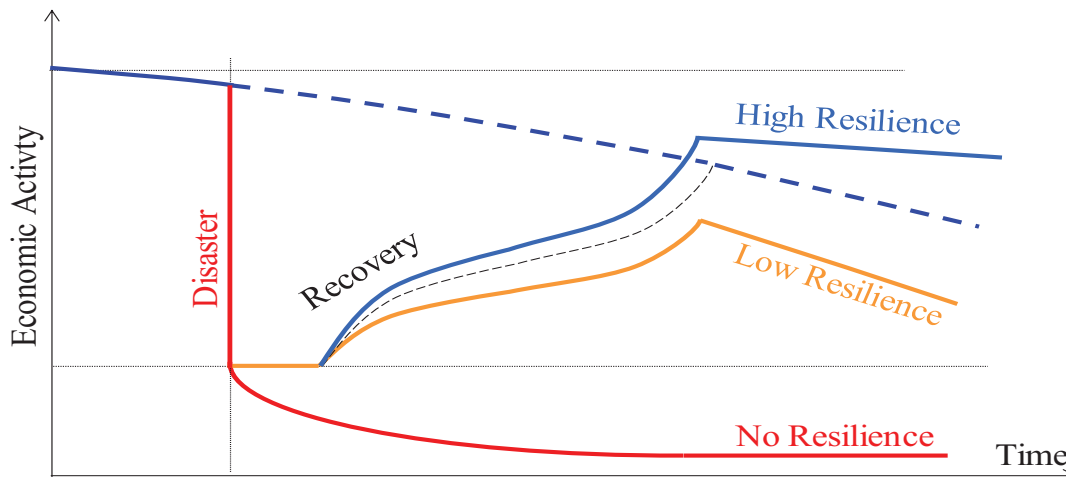
As a consequence of earthquakes, a catastrophic depression of the regional economy is expected. After an immediate drop in the economic activity, and based on the infrastructure system, the interested regional economy can return to pre-earthquake conditions within a few years.

In strong earthquakes, the regional economy may not recover for many years or the socio-economic activity may never recover at all [20]. In the same case, the community continues to decline, reaching an unacceptable standard of living or leading the community to extinction [5]. This process could be realistic for the poorest communities (for example, those with a low or decreasing GDP).

As a matter of fact, post-earthquake repairs are generally affected by great uncertainty and depend on the built system characteristics, which are more complex for historical centres. Proactive strategies (based on retrofitting) must be considered the only correct strategies for modifying and improving the resilience performance of communities (Fig. 1).

As an example, the Italian buildings stock (both public and private) reveals a considerable fragility due to the structural typologies and their interaction, as the most recent seismic events have highlighted. Public resources are not sufficient to renovate these buildings. Consequently, the citizens' cooperation and their financial commitment are unavoidable to reduce the vulnerability of buildings. In Italy, the actual application of the new proposal (*i.e.*, similar to resilience by design) can be far more complex and difficult. In particular, the interaction between historical buildings and Civil Protection activities needs to be considered.

The choice of the retrofit is made by individual building owners; however, government strategies can play a key role based on specific subsidies and incentives, insurance and retrofit obligations, declassification for building use, and so on. In fact, based on the recent medium and strong intensity earthquakes, a new retrofitting process of existing buildings has been defined and regulated by a recent law [23] to reduce the seismic vulnerability of the private building stock.



**Fig. (1).** Conceptual representation of the effects of an earthquake on a regional economy with an initial low and/or decreasing GDP.

The goal is to mitigate the social cost of earthquakes by a legislative stimulus, through tax incentives. The laws need to obtain results and lead to the widespread renovation of private buildings. They provide for the possibility of using an incentive, in terms of tax deduction, for the execution of ‘certified’ retrofitting aimed at reducing seismic risk, which should be carried out between January 1, 2017, and December 31, 2021, in order to reduce the risk through adjustment and seismic improvement. Unfortunately, this approach has not yet been effective; thus, other strategies are needed. Essentially, the issue is not the heavy seismic losses, as no one questions that Italy has a significant earthquake problem. The problem seems to be the implementation of the operation tools and the real consideration of the resilience of communities.

The Italian National Civil Protection has played a fundamental role in the last 40 years, mainly after the medium and strong intensity earthquakes (starting from Friuli, 1976, and Irpinia, 1980). The role of the Department focuses on several risk mitigation activities: prevision, prevention, and mitigation. In particular, in the past years, numerous efforts have been made focusing on post disaster emergency management. In particular, the department has a key role in regional and local emergency management, based on a wide regulation of these activities. The most recent reference is the new Civil Protection code [24]. Unfortunately, even in this new code, the concepts of community resilience have been quite neglected, a sign of the substantial unpreparedness of local communities to apply and plan risk mitigation strategies based on the resilience concept.

To obtain resilient communities, the resilience concepts should first of all be included in the mitigation activities of seismic risk in normal times; these activities ought to replace the current civil protection procedures, and thus, the emergency plan should become the resilience plan of the community. The real and practical application of the resilience concepts ought to be based on the quantitative methods of resilience. In recent years, numerous studies have been conducted in Italy and a

new approach to resilience, based on seismic risk mitigation, seems quite simple. Nevertheless, the actual application of this approach should no longer be delayed. As a matter of fact, based on recent experiences and studies, the turning point in the Italian Civil Protection activities should be the resilience based approach and a strategy based on the planning of public and private seismic vulnerability reduction, according to urban planning. This strategy must be based on the following objectives:

- Reduction of the seismic damage, losses, and probability occurrence.
- Reduction of the recovery time.
- Reduction of the downtime (interruption of activities) to protect the economic activities.
- Use of less financial resources based on mitigation policies in normal times.

Therefore, to mitigate the seismic risk, a new strategy based on overcoming the separation between urban planning, emergency plans for the immediate consequences of a seismic event, and a global risk mitigation policy, is of primary importance.

To pursue these objectives, in this work, the following framework is considered, where each step is based on past studies, research experience, and applications. For this reason, the proposal may not seem to be a real scientific advancement; however, it aims to be a new application for the improvement of the Civil Protection activities based on existing and well-known procedures. Therefore, the study provides a strong link between research and its application, and the proposed framework can be considered immediately applicable.

The core of the proposal is the application of the concepts of resilience. A community resilience index [9] is considered based on a combination of resilience for building types in specific areas (at the urban scale). The resilience of a community is quantified as:

$$R_{\text{index}}(I) = \sum_{\text{area}=1}^n \left\{ W_{\text{area}} \cdot \left( 1 - \sum_{\text{type}=1}^m \frac{E\left[T_{\text{RB}} \mid C_{r,r|I}\right]}{T_{\text{LC}}} E\left[C_{r,r} \mid d_{l,\text{type}|I}\right] P\left[d_l = d_{l,\text{type}} \mid I\right] \right) \right\} \quad (1)$$

where the weight factor is considered to define the relative importance of a single area of the community rather than the others. The evaluation is based on a seismic scenario; thus, the expected ratio is defined. The considered resilience model links the functionality losses directly to the seismic vulnerability of buildings. Finally, the building recovery time and the control time are needed, and they are defined based on the level of damage, difficulty in work activities, and available economic resources.

Based on available data, it is possible to define the optimal way to analyse and evaluate. The goal is to define the exceedance probability for each considered performance level (PL). Currently, the most used approach is based on the FC concept. Nevertheless, other approaches can be used, particularly on a wide territorial scale and historical centre (for example, damage probability matrix, DPM [25]). In equation (1), the vulnerability characterization in a probabilistic way is defined as:

$$P\left[d_l = d_{l,\text{type}} \mid I\right] \quad (2)$$

where is the performance (in terms of damage) achieved by each building type, and is the considered damage level and corresponding seismic intensity I.

Then, the repair cost (RC) and repair time functions are based on the seismic damage level evaluated above. Conceptually, based on the suffered damage level and the building type, the expected value of the repair cost function for each building type, performance level and seismic intensity is

defined as:

$$E\left[C_{r,r} \mid d_{l,\text{type}|I}\right] \quad (3)$$

where is the relative repair cost; it is evaluated as the ratio of the cost of repair to the cost of replacing the building.

The relationship between the expected value of the building recovery time (influenced by the level of damage to a building, difficulty in work activities, available economic resource) and the control time is defined as:

$$\frac{E\left[T_{\text{RB}} \mid C_{r,r|I}\right]}{T_{\text{LC}}} \quad (4)$$

As it is now unanimously agreed upon, the resilience of communities can be considered as the aggregate performance of individual structures and infrastructure systems (such as the building stock and infrastructure network). Their convolution results in obtaining the total resilience of the community. Moreover, the socioeconomic conditions (which are a very complex problem) must be considered. Nevertheless, as reported in previous studies [5, 9], the peculiarity of the Italian condition has often highlighted the key role of the residential building stock on the overall measure of community resilience. For this reason, this study focuses on the residential building stock but with a clear awareness that it is a component (although very relevant) of the overall measure of community resilience. Operatively, to assess and use the seismic resilience, the approach is based on the following steps (Fig. 2).

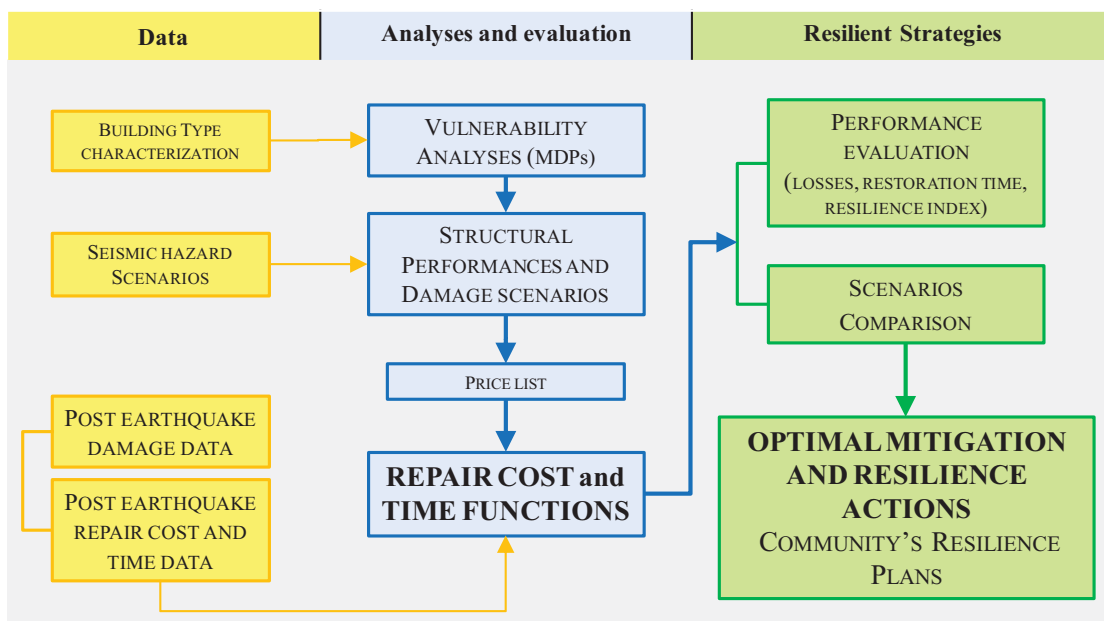


Fig. (2). Flowchart of the proposed approach.

1. Selection of the seismic event for the scenario.
2. Evaluation of seismic vulnerability (based on a well-validated model).
3. Analysis of the seismic scenario.
4. Performance evaluation in terms of losses, restoration time, and resilience index for the considered scenario.
5. Comparison of different economic scenarios with different performance levels based on optimal mitigation and resilience actions.

Based on this approach, emergency plans become the community resilience plans containing prevision, tools to forecast losses, and strategies for prevention in a practical way. Conversely, when the facility performance objective is to be determined so that the community resilience objectives are achieved, the same three functions are also required during the resilience de-aggregation process.

Based on previous studies and existing post-earthquake data reconstruction processes (9), the community's resilience function is defined. Three different parts are considered Fig. (3): (i) a partial and rapid return to limited functionality in the short term (a few days), linked to the emotive reaction of the inhabitants (usable and non-damaged buildings and reactivation of services on the buildings); (ii) a pseudo-horizontal phase comprising the planning and implantation of preliminary activities for the reconstruction process; this phase is strictly linked to the damage level of the buildings, *i.e.*, seismic intensity and vulnerability. (iii) Increase in functionality due to the progressive distribution of funds and the resulting repair works.

### 3. RESULTS AND DISCUSSION

To demonstrate the transition from the current emergency management plans to community resilience plans, a first practical application is reported in this study. It considers the town of Miglionico (Matera), a little town in the south of Italy (Fig. 4). This town was chosen because it can be considered a typical mountain historical centre in Italy, where the mitigation needs must coexist and overlap with the conservation requirements of historic buildings, in an economic context that

is not rich. Moreover, it is located in a medium to low seismicity zone, but with a significantly high vulnerability because of the lack of attention to mitigation due to its medium-low hazard level. In these cases, the risk and consequent losses can be very high, as shown below. The case study is focused on evaluating the effects of the optimal interventions needed to increase community resilience.

Based on the proposed framework, numerous studies have been conducted on each of the phases. Moreover, each of these issues is strongly complex and this work did not advance in the single steps because this is not its goal. The resilient analysis is considered in a de-aggregate way. The vulnerability of the buildings is investigated, and their performance is evaluated in terms of seismic damage. Consequently, some typical retrofit strategies are considered regarding retrofit goals and repair costs. The town under consideration has been divided into two main residential areas: the historical centre and the new neighbourhood. An earthquake scenario event is considered.

Fragility and vulnerability evaluation for buildings is based on analytical models and methodologies (for example, non-linear analyses, comparison with benchmark structures or real existing data, *etc.*). These methodologies can be accurate for reinforced concrete buildings; however, there is currently no uniform and sufficiently tested understanding of masonry buildings, particularly on a wide territorial scale and in historical centres.

Several approaches are available which can be used to assess the seismic vulnerability of buildings from empirical methods based on post-earthquake damage observation and building data such as the Damage Probability Matrix [25] or the Vulnerability Index, analytical methods based on numerical models and hybrid methods.

In this study, damage probability matrices (DPMs) are considered in order to estimate the building damage. They are empirically derived from existing post-earthquake damage and are a well-established tool [25]. Moreover, they provide a probabilistic distribution of the damage which is coherent with the EMS98 level [26]. This approach can be considered an optimal solution to study the seismic performances of the existing masonry buildings considered.

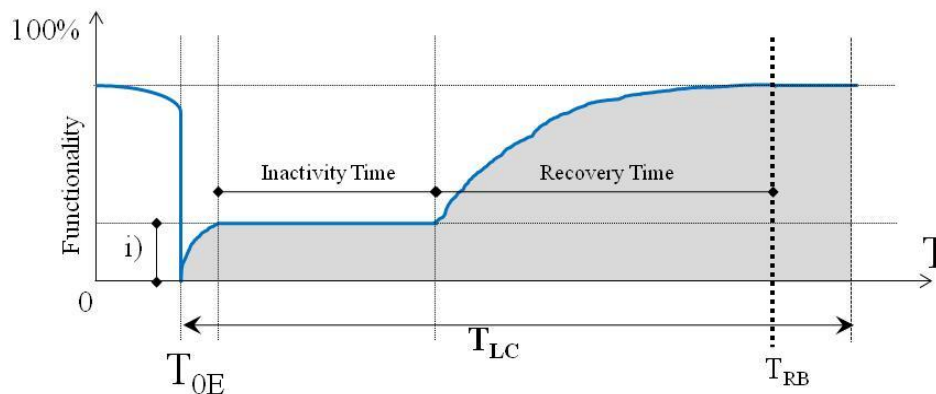


Fig. (3). Resilience-based flowchart of the adopted methodology.

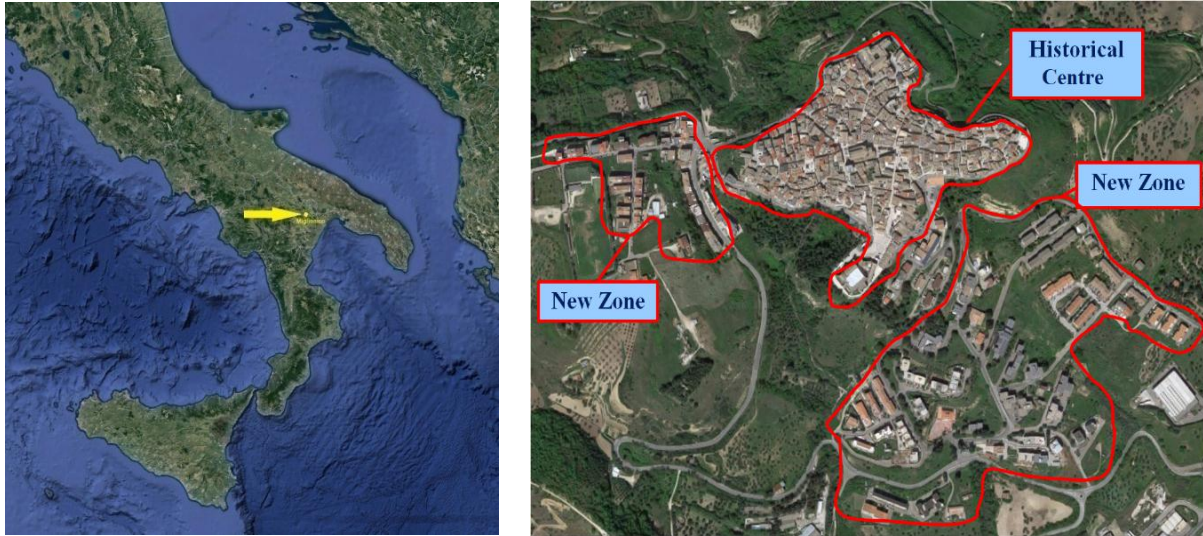


Fig. (4). View of the Miglionico village.

### 3.1. Loss Evaluation and Seismic Resilience Performances

Owing to the peculiar characteristics of the available data, the main steps of the procedure are as follows:

- Inventory of buildings and analysis of building types;
- Seismic vulnerability class assessment;
- Selection of earthquake scenarios;
- Representation of the damage scenario based on DPMs.

The seismic vulnerability of the building stock, both in the historical centre and in the new areas, is evaluated. An EMS-98 intensity is used as seismic input in the DPMs to obtain the damage scenario of the residential buildings under study. This approach is based on four vulnerability classes, ranging from high (class A) to low (class D). After the typological analysis, each building is classified in one of the four classes, according to its structural characteristics (horizontal and vertical structural type, seismic retrofitting, age) as the seismic code.

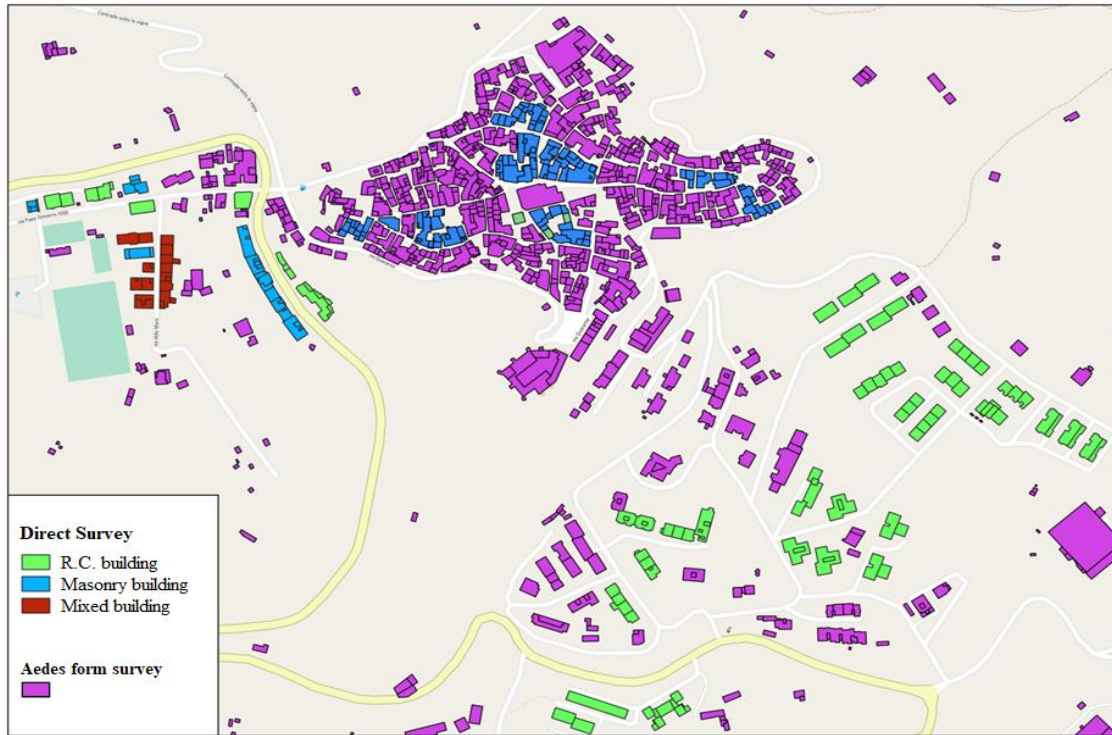
The geometrical and quantitative characteristics of all the buildings were also collected, including height, plan and elevation configurations, age, type of vertical and horizontal structure, roof type, possible retrofitting, state of preservation, etc. Based on the typological survey [27], the seismic vulnerability evaluation is obtained following a well-known approach [25]. The building stock is defined by an in-situ survey and the buildings are generally organised in aggregates. This topic plays a key role in the urban configuration of historical centres. Some recurrent cases with the most widespread materials and structural configuration (*e.g.*, the thickness of the masonry walls, connections between orthogonal masonry walls, and connections between masonry walls and slabs) are investigated and defined based on detailed

information and interior inspections. For all buildings, the in-situ survey is coherent to the most commonly used survey form, based on the typological part thereof, for usability and damage (AeDES). Vertical and horizontal structural type (based on materials and structural configuration), age of construction and/or of retrofitting, number of storeys and surface are obtained and reported in GIS (Geographical Information System).

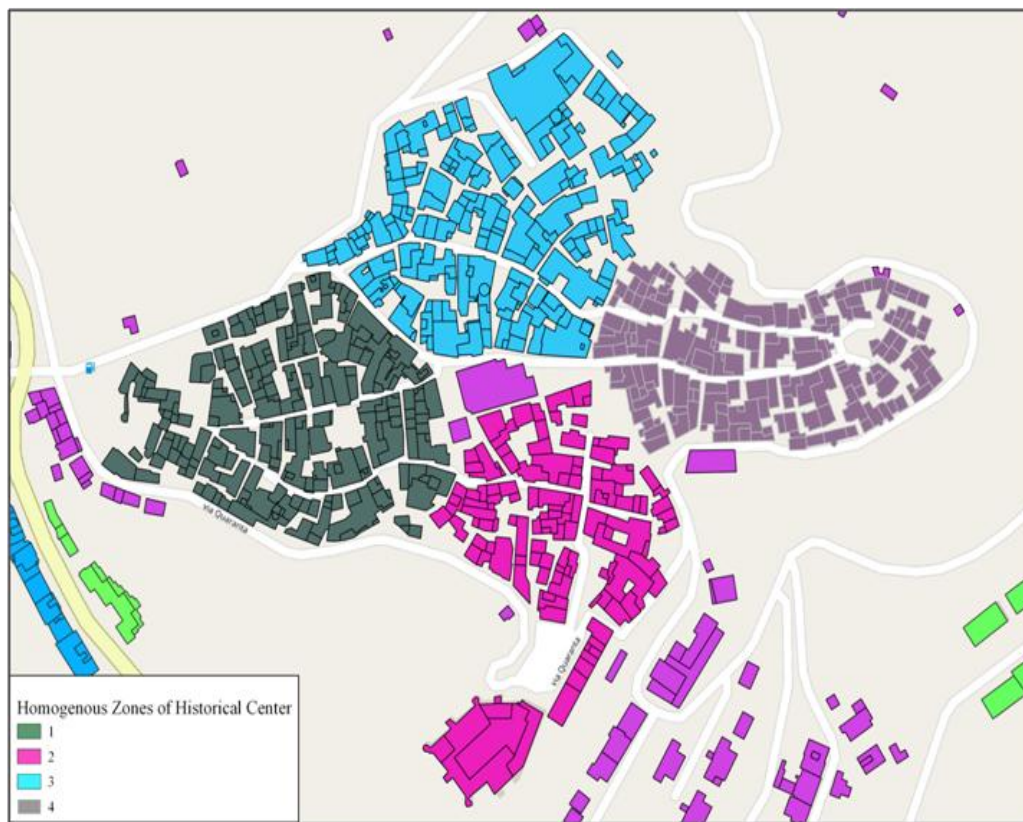
The survey form has been widely used in past seismic risk studies and enables a simple and effective correlation between typological features and seismic vulnerability. In Fig. (5), the surveyed buildings are reported: for recurrent cases, the main structural types are reported. Based on the typological survey, six homogenous zones have been identified according to the structural type.

The historical centre is divided into four homogenous zones based on the structural typologies, materials, and age of buildings. In Figs. (6 and 4) zones, which have been identified in the historical centre, are reported while another two zones (new zone 1 and new zone 2) have been considered outside the historical centre.

Using a well-established DPM-based approach [25], a vulnerability class is allocated to each building starting from its vertical and horizontal structural type, age of construction and/or retrofitting. The high, medium, medium-low, and low vulnerabilities (vulnerability classes A, B, C, and D, respectively) are considered. Low vulnerability (class D) is assigned to those structures built or retrofitted according to the seismic classification after 1980 with modern seismic code. The choices adopted herein, in assigning a vulnerability class to each building are reported in Table 1. Fig. (7) depicts the vulnerability distributions in terms of the number of buildings.



**Fig. (5).** In situ direct survey. Recurrent cases (with the most widespread materials and structural configurations) and typological survey (Aedes form).



**Fig. (6).** Four homogenous zones (1, 2, 3, 4) in the historical centre based on structural typologies, materials, and age of buildings.



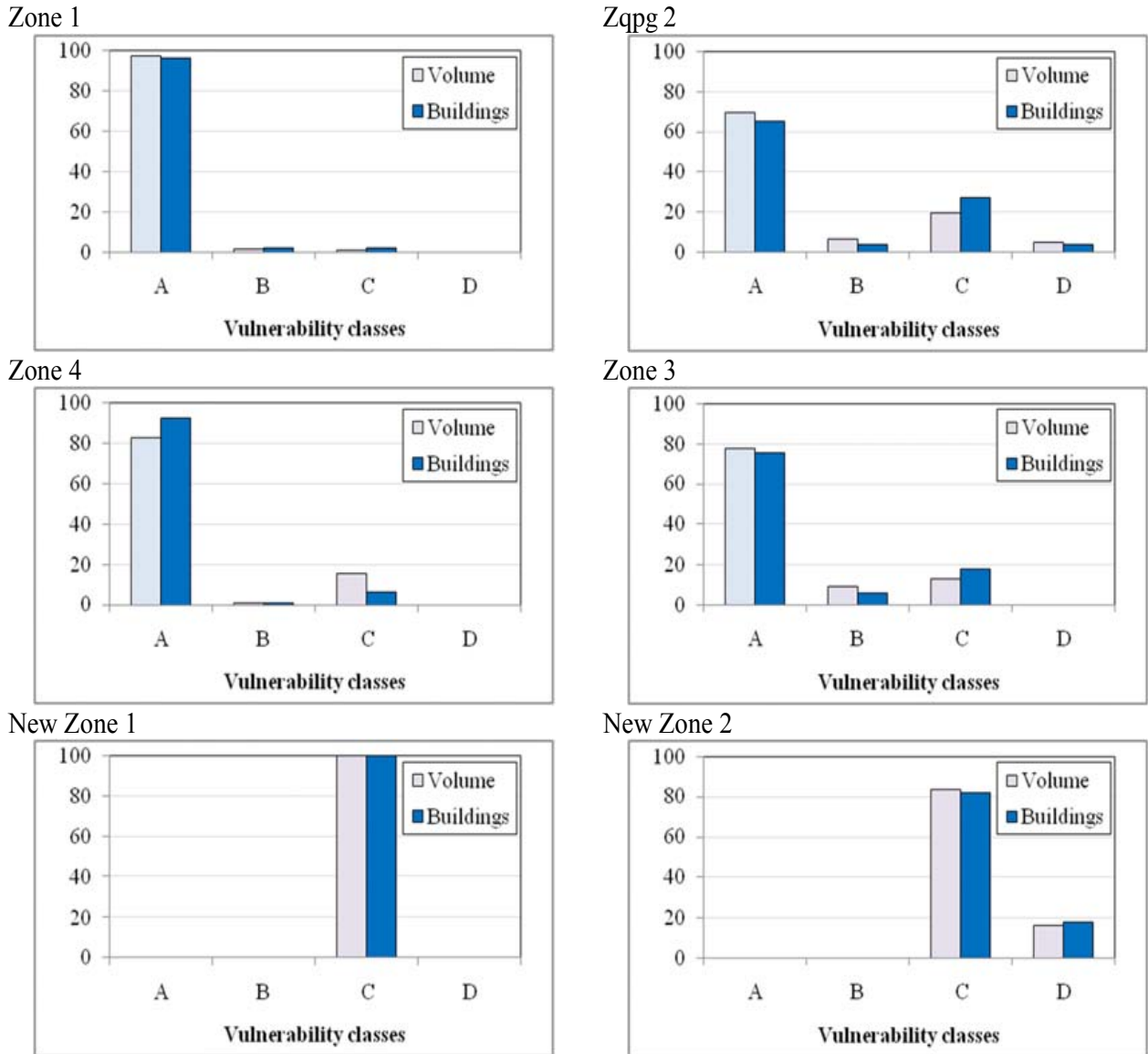


Fig. (7). Statistical distributions of the vulnerability Classes in the village of Miglionico.

To achieve the goal of this study, one damage scenario for the entire building stock is defined based on the seismic hazard study; is considered uniformly applied to the whole town (based on CPTI15, Parametric Catalogue of Italian Earthquakes 2015, <https://emidius.mi.ingv.it/CPTI15-DBMI15>).

In the selected case study, an only scenario event is considered. Based on the historical seismic data, the selected

seismic intensity is the highest intensity for the town under consideration (Fig. 6). Nevertheless, the historical data used shows a clear lack of information until 1800. Consequently, another event ( $I_{EMS98} = VIII$ ) with a higher intensity is selected. It is the highest return period event.

Obviously, more accurate hazard analyses can be carried out, but they are outside the scope of this study.

Table 1. Allocation of vulnerability class based on vertical and horizontal structures (more details in [27]).

		Vertical structures		
Horizontal structures		Masonry	Mixed	RC
Vaults	Without tie-beams	A	B	-
	With tie-beams	A	B	-
Floors	Deformable (wood or steel)	A	C	C
	Semirigid (wood, steel, RC)	B	C	C
	Rigid, RC	B	C	C

By combining the building vulnerability and selected earthquake event, an estimate of the building damage is obtained. Using the DPMs, the damage distribution of the building stock is evaluated. As a consequence, the losses can be estimated based on the resilience concepts. The resilience is evaluated based on the functionality curve (Fig. 7) of the building stock; in particular, for the considered seismic scenario, the curve is defined for the historic centre, each of the four areas, and the two expansion zones. Consequently, the robustness is evaluated as the residual functionality, linked to the non-damaged buildings.

The recovery time plays a key role in community resilience and can be considered the main issue for decision-making in the retrofitting strategies based on the resilience concept. The recovery time is clearly dependent on the building types and their estimated damage, socioeconomic and political conditions, and financial resources. The strategies for the recovery process can be considered as a consequence of these issues.

The recovery time is assessed based on the data available from the L'Aquila earthquake (2009) and the subsequent reconstruction process. In previous studies [28, 29], the trends in granting financial contributions for the repair and reconstruction activities are reported. Furthermore, in another research [30], data regarding the process of return of the population to their homes in the historical centre and suburbs are reported.

The above available data on the progress of the reconstruction process is used to define the step functions in the current state. In a previous study, the key role of the pseudo-horizontal phase has been highlighted. Rapidity is based on repair operations and their costs; however, it is strongly conditioned by the sub-horizontal part of the recovery time, which depends on the seismic damage.

For this case study, the repair costs have been defined considering those related to the evaluated damage levels. Economic quantifications of repair activities were based on the price list for the Basilicata Region and validation was carried out considering the L'Aquila reconstruction process data. A global repair cost was assigned and then standardized to a rebuilding cost of 1100 €/m<sup>2</sup>. In turn, datasets of global repair and retrofitting costs were developed (Table 2).

**Table 2. Allocation of vulnerability class based on vertical and horizontal structures.**

	Repair cost [€/m <sup>2</sup> ]		Retrofitting cost [€/m <sup>2</sup> ]	
	Light damage	Heavy damage	1 class of risk	2 or more classes
<b>Masonry buildings</b>	220	450	70	320
<b>RC buildings</b>	185	535	34	310

The recovery process is the sum of the inactivity time (pseudo-horizontal phase) and the recovery time (re-pair and reconstruction activities). Obviously, the inactivity time

precedes the actual recovery time. These time intervals are estimated considering the abovementioned post-earthquake data. The inactivity time is evaluated at 21 months for the four areas of the historic centre and 9 months for the two expansion zones. The trend of the functionality curve first considers the recovery of buildings with a low damage level and then considers the recovery of buildings with higher damage levels. The considered control time is.

Based on the evaluated damage levels, the cost ratios calculated, which ranges between 0 and 1. Based on a similar approach, the recovery time is estimated, considering the required time to restore a particular damage level. In particular, the cost and time models are validated following the same procedure used in a previous study [9], *i.e.*, according to the repair cost function and the pairing time function derived from the available reconstruction process data.

The set of repair work activities is evaluated in accordance with the most widespread repair and strengthening techniques [28, 29]. The economic and temporal quantifications are evaluated based on the current price list for the Basilicata Region. Lastly, the resilience performances of the community are evaluated in terms of functionality losses and restoration time, as depicted in Fig. (8). The post-earthquake resilience is evaluated for each zone, and a significant difference between the historical centre and the new areas is observed.

### 3.2. Mitigation Strategies

In this section, some mitigation strategies for municipal territory are considered. The basic principle to define an effective strategy to enhance resilience is derived from the target performance of buildings after the retrofit program. To define an operative resilience plan, the resilience-based strategy is developed considering the goal of the retrofit process (performance target), priority for those building types that must be primarily retrofitted, the total cost of the different strategies, and their socio-economic benefit. The above issues can be considered the base for territorial governance and seismic risk mitigation policies.

To develop and demonstrate the proposed procedure, the possible increase in the performance of buildings is evaluated. Three different levels of seismic retrofit are considered, which are consistent with the recent Italian law and based on tax deductions for interventions, with up to a 75% tax deduction per unit if it passes to a lower risk class and 85% if it passes to two lower classes. The recent Italian law allows homeowners to gain up to 85% of the total retrofit expenses, depending on the degree of improvement that the intervention obtains. In fact, the seismic class is linked to the expected annual losses (EAL) [23]. It depends on the most likely damage and repair costs (for structural and non-structural elements). The seismic risk class must be evaluated and compared in pre- and post-retrofit conditions to determine the tax deduction, which is linked to the seismic upgrade and based on the following upgrade of the risk class:

- 70–75% for 1 class of risk;
- 80–85% for 2 or more classes.

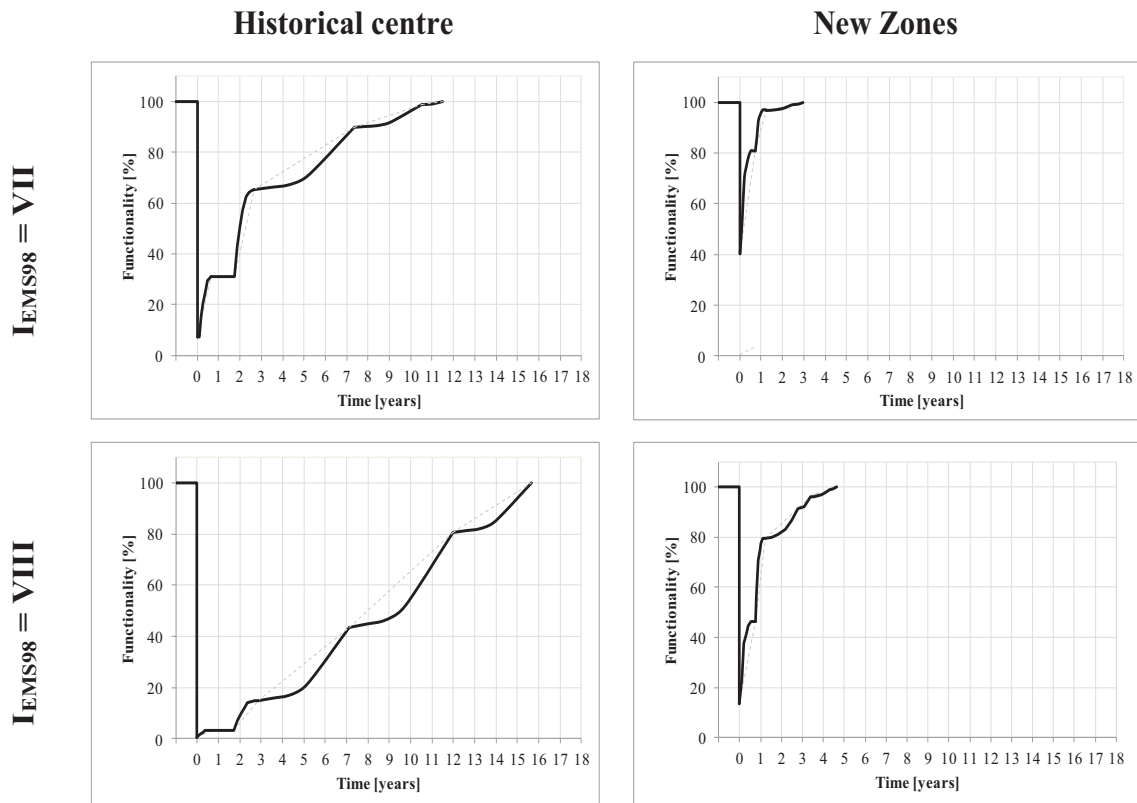


Fig. (8). Resilience performance in terms of functionality losses and restoration time for the historical centre and new zones.

As a result, it is considered that the interventions that reduce the seismic vulnerability of the buildings follow the code requirements. Therefore, regardless of the type of seismic retrofit (local or global upgrade), a shift to a lower vulnerability class from the current one is taken into account. As a matter of fact, the risk class is directly linked to the vulnerability class. To define the functionality curve, the same procedure used in the previous section is considered. A direct proportionality relationship is considered between functionality reduction and inactivity time.

To improve resilience, different effective strategies are considered through three building retrofit programs and each retrofit plan is based on its goal, number of buildings to retrofit for each considered area, vulnerability class shift, and related cost. The first retrofit plan is based on one shift of vulnerability class (1-V); the second retrofit plan is based on two shifts of the vulnerability class (2-V); and the third retrofit plan is based on the total upgrade (TU) of the buildings that are to be compliant with the current building code. Consequently, for each retrofit plan, different vulnerability class distributions are obtained, an update seismic scenario is evaluated ( $I_{EMS98} = VII$

and  $I_{EMS98} = VIII$ ), and a different post-earthquake resilience is obtained. The retrofit plans are compared with each other and with the initial condition according to the functionality losses and restoration time (Fig. 9).

As is clearly depicted in Fig. (8), the resilience index strongly depends on the seismic intensities and choice of the control period, which, in the current state (CS) and considering very long recovery times (defined according to the historical data), is considered equal to 12 years and 18 years respectively for  $I_{EMS98} = VII$  and  $I_{EMS98} = VIII$  (Tables 3-5).

If the decision-maker wants to evaluate the effect of the different plans correctly, he must consider different control times. Moreover, 12 or 18 years should not be regarded as a monitoring time, because after 12 or 18 years, a community cannot be considered resilient (Table 3). Consequently, a good decision-maker must evaluate the performance of his community over much shorter time control periods. For this reason, different control time values (2, 5 years) are considered; very different RI values are obtained, and thus, the effects of the retrofit plans are better highlighted.

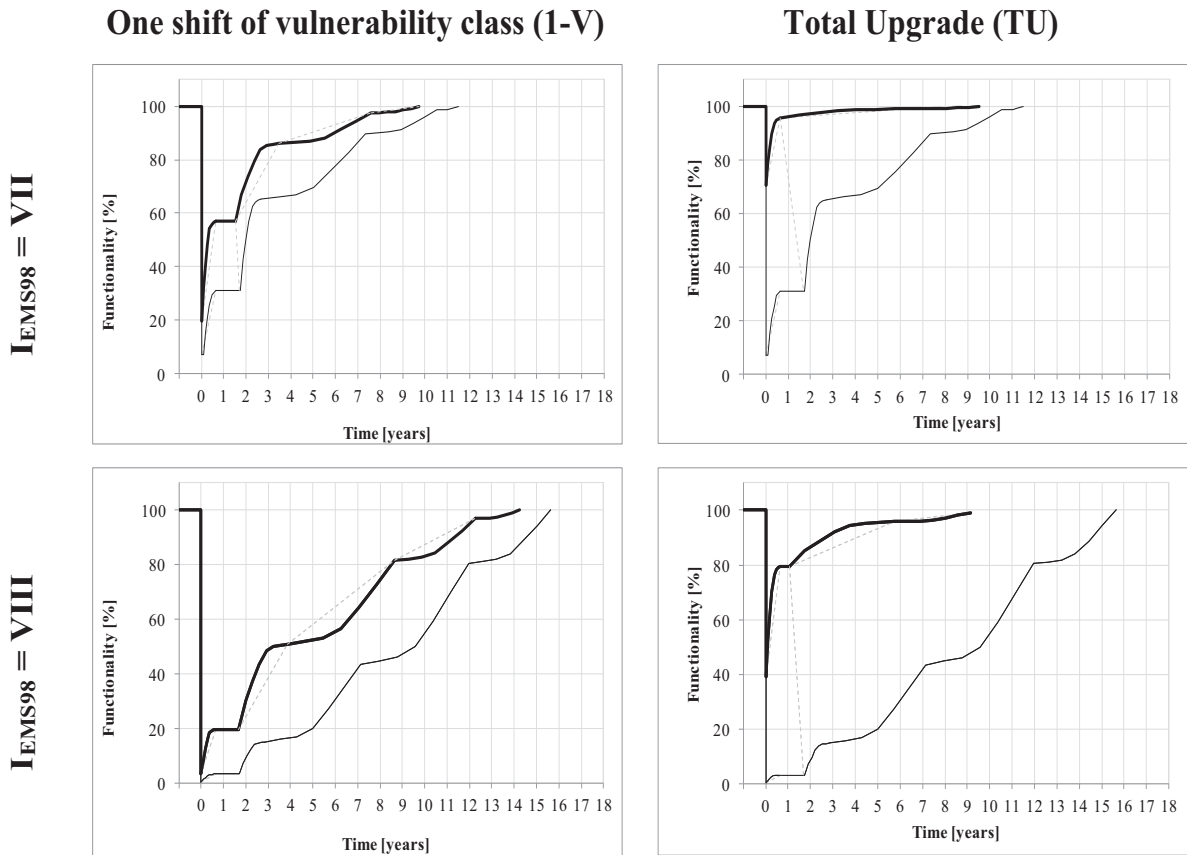


Fig. (9). Resilience performance in terms of functionality losses and restoration time for considered retrofit plans: one shift of vulnerability class (1-V) on the left and total upgrade (TU) on the right.

Table 3. Resilience Index for different seismic mitigation strategies and two considered seismic scenarios.

	$I_{EMS98} = VII$				$I_{EMS98} = VIII$			
	Resilience Index ( $T_{LC} = 12years$ )				Resilience Index ( $T_{LC} = 18years$ )			
	CS	Pre earthquake retrofit plan			CS	Pre earthquake retrofit plan		
1-V		2-V	TU	1-V		2-V	TU	
Zone 1	0.66	0.86	0.92	0.98	0.37	0.61	0.82	0.96
Zone 2	0.71	0.88	0.93	0.99	0.47	0.68	0.83	0.96
Zone 3	0.67	0.86	0.92	0.98	0.38	0.62	0.82	0.96
Zone 4	0.69	0.87	0.92	0.98	0.43	0.65	0.82	0.97
New Zone 1	0.87	--	--	0.98	0.95	--	--	0.88
New Zone 2	0.88	--	--	0.99	0.95	--	--	0.87

Table 4.  $I_{EMS98} = VII$ : Effects of different seismic mitigation strategies: resilience index for  $T_{LC} = 2years$  and  $T_{LC} = 5years$ .

	Resilience Index ( $T_{LC} = 2years$ )				Resilience Index ( $T_{LC} = 5years$ )			
	CS	Pre earthquake retrofit plan			CS	Pre earthquake retrofit plan		
		1-V	2-V	TU		1-V	2-V	TU
Zone 1	0.19	0.60	0.84	0.94	0.45	0.69	0.82	0.96
Zone 2	0.32	0.67	0.85	0.95	0.57	0.74	0.83	0.97
Zone 3	0.21	0.61	0.84	0.80	0.47	0.69	0.82	0.99
Zone 4	0.27	0.64	0.83	0.81	0.51	0.71	0.82	0.97
New Zone 1	0.84	--	--	0.89	0.33	--	--	0.96
New Zone 2	0.86	--	--	0.96	0.74	--	--	0.98

**Table 5.  $I_{EMS98} = VIII$ : Effects of different seismic mitigation strategies: resilience index for  $T_{LC} = 2years$  and  $T_{LC} = 5years$ .**

	Resilience Index ( $T_{LC} = 2years$ )				Resilience Index ( $T_{LC} = 5years$ )			
	Pre earthquake retrofit plan				Pre earthquake retrofit plan			
	CS	1-V	2-V	TU	CS	1-V	2-V	TU
<b>Zone 1</b>	0.07	0.22	0.46	0.74	0.25	0.40	0.63	0.97
<b>Zone 2</b>	0.19	0.30	0.47	0.75	0.36	0.47	0.64	0.97
<b>Zone 3</b>	0.08	0.23	0.46	0.74	0.25	0.40	0.63	0.97
<b>Zone 4</b>	0.14	0.27	0.46	0.75	0.30	0.43	0.63	0.98
<b>New Zone 1</b>	0.62	--	--	0.83	0.25	--	--	0.95
<b>New Zone 2</b>	0.65	--	--	0.85	0.92	--	--	0.96

Although based on simple data and not very accurate information regarding the typological characterisation of buildings and the quality of constructions, the results demonstrate that the proposed procedure leads to enhanced resilience of the community. Moreover, an improvement in community resilience can be evaluated and is strictly related to financial investments in preventive mitigation strategies.

The comparison between a repair cost without a retrofit plan (CS) and different seismic mitigation strategies of intervention (1-V, 2-V, TU) alone may not be significant. In order to obtain an effective cost – benefit evaluation of mitigation measures, other costs and benefits can play a role such as: indirect costs of vulnerability reduction, costs related to loss of functionality, social costs, *etc.* This is a highly multidisciplinary study and is worthy of being widely and separately studied.

## CONCLUSION

In this study, the core of the resilience approach is closely tied to community performance goals and their quantification. The concepts of resilience and their quantification can (and must) have a direct impact on urban regulations and planning. Improving the procedures of policy makers is only possible by defining an effective resilience-based decision process for seismic risk prevention. This approach is more stringent on the mitigation strategies and, consequently, on the structural design and retrofitting criteria. Individual decision makers and stakeholders are required to take community resilience goals and indexes into account in the management of urban planning. These choices imply several constraints and indications for the design and construction of individual buildings or the retrofit of existing buildings.

This study is based on the resilience concepts and their de-aggregation in community resilience goals to investigate individual areas, facilities, or subparts of a community. In particular, the proposed methodology is applied to residential buildings, and other parts of the community resilience are not considered.

The study focuses on a case study, in which a typical small mountain town in Italy is considered. The town is in a region with low to moderate seismic hazard. Nevertheless, earthquakes can be extremely costly from an economic and social point of view. Several interesting seismic risk reduction strategies are defined and the operational tools are determined.

Moreover, the proposed procedure should be considered an

improvement of the new Italian Civil Protection code, which currently disregards operational approaches based on the resilience concepts. As a matter of fact, in the current planning tools, communities do not consider the resilience concept as the time of full recovery of their building stock, physical infrastructures, related costs and losses after a disaster.

The proposed resilience-based approach can be considered the most effective approach and quantitative tools are required to demonstrate the real benefit of this approach. This study proposes a new approach, which replaces the existing Civil Protection plan with a resilience community plan. The application of the concepts of resilience is limited to the study of the seismic risk of the existing buildings that have been shown to be a critical and decisive element in the long-term resilience of communities in the past. The emergency plans become community resilience plans, which need to be defined as an optimal tool for urban planning, emergency management, and socioeconomic dynamic analysis based on the concepts of resilience.

Clearly, the identification of alternatives and more accurate approaches for each step of the proposed methodology (for example, developing new DPMs and/or specific, accurate, or simplified procedures [31, 32] for fragility curves, seismic hazard analysis, and so on) can lead to a more accurate resilience evaluation. Moreover, further developments could be based on proposed multidisciplinary approaches [10].

The concept of changing from an emergency plan to a resilience plan is considered as a natural evolution of the emergency plan itself. Obviously, in this study, the increase of resilience based exclusively on vulnerability reduction is considered. A resilience plan considers several mitigation activities and measures to be taken in periods of seismic quiet. These measures and emergency management will become components of resilience plans and several improvements can be proposed. However, based on the goals of this study, the results are clear: mainly, the significant impact of the resilience plan by replacing the classic Civil Protection plan.

– The proposed resilience plan is conceptually based on the Resilience index. This is an original and innovative approach.

– Referred only to the residential building stock, the Resilience index is defined based on convolution between the state of the damage (probability of occurrence) for a specific seismic intensity, corresponding expected ratio cost and expected ratio time.

– The proposed approach allows to define the optimal mitigation strategies based on the quantitative resilience evaluation.

#### CONSENT FOR PUBLICATION

Not applicable.

#### AVAILABILITY OF DATA AND MATERIALS

Not applicable.

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None.

#### CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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Declared none.

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