Structural Durability &
Health Monitoring

Tech Science Press

DOI: 10.32604/sdhm.2023.028247

REVIEW

An Overview of Seismic Risk Management for Italian Architectural Heritage

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Received: 07 December 2022 Accepted: 17 April 2023 Published: 07 September 2023

ABSTRACT

The frequent occurrence of seismic events in Italy poses a strategic problem that involves either the culture of preservation of historical heritage or the civil protection action aimed to reduce the risk to people and goods (buildings, bridges, dams, slopes, etc.). Most of the Italian architectural heritage is vulnerable to earthquakes, identifying the vulnerability as the inherent predisposition of the masonry building to suffer damage and collapse during an earthquake. In fact, the structural concept prevailing in these ancient masonry buildings is aimed at ensuring prevalent resistance to vertical gravity loads. Rarely do these ancient masonry structures offer relevant resistance to actions other than vertical ones and then they are intrinsically vulnerable to stresses induced by the earthquakes. One of the main technical activities carried out by the Civil Protection after an earthquake is to assess the damage in the buildings and to evaluate their own usability. Regarding historical buildings, ad-hoc synthetic forms, drafted in agreement between the Italian Civil Protection Department and the Ministry of Cultural Heritage and Activities and Tourism and based on visual inspection, are adopted by qualified technicians. In this paper, such activities are described and discussed along with the Italian Civil Protection System. However, given the complexity of the main technical activities to be performed after an earthquake there is a need for more accurate methods based on Structural Health Monitoring.

KEYWORDS

Architectural heritage; damage assessment; usability evaluation; visual inspection; structural health monitoring

1 Introduction

Italy is characterized by a high concentration of cultural heritage. As reported in the list of sites of inestimable value for humanity drawn up by United Nations Educational, Scientific and Cultural Organization (UNESCO), following the World Convention concerning the Protection of World Cultural and Natural Heritage adopted on 16 November 1972, 58 sites are recognized as the Intangible Cultural Heritage of Humanity placing Italy at the top. Besides, the immense Italian cultural heritage consists of over 200,000 architectural, monumental, and archaeological cultural assets, 3,400 museums and about 2,000 archaeological areas and parks [1]. According to the first Resource Manuals published by UNESCO as a joint undertaking by the three Advisory Bodies of the World Heritage Convention (ICCROM, ICOMOS and IUCN) and the UNESCO World Heritage Centre [2]:

Risk*: The chance of something happening that will have an impact upon objectives* [3].

Hazard*: Any phenomenon, substance, or situation, which has the potential to cause disruption or damage to infrastructure and services, people, their property, and their environment* [4].

Vulnerability*: The susceptibility and resilience of the community and environment to hazards. 'Resilience' relates to 'existing controls and the capacity to reduce or sustain harm. 'Susceptibility' relates to 'exposure'* [3].

The most common hazards that may lead to a disaster are [5]*:*

- *meteorological: hurricanes, tornadoes, heat-waves, lightning, fire;*
- *hydrological: floods, flash-floods, tsunamis;*
- *geological: volcanoes, earthquakes, mass movement (falls, slides, slumps);*
- *astrophysical: meteorites;*
- *biological: epidemics, pests;*
- *human-induced: armed conflict, fire, pollution, infrastructure failure or collapse, civil unrest, and terrorism;*
- *climate change: increased storm frequency and severity, glacial lake outburst floods (GLOFs).*

According to the above manual, there are three main stages of Disaster Risk Management: before, during and after disasters (Fig. 1). The activities to be undertaken before a disaster include risk assessment, prevention, and mitigation measures for specific hazards (maintenance and monitoring and formulating and implementing various disaster management policies and programs).

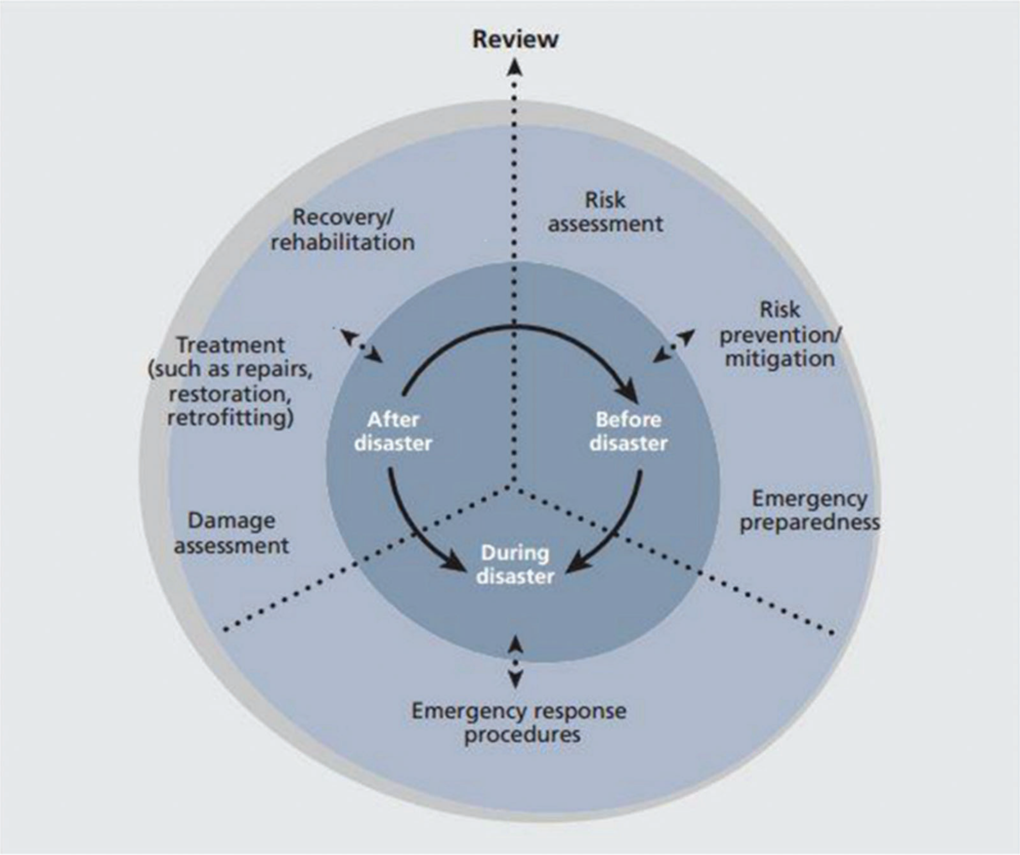

Figure 1: Disaster Risk Management cycle [2]

Emergency preparedness to be undertaken before a disaster includes measures such as creating an emergency team, an evacuation plan and procedures, warning systems and drills and temporary storage.

After a seismic event, one of the problems to be at once addressed is a rapid, accurate and reliable assessment of the damage, which is useful for the management and coordination of immediate measures for the safety and/or clearance of buildings damaged by the earthquake.

Italian Civil Protection Department deals with the prediction prevention and management of emergency events. The Department has been grounded in the offices of the Presidency of the Council of Ministers since 1982 with the role of the highest level of Civil Protection in the Italian organization. The main activities are performed aiming at protecting life, physical integrity, assets, settlements, animals, and the environment from damage or from the danger of damage deriving from disasters of natural origin or deriving from human activity, as defined in article 1 of the Italian Civil Protection Code.

In Italy, the need of a Civil Protection Department raised from the occurrence of natural disasters such as the 1963 Landslide of the Vajont Dam, the 1966 flood of the Arno in Florence, the 1976 Friuli earthquake and the 1980 Irpinia earthquake, among others. In 1981, the President of the Republic appointed a minister for the coordination of civil protection with the task of reorganizing the Civil Protection and subsequently, in 1982, with the establishment of the Civil Protection Department within the Presidency of the Council of Ministers.

In 1992, the National Civil Protection Service was established according to the following statement: “the national civil protection service was established in order to protect the integrity of life, goods, settlements and the environment from damage or danger of damage resulting from natural disasters, catastrophes and other calamitous events.”

The operational structures of the Civil Protection service are the National Fire Brigade, the Armed Forces, the Police Forces, the Carabinieri, the National Technical Services, the National Scientific Research centers, the Italian Red Cross (Croce Rossa Italiana, in Italian), the structures of the National Health Service, Voluntary Organizations (Association of Volunteer Engineers for the Emergency-AIVEM, among others), the National Alpine Rescue Corps.

In 1996, a precise organization was proposed through the development of a new management method, called the Augustus Method. This method takes its name from the Roman Emperor Octavian Augustus who stated about two thousand years ago that “the value of planning decreases with the complexity of the state of things.”

The Augustus method is based on subsidiarity principle, starting on the first responsible of citizens safety, the Mayor, until the Civil Protection Department. Furthermore, it constitutes the basis aimed at planning activities at any level of responsibility, either in the emergency phase with the responsibility for the actions of local authorities, or in the ordinary phase through a preventive planning that requires the collection of information, the preparation of monitoring functions and the identification of risk scenarios.

A further reform of the Civil Protection system took place in 2012. The importance of this reform lies on some relevant issues for the entire civil protection system, among which it is possible to find the classification of disasters, civil protection activities, the declaration of a state of emergency and the power of ordinance.

Currently, the civil protection integrated system is configured according to the Code issued in 2018, being made up of a plurality of actors, institutional and non-institutional, which operate under the coordination of the Civil Protection Department of the Presidency of the Council of Ministers.

An important novelty introduced by the Code is represented by the central and peripheral divisions of the Ministry for Cultural aimed at managing the activities of securing and safeguarding the cultural heritage in case of emergencies deriving from calamitous events. Briefly, the innovations introduced by the new Civil Protection Code can be summarized in four key points:

1. Management of national emergencies;
2. Duration of the state of emergency;
3. Civil protection planning;
4. Risks of civil protection.

For the first time the citizens take official part of Civil Protection System. They assume the role of active part of the system.

The conservation and protection of the Italian historical and cultural heritage depend on the physical characteristics of the territory where it is located. In this sense, the Italian territory is strongly characterized by its exposure to natural hazards of hydrogeological and seismic origin which seriously threaten the heritage, very often in combination with each other.

In 2000, a collaboration was started between the Italian Higher Institute for Environmental Protection and Research (ISPRA) and the Italian Higher Institute for Conservation and Restoration (ISCR), to evaluate and quantify the damage caused by atmospheric pollution and other environmental factors, such as events of natural and/or anthropogenic origin, on the Italian cultural heritage.

After a seismic event one of the problems to be at once addressed is a rapid, accurate and reliable assessment of the damage, which is useful for the management and coordination of immediate measures for the safety and/or clearance of buildings damaged by the earthquake.

Regarding historical buildings, synthetic forms are adopted for the evaluation of damage and usability. The aim of this narrative review is to provide an overview of risk management of Italian Architectural Heritage and to highlight the importance of the methods based on Structural Health Monitoring (SHM) for Architectural Heritage Conservation.

2 The Exposure of Architectural Heritage to Seismic Risk Phenomena

Italy is characterized by a high exposure to natural hazards. From a seismic point of view, Italy is the country with the highest level of seismicity in Europe. Seismic hazard is the expected shaking of the soil at a given site with a certain probability of excess in each time interval, or the probability that a certain shaking value will occur in each time interval. The seismic hazard on the entire national territory, as reported in Italian Code NTC2008 [6], provides the parameters of the seismic action as a function of the geographical coordinates starting from a side lattice equal to about 5 km and for return periods between 30 and 2475 years.

Some of the most important seismic phenomena detected in Italy in the last 50 years are:

On May 06, 1976, Gemona del Friuli, a town in the foothills of the Alps in the extreme northeast of Italy, was hit by a seismic sequence with a mainshock of moment magnitude of 6.5 Mw. The earthquake was felt in Venice. Many churches, Renaissance castles, historical landmarks, and important art treasures were ruined.

On November 23, 1980, Campania and Basilicata were hit by one of the major seismic events that hit Italy so far, which today is remembered as the Irpinia earthquake. The devastating effects of the earthquake with a moment magnitude of 6.9 Mw were accentuated by the precariousness of the buildings, due to the earlier events of 1930 and 1962, and by the delay in rescue operations due to the difficulty of accessing the emergency vehicles to the area affected by the earthquake, as well as by the lack of a civil protection body, useful for intervening in a coordinated and above all prompt manner.

After the Irpinia earthquake, another large-scale seismic event occurred in 2009 in the territories of the city of L′Aquila with the main earthquake of magnitude of 6.3 Mw. This event caused considerable damage to the historical heritage, especially within the city of L′Aquila, which is particularly rich in churches and basilicas together with the historic buildings in the historic center.

In 2016, Central Italy was hit by a seismic sequence that began on 24 August with an earthquake of magnitude Mw 6.0 located in the province of Rieti, continued with other events of magnitude above 5.0 and with the earthquake of magnitude Mw 6.5 of 30 October which is the strongest earthquake ever recorded by the National Seismic Network in operation since the early 1980s. This sequence of events hit the hinterland of four Italian regions, and in particular the cities of Norcia and Amatrice, causing many damages in many historic buildings.

In earthquake engineering and many seismic codes, the most significant measure that characterizes the destructive capacity of the earthquake is conventionally the maximum ground acceleration, or Peak Ground Acceleration (PGA), that occurs during earthquake shaking at a location. PGA is measured by special instruments called accelerographs and is commonly plotted on seismic hazard maps. These maps are based on past earthquakes and soil geology and provide the expected PGA in a certain interval of time at a given area.

According to the Italian "Ordinanza Presidente del Consiglio dei Ministri-OPCM 28 April 2006, n. 3519, All. 1b", the expected ground motion values are obtained from the following reference seismic hazard map of Italy (MPS04) [7].

"The colors in map show different range of ground motion acceleration [g] that have the 10% of probability to be exceeded within 50 years. In general, the colors associated to low values of acceleration refer to areas that are less hazardous and stronger earthquakes repeat less frequently, although they may still occur" [7].

2.1 Seismic Risk Analysis

To determine the seismic risk (R) of a building or other territory entity, it is also necessary to know the values of vulnerability (V) and exposure (E). Vulnerability represents the propensity of an element to suffer damage after an earthquake; exposure is the value of the elements exposed within the risk area. It is important to highlight how the 'exposure' factor refers not only to individual constructions but also to goods and human presence, which could suffer damage and loss due to earthquake.

Conventionally, the risk can be calculated according to the following equation:

$$R = H \cdot V \cdot E \tag{1}$$

In recent decades, some databases of the damage to the monumental heritage have been created in Italy. Comparing the damage that has occurred in the different territories, a scenario of similarities and differences appears. The typical recognized mechanisms tend to reproduce in different situations, but also vary as the architectural configurations in diverse cultural realities change. Similarly, the variation of constructive traditions and of the used materials affects the evolution of the damage and specific vulnerabilities.

Therefore, the vulnerability analysis of the historical masonry buildings can be articulated according to the observed damages due to earthquakes in typical vulnerabilities with damage mechanisms extended to parts, the so-called "macroelements" [8] and specific vulnerabilities linked to the evolution that the phenomenon had in that given case. The former are attributable to the planovolumetric configuration of the construction typology (churches, castles, etc.), the latter are attributable to the technique and construction history, the history of damage and degradation.

In the second half of the twentieth century, the need to know the state of conservation after many calamitous events of cultural heritage was highlighted to decide the operational priorities to be implemented for a better planning of protection, conservation and of land use. Therefore, automated, and interoperable systems were developed to exchange information useful for intervening in the shortest possible time and with the most effective measures.

The "Risk Map of the Italian Cultural Heritage" is an information system created by Central Institute for Restoration (ICR) in support of the scientific and administrative activities of Institutes and State bodies responsible for protecting, safeguarding, and preserving the cultural heritage [9]. It is configured as a Territorial Information System (GIS (Geographical Information System)) which has the purpose of defining a system aimed at showing those architectural and archaeological heritage most exposed to risk phenomena, to plan the interventions to be carried out. Three main risks are considered:

- Static–Structural Risk
- Environmental–Air Risk
- Anthropic Risk

In reference to the seismic risk, the Italian Institute for Environmental Protection and Research, ISPRA highlights an overview of the territories characterized by the presence of cultural heritage strongly exposed to seismic phenomena. There are about 86,447 cultural assets, corresponding to 42% of the total surveyed. The distribution of the territories is consistent with the Cartography of the seismic classification according to the Italian OPCM no. 3519/2006 (Fig. 2).

3 Damage Assessment and Usability Evaluation: The Case of the Italian Churches

In the stages following a seismic event one of the problems to be addressed is the rapid, accurate and reliable assessment of damage, which is useful for the management and coordination of immediate measures for the safety and/or people evacuation of buildings damaged by the earthquake. This assessment is carried out by technicians using traditional methods based on visual inspection and available damage mechanisms.

Although the typological variety of the monumental buildings is large (masonry bridges, towers, city walls, castles, archaeological sites etc.), a particular role can be attributed to the masonry churches due to the considerable number of such buildings in Italy. The observation of the post-earthquake damage in the churches of Friuli after the earthquake of 1976 [8] has determined the development of a vulnerability analysis methodology filling in a detailed form which refers to three phases: a) description of the geometry, the materials, and the cracked framework; b) subdivision of the building into macroelements, that are recognizable and unitary parts in terms of seismic response (facade, apse, bell tower, etc.); c) identification of possible modes of damage and mechanisms of collapse associated with each macroelement. This methodology allows a rapid and schematic examination of the damage caused by the earthquake.

This form "GNDT-S3" was tested in the 1987 earthquake in Emilia Romagna Region and, after being improved and integrated, in 1996 earthquakes in the same Region, in 1997 earthquakes in Umbria and Marche Regions. Subsequently, the forms for the detection of damage to movable and immovable property belonging to the national cultural heritage have been approved by Decree Interministerial on 03 May 2001, published in the Italian G.U. 21 May 2001 no. 116. These forms were used in the 2002 earthquakes in Molise and Puglia and in 2004 in the province of Brescia. After being improved and integrated again, the forms have been approved by the President's Decree of the Council of Ministers on 23 February 2006, published in the G.U. of 07 March 2006 n. 55 [10]. Note that in this last version the collapse mechanisms increase from 18 to 28. Examples of three collapse mechanics are reported in Figs. 3–5.

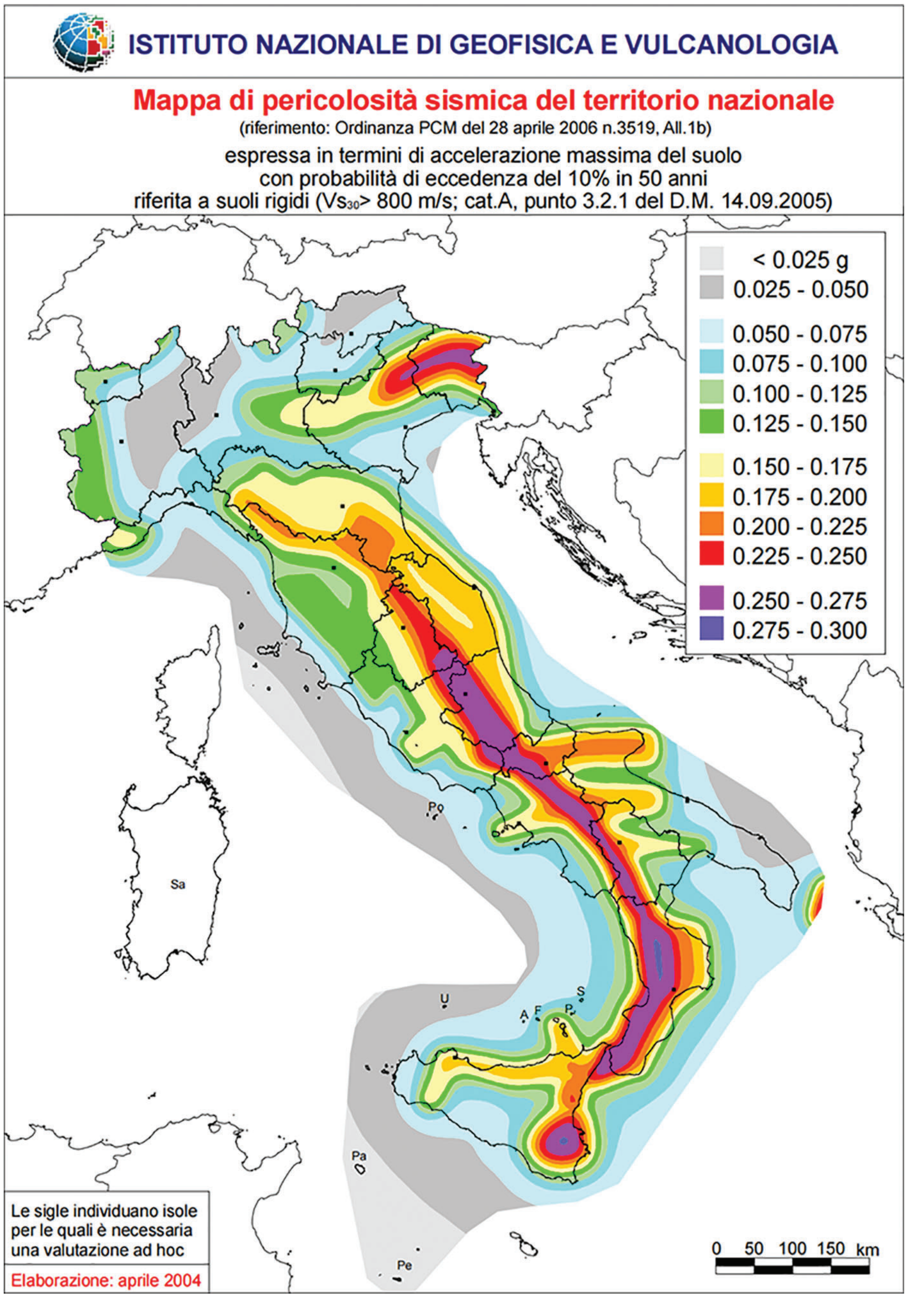

Figure 2: Seismic hazard map of Italy [7]

The screening can be carried out by means of such survey form “A-DC Scheda chiese” [10], drafted in agreement between the Italian Civil Protection Department and the Ministry of Cultural Heritage and Activities and Tourism (MiBACT). In particular, the form is divided into three distinct parts: the first dedicated to knowledge general of the factory; the second destined to the definition of a judgment on the damage of the church; the third finally is a free section, to insert information not schematized in the previous sections. Focusing on the second section, the assessment must be carried out in relationship to 5 levels of damage, graduated by the level “0” corresponding to the absence of damage up to level “5” relative to the complete collapse in agreement with the European Macroseismic Scale, EMS98 [11].

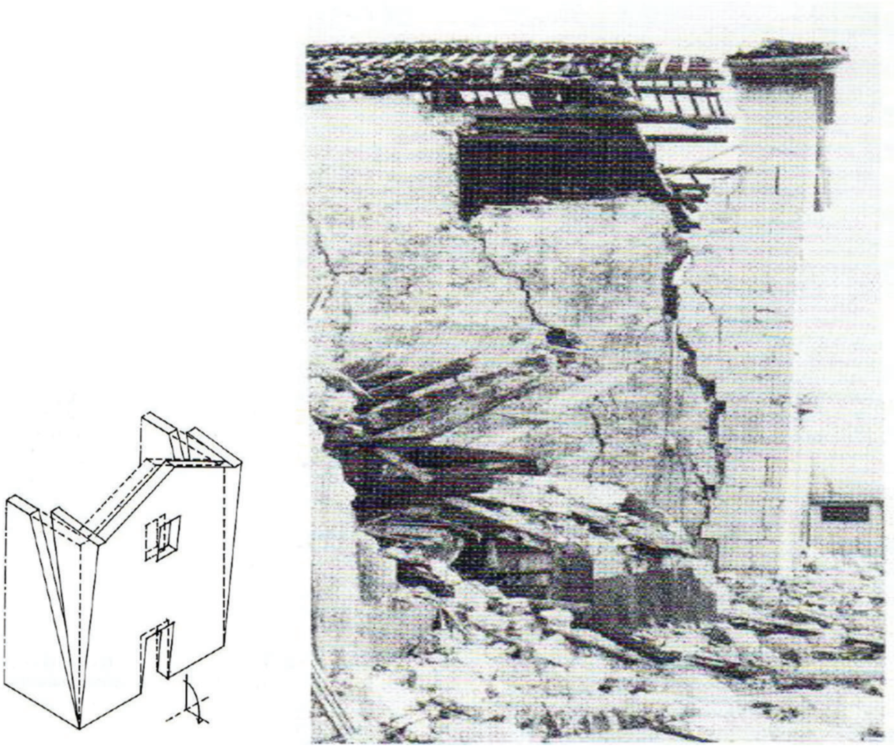

Figure 3: Out-of-plane overturning of façade

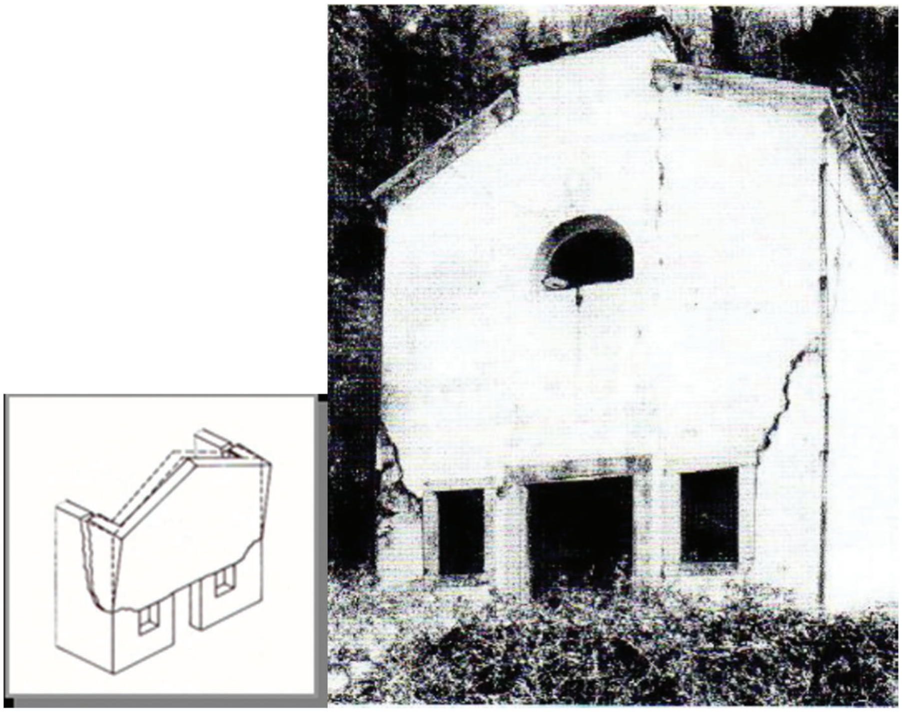

Figure 4: Out-of-plane overturning of façade

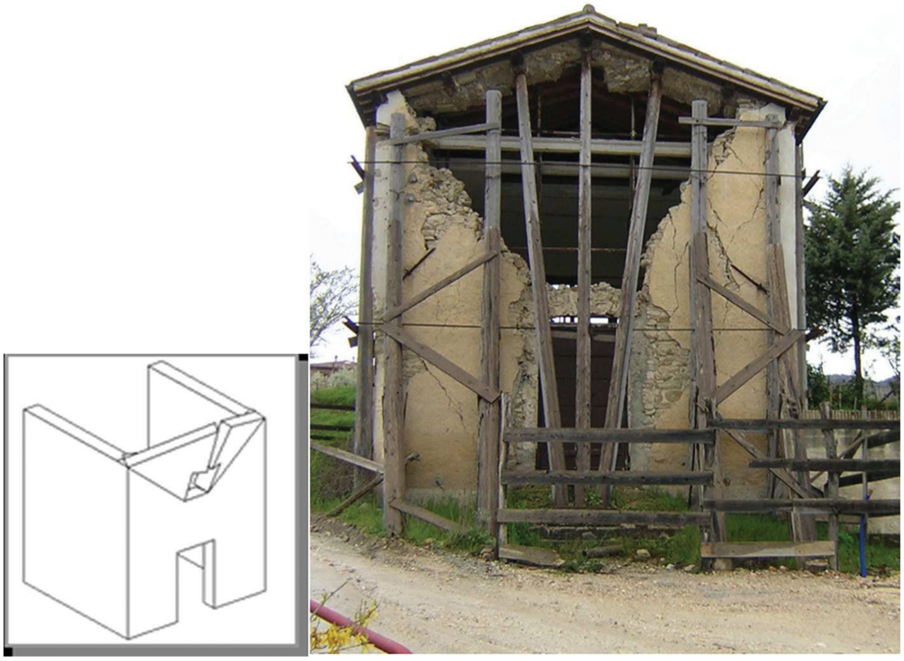

Figure 5: Out-of-plane overturning of tympanum

The form allows the assessment of the damage index (i_d with values between 0 and 1), which quantifies the average level of damage suffered by the church. The index is obtained through a normalized average of the damage level (d_k) detected for each mechanism—of the 28 possible identified by the form—based on the number of mechanisms detected in the church. That is according to the relation:

$$i_d = d/5n \tag{2}$$

where n = number of detected mechanisms ($n \leq 28$) and

$$d = \sum_{k=1}^{n} d_k \tag{3}$$

with d_k the level of damage associated with each detected mechanism assuming integer values between 0 and 5 (0 = zero damage; 1 = slight damage; 2 = moderate damage; 3 = severe damage; 4 = profoundly considerable damage; 5 = collapse). Note that in the most updated relevant legislation for interventions on heritage buildings, represented by the guidance document "Le Linee Guida per la valutazione e riduzione del rischio sismico del patrimonio culturale–allineamento alle nuove Norme tecniche per le costruzioni, G.U. 26.02.2011, n°47 [12], the damage index i_d is defined as a normalized average function of assigned weights (ρ_k) and levels of damage associated with each mechanism:

$$i_d = \frac{1}{5} \frac{\sum_{k=1}^{N} \rho_k d_k}{\sum_{k=1}^{N} \rho_k} \tag{4}$$

being the summation extended to N mechanisms identified as potentially actionable for the item in question. The weights are fixed and placed equal to 1 for the most important macroelements, while for those secondary (related to protyrus-narthex, transept, chapels) an interval between 0.5 ÷ 1 is proposed with respect to which the detector can vary the importance of the macroelement within the building.

The usability condition of the churches can be established from the above rapid visual survey. The following usability rating can be assigned:

- Usable
- Partially usable
- Usable with precautions
- Temporarily unusable
- Unusable
- Unusable for external risk

The template B-DP PCM-DPC [10], for palaces, has a similar structure and the damage is also associated to 22 specific collapse mechanisms, including failures of timber floors and roofs.

4 Structural Health Monitoring

At present, visual inspections are the only instrument used for post-earthquake checks. By its nature, the results of inspections are subjective and not reliable due to the few tools available and limited time. In addition, visual inspections are not in a position, in many cases, to detect damage, especially if it is small or in areas that are not very visible or difficult to inspect (for example in the presence of suspended ceilings, etc.).

As reported in the Handbook of FEMA (Federal Emergency Management Agency) [13], "*The RVS (Rapid Visual Screening) procedure can be implemented quickly and inexpensively to develop a list of potentially seismically hazardous buildings…. If a building receives a high score (i.e., above a specified cut-off score), the building is considered to have adequate seismic resistance to prevent collapse during a rare earthquake. The building score reflects probability of collapse or partial collapse only (as defined in the sidebar) and is not meant to be an indicator of the probability that the building will be usable following an earthquake. If a building receives a low score based on this RVS procedure, it should be evaluated by a design professional experienced in seismic design. Based on a detailed inspection, engineering analyses, and other detailed procedures, a final determination of the seismic adequacy and the need for retrofit can be made.*"

In the case of severe earthquakes, the procedure used by visual inspections implies that the response times of the usability rating to include in the above forms are not fast. Making reliable judgements requires experts to include visual inspection as a step of a wider monitoring program. Visual inspection has been used as an early method for SHM (Structural Health Monitoring) and condition assessment of bridges. Most of the decisions in relation to maintenance work are based on visual inspection, even for infrastructure that has been installed with modern equipment including sensors and actuators. However, the availability of new methods such as signal processing, image processing, neural networks, fuzzy logic, damage detection, non-destructive testing (NDT) methods can lead experts to make the best decisions [14,15]. Visual inspection can be also viewed as a periodic control of the onset or stable propagation of cracking patterns, degradation phenomena and represents in most cases the starting point of this activity.

To set up a monitoring program it is necessary to define the most significant parameters (such as accelerations, displacements, rotations, crack openings, stresses, etc. …) to be measured continuously or with adequate deadlines, allowing experts to certify its good behavior or to evaluate any structural damage reducing the stability of the whole building or of its individual parts. Reliable information can be acquired through instrumental monitoring of such parameters [16–18]. Continuous and remote monitoring can detect damage progression. Geometric control of the construction can be performed using topographic, photogrammetric survey procedures, or using innovative techniques, such as the generated point cloud by laser scanner. The monitoring project requires a preliminary interpretation of the failure mechanism. Recently, a new artificial intelligence-based structural health monitoring strategy has been proposed [19]. It is based on neural network modeling which is an improved approach for the non-destructive evaluation of mechanical parameters [20].

In Italy, permanent monitoring is performed on some public buildings-schools, hospitals, town halls, bridges, dams carried out by the Seismic Observatory of Structures (OSS in Italian) managed by the Italian Civil Protection Department. The monitored public constructions amounted to 156 in January 2022. The monitoring system consists of sensors distributed over the construction and on the ground. When a construction is stricken by a significant earthquake, monitored constructions are instrumented by accelerometers connected to an alert system which sends an alarm message if the threshold acceleration values are exceeded. With this procedure the recorded data are processed to estimate damage parameters or to calibrate and update numerical structural models.

4.1 SHM in Guidelines for Architectural Heritage Conservation

SHM can be considered a nondestructive technique for structural assessment of architectural heritage, suitable for conservation according to the principle of minimum intervention. In ICOMOS CHARTER [21], the decision-making process related to conservation activities on heritage structure is based on the four phases of anamnesis, diagnosis, therapy, and control. SHM supplies knowledge to all four phases and is the major support for Anamnesis and Control.

In reference to the Disaster Risk Management cycle shown in Fig. 1, SHM system supplies information [22]:

A) Before the emergency, allowing to monitor the actual structural conditions without invasive structural interventions, to improve knowledge of the actual structural conditions taking also into account degradation due to ageing, to perform maintenance according to actual structural condition instead of planned condition, to act as a deterrent for vandalism, to supply early warning about a possible hazard event for the adoption of emergency measures.

B) During the emergency, allowing to know the actual state of the structures and other cultural goods such as frescoes on the walls, to know the structural behavior under extreme events, to manage the emergency most efficiently.

C) After the emergency, allowing to know the actual structural condition after the event that constitutes a support for decision making related to different interventions, to check the effectiveness of the past interventions, to know the structural safety to evaluate any possible intervention even in the absence of visible damage.

According to ICOMOS/ISCARSAH (International Scientific Committee for Analysis and Restoration of Structures of Architectural Heritage) [23] "*Structural observation over a period may be necessary, not only to get useful information when progressive phenomena is suspected… A monitoring system usually aims to record changes in deformations, cracks, temperatures, etc. Dynamic monitoring is used to record accelerations, such as those in seismic areas. Monitoring can also act as an alarm bell. The simplest and cheapest way to monitor cracks is to place a 'tell-tale' across them. Some cases require the use of computerized monitoring systems to record the data in real time. As a rule, the use of a monitoring system should be subjected to a cost-benefit analysis so that only data strictly necessary to reveal progressive phenomena are gathered.*" The Recommendations are split into two parts: the Principles, containing the basic concepts of conservation and restoration, and the Guidelines, where procedures and methodologies to be followed in preliminary studies and design are set out. Currently, the ISCARSAH Committee continues to work on a set of Guidelines which are to be used in tandem with the Principles by experts involved in the conservation of Architectural Heritage.

As pointed out in [24], *the guidelines distinguish between* ***static*** *monitoring, consisting in the recording of structural parameters (such as displacements, rotations, crack openings, stresses, etc. ...) over an extended period, and* ***dynamic*** *monitoring, used to record the response of the structure during the occurrence of seismic events, strong wind episodes or other episodic (normally dynamic) actions. Some criteria are supplied on how to apply both types of monitoring. In specific, about static monitoring, some requirements are mentioned as necessary for an adequate post-processing and interpretation of the registered data. These requirements are :(1) the identification of the critical variables (movements, crack widths), (2) the measurement of not only structural parameters (as crack openings) but also environmental ones (wind speed, temperature, and humidity) and (3) a sufficiently long monitored period. Monitoring may be oriented to either survey the evolution of a non-intervened structure or to assess the effectiveness of an intervention. During the diagnosis phase, structural analysis can be used to investigate the performance of the structure under past actions. These actions may include gravity loads, earthquakes, wind, soil settlements, chemical or physical attack, anthropogenic alterations, and thermal cycles, among others. Structural analysis can be used to characterize the possible contribution of different actions to existing damage and possible partial collapses. Structural analysis always involves the adoption of a model whose hypotheses and assumptions should be carefully chosen and taken into consideration in the interpretation of the results*. Examples of SHM systems applied to architectural heritage are reported in [25–28].

The theme of architectural heritage monitoring is also addressed in the Italian "Guidelines for the Assessment and Reduction of Seismic Risk of Cultural Heritage" (2011). In the paragraph referring to the study of the behavior of historical structures, it is stated that: "*periodic inspection of the construction is a highly desirable practice as it is the primary tool for conscious conservation, as it allows maintenance to be planned and repairs to be carried out in time, when really appropriate, in case of structural damage, and consolidation, aimed at prevention. It should be noted that, in line with the approach adopted in 2.4 for the assessment of seismic safety levels, the definition of a defined monitoring programme is essential to ensure to the construction the expected nominal life.*"

Based on the above guidelines, conscious conservation of architecture heritage calls for reliable structural monitoring systems. Relying on a visual inspection to give a usability judgment becomes problematic for any technician using the above forms related to quick and simplified survey procedure. In our opinion, the best solution for masonry buildings, especially in seismic zone, is to install a combined monitoring system consisting of two architectures: the first, dynamic monitoring, which has the prerogative to continuously acquire and control the acceleration levels in particular areas of the construction induced by a seismic event, the second, static monitoring, which can be queried at any time and measures structural parameters (such as displacements, rotations, crack openings, stresses, etc. …) In addition, the joint system makes the decision-making activities related to the subjective interpretations of the technicians more reliable.

It should be highlighted that in the case of architectural heritage modern SHM systems develop modern technologies to preserve artefacts and cultural goods. For example, an innovative contactless technology employing a high-resolution video camera shown in Fig. 6 to avoid any damage to the frescoed surface has been designed and installed in the Hall of Flagellants in the Conegliano Cathedral (TV), with the aim of monitoring a serious crack pattern [29].

The monitoring project requires a preliminary interpretation of the failure mechanisms. In the case of churches and palaces, when the main collapse mechanics are known and can be defined as safety thresholds, monitoring is essential for architectural heritage conservation according to the principle of minimal intervention.

Figure 6: High-definition Optical video camera for nondestructive static monitoring [29]

5 Conclusion

After a seismic event, one problem to be addressed is a rapid, accurate and reliable assessment of the damage and the evaluation of the usability. Since the Umbria-Marche 1997 earthquake, the damage and usability assessment of buildings has been made by the first level AeDES form. It is a rapid tool to assess the damage and usability based on the visual in situ inspection of the building. This crucial tool is at once useful for the management and coordination of immediate measures for the safety and/or clearance of buildings damaged by the earthquake.

Recently, to evaluate the exposure and vulnerability information and harmonize it according to recognized international standards, an innovative methodology has been proposed in [30] to convert the information collected through the AeDES form in a wide database reported in a web-based platform "Database of Observed Damage" (Da.D.O.), to formats more suitable for a large-scale risk evaluation.

Ad hoc forms have been drafted in agreement between the Italian Civil Protection Department and the Ministry of Cultural Heritage and Activities and Tourism (MiBACT) for the damage and usability assessment of particular architectural heritage (Churches and Palaces). They are still based on the visual in situ inspection performed after a seismic event. In this paper the reliability of this last rapid post-earthquake damage and usability survey is discussed along with the adoption of the more reliable method based on Structural Health Monitoring. In my opinion, structural health monitoring together with a decision-making and alert system can be of considerable help in managing seismic risk of buildings belonging to architectural heritage.

Last, the importance of an integrated and multi-disciplinary approach for an effective post-earthquake damage and seismic vulnerability assessment of masonry churches should be highlighted [31].

Acknowledgement: Not applicable.

Funding Statement: The author received no specific funding for this study.

Author Contributions: The author confirms all the following contributions to the paper: study conception and design; data collection; analysis and interpretation of results; draft manuscript preparation. The author reviewed the results and approved the final version of the manuscript.

Availability of Data and Materials: The data presented in this study are openly available in https://doi.org/10.13127/sh/mps04/db and in https://rischi.protezionecivile.gov.it/en/seismic/activities/emergency-planning-and-damage-scenarios/oss-seismic-observatory-structures.

Conflicts of Interest: The author declares that he has no conflicts of interest to report regarding the present study.

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