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Architectural Heritage and seismic vulnerability: mapping the available knowledge to reduce damage during an emergency

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Abstract
Vernacular architecture has become a full part of our cultural heritage, since it constitutes evidence of our material culture and is tied to specific historical/geographical contexts. This type of 'lesser' heritage has withstood various transformations over time, whether negative transformations due to abandonment, or positive transformations due to expansion and renovation work on historical buildings or their simple adaptation to new living conditions. Thus, vernacular architecture often presents intrinsic vulnerabilities resulting from all the transformations it has undergone. The presence of this type of vulnerability within the vernacular built heritage also constitutes an even greater risk for buildings located in seismic areas, as this could lead to an increase in the level of damage due to an earthquake, often with irreversible losses. Achieving a good level of knowledge about the vulnerability of historical buildings in seismic areas is therefore important for their adequate preservation. This not only allows preventive maintenance to be planned, but also because when an earthquake occurs, this type of knowledge would allow decisions to be made with greater awareness regarding where to intervene first, and to more quickly identify where safety interventions for the most vulnerable buildings must be realised. As is well demonstrated by the collapses caused by the earthquakes that hit Central Italy in 2016, the possibility of promptly securing damaged historical buildings is of fundamental importance for conserving the built heritage damaged by an earthquake. To this end, the contribution describes some of the main instruments available in Italy for technicians and functionaries that intervene during a seismic emergency to secure the architectural heritage, with suggestions as to how these tools can be strengthened.

Keywords: *seismic risk and seismic vulnerability; emergency management; interoperability.*

1. Introduction

Architectural heritage is an important element of the cultural heritage: it bears witness to traditional architectural techniques and to artistic values and crafts specific to certain ages and places. Local populations have always ascribed a major value not only to the great monuments but also to the vernacular heritage, which often still has a social, historical and cultural pre-eminence for them.
In every region of Italy there are many examples of 'vernacular' architectural heritage, of which churches are undoubtedly a particularly significant cultural testimony. In many cases, these buildings seem modest on the outside, but they keep a considerable artistic heritage – i.e. paintings, frescoes, sacred furnishings – on the inside. These churches, even small ones, still play a social role for the local population as a landmark of the local identity.
Churches also represent a building typology that is particularly vulnerable to seismic actions due to the large size of the *aula*, often lacking

of suitable reinforcing elements. Frequently, these buildings are also poorly maintained since they're rarely attended during the year. For these reasons, when an earthquake occurs, churches regularly suffer major damage. The most common causes of their vulnerability are, for instance, the lack of effective seismic protection elements (*presidi antisismici*), the inadequate connection between the walls, the poor quality of the materials, as well as the lack of retrofitting intervention and an inadequate level of general maintenance.

Provisional works, if promptly executed during the first phase of a seismic emergency, may prove to be an effective temporary solution. They could successfully limit the damage caused by seismic aftershocks, especially those of strong intensity, as recent earthquakes that hit Central Italy in 2016-17 have shown.

The ability to promptly install the necessary countermeasures to stop the progression of seismic damage is not a simple process. In order to reach a positive effect, it is necessary to know the characteristics of the building, such as which and where the most vulnerable elements are. Moreover, all the entities that are involved in the emergency should rapidly activate a series of operations in a coordinated manner. Concerning the architectural heritage, the public authorities that intervene to safeguard it are: the Ministry of Culture (MiC), which is responsible for the protection of the heritage; the National Fire Brigade (NFB) and the Civil Protection Department (CPD), which are charged with implementing the interventions. Aiming to promptly manage the emergency, the involved operators should know in advance which are the listed buildings that are located in seismic areas so that they can efficiently organise all the securing activities, from the damage surveys to the realisation of appropriate countermeasures.

1.1 Architectural heritage and emergency

When an earthquake occurs, emergency operators are immediately activated. In Italy, the management of a seismic emergency is entrusted to the National System of Civil Protection, which is designated to manage both the first relief operations and the assistance to affected populations. During the early stages of an emergency, search and rescue activities and measures to assist the displaced population are carried out, together with first surveys to assess the damage that has occurred in the most relevant buildings – i.e. hospitals, administrative centres/public buildings, schools, etc. During this time, an evaluation of where public access should be prohibited is also carried out – i.e. in those areas that show the greatest risk of suffering further damage and collapses. These latter activities are performed by the National Fire Brigade, a component of the Civil Protection Department with specialist teams trained to carry out emergency operations, such as rescuing people, evaluating the stability of structures and implementing technical countermeasures.

In the case of a severe emergency, such as when an earthquake of high intensity causes significant damage, the CPD requires the collaboration of other public security authorities, such as the Italian Army, starting from the corp of *Carabinieri*.

Regarding the architectural heritage, the emergency activities mainly concern:

- for the immovable heritage, the assessment of the occurred damage, the design/execution of securing countermeasures to contain the damage/progression of the activated collapse mechanisms;
- for the movable heritage, the recovery and transfer to temporary warehouses in order to restore the damaged items and to protect them from possible further damage or theft.

When a natural/anthropic emergency occurs, the MiC activates specific crisis units called '*Unità di Crisi per il coordinamento Nazionale – UCCN*' (Crisis Unit for the National Coordination) and '*Unità di Crisi per il coordinamento Regionale – UCCR*' (Crisis Unit for the Regional Coordination). The UCCN does coordination tasks for the activities carried out by the UCCR, and it supports communication with other public authorities that intervene during the emergency. The UCCR instead deals with giving specific indications for the emergency activities that are conducted locally by the officers of the MiC. Each UCCR is organized into different operational units: the 'O.U. for the damage surveys', the 'O.U. for the realisation of the provisional countermeasures

systems' and the 'O.U. for the displacement and restoration of the movable heritage'. During an emergency, the officers of the MiC collaborate directly with both the CPD / NFB and the teams of qualified researchers/professionals.

The officers of the National Fire Brigade play an important role in securing the damaged architectural heritage: they have to evaluate, design and implement technical countermeasures. Starting in 2015, the NFB has defined a specific operating protocol for the realisation of the provisional systems, called 'Short-Term Countermeasures System – STCS'. It regulates the reconnaissance of damage scenarios, the supply of necessary means/materials and the execution of technical countermeasures.
The NFB has a special operative unit named '*Nucleo Interventi Speciali* – NIS' (Team for special intervention), which is trained to design the technical countermeasures. In order to define an intervention, the officers of this unit participate in special surveys called 'GTS surveys'[1]. When the evaluation concerns the architectural heritage, surveys are performed jointly by the NFB, the Civil Protection Department, the local administration and the MiC.

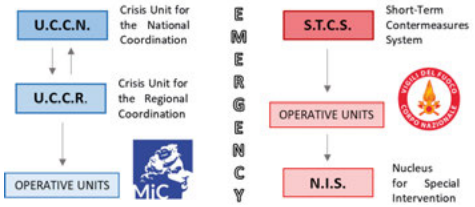

Fig. 1. Emergency Operative Units activated by MiC and NFB.

Moreover, in order to properly design the countermeasures for damaged buildings, the NFB has prepared a specific manual with some technical sheets[2].These documents have been developed based on the experience from the L'Aquila seismic emergency in 2009. They allow the NFB to design and implement the technical countermeasures according to some codified intervention schemes, which define the most appropriate solution starting from the constructive characteristics of a building, also considering the typology/extent of damage and the risk conditions which may exist in the context and/or in adjacent dwellings.

1.2 Tools for finding the preliminary level of vulnerability

It is therefore clear that, at the time of an emergency, the NFB need to know which are the main constructive characteristics of a damaged building, thus being able to define in a correct and a timely way the most appropriate technical countermeasures. The most important data are those related to the structure, including external/internal dimensions, materials and changes occurred over time. Unfortunately, these data are not always available in public/ministerial archives or they are not easily/immediately accessible. Thus, even when these data exist, they are not readily usable at the time of an emergency.
Otherwise, knowing this information before starting to design the countermeasures could be a valuable resource for the NFB since it would make it easier for technicians to understand the effective vulnerability of buildings and, consequently, to design appropriate, urgent technical countermeasures for those parts that might be subject to a greater risk of collapse.

It was several years ago that, aware of the connection existing between the vulnerability of a building and its expected seismic damage, the Italian '*Istituto Centrale per il Restauro* – ICR' (Central Institute for Restoration) started a study to survey the constructive vulnerability of national built heritage. This study is part of a larger project called '*Carta del Rischio'* (CdR), aimed at identifying those natural/environmental or anthropic risks that might threaten the Italian architectural heritage [3]. *'CdR'* is a geographic

[1]The acronym 'GTS' means: '*Gruppi Tecnici di Sostegno'* (Technical Support Groups). These teams include both specialised officers and technicians from different public agencies.

[2]'*Manuale opere provvisionali'* and 'Schede tecniche STOP'.

[3] Nevertheless, this is not the first analysis carried out to define the causes of degradation of the cultural heritage that stands in a territory: a first important project, aimed at mapping this link by identifying methods, professionalisms and experts able to carry out preventive interventions of 'planned conservation', was already proposed in 1975 by G.Urbani, who was the director of the ICR. That project was called

information system developed to map, on a cartographic basis, what are the assessed risk conditions for the architectural and archaeological immovable heritage. The system evaluates the risk of each item by assessing its vulnerability and the hazard of the area. These parameters allow for the evaluation of the level of danger from environmental, hydrogeological or seismic risk.

Fig. 2. An example from the Italian '*CdR'*. The map shows the areas where the seismic risk has already been assessed.

Concerning the seismic risk assessment, the evaluation is determined both through filling in specific forms which catalogue the vulnerability level of buildings[4] and through the seismic hazard level, which is determined by the '*Istituto Nazionale di Geofisica e Vulcanologia* – INGV'(National Institute of Geophysics and Vulcanology) depending on the seismo-geological properties of the region. Some analyses of this type have been carried out in Southern Italy, especially in Calabria and in Sicily. Nonetheless, they have not yet been completed everywhere, nor in those areas that are characterised by high seismic activity.

Therefore, it is not yet possible to have a complete map of seismic vulnerability and risk for the architectural heritage.

2. The earthquake of Central Italy

The earthquake that hit Central Italy on 24th August 2016 was the first in a long sequence, which saw more than 3,000 tremors during the whole year. The earthquake affected an area that stands along the two sides of the Apennines, between the Sibillini and the Laga Mountains, in the inner part of the valley of the River Tronto, among the regions of Lazio, Marche, Umbria and Abruzzo. The seismic sequence, known as the '*Amatrice-Visso-Norcia seismic sequence'*, was characterised by 7 events with a *magnitude* of $M_w \geq 5.5$. Among these events, two occurred on 24th August 2016, whose epicentres were registered near Accumoli (RI) in Lazio and near Norcia (PG) in Umbria. Strong aftershocks occurred again on 26th and 30th October 2016[5] , worsening the damage that had already been induced by the events in August.

Indeed, many buildings which had been damaged by the earthquake of 24th August had not yet been secured. Thus, at the end of October, they suffered further irreversible damage. This was also the case for the architectural heritage, where the most serious damage happened in the churches. Two examples of churches belonging to the vernacular heritage that collapsed almost completely due to the aftershocks at the end of October 2016, after already being damaged by the earthquake of 24th August 2016, will be briefly presented below. These examples are particularly significant as in both the churches, some securing interventions had been started by the NFB, even if they had not been completed by the end of October.

'*Piano Pilota per la conservazione programmata dei beni culturali dell'Umbria'* (Pilot plan for the planned conservation of the Umbria cultural heritage).

[4] There are specific forms that catalogue the 'architectural vulnerability' and the 'seismic vulnerability' of buildings. They differentiated one from other depending on building typologies.

[5] On 2016.10.26, two aftershocks with a *magnitude of* M_w=5.5 and 6.1 occurred, followed, on 2016.10.31, by a further one with a *magnitude of* M_w=6.6. The epicentres of these events were registered in Castelsantangelo sul Nera (PG), and in Norcia (PG) in Umbria. Two strong tremors with a *magnitude* of M_w=5.7 and 5.6 happened on 2017.01.18 in Montereale (AQ).

2.1 S. Antonio Abate church in Frascaro (PG)

Sant'Antonio Abate is a small church in the countryside near Norcia, whose construction started in the 15th century. The church had great artistic and cultural interest with frescoes and polychrome wooden statues from the 16th and 17th centuries inside and a scarved stone portal on the façade, which dated back to the middle of the 16th century. After the earthquake of 24th August , the most evident damage occurred in the carved stone portal, where part of both the lintel and the upper masonry collapsed partially. Cracks had also opened at the impost blocks of the cross vaults inside the church, and the collapse of the portal made the building inaccessible.

After that event, both the damage surveys and the assessment of the technical countermeasures were promptly defined by the functionaries of the MiC, who started the first intervention less than two weeks after 24th August. In September, the NFB also carried out the initial countermeasures, which involved the securing of the collapsed portion of the façade. It was also planned to construct shoring systems on the external walls, hooping them with steel cables and wooden beams in order to prevent the façade from overturning. These countermeasures were not started at the same time or promptly, probably due to some logistical problems, such as the lack of availability of the NFB specialised teams, who were entirely engaged in other securing work. On 26th and 30th October, when the main aftershocks occurred, the church had not yet been completely secured: only the countermeasures that were designed to strengthen the collapsed part of the façade had been finished. Thus, the church of Sant'Antonio Abate suffered an irreversible worsening of the previous damage:it collapsed almost entirely, with only part of the apse wall surviving thanks to the presence of the sacristy dwelling that stood behind it.

The study carried out on archival sources that are kept in the Diocese of Spoleto and Norcia has highlighted that the church had already suffered previous damage as a consequence of the earthquake that hit Valnerina in 1979.

That earthquake had caused damage on the cross vaults and the opening of some deep cracks, both in the external walls and below the belfry. After that event, the church had been restored by consolidating the extrados of the cross vaults with a reinforced concrete layer and by inserting cement mortar and armed perforations, both in the perimeter walls and in the portal of the façade[6].

Fig. 3. The church of *S Antonio Abate* after the earthquake of 24th August 2016 (left) and in 2017, after its collapse (right) (Source: https://frascarodinorcia-noprofit.webnode.it/galleria-immagini/ (a); https://www.iluoghidelsilenzio.it/frascaro-norcia-pg/ (b)).

2.2 S. Maria Assunta in Castelluccio (PG)

The church of Santa Maria Assunta was in Castelluccio di Norcia, a hamlet situated at the top of a mountain, 1,452-metres above the sea level, in the plateau called '*Piano Grande'* within the *Sibillini* Mountains. The church had a square plan and it was possibly built in the 16th century inside the fortified village, partly in adherence to other buildings. This church also had a carved stone portal with a considerable value. It was sculpted in 1528 and it was very similar to the one of Frascaro. Inside the church, which had been repainted in 1862, there were fragments of some frescoes dating back to the 16th century and wooden statues from the same period, albeit restored on several occasions. After the earthquake of 24th August , the worst damage to the church was in the 18th century bell tower, where

[6] Technical reports and drawings are stored in the technical office of the Diocese of Spoleto-Norcia, to whom the church belonged. This was also the case for the second example.

some angular masonry blocks had been inserted. There had also been local collapses of some wall blocks inside the church.

The ministerial officers reacted promptly in this case as well, carrying out the damage surveys at the beginning of September and arranging the recovery of movable heritage to the temporary warehouses that had been set up for restoration – thanks also to the help received from the NFB. The functionaries of the superintendence, coordinated by the UCCR Umbria, defined the necessary countermeasures for the bell tower, aiming to consolidate the ruined portion of the masonry and to hoop steel tie-rods all around the belfry. The first part of the intervention was carried out by the NFB in mid-September, but there is no evidence of other countermeasures being realised to contain the damage inside the church, nor other provisional works outside. After the earthquakes of October, both the bell tower and the church have unfortunately completely collapsed, as well as many other buildings of the hamlet, which had already suffered a great deal of damage on 24th August. It was, however, possible to save the wooden polychrome altar that was inside the large wall niche used as an apse, which had remained intact even after the collapse in October.

Fig. 4. The church of *S.Maria Assunta* before the earthquake of 2016 (Source: http://www.sabap-umbria.beniculturali.it/index.php?it/257/norcia-fraz-castelluccio).

The research has once more highlighted the existence of archival sources, which are stored in the technical archive of the Diocese of Spoleto-Norcia. The archival documents concern the restoration that was carried out during the 80's to repair the damage produced by the 1979 earthquake. That earthquake caused the opening of cracks in the interior walls of the church and also the presence of some vertical bending phenomena in the walls. The restoration was provided by strengthening the internal walls with reinforced plaster and by waterproofing both the roof and the external walls of the church. It also appeared that the roof of the church had been restored a few years earlier, with the external coverage built in concrete.

3. Discussion

The analysis of the 2016 seismic emergency has shown some critical issues related to the realisation of the technical countermeasures for the damaged architectural heritage. These issues have contributed to a reduction in the number of interventions completed in a timely manner. Therefore, most historical buildings that had not yet been secured before the end of October then suffered further damage and collapses. In most cases, precise information regarding materials, structures, the constructive history or previous damage due to past earthquakes weren't available for the built heritage. Moreover, vulnerability analyses provided by the system *'CdR'* hadn't yet been completed for the area affected by earthquake. On the contrary, if these investigations had been carried out in the past, they were not readily accessible at that moment. Thus, they weren't used for the first emergency surveys. In addition to this, the damage provoked by the earthquake meant it wasn't possible to enter the buildings, since it wasn't considered safe. Therefore, this limitation contributed to making the damage surveys incomplete and partial, often only detecting cracks that were visible from the outside. For this reason, the extent of the damage may have been underestimated in some cases, as well as the urgency assessed for the implementation of the technical countermeasures.

Moreover, in many cases it wasn't possible to proceed promptly to secure the architectural heritage due to the insufficient number of NFB, who were already really busy carrying out other public safety interventions. Thus, the finalisation of technical countermeasures for cultural heritage were executed only after having completed other public interventions assumed more urgent.

Therefore, when the aftershocks at the end of October occurred:

- not all the damage assessments for the buildings belonging to the architectural heritage had been carried out;
- some surveys were carried out only externally, giving an incomplete assessment of the real extent of damage;
- many of the necessary technical countermeasures for the architectural heritage had not yet been completely realized.

4. Conclusions

During the seismic sequence of 2016, the recurrence of severe aftershocks two months after the first event demonstrated for the built heritage the importance of prompt technical countermeasures to reduce possible further damage and/or collapses. During the emergency, the employment of a large number of specialised units was required, due to both the extension of the affected area and the need to carry out damage surveys in order to understand where countermeasures were urgently required. This was true not only for the functionaries of the MiC but also for those of other public agencies that intervene during emergencies. Thus, the earthquake of Central Italy has shown that it would be desirable to increase the number of firefighters specialised in the 'STCS' procedure, as they are also able to realise the technical countermeasures for the architectural heritage.

The problem related to an insufficient availability of specialised operators in the affected area also concerns the number of qualified restorers who, already knowing the damaged heritage, would be able to promptly intervene – i.e. protecting the movable pieces at the very least.

In fact, this problem did not come to light only recently: indeed, it had already been highlighted after the seismic emergency that hit the Umbria Region in 1997. Some negative issues were also identified in that period. They were not only the lack of knowledge on buildings and churches – also those belonging to the 'vernacular' heritage – or the absence of preventive maintenance intervention but also an insufficient number of both qualified professionals and means/materials needed to promptly install the countermeasures or to safely remove the sacred furnishings and artworks from churches. Conversely, in 1997 some qualified restorers who had previously completed specific training courses organised by the Umbria Region and the ICR were present in the affected territory. The availability of these specialised professionals, who had the specific knowledge of both the damaged heritage and the operating procedures that were useful to realise the protection/transport of movable artworks, in some cases enabled the prompt securing of cultural heritage [7].

Fig. 5. The provisional intervention on the bell tower of *Santa Maria Assunta*, realized by the MiC and the NFB (© *Vigili del Fuoco*) (Source: https.//www.vigilfuoco.tv/umbria/perugia/ norcia/ messa-sicurezza-chiesa-smaria-assunata).

Finally, the difficulties encountered during the surveys, especially regarding the availability of detailed information on both the constructive history and the level of vulnerability of built heritage, highlighted the importance of carrying out the analysis in advance, before the occurrence of an earthquake. Indeed, knowing these data at the time of an emergency would be an advantage for both technicians and public functionaries. On the one hand, knowing the existent vulnerability of the architectural heritage would allow damage surveys to be carried out primarily in those buildings that are exposed to a greater risk. On the other hand, the firefighters who

[7] Some meaningful examples are the safety intervention that has been realised by some trained restorers to protect the paintings of Benozzo Gozzoli in the apse of San Francesco in Montefalco (PG) or the one achieved in the homonymous church in Nocera Umbra (PG). On the contrary, the same result hasn't been achieved in Sellano (PG), due to the lack of both means and materials.

are entrusted with designing the technical countermeasures could better understand where the most vulnerable elements of a building are, therefore also predicting the evolution of damage and defining the most appropriate intervention more easily.It is thus clear that it is desirable to continue enforcing the collaboration between the MiC and the NFB.

A further advantage in the management of the emergency operations for the architectural heritage could be given by:

- increasing the number of NFB units that are specialised in architectural heritage;
- extending the number of the surveys aimed at deepening the knowledge of the Italian architectural heritage in order to understand the level of vulnerability and other important parameters, such as materials, structure and constructive history of buildings.

  The systematic organisation of this knowledge could be implemented by exploiting the already existing databases / information systems, such as the *'CdR'* project.

References

Archives of the Diocese of Spoleto-Norcia (ADSN), Technical Office of Spoleto, Folder: "69 - Lavori sisma Frascaro, Norcia, chiesa parrocchiale di S. Antonio abate", subfolder: "36B - Chiesa e casa parrocchiale di S. Antonio Frascaro in comune di Norcia - PG - (esercizio 1985)", envelope: "Progetto L-10214 chiesa di S. Antonio abate in Frascaro di Norcia - PG- n. 36".

ADSN, Technical Office of Spoleto, Folder: "Progetto - L 10050 - Castelluccio - Chiesa di S. Maria Assunta".

Brusa, E. (2021). The Italian emergency management for the built heritage after the 2012 earthquake: Emilia-Romagna – and Lombardy. In Arefian F., Ryser J., MacKee J. & Hopkins, A. (Eds), *Historic Cities in the Face of Disasters*.

Cacace, C. (2019). La carta del rischio per il patrimonio culturale. In Fiorani, D. (Ed.), *Il futuro dei centri storici - Digitalizzazione e strategia conservativa*. Quasar.

Chesi, C. (2018). L'acciaio nell'emergenza post-sisma. *Costruzioni metalliche*, 5.

Chiaraluce L., Di Stefano R., Tinti E., Scognamiglio L., Michele M., Casarotti E., Cattaneo M., De Gori P., Chiarabba C., Monachesi G., Lombardi A., Valoroso L., Latorre D. & Marzorati S. (2017). The 2016 Central Italy seismic sequence: a first look at the mainshocks, aftershocks, and source models. *Seismological Research Letters*, 88 (3).

Cutarelli, S. (2019). Gestire l'emergenza: la Carta del Rischio del Patrimonio Culturale per il recupero delle opere d'arte nelle aree terremotate. *Archeomatica*, 3.

Della Torre, S. (2021). Italian perspective on the planned preventive conservation of architectural heritage. *Frontiers of Architectural Research*, 10.

Della Torre, S. (2018). The management process for built cultural heritage: preventive systems and decision making. In Van Balen, K. & Vandesande, A. (Eds), *Innovative Built Heritage Models* (pp.13-20), Taylor & Francis Group.

Doglioni, F., Moretti, A. & Petrini, V. (Eds.) (1994). *Le chiese e il terremoto.* National Research Council - Gruppo Nazionale per la Difesa dai terremoti. Lint Editoriale.

Galanti, E., Goretti, A., Foster, B. & Di Pasquale, G., (2008). Civil Protection Management. In Oliveira, C.S., Roca, A. and Goula, X. (Eds), *Assessing and Managing Earthquake Risk. Geotechnical, Geological And Earthquake Engineering*. Springer.

Grimaz, S., Malisan, P. & Zorzini, F., (2018). Short-term countermeasures for securing cultural heritage buildings during a seismic emergency: improvements after the 1976 Friuli earthquake. *BGTA*, 59 (4).

Konsta, A. & Della Torre, S. (2021). Risk Management and Built Heritage: towards a systematic approach. In Roca, P., Pelà, L. & Molins, C. (Eds.), *SAHC 2021, Proceedings of the 12th International Conference*.

Parisi M.A., Chesi C. & Sferrazza Papa, G. (2018). Damage evolution in churches due to repeated earthquake shocks. In *Proceedings of the 16th ECEE European Conference on Earthquake Engineering, Thessaloniki, 18-21 June 2018.*

Podestà, S. & Scandolo, L. (2017). L'assenza di opere di pronto intervento: l'evoluzione del danno nelle chiese a seguito degli eventi sismici del Centro Italia. In *L'ingegneria sismica in* Italia, *Proceedings of the XVII National Conference, Pistoia, 17-21 settembre 2017*.

Rossi A., Tertulliani A., Azzaro R., et al. (2019). The 2016-2017 earthquake sequence in central Italy: macroseismic survey and damage scenario through the EMS-98 intensity assessment, *Bulletin of Earthquake Engineering*, 17.

SABAP Umbria (2021, November 17). *L'Umbria che resiste*.
http://www.sabap-umbria.beniculturali.it/index.php?it/257/norcia-fraz-castelluccio

Tonna, S., Boriani, M., Giambruno M.C. & Chesi, C., (2021). Criteria for the vulnerability analysis of structural aggregates in historical centers. In Roca, P., Pelà, L. & Molins, C. (Eds.), *SAHC 2021, Proceedings of the 12th International Conference.*

Urbani, G. (2000). Piano pilota per la conservazione programmata dei beni culturali dell'Umbria. In Zanardi, B. (Ed.), *Intorno al restauro*. Skira.

Zanardi, B., (1999). *Conservazione, restauro e tutela. 24 dialoghi*. Skira.