buildings

MDPI

Article

Reducing the Loss of Built Heritage in Seismic Areas

Giuliana Cardani * and Paola Belluco

Department of Civil and Environmental Engineering, Politecnico di Milano, Piazza L. da Vinci 32 instead of P.za L. da Vinci 32, 20133 Milano, Italy; pao.belluco@gmail.com

* Correspondence: giuliana.cardani@polimi.it; Tel.: +39-02-2399-4204

Received: 14 December 2017; Accepted: 23 January 2018; Published: 29 January 2018

Abstract: The presence of the largest part of World Heritage sites in a seismically-prone area, like Italy, demands always greater measures to protect the most important built heritage, as well as the minor architecture. This requires a constant improvement of the current protocol from the damage survey and the provisional safety measures to the final intervention. This procedure is summarized, briefly, here and additional practical suggestions are given to improve the activities, based on the experience of on-site volunteers during the damage survey after the earthquake that struck Italy in 2016. Basic issues on the recurrent characteristics of historic masonry buildings, that make them often complex constructions with unexpected behaviour, are fundamental in the preparation of the volunteers in surveying damage. This helps in reducing evaluation mistakes and in designing the provisional safety structures aimed at the preservation of built heritage to the extent possible. Some examples of incorrect interpretation of the damage in historic buildings are reported here. In conclusion, only the awareness that it is necessary that a correct understanding of the recurrent or, on the contrary, peculiar, characteristics of a historic building plays a key role in the damage evaluation and in its subsequent protection from further damage.

Keywords: built heritage; masonry; damage survey; geometrical survey; crack pattern; provisional intervention; seismic vulnerability; earthquake; emergency

1. Introduction

Italy has the highest number of UNESCO world heritage sites and, at the same time, is affected by a high seismic activity; particularly in the last forty years, main shocks had been followed by several aftershocks. As a result, the existing buildings are highly vulnerable [1].

Traditional expertise in restoring and strengthening masonry constructions differs from North to South, according to the knowhow and experience present in each area. To cite an example, after the severe seismic events that took place in Calabria and Sicily in 1783, the Borbonic Kingdom drew up the first regulations in Europe, giving instructions to rebuild new earthquake resistant buildings and entire towns, in 1786 [2]. Locally, every small historic centre made its own rules to repair damage, according to the typology of local buildings, using compatible materials and techniques. In case of less severe earthquakes, to prevent total collapse, buildings were constantly repaired and reinforced with new materials, while preserving the constructive typology.

An analysis of documents in historical archives together with careful visual observations on site allows to detect whether a historic masonry building has been subjected to repairs, alterations, or extensions using different materials, or where partially rebuilt after a local collapse. These events leave lasting traces in the walls, often affecting the structural behaviour of a building, locally or globally, resulting in a level of performance far from the original, designed and implemented at the time of its construction. Historic buildings frequently reveal themselves to be intrinsically weak, and those weaknesses represent their scars, which should be recognized, analysed, and cured. It is rare that they can be remedied for conservation reasons, too. The greater the number of such scars, the greater is the vulnerability of a historical building, particularly in the case of traumatic events such as earthquakes.

Studying the latest earthquakes that affected Central Italy in 2016, one of the principal causes of collapse in historic masonry buildings should not be attributed solely to the age of buildings or to poor construction quality, but also to their vulnerability acquired and increased after repeated shocks over the centuries. The more the transformation or repair work differs from the original structural behaviour, the higher the vulnerability of a masonry building is, as in the case of use of modern materials and techniques, with no regard to their compatibility [3,4]. It should be remarked that the value of an architectural heritage is related not only to its appearance, but to its materials and structural integrity, which kept it unique and authentic as a distinctive example of construction technology from a specific historical period and place. By preserving the material component, we gain a better understanding of the character and logic behind its structural system. Therefore, it is important to repair it with compatible techniques and without structural changes, or substantial additions or substitutions, which relegate the original structural materials to a merely historical backdrop.

In the second half of the 20th century, several historic masonry buildings and architecture of great value were subjected to structural reinforcement by introducing modern materials and techniques (such as reinforced concrete structures) without a careful consideration as to their compatibility. The rash use of such interventions, sometimes without rational analysis to validate the efficacy, revealed itself to be damaging over time to the material and the structure [1,5,6]. Improperly-retrofitted buildings have been affected by subsequent earthquakes resulting in traumatic damage both as regards the extent and also the severity of such, making repair impossible.

The conservation of materials and structures, therefore, means maintaining their role within the building, removing, reducing, or controlling the causes of the damage [7]. This principle is valid both for the main architecture heritage and for that of minor importance: the methodology to be used in times of emergency should be based on accurate damage surveys, well-designed provisional structures and, lastly, efficient repair, all with the aim of implementing a genuine preservation.

2. Action during Seismic Emergency

The Italian procedure for the protection of cultural heritage following rapidly after the earthquake events is now well organized, due to the experience acquired after many subsequent and closely following seismic events: 1997 in Umbria-Marche regions, 2009 in Abruzzo, 2012 in Emilia, and 2016 in Central Italy. These activities have been centralized in a structure, called *Protection of Cultural Heritage*, managed by the Civil Protection Department. This allows for cooperation among the different bodies involved (Ministry of Cultural Heritage officers, experts on structural engineering from the universities, and fire brigade teams). The cooperation of the universities activities is nowadays organized by the ReLUIS consortium [8,9]. Keystone to operations is the standardization of the damage survey and its immediate and correct interpretation, through dedicated survey forms for *churches* and *palaces*, developed by the Civil Protection group GLABEC (a working group delegated to the protection of cultural heritage from natural hazards) [10]. The two templates are based on different indicators, each one representative of possible collapse mechanisms for macro-elements. The subdivision of churches or palaces into macro-elements consists in the identification of architectonic elements in which the seismic behaviour may be considered almost independent from the building: facade, vaults, roof, apse bell tower, chapels, and so on. Each macro-element is analysed for its typology and its connection to the rest of the building, so that it is possible to analyse the damage and identify the collapse mechanisms. During inspection operations, the surveyors must indicate: (a) the actual macro-elements; (b) the level of damage; and (c) the vulnerability of each edifice to each possible mechanism, drawn from a clearly outlined list. From these data a damage score is defined, which goes from 0 to 1, obtained as a normalized mean of the damage grades in each mechanism. The correlation between macro-seismic intensity and damage is then defined thanks to the analysis of collected data [11].

At a subsequent level this can thus begin by providing technical and scientific support, based on past experiences in the field, with temporary propping and safety measures which are entrusted to fire fighters. The economic estimate of the damage is an additional part and concludes the technical survey.

The third level after the emergency phase is monitoring the possible progression of damage and improving a knowledge of the construction, by means of on-site diagnostic assessment [12].

To finish it must be noted that not only sudden natural disasters cause damage to cultural heritage, this can also be affected by continuous and progressive damage, due to lengthy period without maintenance work being carried out, that may lead to water infiltrating, then decay, biological attacks and small damages to wooden structural elements leading to their local collapses.

3. Basic Issues When Surveying Damage in Historic Masonry Buildings

To prepare volunteers to survey damage after a seismic event, they should know that historic masonry buildings present some recurrent characteristics. Normally in a restoration project, it is essential to devote sufficient time to the study and knowledge of the structures, especially where new structures are to be inserted. Historic masonry structures, even the simplest, cannot be standardized on a large scale, as with modern buildings of the post-war period. Each masonry, especially the stonework, is often unique, influenced by the materials and the construction techniques commonly used in a given place and in a given historical period, and are related to the function of the edifice and the requirements to make it durable. Where changes have occurred, be they modern or historical, the building will present geometry variations, at times visible to the naked eye, otherwise evident only through a careful and detailed geometric survey. Therefore, the survey must not simplify the geometric complexity, or the correct thickness of the walls, their orientation, the correct size of the corners, discontinuities, misalignments, etc.

The building may have evolved in the course of time: for instance, where it was born as an isolated building, it could have transformed to a row of buildings or a more complex one, after the addition of several volumes (Figure 1). The more complex the building, the more difficult to detect its vulnerability; therefore, it is important to know as much as possible about its structural evolution [12–14].

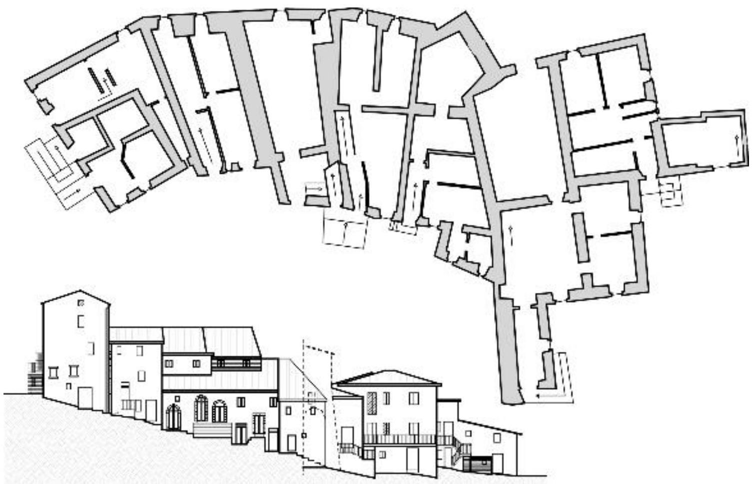


Figure 1. Example of a map and elevation of a complex civil building in a historic centre [3].

Thanks to a partial lack of decayed plaster, or to diagnostic techniques, such as thermography, it is possible to recognize the different masonry textures which help to understand characteristic anomalies of a historical building, and so carry out a volumetric stratigraphic reading.

A volumetric stratigraphy [15] allows the subdivision of the building into homogeneous blocks, characterized by relative chronological relationships. Any single block corresponds to a unique building phase and can be recognized by observing the construction details; its relation to other blocks may be precedent or subsequent, often without the possibility to arrive at an absolute date. Critical connections between blocks need to be investigated in order to clarify the phases of transformation to the complex and so identify the most vulnerable points. The study can then be completed by an investigation of dated elements, such as the type of brick and its dimensions and by a chronological characterization of the different masonry typologies.

Such anomalies should not be considered mere historic construction errors or survey mistakes; on the contrary, they should be put into evidence. Serious mistakes can occur when those traces in the masonry structure are not examined carefully before carrying out repairs, reinforcement work, or adding new structures or effecting structural changes, especially in seismic areas, as well as when adding provisional work. An effective approach to the study of historic masonry construction must begin with an understanding and knowledge of the structural logic, with all the specific peculiarities and intrinsic weaknesses, as well as that of the global damage and all visible cracks. A crack pattern survey must be carried out in order to interpret the type of damage and its causes.

This damage survey, followed by a correct analysis and investigation of damage causes, helps recognize the cracks that indicate local or global suffering or future possible collapse mechanisms [4,10,12,16], that damage causes could be due to a sudden traumatic event or to some still-active events. Damage, which is frequently attributed to an earthquake, may be of a different origin, caused by an excessive dead load or by soil settlement, or simply be due to a lack of maintenance over an extended period. All cracks should be clearly represented on the elevation drawings of the building drawings, with their precise location and shape and whether they pass through the whole cross-section of the wall or not. In the case of stone masonry, the load-bearing capacity depends strictly on a deficiency of constructive details, which may be the cause of a local mechanism. Finally, different crack patterns observed at different periods make it possible to follow the evolution of the cracks.

Damage and crack pattern surveys become an essential topic in a preservation project, in order to distinguish recently-arisen problems from the already existing ones that were never fully resolved. Cracks usually form where the structure is already weakened and particularly in the presence of discontinuities. Therefore, their analysis helps to set up a strengthening design, which needs to be effective and durable. Furthermore, a monitoring system design of correctly-selected cracks serves to define the speed and evolution of the damage.

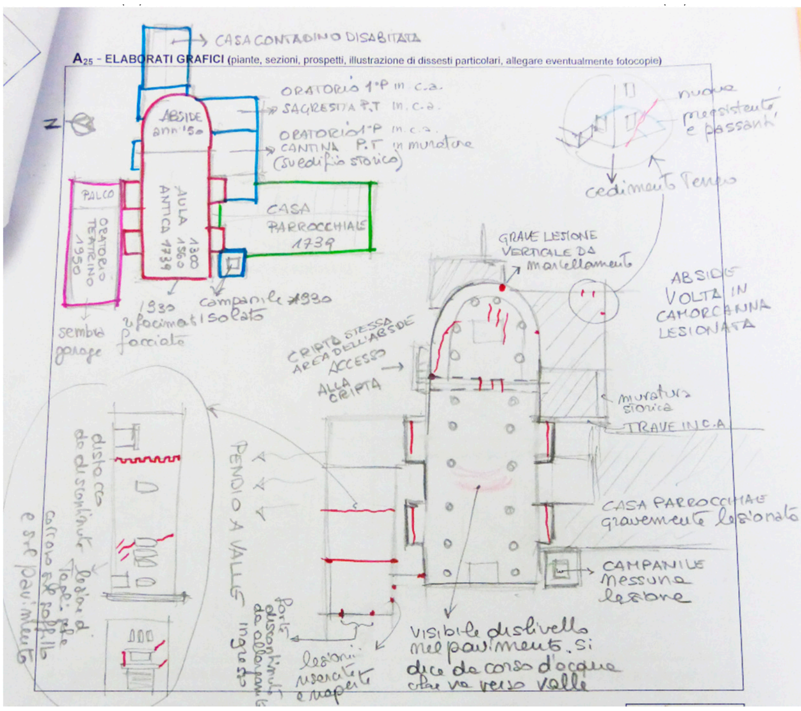
Earthquakes usually render already-existing damage evident. If a historic building was constructed following the rules of art, presenting a compact and regular geometry, and, substantially, if it has not been modified over the centuries, it will be more homogenous and present less damage, compared to a similar building which underwent transformation, reconstruction, and reinforcement. The incompatible strengthening interventions of the past forty years were one of the main causes of damage, as also observed following the seismic event that struck Central Italy in 2016.

In Figure 2 we have an example of the damage survey of a church struck by the 2016 earthquake and reported in the forms Model A-DC, covering the aforementioned issues.

(a)

(b)

Figure 2. *Cont.*



(**c**)

Figure 2. Example of a damage survey of a church struck by the 2016 seismic event: (**a**) vertical crack in the apse in correspondence to a perpendicular wall situated at the back; (**b**) diagonal cracks in the sacristy corner; and (**c**) the church survey form reporting the volumetric stratigraphy and the crack pattern sketches.

4. The Effect of an Incorrect Interpretation of Built Heritage Damage after a Seismic Event

Some examples of incorrect interpretation of the damage in historic buildings are reported here.

All strengthening intervention against seism should take into account the history and constructive evolution of the building, with all the modifications made over the centuries, right up to the recent ones. As already reported above, the presence of such discontinuities makes a historic building much weaker than a similar one, but homogenous and compact, and often concurs to add irregularities both in the plane and in the height, as shown in Figures 1 and 2.

Any application of provisional strengthening systems should also take into account pre-existing weak points, with the discontinuities and constructive historic evolution, in addition to the observed damages and the current damage mechanisms revealed. The aim is to avoid wrong, heavy, or useless invasive intervention on architectural heritage sites, as observed in the historic centre of L'Aquila after the 2009 earthquake. Massive safety intervention is certainly able to avoid collapses during the aftershocks, but has unnecessarily created additional manipulation to structures, making restoration more difficult after their removal (Figure 3a), unless a reconstruction is planned.

As an example, in the historic palace shown in Figure 3b–d, another example of excessive safety measures is reported: after the first shock in 2016, cracks formed mainly along one corner, where the southerly walls are not aligned (Figure 3b). Due to the emergency, an array of iron tie-rods were immediately inserted in the two upper floors of the whole building, with the aim to stop the overturning of the southern façade. Probably, having a correct geometrical survey during the first damage survey would have shown that, instead of having overturning problems, there were more hammering problems exactly in the damaged corner. The different walls' thickness, pillar dimensions, and floor typology (clearly visible in the drawings), together with the crack's location, could immediately have shown the transformation of the building over the time: two lateral box-shaped volumes and a third one, in between, closed in a second time. Thus, the weak point is exactly this last added volume and, as a consequence, the provisional intervention should have mainly improved this weakness from the top to the base, instead of being spread through the building, reducing the number of tie rods. It must be then reported that this realized provisional intervention was not able to prevent the formation of fresh new cracks, after further shocks, localized around the same corner, but in the basement vaults (Figure 3b,d), where tie rods maybe should have been added before. The complex geometry of the building with its historical evolution, together with recent provisional safety measures, contributed to make the building more vulnerable and now with many rooms obstructed in their use [17].

(**a**) (**b**) (**c**) (**d**)

Figure 3. Example of massive safety intervention: (**a**) in a palace in L'Aquila and (**b**) in a palace in Recanati, where (**c**) all iron tie-rods are visible inside a room and (**d**) new cracks formed in the vaulted basement.

On the other hand, delay or the absence of inserting provisional propping works, following the survey and the filling form [10] can be considered to be the main cause of collapses of cultural heritage buildings, as was the case during the sequence of shocks in central Italy in 2016 [18].

A box-like masonry structure, where all elements are well connected to each other, behaves correctly when subjected to seismic action. Many observed palaces of 15th and 16th century, with regular shape, never transformed over time and, well maintained and correctly repaired, did not show serious damage after the earthquake in 2016. Nevertheless, in many historical buildings it is not difficult to recognize different volumes joined and overlapped in the course of centuries without proper connections, and this phenomenon, together with the low quality of some material cannot be overcome easily [19]. Historic masonry buildings, when heavily transformed over time, can hardly reach their initial homogeneous shape and their original structural performance, which can be reached with a total reconstruction only. This point should be clearly taken into account in the analysis and in the structural intervention. Otherwise, the aim to reach the structural performance of the origin or even a better one, more similar to the approach used for new constructions, will make structural analysis difficult, resulting in unpredictable and altered structural performance during further seismic events [20].

The last seismic events from 1997 to 2016 in Central Italy highlighted that the retrofitting interventions (upgrading) with modern techniques were unable to guarantee the expected structural safety, but, on the contrary, were the cause of greater damage (Figure 4), mainly causing the out-of-plane rotation of the lower walls [3,4].

(**a**) (**b**) (**c**)

Figure 4. Example of damaged load bearing masonry walls due to the hammering of: (**a**) r.c. tie beam at floors level; and (**b**,**c**) at roof level.

Similar unexpected damage was also observed when a total reconstruction of the damaged upper floors was carried out (with clay block masonry inside and stone veneer outside), while the ground floor was repaired and the masonry walls strengthened, preserving the original barrel vault internally. Ignoring the adopted technique used to connect old and new masonry parts, it resulted in different patterns of behaviour: for example, where no cracks were evident or the external stone veneer did not collapse (as in Figure 5a), the upper portion translated and rotated over the weaker ground floor, causing serious partial collapse (Figure 5b,c).

(**a**) (**b**) (**c**)

Figure 5. Example of differential retrofitting with reconstruction of the upper floors: (**a**) damage in the upper floors and collapse in the ground floor; and (**b**,**c**) no damage to the upper floor, but roto-translation above the partially collapsed ground floor.

Finally, the most unexpected behaviour was shown by buildings subjected to global structural retrofitting (upgrading intervention), carried out during the 1970s–1980s with the aim to reach, or improve, the original structural performance (with a mix of different materials, such as RC structures in substitution of wooden flooring and roofs, cement-based grout injection, masonry jacketing, new stone masonry veneer application, overlapping with tuff masonry walls, etc.). Those buildings, due to the previous shocks in 1997, which caused no evident damage, and a supposed lack of subsequent maintenance, collapsed completely during the 2016 main event (Figure 6), highlighting the vulnerability caused by a loss of constructive homogeneity, despite the simple and regular shape of the building [21].

(a) (b)

Figure 6. Example of a historic masonry building (**a**) retrofitted in the past; and (**b**) its total collapse after the main shock in 2016.

5. Some Suggestions to Obtain Greater Benefit from Damage Survey during the Emergency Phase

After some example of problems caused by the lack of knowledge in historic constructions and, as a consequence, in the damage analysis, a few suggestions are made here in order to improve the damage analysis during the emergency phase.

Local Ministry of Cultural Heritage officers, together with the local town technical office employees, should, in non-emergency times, gather documents and drawings of the built heritage, in digital copies, in order to be able to provide the relevant documents efficiently at the time of emergency. The important force is constituted by the presence in situ of the local Ministry of C. H. officials, able to share their knowledge of the characteristics of the surveyed buildings with the structural engineers in order to interpret the real new damage. Their knowledge, together with users and/or inhabitants, can also be of help to define their previous state of conservation and, consequently, previous structural damages, that may justify the presence of more severe damage than was to be expected. This aspect is sometimes neglected for fear of not receiving the economic resources due for repair.

Other important help is given by volunteers, structural engineers coming from all over the country to map the damage area as rapidly as possible. The suggestion is that of encouraging expert professionals to join in the survey as volunteers, considering this activity as professional formation and duly accredited. It is also necessary to develop young volunteers with free technical courses, transferring to them part of the experience gathered by the experts in the analysis carried out with times and scientific methods outside the emergency situation, so as to avoid gross evaluation mistakes. Volunteers should be able to read the crack pattern survey of built heritage without generalizing it. The latter part of their education should be carried out directly on site, working with experts, right from the very start of the damage survey. These young volunteers should also be taught to design propping safety interventions, having a low economic impact and without being too invasive, according to the value of the heritage. They should know that every region in Italy or single area may have devised its own system of defence from earthquakes, based on long experience, event after event (more evident in the case of subsequent closely-occurring shocks), founded on its cultural knowledge and availability of local materials. It is mistaken to draw comparisons with other places, having different constructive techniques, to highlight the weaknesses or deficiencies of a building. As in every seismic area, there is a historical tradition in facing up to earthquakes that allowed them to reach our time and to be repaired many times; it is so fundamental to know the local historical traditions in masonry constructions and repairs in order to preserve the surviving heritage buildings.

The already-cited Italian damage survey forms of churches and palaces need to be reviewed periodically in order to be more efficacious on site, for instance, by taking into consideration the presence of landslide or soil settlement provoked by the earthquake, causing damage to the buildings above. This damage is not linked to the collapse mechanism currently listed in the survey form (Figure 7).

(**a**) (**b**)

Figure 7. Example of damage due to soil settlement occurring after a seismic event: (**a**) visible outside a church; and (**b**) inside a church.

When a sequences of shocks occurs, more than one survey on the same building needs to be organized. In this circumstance, it could be extremely helpful, to have to hand a list of previously-filled survey forms, so as to be able to compare the damage and its evolution.

6. Conclusions

In Italy, after a long series of seismic events recently, emergency action and investigation of the cultural heritage is now well organized, but should always take into account that every earthquake is a new story, not only from the seismologic and human point of view, but also as regards the cultural heritage present in the area. In fact, in every seismic area, there is a historical tradition in facing up to earthquakes that has allowed them to reach our time and to be repaired many times. The methodology constantly used in the past for repairing and reinforcing historic masonry constructions should be analysed before thinking to repair them with modern and better-known techniques, valid for modern masonry buildings.

For the above-mentioned reason, before a seismic event occurs, every town, with the help of local historians and professionals with long experience, should collect technical data on the architectural heritage, including the minor architecture, with special reference to the present recurrent masonry typology and the earthquake-proof systems adopted that had proved to be efficient throughout the centuries. This collected data, immediately available, must be supplied to the volunteers soon after the event, during the damage survey, together with clear basic drawings. This aspect is extremely important for an understanding of the effect and extension of a new natural disaster to the historic heritage, and also to realistically design adequate provisional protection, in order to better preserve the cultural heritage, as was done by historic technicians in the past.

Basic issues on the recurrent characteristics of historic masonry buildings, that make them often complex constructions with unexpected behaviour, are fundamental in the preparation of the volunteers in surveying damage. This helps in reducing evaluation mistakes and so in designing the provisional safety structures aimed at the preservation of built heritage to the extent possible.

Current Italian technical standards appear to be more aware of the need to safeguard the architectural, constructive, artistic, and environmental values of existing historical buildings. However, the lack of trust reposed in historic masonry materials and constructive techniques and, on the other hand, the confidence in modern materials and techniques, led to the recurrent intervention typologies that preferred total or partial reconstruction of the damaged masonry building with modern anti-seismic masonry, then covered by an external stone masonry layer without a structural role. This solution only respects the volume and traditional external aspects. In addition, this has contributed to the increase in collapsed buildings in many historic centres. Those few buildings, which still present their original structures, should be subject to special attention and repaired in the best way, so as to enhance the constructive typology traditionally present on site, based on the experience of the seismic history of the place, without the standardization of modern buildings.

One of the causes more responsible for damage in the built heritage is a lack of maintenance, extending over lengthy periods, even where the construction is homogeneous and follows the rule of art. This is also the cause of some total collapses observed. On the other hand, some masonry buildings extensively retrofitted after a seismic event and subsequently showing no apparent damage after an additional seismic event, totally collapsed anyway after the last event in 2016. The best methodology is therefore in the middle.

Many historical masonry buildings, with traditional earthquake-proof systems, such as thick buttresses, wood and iron tie-rods, peculiar constructive details, etc., were able to survive strong and repeated shocks, enabling to save human lives and to repair the damage, thanks to their residual strength. As has occurred in the past, despite modern and efficient techniques, it must be a priority when repairing damages to carefully preserve the original constructive characteristics.

After the emergency phase, only a deep knowledge of the building, of its historical transformations, its tradition to improve seismic performance over the centuries, that make it now peculiar and unique, together with constant, minimal maintenance, plays an essential role in reducing the loss of built heritage in seismic zones.

Acknowledgments: The research enters the frame of project AQ DPC/ReLUIS 2014-2018.

Author Contributions: Giuliana Cardani wrote the paper based on her experience on site, thanks to the contribution of Paola Belluco, who dedicated long time in the cultural heritage survey in Abruzzo region after the 2016 earthquake.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Parisi, F.; Augenti, N. Earthquake damages to cultural heritage constructions and simplified assessment of artwork. *Eng. Fail. Anal.* **2013**, *34*, 735–760. [CrossRef]
2. Sarconi, M. Istoria de' Fenomeni del Tremoto Avvenuto Nelle Calabrie, e nel Valdemone Nell'anno 1783 Posta in Luce Dalla Reale Accademia Delle Scienze, e Delle Belle Lettere di Napoli, Atlante Iconografico. Publisher: Napoli 1784, Presso Giuseppe Campo Impressore Della Reale Accademia, Re-Printing in Fac-simile, Mario Giuditta Editore, Roma-Catanzaro, 1987. Available online: https://ingvterremoti.wordpress.com/2014/02/19/speciale-i-terremoti-nella-storia-i-borboni-di-napoli-e-il-grande-terremoto-delle-calabrie-del-1783/ (accessed on 2 December 2017).
3. Binda, L.; Cardani, G.; Saisi, A.; Valluzzi, M.R.; Munari, M.; Modena, C. Multilevel approach to the vulnerability analysis of historic buildings in seismic areas, Part 1: Detection of parameters for vulnerability analysis through on site and laboratory investigations. *Restor. Build. Monum.* **2007**, *13*, 413–426.
4. Binda, L.; Cardani, G.; Saisi, A.; Modena, C.; Valluzzi, M.R.; Marchetti, L. Guidelines for restoration and improvement of historical centers in seismic regions: The Umbria Experience. In Proceedings of the IV SAHC: International Seminar on Structural Analysis of Historical Constructions, Padova, Italy, 10–12 November 2004; Modena, C., Lourenço, P.B., Roca, P., Eds.; Taylor & Francis Group plc.: London, UK, 2004; Volume 2, pp. 1061–1068.

5. Penazzi, D.; Valluzzi, M.R.; Cardani, G.; Binda, L.; Baronio, L.; Modena, C. Behavior of historic masonry buildings in seismic areas: Lessons learned from the Umbria-March earthquake. In Proceedings of the 12th International Brick and Block Masonry Conference, IB2Mac, Madrid, Spain, 25–28 June 2000; Adell, J.M., Ed.; Construction and Architectonic Technology Department of the Polytechnic University of Madrid: Madrid, Spain, 2000.
6. Binda, L.; Cardani, G.; Penazzi, D.; Saisi, A. Performance of some repair and strengthening techniques applied to historical stone masonries in seismic areas. In Proceedings of the International Conference on Performance of Construction Materials in the New Millenium (ICPM), Cairo, Egypt, 18–20 February 2003; El-Dieb, A.S., Reda Taha, M.M., Lissel, S.L., Eds.; Elmaarefa Printing House: Cairo, Egypt, 2003; Volume 2, pp. 1195–1204.
7. ICOMOS Charter, Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage (2003). Available online: https://www.icomos.org/charters/structures_e.pdf (accessed on 1 December 2017).
8. Di Ludovico, M.; Moroni, C.; Abruzzese, D.; Borri, A.; Calderoni, B. The contribution of ReLUIS in the activities supporting the 2016 Central Italy seismic emergency. In Proceedings of the 17° Convegno Nazionale su "L'ingegneria Sismica in Italia", Pistoia, Italy, 17–21 September 2017; Braga, F., Salvatore, W., Vignoli, A., Eds.; Pisa University Press: Pisa, Italy, 2017.
9. Lagomarsino, S. Damage assessment of churches after L'Aquila earthquake (2009). *Bull. Earthq. Eng.* **2012**, *10*, 73–92. [CrossRef]
10. Model A-DC and Model B-DP, PCM-DPC, Scheda Per il Rilievo del Danno ai Beni Culturali—Chiese e Palazzi; G.U. No. 55, 7/03/2006. Prime Minister Decree of 23/02/2006, Approval of Forms for the Seismic Damage Assessment of Cultural Heritage Buildings. Available online: www.beniculturali.it (accessed on 1 December 2017). (In Italian)
11. Lagomarsino, S.; Podestà, S. Seismic Vulnerability of Ancient Churches: I. Damage Assessment and Emergency Planning. *Earthq. Spectra* **2004**, *20*, 377–394. [CrossRef]
12. Binda, L.; Cardani, G. Seismic vulnerability of historic centers: A methodology to study the vulnerability assessment of masonry building typologies in seismic area. In *Handbook of Research on Seismic Assessment and Rehabilitation of Historic Structures*; Asteris, P.G., Plevris, V., Eds.; IGI Global: Hershey, PA, USA, 2015; Chapter 1; pp. 1–29. ISBN 9781466682870.
13. Binda, L.; Cardani, G.; Saisi, A. Edifici complessi: Una questione aperta. In *Sicurezza e Conservazione Degli Edifici Storici in Funzione Delle Tipologie Edilizie, Della Concezione Costruttiva e dei Materiali*; Binda, L., Ed.; DIS-Politecnico di Milano: Milano, Italy, 2006; pp. 13–20.
14. Binda, L.; Anzani, A.; Cardani, G. Methodologies for the evaluation of seismic vulnerability of complex masonry buildings: Case histories in the historic centre of Sulmona. In Proceedings of the 11th International Conference on Structrural Repairs and Maintainance of Heritage Architecture, STREMAH IX, Tallinn, Estonia, 22–24 July 2009; Brebbia, C.A., Ed.; WIT Press: Southampton, UK; pp. 395–406.
15. Mannoni, T. *Caratteri Costruttivi Dell'edilizia Storica*; SAGEP: Genova, Italy, 1994.
16. Cardani, G.; Anzani, A.; Binda, L.; Saisi, A. On site structural assessment of churches in stonework damaged by the earthquake. In Proceedings of the 2nd Canadian Conference on Effective Design of Structures, Hamilton, ON, Canada, 20–23 May 2008; Chidiac, S., Ed.; McMaster University Centre for Effective Design of Structures: Hamilton, ON, Canada, 2008; pp. 1–10.
17. Cardani, G.; Belluco, P. The Architectural Heritage in Seismic Area: Geometrical Survey for Damage Analysis and Strengthening Design. In Proceedings of the 5th INTBAU International Annual Event—Putting Tradition into Practice: Heritage, Place and Design, Politecnico di Milano, Milano, Italy, 5–6 July 2017; Amoruso, G., Ed.; Springer International Pub.: Cham, Switzerland, 2017; pp. 84–93.
18. Podestà, S.; Scandolo, L. L'assenza di opere di pronto intervento: L'evoluzione del danno nelle chiese a seguito degli eventi sismici del centro Italia. In Proceedings of the 17° Convegno Nazionale su "L'ingegneria Sismica in Italia", Pistoia, Italy, 17–21 September 2017; Braga, F., Salvatore, W., Vignoli, A., Eds.; Pisa University Press: Pisa, Italy, 2017.
19. Giuffrè, A. *Sicurezza e Conservazione dei Centri Storici. Il Caso Ortigia*; Laterza ed.: Roma, Italy, 1993.

20. Borri, A. Strutturisti e restauratori: Sicurezza vs conservazione? Problemi, dubbi e proposte. *Recupero e Conservazione* **2015**, 127. Available online: https://s3-eu-west-1.amazonaws.com/bolling%2Fallegati-articoli%2FNM2NZxiPzX3i9vDuD-Borri%20x%20web.pdf (accessed on 1 December 2017). (In Italian)
21. Cardani, G.; Binda, L.; Giaimi, P.; Belluco, P. A simplified method of analysis to define the seismic vulnerability of complex buildings in historic centres. In Proceedings of the 12th North American Masonry Conference (12NAMC), Denver, CO, USA, 17–20 May 2015.