Super Case Study

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Earthquakes in Central Italy in 2016-2017

Online Version

Super Case Study 1:

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1 Introduction

Starting on 24 August 2016, a long-lasting seismic sequence struck a very large area of central Italy, partially overlapping the areas affected by the 1997 Umbria–Marche and 2009 L'Aquila earthquakes (Figure 1).

Figure 1. a) *Central Italy 2016–2017 seismic sequence projected on the National Seismic Hazard Map of Italy along with the nearby Umbria–Marche 1997 and Abruzzo 2009 seismic sequences.* ***Source:*** *Stucchi et al., 2004.* ***Figure 1. b)*** *Map of the average expected numbers of dwellings affected by Damage Level 5 (partial or total collapse) in 1 year in proportion to the total number of dwellings in the municipalities.* ***Source****: DPC, 2018a.*

Figure 1 a)

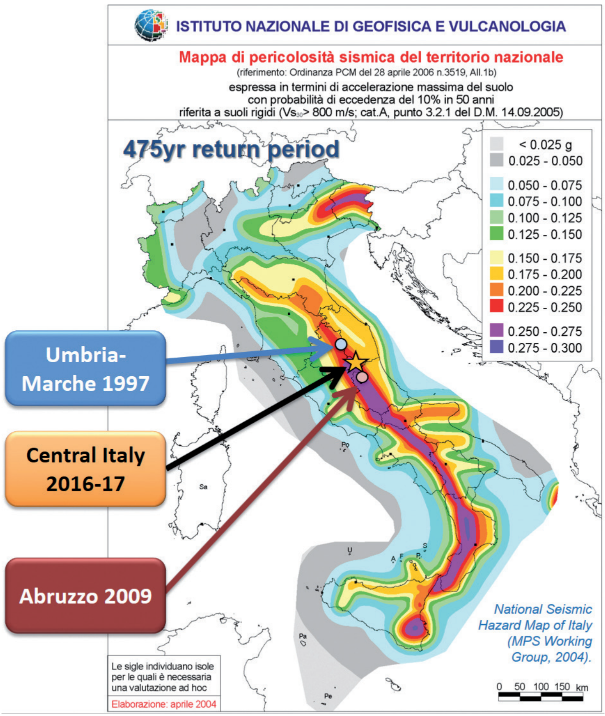
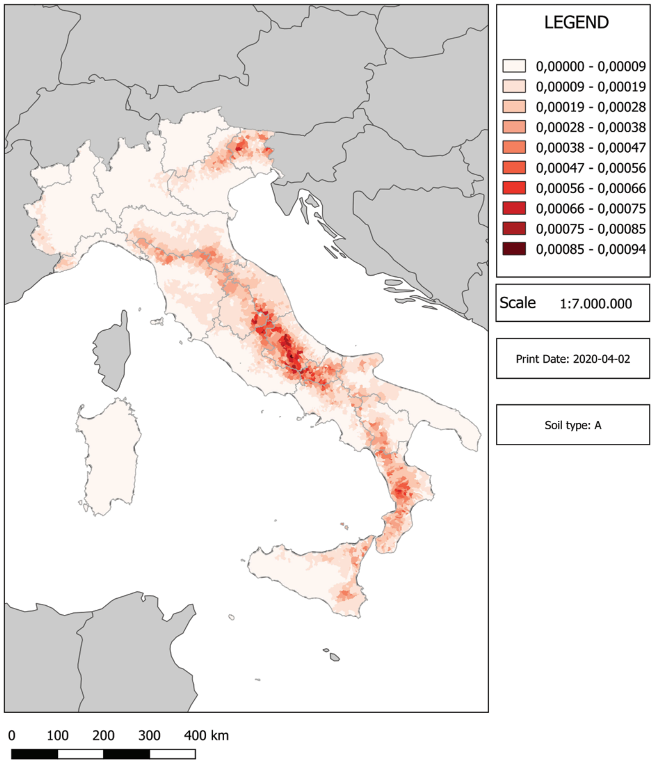


Figure 1 b)

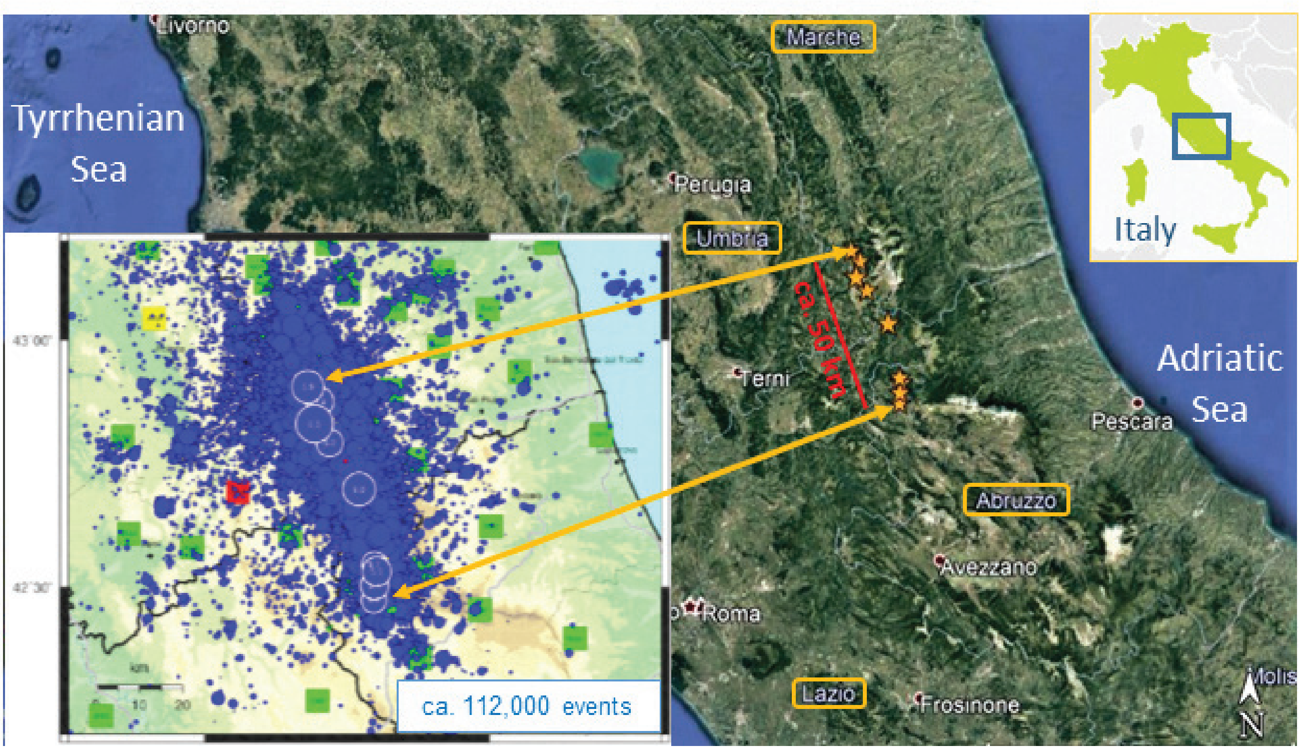


Nine major shocks with moment magnitude (Mw) greater than 5 occurred in 5 months (Istituto Nazionale di Geofisica e Vulcanologia, n.d.), with epicentres spread over c. 50 km following a NNW–SSE strike in the central Apennines (Figure 2). The two strongest earthquakes had Mw 6.0 (24 August 2016) and Mw 6.5 (30 October 2016).

After the first main shock, macroseismic (Mercalli–Cancani–Sieberg – MCS) intensities up to X or XI (ruinous or catastrophic) were observed (Galli et al., 2016). After 30 October 2016, the damaged area enlarged considerably. The maximum observed (cumulative) intensity was XI (Tertulliani and Azzaro, 2016a,b, 2017; Galli et al., 2017). The area with IMCS ≥ VII (very strong) was about 70 km long and 30 km wide (Figure 3). Very high values of peak ground

acceleration (PGA) (Table 1) and of other instrumental parameters were recorded (DPC, n.d.).
Co-seismic effects encompassed surface fracturing and faulting processes (Emergeo Working Group, 2017), which mainly reactivated already known pre-existing faults (e.g. Boncio et al., 2004; Pizzi and Galadini, 2009; Valensise et al., 2016). Many landslides and rockfalls affected the entire region and were in part responsible for disruptions of the transportation system.

Figure 2. *Central Italy 2016–2017 seismic sequence in the regional context. The four regions involved are marked in yellow. Bottom left insert: seismic sequence updated at 1 October 2019.* ***Source****: Authors, using Google Earth: Image Landsat / Copernicus - © 2018 Google - Data SIO, NOAA, U.S. Navy, NGA, GEBCO and Istituto Nazionale di Geofisica e Vulcanologia, 2019*



The first main shock killed 299 people and injured 392, whereas the strongest one did not cause any further fatalities, but injured only 38 people (Table 1). This occurred because (1) damaged buildings and highly damaged areas ('red zones') had already been evacuated, (2) the vulnerability of undamaged buildings near the epicentre of the strongest earthquake was low thanks to previous retrofitting and (3) emergency operators were not active yet at the time (7.40) the Mw 6.5 earthquake occurred.

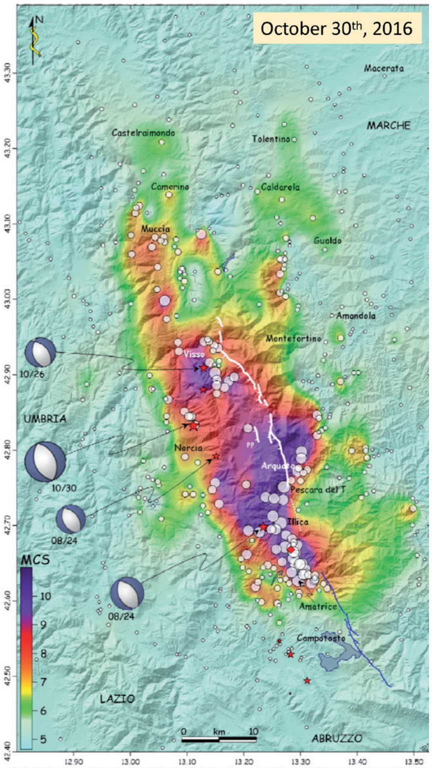
The emergency response of the National Civil Protection Service was coordinated by the National Civil Protection Department (DPC) until 7 April 2017, when the administrations of the four affected regions took over the management of most of the ongoing emergency activities. Meanwhile, the reconstruction process started on 9 September 2016, when a special commissioner for the reconstruction was appointed by the President of the Republic.

Besides search and rescue, civil protection activities were focused on assisting the population, by providing shelters and food. Up to 4 807 people were assisted in the first few days. At the end of August 2016, 43 tent camps had been set up, but their use was limited to a few weeks and then they were replaced by containers, because of the cold weather in the epicentral areas.

***Table 1**. 2016-17 Central Apennines seismic sequence: Mw≥5.5 earthquake.*
***Source**: Authors, based on Istituto Nazionale di Geofisica e Vulcanologia, n.d.; DPC, n.d.; DPC, 2018b.*

2016-17 CENTRAL APENNINES SEISMIC SEQUENCE: MW≥5.5 EARTHQUAKE							
Date	Mw	Zone	Lat.	Long.	PGA max (cm/s2)	Fatalities	Injured
2016-08-24	6.0	1 km W Accumoli (Rieti)	42.70	13.23	916	299	392
2016-10-26	5.9	3 km NW Castelsantangelo sul Nera (Macerata)	42.91	13.13	684	0	0
2016-10-30	6.5	5 km NE Norcia (Perugia)	42.83	13.11	650	0	38
2017-01-18	5.5	2 km NW Capitignano (L'Aquila)	42.53	13.28	584	0	0

Other temporary shelter solutions were set up in safe sports arenas and gyms available in the affected area, while most of the population was moved from the disrupted villages to the hotels in the Adriatic coast. On 25 October 2016, 1 136 people were assisted, but at the end of the same month the population directly assisted increased again, to 31 763 people, owing to the increase in damage and the widening of the affected area.



The aim of this chapter is to identify some practical actions for preparedness, prevention and mitigation that could be implemented in the very near future to achieve an overall seismic risk reduction in the long term. Focusing on the impact on the main assets, it identifies lessons learned and gaps to be filled.

A comprehensive exploration of all the possible insights is out of the scope of this work, but some lessons are drawn from the fields of emergency and recovery, prevention and mitigation, management and governance at national and European levels.

***Fig. 3.** Macroseismic survey of the 2016–2017 Central Italy seismic sequence in the Mercalli Cancani Sieberg (MCS) Intensity scale after the October 30th, 2016, strongest main shock **Source**: Galli et al., 2017.*

2 Impact on the main assets

Residential buildings, schools, hospitals, cultural heritage, livestock farms, roads and other lifelines were severely affected, with direct economic losses in the order of EUR 21 billion and considerable indirect social and economic impacts.

The damage to the various assets was devastating, owing to the cumulative effect of the several main shocks: residential buildings, schools, hospitals, cultural heritage, livestock farms, roads and other lifelines were strongly affected. Some relevant damage is shown in the photo reports released by ReLUIS([1]), the Laboratories University Network of seismic engineering , the Laboratories University Network of seismic engineering, e.g. those by Celano et al. (2016), Dall'Asta et al. (2016), Del Vecchio et al. (2016) and Menna et al. (2016), and in the works by Tertulliani and Azzaro (2016a,b, 2017). This damage resulted in huge direct economic losses, estimated at c. EUR 21 billion, accompanied by considerable indirect social and economic impacts.The impact on the main building assets was quantitatively well monitored through the c. 220 000 damage and usability inspections carried out after the main shocks (Dolce and Di Bucci, 2018). Some buildings were inspected more than once, because of the subsequent main shocks.

A total of 2 678 inspections of school buildings were carried out; 66 % of the buildings were judged safe and the remaining 34 % (27 % slightly, 7 % very) unsafe (Di Ludovico et al., 2018, 2019).

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Table 2. *Summary of the results of the damage and usability inspections on public and strategic buildings and structures* ***Source:*** *DPC*

Public and strategic buildings and structures	Safe	Slightly unsafe	Very unsafe	Total	Safe	Slightly unsafe	Very unsafe	Safe	Slightly unsafe	Very unsafe
					% of total			% of category		
Hospital and socio-health buildings	241	102	75	418	6	3	2	58	24	18
City hall buildings	240	167	89	496	6	4	2	48	34	18
Civil collective activity buildings	366	252	149	767	9	6	4	48	33	19
Military collective activity buildings	212	83	51	346	5	2	1	61	24	15
Religious collective activity buildings	92	109	129	330	2	3	3	28	33	39
Technological service buildings	80	25	45	150	2	1	1	53	17	30
Transportation structures	12	9	5	26	0	0	0	46	35	19
Other public sector buildings	768	382	355	1505	19	9	9	51	25	24
Grand total	2.011	1.129	898	**4.038**	**50**	**28**	**22**			

Almost 50 % of the 4 038 public and strategic buildings, excluding schools, were found to be unsafe, as shown in Table 2. The hospital system suffered serious consequences. Inspections on 18 complexes, made up of 80 different buildings, found 14 hospital complexes and 32 buildings to be unsafe.

The road network in the affected area has a total length of more than 15 000 km and serves a territory with 1 770 widespread towns and villages. The interplay between seismic events and associated geological co-seismic effects (e.g. landslides and rockfalls) had a strong impact on it (Dolce and Di Bucci, 2018; Durante et al., 2018). The rehabilitating interventions on the roads were all entrusted to the national road company ANAS, with EUR 769 million of total investment (Soccodato et al., 2019). Local electrical and telecommunication blackouts and

([1]) http://www.reluis.it/index.php?option=com_content&view=category&id=80

other issues were observed during the seismic sequence. However, the longest and most widespread blackout was caused by the extraordinary European cold wave of January 2017, probably connected to climate change, which occurred along with the seismic events of 18 January 2017 (parameters for the strongest of these seismic events in Table 1).

Local electrical and telecommunication blackouts and other issues were observed during the seismic sequence. However, the longest and most widespread blackout was caused by the extraordinary European cold wave of January 2017, probably connected to climate change, which occurred along with the seismic events of 18 January 2017 (parameters for the strongest of these seismic events in Table 1). Local unavailability of drinkable water and damage to gas infrastructure occurred during some stages of the seismic sequence. Hydrochemical changes in water have been described by Rosen et al. (2018) and De Luca et al. (2018). No or very limited damage to dams was observed. Infrastructure components are further discussed by Stewart et al. (2018). The limited impacts on, and the role of, the mobile telecommunication network in the different phases of the chain of events have also been pointed out (GSMA, 2017).

Some 5.200 damage inspections were carried out on immovable cultural heritage assets, 1 670 of which underwent post-earthquake stabilisation (MiBAC, 2018). These data do not include historic centres, such as those of the villages in the epicentral areas (see for example Sorrentino et al., 2018; Pessina et al., 2019). In these cases, there were significant impacts on tangible and intangible heritage. A huge number of movable cultural heritage assets were recovered: 22 131 artistic and archaeological assets, 5.44 km of archives and 15 229 books Before the earthquake, the affected areas shared a slow but inexorable demographic and productive decline, which involved at first the manufacturing sector, but also agriculture, tourism, craftsmanship, the food industry and, consequently, trade. However, the socioeconomic impact was different from zone to zone, both because of the different shaking intensity and because not all the sectors and productive activities reacted the same way to the earthquake (Esposti et al., 2019).

The landscape, understood as the fruit of the relationship between humans and nature (Council of Europe, 2000; Priore, 2009), is likely to be greatly affected too. The temporary abandonment of territories, if prolonged over time, will potentially cause the loss of the landscape in that sense (Sargolini, 2017a).

3 Lessons learned

Time turns out to be a critical factor in post-earthquake recovery scenarios, because of multiple socioeconomic and other external factors.

3.1 Emergency and recovery

The damage and safety assessment of buildings has an important role in both the emergency management and reconstruction phases. In Italy, it is usually performed in accordance with the AeDES inspection form and the associated procedure (Baggio et al., 2007; Dolce et al., 2009; Papa et al., 2016a,b), but, after the October 2016 earthquakes, a procedure based on a simplified inspection form had to be introduced to speed up inspections (Dolce and Di Bucci, 2017). A total of c. 8 000 operators were employed in the surveys. The continuity of school activity is crucial to avoid depopulation and support a rapid recovery to normal life conditions. Slightly damaged school buildings were quickly repaired, while alternative temporary solutions for seriously damaged schools were implemented, such as temporary allocation of students to safe school buildings or in temporary prefabricated schools. Moreover, many students attended schools in the Adriatic coast towns, where part of the population of the disrupted villages was hosted.

Strong coordination of the health emergency management turns out to be essential. A coordination centre for health rescue in case of disaster was established for the rational deployment of resources, health experts and materials required in the affected area, and to prepare the assisted evacuation of patients in a critical condition. Eight advanced medical points, supplied by the four regions involved, were deployed as well as a socio-health assistance point. Three further socio-health assistance points came later from other regions. The medical assistance in the affected area was directed to the main provincial and regional hospitals, since only minor hospitals had to be evacuated.

Infrastructure disruptions over time call for continuous adaptation of the response. In performing emergency and recovery infrastructural interventions, the dual aspect of urgent actions and long-term recovery had to be addressed. Public–private cooperation was very useful to handle infrastructure disruption and recovery. This was enabled by the organisation of the National Civil Protection Service, which includes companies dealing with road and railway networks, energy and telecommunication (Dolce and Di Bucci, 2018). Real-time monitoring of infrastructures can be very useful for emergency management. Indeed, some key infrastructure components (e.g. bridges, dams) were already monitored through the DPC-OSS and DPC-RAN national monitoring networks (OSS for Osservatorio Sismico delle Strutture, Seismic Observatory of Structures; RAN for Rete Accelerometrica Nazionale, National Strong-Motion Network; Dolce et al., 2015), giving potential insights into structural response that are useful for management decisions.

The production continuity of livestock farms is a priority for overcoming emergencies and for economic recovery. Many of them had their structures damaged. To allow farmers to continue their activities, most actions were aimed at assessing the safety of zootechnical constructions; evaluating the impact on zootechnical production and livestock health; conducting a livestock census; identifying solutions and tools to overcome zootechnical critical issues; and providing assistance programmes to farmers (see also United Nations, 2015). Temporary structures were placed near damaged farms to house farmers' families and to provide for recovery of livestock, storage of feeds and milk conservation.

Cultural and architectural remains from collapsed heritage buildings have to be recovered for future restoration work. The Cultural Heritage Ministry provided procedures for the removal, classification and recovery of huge amounts of valuable rubble. Safe housing of rescued movable cultural heritage assets also requires facilities for their restoration. Adequate pre-existing facilities were not available in all the four affected regions, thus delaying recovery operations (Osservatorio Sisma, 2018). Umbria had already constructed a 5000 m2 earthquake-safe storage facility, where c. 7 000 movable assets as well as heritage rubble remains of the region were stored.
For all the aspects dealt with so far, time turns out to be a critical factor in post-earthquake recovery scenarios, because of multiple socioeconomic and other external factors.

3.2 Prevention and mitigation

The poor quality of the masonry in general and of its mortar in particular, as well as the lack of retrofit measures in masonry structures, combined with strong shaking, led to high collapse rates (Sorrentino et al., 2018). In contrast, previous structural retrofits typically preserved structures from collapse, thus saving lives inside (Stewart et al., 2018). This was the case in the historical centre of Norcia, where extensive retrofitting was implemented after the 1979 and 1997 earthquakes. Adequate seismic performance was observed in modern masonry buildings made of hollow clay blockwork. Such a positive response is an encouraging indication for future building activity. The serious damage to non-structural parts (typically infill masonry walls) of reinforced concrete buildings implies high repair costs. Moreover, structural and non-structural damage was observed on several buildings previously subjected to energy efficiency upgrades, thus jeopardising the retrofitting investment. Therefore, in earthquake-prone areas, energy upgrading should be combined with seismic retrofitting in an integrated approach; otherwise, handling energy and structural/seismic retrofitting separately can turn out to be excessively expensive (Bournas, 2018; Gkournelos et al., 2019).

Awareness of interdependencies among different infrastructures was raised (GSMA, 2017). Mobile network operators reported that severe problems were caused by power shortages in the area. They asserted the importance of redundancy, in terms of both backup energy and mobile emergency equipment, as well as of prevention, training and communication.

The need to provide heritage assets with adequate seismic protection has to be emphasised. Aside from their cultural and socioeconomic importance, some of them, e.g. churches, can be crowded at certain times. Improving their seismic performance seems a logical step, but the reality is different. The complex structural behaviour of this type of buildings makes their seismic retrofitting technically challenging (e.g. Cardani and Belluco, 2018). Moreover, there is a cultural divide between the engineering and conservation views of cultural heritage preservation. Borri and Corradi (2019) refer to examples of conservation bodies promoting the restoration of internal assets in churches without improving their seismic behaviour, not even using simple, inexpensive seismic devices (Penna et al., 2019).

3.3 Management and governance at national level

Prevention and mitigation strategies have always been strongly influenced, in Italy, by the occurrence of catastrophic events. After the Mw 6.9 Irpinia earthquake in 1980, a new classification of the national territory was adopted and, in 1982, the DPC was established. During the Mw 5.9 Umbria–Marche earthquake emergency in 1997, the civil protection system positively tested both its organisation and a new technical emergency management system (Baggio et al., 2007). After the Mw 5.7 Molise earthquakes in 2002 (Valensise et al., 2004), a Prime Minister's ordinance enforced new seismic classification and seismic code aligned with the European Code (EN-1998, 2004). It also established that strategic and important public buildings and infrastructures had to be subjected to safety evaluations.

Following the Mw 6.3 L'Aquila earthquake in 2009 (Dolce, 2010), new technical standards were enforced and almost EUR 1 billion was allocated for microzonation and seismic upgrading of strategic public buildings and infrastructures and of private buildings (Dolce, 2012). The Mw 5.9 Emilia earthquake in 2012 (Dolce and Di Bucci, 2013) boosted initiatives for resilience improvement in the private production sector. Finally, after the central Italy 2016–17 sequence, technical standards were updated, and tax incentives for seismic retrofitting of private buildings were introduced, based on their risk classification (Cosenza et al., 2018).
Standard residential property insurance policies in Italy typically do not cover seismic damage (OECD, 2018). It is estimated that only 1 % of Italian residential properties are covered against earthquake risk. Introducing compulsory seismic risk insurance would allow the Italian state to save progressively money paid for damage and then invest more in prevention.

According to the Italian Senate (Senato della Repubblica – Ufficio Valutazione Impatto, 2017), about 75 % of the

EUR 13 billion budget allocated for the reconstruction is devoted to infrastructure and real-estate assets. A large amount of the budget (c. 20 %) is also committed towards the resumption of economic activities and supporting the economic needs of the population.

Emergency and reconstruction management are closely related. Many of the choices made in the emergency phase can affect the success of the reconstruction and vice versa, as they are partly overlapping in time and activities. At the national level, this was managed through close relations between the civil protection and the special commissioner for the reconstruction. Similarly, continuous and close collaboration is needed among the national, regional and local levels of governance on the reconstruction process. The commissioner issued ordinances to guide the decision-making activity of regions and municipalities. He also established a technical scientific committee, which provided advice on planning and realizing the interventions of seismic adaptation and restoration of destroyed buildings. The interventions must be compatible with the protection of the architectural and environmental aspects, to obtain eco-sustainable architecture and energy efficiency (United Nations, 2015; Stimilli and Sargolini, 2019).

The reconstruction process must take into account the need for reinterpretation of the landscapes, as not everything can be rebuilt where it was and how it was. Only the renewal of the landscapes will be able to support the conservation of the Apennines' culture (Gambino, 1997).

3.4 Management and governance at European level

Major European earthquakes over the last few decades – mostly in Italy (2002, 2009, 2012, 2016, 2017), Greece (2014, 2016), Iceland (2014) and Spain (2011) – have not only caused the loss of c. 1 000 lives, but also inflicted huge economic losses across Europe. The European Commission focused many European research projects on this topic, dealing with seismic hazard, vulnerability and risk assessment for buildings and critical infrastructures, and on real-time risk reduction. In particular, the SHARE (Seismic Hazard Harmonization in Europe) project developed the 2013 Euro-Mediterranean Seismic Hazard Model (ESHM13). Nevertheless, as observed in the vision paper produced by the Enhancing Synergies in the European Union (ESPREssO) project (Zuccaro et al., 2018), to support decision-making processes, such improved hazard models need to be integrated within risk/impact assessment approaches, to enable alternative mitigation and/or adaptation measures to be compared. In this direction, the ongoing SERA project (Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe; European Commission, 2020), which builds on SHARE([2]) , is developing the ESHM20 hazard model and a new risk model for Europe.

From an emergency management perspective, the relevance of improved emergency communications and monitoring tools to effective coordination and deployment of response bodies is evident. Within the Union Civil Protection Mechanism (UCPM), the consolidation of the Emergency Response Coordination Centre Common Emergency Communication and Information System allows better interinstitutional coordination, providing a web-based alert and notification application. Moreover, the strengthening of the Copernicus Emergency Management Service can add value by rapid satellite mapping, responding to the need to support emergency response in the early operation phases, and to monitor recovery actions over time.

Structural prevention is one of the most important general policy targets for disaster risk reduction to be implemented in the coming years. For this reason, EU policy should consider incentivising seismic, as well as energy, retrofits in earthquake-prone regions. As of 2019, the Joint Research Centre is working on iRESIST+ (innovative seismic and energy retrofitting of the existing building stock; European Commission, 2019), a project

([2]) *http://www.sera-eu.org/en/activities/joint-research/*

for the development of a novel approach to the simultaneous seismic and energy retrofitting of existing buildings. Action 9 of the European framework for action on cultural heritage published in 2018 (European Commission, 2018) recognises that seismic upgrading of historical buildings in Europe is increasingly important. In the framework of the UCPM (European Commission, 2017), the European Commission finances prevention and preparedness projects, including for cultural heritage, which will enhance the collection of data and foster prevention, preparedness and response capacities in case of natural disaster.

4 Filling the gaps

National and local governments should seek new and creative ways to build awareness, by involving communities in disaster planning and preparedness activities, and in the decision-making process.

4.1 Understanding risk

Population ageing, the depopulation of some areas, the effectiveness of educational and health infrastructures, and either a cohesive or a disintegrated social fabric affect earthquake impacts (Ismail-Zadeh and Cutter, 2015; Sartori, 2017). The discovery of the different dimensions of the vulnerability of communities adds knowledge necessary to promote resilience, i.e. the ability to channel community energy and territorial resources positively. Social and psychological aspects are important components of this vulnerability. They are analysed and taken into account in Italy, for instance to prepare a more effective emergency management (see, for instance, activities by "*Psicologi per i Popoli*" (3) ; Vaudo, 2018). This issue should be more developed in order to build up communities' awareness and resilience. The policies for the affected areas should be designed so that post-earthquake reconstruction relaunches them strategically.

The Principles for the analysis, conservation and structural restoration of architectural heritage (ICOMOS, 2003, statement 3.5) state that 'each intervention should be in proportion to the safety objectives set, thus keeping intervention to the minimum to guarantee safety and durability with the least harm to heritage values'. The co-operation of several sectors and types of expertise is needed, including to deal with the considerable uncertainties in the knowledge of the construction, its old materials, its complex structural behaviour, and the interaction between the construction and the modern retrofitting solutions (Cardani and Belluco, 2018; Penna et al., 2019). Recent advances in some materials suggest interesting new solutions (Valluzzi, 2016; Rousakis, 2018), but a careful approach is necessary, promoting scientific tests to validate new retrofitting materials and techniques, as well as dissemination to professionals.

Structural response monitoring has shown its usefulness for understanding risk. During the three main shocks, 37, 59 and 60 structural monitoring systems of DPC-OSS(4) (Dolce et al., 2015) were triggered. The scientific exploitation of the relevant records provides important contributions to understanding the seismic response of structures. Future advances in information and communication technology and lower instrument and telecommunication costs can hugely increase the number of constructions monitored.

Post-seismic surveys after major earthquakes are fundamental to learn lessons from the field, and train young

(3) *http://www.psicologiperipopoli.it/*
(4) *http://oss.protezionecivile.it*

specialists. Their objective is to collect factual information, draw important lessons and promote preventative recommendations (earthquake-resistant design, monitoring data, population information, town planning, socioeconomic aspects). From a regulatory viewpoint, the second generation of Eurocode 8, to be published in 2021–22, is an opportunity to step back and take stock.

4.2 Planning risk reduction

Only responsible regional and municipal planning offers a response to the increasingly complex realities faced by communities, by linking disaster risk reduction, emergency management and response with other policy fields (Sargolini, 2017b). Risk assessment and management should be an integrated part of the planning and governance process (Moroni, 2010).

A multilevel and multi-stakeholder participation approach would be most effective (UNISDR, 2015). Possible roles of territorial planning in disaster risk reduction are (Greiving et al., 2007) (1) classifying different land use settings for disaster-prone areas; (2) regulating and differentiating land use or zoning plans with a legally binding status related to a given hazard/vulnerability combination; (3) providing evidence bases, such as hazards and risk maps, and detailed datasets of information to evaluate territorial plans against, in order to understand the possible consequences of disasters on land use allocations, also considering some degree of risk acceptability. According to the Incheon Declaration (Incheon, 2009), the most appropriate level to implement the functions of territorial planning in disaster risk reduction is the local government level.

The seismic vulnerability of school buildings (Dolce, 2004; Di Ludovico et al., 2019) deserves special care for the social consequences that their damage and collapse bring about. A specific comprehensive plan is needed to seismically upgrade the huge number of inadequate schools within a reasonable time horizon. Moreover, a plan for school emergency management should be prepared by the ministry of education and the civil protection national authority.

4.3 Implementing risk reduction

National and local governments should seek new and creative ways to build awareness, by involving communities in disaster planning and preparedness activities, and, more generally, in the decision-making process (Johnson et al., 2005; Di Bucci and Savadori, 2018). The attention of the media after major events should be exploited to increase public awareness, disseminate basic technical knowledge and promote political actions to increase prevention, preparedness and resilience. It is necessary to engage the population in three disaster phases: (1) preparing for disasters, when risk awareness and resilience preparedness are key concepts; (2) reacting to a disaster situation, when emergency communication and community integration have to be ensured; (3) overcoming a disaster event, when the affected area should be integrated with community and recovery support.

For a true community-based support approach after a disaster, optimal use of local skills and resources has to be made. It is also important to consider recovery support as a process, and not simply as the supply of products and services. Currently, a substantial gap still remains in the research (Djalante and Thomalla, 2011; Banba and Shaw, 2017). More specifically, there is a literature gap on the connection between the notions of participatory governance, disaster governance and building community resilience. One specific design of reflexive and participatory governance is in the concept of transition management (Kemp and Rotmans, 2009; Loorbach, 2010).

5 Final remarks

The reconstruction process, while reducing risk, should preserve the specific characteristics and landscape of the territory, and promote innovation in production systems to avoid further depopulation.

The impact of the 2016–2017 moderate to strong earthquakes on assets and communities was high. Management of the emergency was made difficult by the long duration of the sequence, which struck a territory that was vulnerable from both physical and socioeconomic points of view. The main assets, especially dwellings, schools, hospitals, transport infrastructure and cultural heritage, were severely damaged, and the communities and the local production systems, mainly based on rural micro-enterprises, were severely affected.

Many important lessons can be learned in various fields, from the most technical ones to those related to the reconstruction process, which should also preserve the identity and the landscape of the territory, while promoting innovation in the production system to allow people to remain there.

The recurrence of strong earthquakes for 5 months made the emergency and recovery phases extremely complicated, and time has turned out to be critical owing to multiple socioeconomic and other external factors. Damage and safety assessment is crucial for both phases, since its outcome is needed to ensure safety and the continuity of residence, schooling and production, especially by zootechnical firms in the central Italy case. This continuity and effective infrastructures are fundamental to avoid depopulation and to support a prompt recovery to normal life conditions. In this case study, the repeated infrastructure disruptions over time called for continuous adaptation of the response, and public–private cooperation was very useful to handle infrastructure disruption and recovery.

Structural prevention is sorely needed, especially because of the high vulnerability of old masonry buildings. Indeed, seismic retrofitting of old buildings, as well as the use of modern masonry in new buildings, has turned out to be effective in avoiding collapse and reducing damage. Non-structural parts of modern reinforced concrete buildings not designed in accordance with the most recent codes underwent severe damage. Special attention is required when energy efficiency upgrading is carried out. Generally speaking, in future it should be combined with seismic retrofitting. In any case, the interventions must be compatible with the protection of the architectural and environmental aspects, to obtain eco-sustainable architecture and energy efficiency. A specific comprehensive plan is especially needed to seismically upgrade the huge number of inadequate schools within a reasonable time.

Cultural heritage requires a great effort in the emergency phase, not only to secure damaged immovable assets but also to recover cultural and architectural remains from collapsed heritage buildings for future restoration work. Facilities are also needed to safely house rescued movable cultural heritage assets, and to restore them. The need to provide heritage assets with adequate seismic upgrading is emphasised once again. However, a careful approach is necessary, promoting scientific tests to validate new retrofit materials and techniques for built heritage, as well as dissemination to professionals.

Interdependencies among different infrastructures were demonstrated, and there is a need for greater attention to them and for public–private cooperation to deal with this problem in a more comprehensive way.

Disaster risk reduction, and particularly structural prevention, is one of the most important general policy targets to be implemented in the coming years. For this reason, besides energy retrofitting, EU policy should consider incentivising seismic retrofits in earthquake-prone regions. Discovering different dimensions of the community's vulnerability adds knowledge that is necessary to promote resilience. National and local governments should seek new and creative ways to build awareness, by involving communities in disaster planning and preparedness activities. Optimal use of local skills and resources should be looked for. Only responsible, regional and municipal, comprehensive planning offers a response to the increasing complexities faced by communities.

Emergency and reconstruction management are closely related. Many of the choices made in the emergency phase can influence the success of the reconstruction and vice versa as they are partly overlapping in time and activities. The reconstruction process must take into account the need for reinterpretation of the landscapes, since not everything can be rebuilt where it was and how it was. A continuous and close multilevel collaboration is needed among local, regional, national and EU governance on the reconstruction process.

Not all issues related to the disaster caused by the 2016–2017 central Italy earthquakes could be considered in this chapter. However, the wide variety of issues discussed provides an example of complex emergency management, prevention activities and governance at national and European levels, and shows how long the process is to reach an effective disaster risk reduction strategy.

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