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Etna 2018 earthquake: rebuild or relocate? Applying geoethical principles to natural disaster recovery planning

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Abstract

Etna's eastern flank is crossed by numerous seismogenic faults which cause surface faulting, resulting in the destruction of buildings and exposing the local population to risk. Rebuilding damaged buildings in earthquake-prone areas raises ethical and economic concerns. The M_W 4.9 earthquake on 26 December 2018 damaged over 3,000 buildings in an area of 205 km² inhabited by ~140,000 people on the Etna's eastern flank. The earthquake caused ground rupture of over ten kilometres, including some urban areas. It was thus imperative to undertake a preliminary geostructural study to identify the most vulnerable tectonic zones and upgrade targeted the buildings. The study identified the homogeneous microzones in seismic prospection, namely the Zones of Attention (ZA_{ACF}), Susceptibility (ZS_{ACF}) and Respect (ZR_{ACF}) of the faults activated during the 2018 earthquake. Buildings in the ZR_{ACF} were not allowed to be repaired because they were at serious risk of future damage. Owners were offered financial compensation to rebuild in seismically safer areas. Some people initially demonstrated reluctance to accept the proposed relocation. These issues were addressed through empathetic engagement with the affected population and through the provision of clear explanations regarding the rationale for the relocation. This case study highlights the necessity of providing comprehensive support to people, taking *into account the significant psychological challenges they are facing. This approach is currently being implemented in the reconstruction of other seismic areas in Italy. It has the potential to become a common and sustainable model for the reconstruction of areas affected by natural disasters.*

Keywords: Geohazard; Geoethics; Post-earthquake reconstruction; Fault; Risk reduction; Relocation; Disaster psychology; Etna

1. Introduction

Italy has a vast architectural heritage of exceptional historical and cultural value, which has been repeatedly damaged and sometimes destroyed by devastating earthquakes. Historically, there has been a tendency to rebuild damaged buildings in the same locations in order to preserve the memory of places that have been inhabited for hundreds or thousands of years. In cases where the damaged building has no historical or architectural value, it is pertinent to question the ethical and practical merits of continuing to rebuild in such dangerous areas. It can be argued that a more ethical and economically sound approach would be to employ criteria that are more respectful of the geological hazards that characterise some areas of the territory. This article addresses this question by examining the rebuilding efforts on the eastern flank of the Mount Etna volcano, which was struck by a destructive earthquake in 2018.

The eastern region of Sicily is prone to seismic activity, largely due to the presence of the Malta Escarpment and the tectonic faults that displace the Strait of Messina. These geological features have resulted in the formation of tectonic scarps, which are elevated structures reaching heights of hundreds of metres, both inland and along the seafloor [Neri et al., 2018; Gambino et al., 2021; 2022; Barreca et al., 2022], (Figure 1). Additionally, Eastern Sicily is home to Mount Etna, an impressive stratovolcano that has been active for over five hundred thousand years. Etna is one of the most active volcanoes in the world, and as a result, the population living on its slopes is highly exposed to volcanic risk including lava invasion. This is evidenced by numerous historical chronicles (Del Negro et al. [2013], and references therein). Furthermore, a multitude of shallow faults, measuring less than 4 - 5 km in depth, traverse the flanks of the volcano. Many of these faults are linked to the gradual collapse of the eastern flank (see yellow arrows in Figure 1), which is evidenced by a persistent aseismic creep along the fault planes, affecting and severely damaging several urban centres (Barreca et al. [2013], and references therein).

On 26 December 2018, a M_W 4.9 earthquake struck the eastern flank of Mount Etna [Bonforte et al., 2019], damaging over three thousand buildings in an area of ~205 km^2 inhabited by approximately one hundred and forty thousand people. The reconstruction was entrusted to a commissioner appointed by the Italian government [D.L. 32, 2019]. The commissioner's technical team carried out a geostructural study to identify the most tectonically vulnerable areas, and then issued the regulations that planned the reconstruction of the houses destroyed by the earthquake. This was the first attempt in Italy to guide the post-earthquake reconstruction processes through the preliminary identification of the geological characteristics of the territory affected by a catastrophic event, favouring geoethical criteria based on the utmost prudence and safety to protect people's lives and guarantee the durability of the built heritage over time [Ordinanza n.18, 2020]. Subsequently, the other post-earthquake reconstruction processes active in central Italy (2016 earthquake, Ordinanza n.119 [2021]) and Ischia (2017 earthquake, Ordinanza n.24 [2023]) have also adopted the same geoethical criteria.

This article illustrates the principles that guided the reconstruction and the decisions taken by the government's technical team, some of which were accepted by the population only after a wide dissemination of the criteria used to plan the interventions. Indeed, a fundamental aspect was the establishment of a transparent and continuous dialogue with the population, which took into account some psychological aspects underlying the traumas suffered by people affected by a natural disaster.

2. The 2018 flank eruption and associated ground deformation

A brief lateral eruption of Mount Etna commenced on 24 December 2018 and concluded on 27 December 2018. Magma was observed to erupt from a fissure extending approximately 2 km to the southeast from the Southeast Crater, along the western wall of Valle del Bove (illustrated by the yellow dashed lines in Figure 2a). The lava flow reached a minimum elevation of 2,400 metres above sea level (asl). Initially, a lava fountain erupted from the fissure for approximately one hour. The lava flow crossed the western wall of the valley and spread along the valley floor for a total distance of approximately three kilometres.

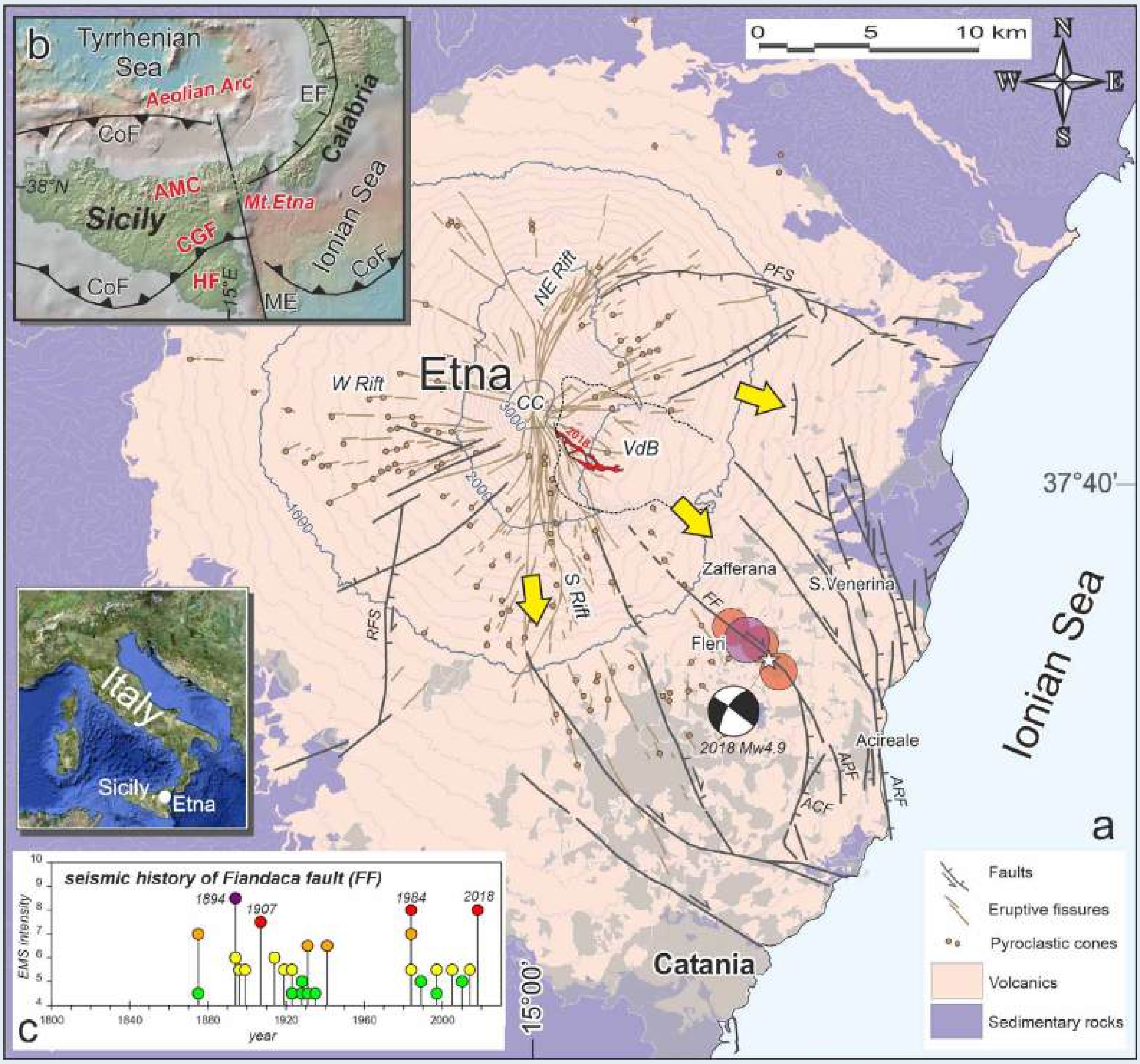

Figure 1. *a) Volcano-tectonic map of Mount Etna showing the spatial distribution of the main faults and eruptive fissures of the last 2 ka; b) highlighted are the 2018 lava flow, the M_W 4.9 earthquake of 26/12/2018 (white star), and the main historical earthquakes generated by the Fiandaca Fault (FF). Yellow arrows indicate the direction of movement of the volcano's unstable flanks (Barreca et al. [2013], and references therein). PFS = Pernicana Fault System; RFS = Ragalna Fault System; ARF = Acireale Fault S; ACF = Aci Catena Fault; APF = Aci Platani Fault; VdB = Valle del Bove. Urban areas are shown in gray. Regional tectonic context is shown in inset; AMC, Appennine-Maghrebian chain; CGF, Gela-Catania foredeep; HF, Hyblean foreland; ME, Malta Escarpment; CoF, compressional front; EF, extensional front; c) box (modified after Azzaro and D'Amico [2014]) highlights the seismic history of the Fiandaca Fault (FF).*

The volume of erupted material was relatively modest, totalling approximately three million cubic metres [Calvari et al., 2020]. The eruption was accompanied by a notable seismic swarm and ground deformation that occurred prior to, during, and following the eruption, and persisted for several weeks [De Novellis et al., 2019]. The continuous 24-hour monitoring system operated by the National Institute of Geophysics and Volcanology (available at https://www.ct.ingv.it/ accessed 18 November 2024) identified the occurrence of several thousand earthquakes within a few days. The seismic events had epicentres both along the eruptive fissure and on the flanks of the volcano. Fault systems such as Ragalna (SW flank, RFS) and Pernicana (Northeast flank, PFS), which represent the primary structural boundaries of the volcano's unstable blocks (see Figure 1), exhibited heightened activity [Neri et al., 2009; Barreca et al., 2013; Acocella et al., 2016]. The largest of these earthquakes (M_W 4.9) occurred at 03:19:14 local time on 26 December. This earthquake originated on the Fiandaca fault (FF in Figure 1). The epicenter was located about 1 km west of Pennisi (a suburb of the municipality of Acireale) and the hypocenter was near sea level. The focal mechanism of the earthquake indicated a transtensive type, which was further supported by the coseismic ruptures observed on the ground [Civico et al., 2019; Villani et al., 2020; Tringali et al., 2023]. As several authors have suggested [De Novellis et al., 2019; Bonforte et al., 2019], the seismic swarm that accompanied the eruption can be attributed to the lateral expansion of the magmatic dyke from the central conduit to the southeast. The intrusion of the dike also caused a pronounced deformation of Etna's eastern slope (Figure 2b), activating the Fiandaca fault and allowing magma to drain to depth. As a result, the upward movement of the dyke was hindered. In other words, the earthquake of 26 December may have prevented an eruption along the lower southern flank of the volcano [Bonforte et al., 2019]. Satellite interferometry has revealed significant horizontal displacements (up to tens of centimetres) between fault-separated blocks, accompanied by notable vertical movements in the vicinity of the eruptive fissures [Bonforte et al., 2019; De Novellis et al., 2019], (Figure 2b). Furthermore, the displaced fault planes exhibited notable surface faulting along a band measuring tens to a few hundred metres in width and over 10 km in length, primarily along the trace of the Fiandaca, Aci Platani and Aci Catena faults (FF, ACP and ACF, respectively, as illustrated in Figure 1). This resulted in significant damage to the urban fabric traversed by the faults, compelling numerous inhabitants to abandon their residences permanently.

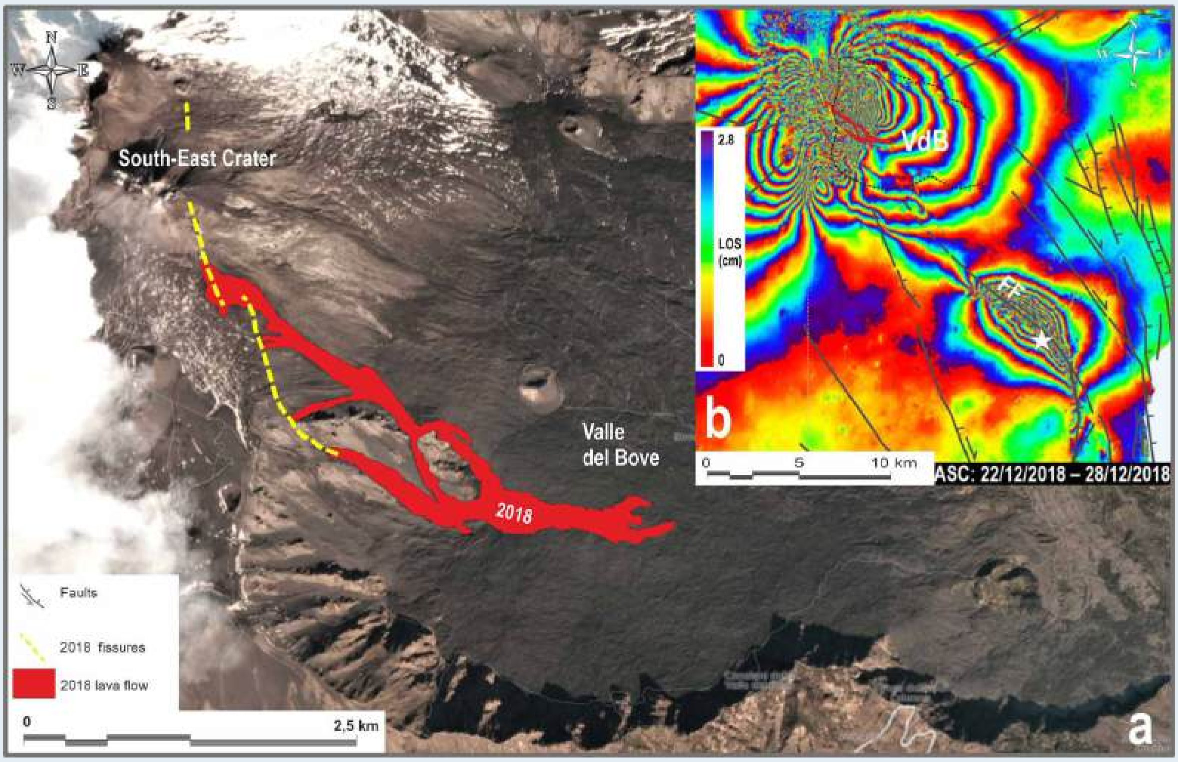

Figure 2. *a) Fissures and lava flows caused by the December 24-26, 2018 Etna eruption; b) box: line-of-sight (LOS) interferograms generated from Sentinel-1 image data pairs acquired on 22 and 28 December 2018, wrapped ascending (modified after De Novellis et al. [2019]). The white star represents the M_W 4.9 earthquake of 26 December. FF = Fiandaca Fault, VdB = Valle del Bove.*

3. Methods

In the aftermath of the earthquake, there was an urgent need to commence the reconstruction of the affected areas in a safe and expedient manner. In the absence of comprehensive seismic microzonation studies, scientific publications that were published shortly after the earthquake were subjected to analysis [Bonforte et al., 2019; De Novellis et al., 2019; Civico et al., 2019; EMERGEO WG, 2019a; b]. The results of the QUEST WG [2019], Pezzo et al. [2020], Villani et al. [2020], Calvari et al. [2020] and Aloisi et al. [2020] were integrated with those of further geostructural studies, which were conducted at a more detailed level. Specific focus was dedicated to urbanised areas traversed by faults, where the coseismic dislocations were distinctly discernible on the buildings and roads. This enabled the acquisition of accurate data on the kinematics of the faults and the extent of the tectonic disturbance bands. The processing of the maps of homogeneous microzones was conducted in accordance with the guidelines for the management of the territory in areas affected by active and capable faults (ACF) (Technical Commission for Seismic Microzoning, 2015). The fault mapping was conducted by a team comprising experts from the Extraordinary Commissioner's Office, Genio Civile (the Department of the Sicilian Region), the national agency Invitalia, and geologists from the National Institute of Geophysics and Volcanology, who conducted a comprehensive analysis of the 2018 earthquake. The work was primarily coordinated and executed by one of the authors (see Neri [2020]; Neri and Carbone [2020]; Neri et al. [2020]), who concurrently serves as Vice-Commissioner and Head of the Geological Area of the Government Commission Structure[1].The findings have been incorporated into maps published in PDF format (at a scale of 1:10,000) and WebGIS (see footnote 1). The WebGIS maps have been further enhanced with the incorporation of the coordinates of public and private buildings for which a contribution was solicited by the government. This allows for continuous monitoring of all phases of reconstruction. The maps identify homogeneous microzones of active and capable faults (ACF) and delineate areas affected by hydrogeological instability. The latter highlights areas prone to flooding, landslides and morphologically unstable areas; it is represented without changing any data by consulting the Hydrogeological Management Basin Plan (P.A.I. - Piano Assetto Idrogeologico), published by the Sicilian Region[2]. Once these preparatory studies were completed, it was possible to proceed with the drafting of the Government Commissioner's Regulations and the adoption of the reconstruction or relocation plans (Figure 3). All activities are currently publicised on the website in the footnote 1 and on social media pages[3].

From the earliest stages, all activities of the Government Commissioner structure were disseminated through frequent meetings with representatives of the affected municipalities and citizens. Numerous meetings were organised both remotely (through events held online during the COVID-19 pandemic) and in person. From 2020 onwards, 2 to 4 scientific dissemination conferences were organised every year, both in the main cities affected by the earthquake (Acireale and Zafferana Etnea) and in the most affected villages (Fleri, Pisano, Aci Platani, Aci Sant'Antonio). The main local club services (Kiwanis International, Lions, Rotary) and voluntary associations were also involved. At all these events, the principles of the reconstruction process, and in particular the relocation plan, were presented and

[1] https://commissariosismaareaetnea.it/ (accessed 18 November 2024).
[2] https://www.sitr.regione.sicilia.it/pai/ (accessed 18 November 2024).
[3] https://www.facebook.com/sisma2018; https://www.youtube.com/channel/UCRyS4cPd-u_ZA0tMJWj5Rkg (accessed 18 November 2024).

discussed in detail. A system designated the "Citizen's Desk" has been established via web[4] for the purpose of providing assistance to those affected by the earthquake and addressing their queries and concerns. Finally, a collaboration was established with Prof. Mara Benadusi (Department of Political and Social Sciences, University of Catania), through the project "Faglie di rischio: vulnerabilità, delocalizzazioni, spaesamenti e appaesamenti", which focused on local perceptions of seismic risk among individuals and social groups involved in the relocation of properties originally located on active and capable faults.

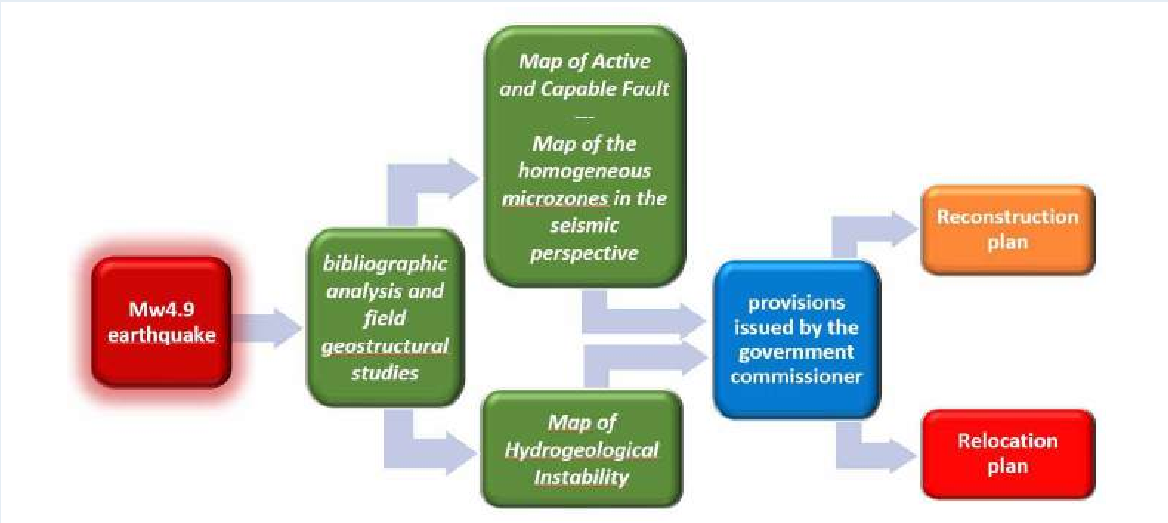

Figure 3. *Flowchart of actions taken by the Extraordinary Commissioner's team, from baseline to adoption of reconstruction and relocation plans. The figure depicts the sequence of actions undertaken by the Extraordinary Commissioner's team in the aftermath of the earthquake (dark red). The team initially conducted a comprehensive examination of the affected region, which resulted in the production of foundational thematic maps (green). Subsequently, the team was able to legislate on land use by issuing the application regulations (blue), followed by the generation of the Reconstruction Plan (orange) and the Relocation Plan (light red).*

4. Active and Capable Faults (ACF) activated during the 2018 earthquake and related hazard zones

An active fault is defined as a fault that has been known to move in the past and is expected to move again in the future. In accordance with the criteria established

[4] https://commissariosismaareaetnea.it/lo-sportello-telematico-del-cittadino/ (accessed 18 November 2024).

by the SM Working Group [2015], an active and capable fault (ACF) is defined as an active tectonic structure that has moved within the last 40,000 years and is capable of permanently rupturing the ground surface.

The 26 December 2018 earthquake caused coseismic rupture of the ground in a NW-SE to N-S band of an area ~10 km long and tens-to-hundreds of meters wide. The main tectonic structure activated is known as the Fiandaca fault (Figure 1); however, the surface faulting also extended to the southeast, through aseismic creep involving segments of the neighboring Aci Platani and Aci Catena faults, which were activated in the hours/days after the earthquake [Tringali et al., 2023]. The kinematics were predominantly right-lateral along the Fiandaca fault, with an extensional component added in the SE part of the fracture belt, corresponding to the Aci Platani and Aci Catena faults. Individual fractures exhibited right strike-slip, extension, grabens, vertical movements of decimeter height, and small compression zones. The latter were observed at the point where the Fiandaca fault changed direction from NW-SE to NNW-SSE. The Fiandaca fault has been responsible for a number of earthquakes of historic magnitude (CMTE Working Group [2008]; see box c in Figure 1). Furthermore, these earthquakes, including the 26 December 2018 earthquake, have demonstrated the Fiandaca fault's capacity to induce permanent deformation of the Earth's surface through the generation of extensive coseismic ground ruptures.

The reconstruction of earthquake-affected areas in the Etna region was preceded by the identification of homogeneous microzones from a seismic perspective, specifically in relation to the faults that were activated during the 2018 earthquake. The homogeneous microzone of an Active and Capable Fault (ACF) is defined as an area that encompasses the main fault plane and the associated ground fractures situated in its vicinity. In accordance with the guidelines set forth by the Technical Commission for Seismic Microzonation [2015], three distinct types of homogeneous microzones have been identified: the Zone of Attention (ZA_{ACF}), the Zone of Susceptibility (ZS_{ACF}), and the Zone of Respect (ZR_{ACF}) (Figure 4). The map developed by Neri et al. [2020] depicts both certain and uncertain fault segments. However, some issues pertaining to the reliable mapping of faults remain unresolved, particularly in the transition zones between adjacent fault segments. In order to address the inherent uncertainties, the government structure identified a series of specific geological, structural, geognostic, and geophysical studies that were deemed necessary to support requests for contributions for the reconstruction of buildings that had been destroyed by the 2018 earthquake. The objective of these studies was to ascertain the absence of active and potentially active faults located beneath the foundation structures of the buildings or in their immediate vicinity.

Seismic zoning has been developed in two major phases of the study. The first step was to define the Zone of Attention (ZA_{ACF}) around the faults [Neri, 2020]. The ZA_{ACF} contains the trace of the main fracture surface and the surface deformation phenomena associated with the main fault plane. The ZA_{ACF} was delimited to a minimum distance of 200 metres from each fault. Upon completion of the initial study phase, which spanned a period of less than two months, reconstruction was authorised in areas situated outside the ZA_{ACF}. The second phase of the study aimed to enhance the geostructural understanding of the territory, with the objective of delineating the Susceptibility Zone (ZS_{ACF}) and the Respect Zone (ZR_{ACF}) in the vicinity of the identified fault traces (see Figures 4 and 5). This approach facilitated the orientation of the reconstruction process, thereby avoiding the most seismically hazardous areas [Neri and Carbone 2020; Neri et al., 2020].

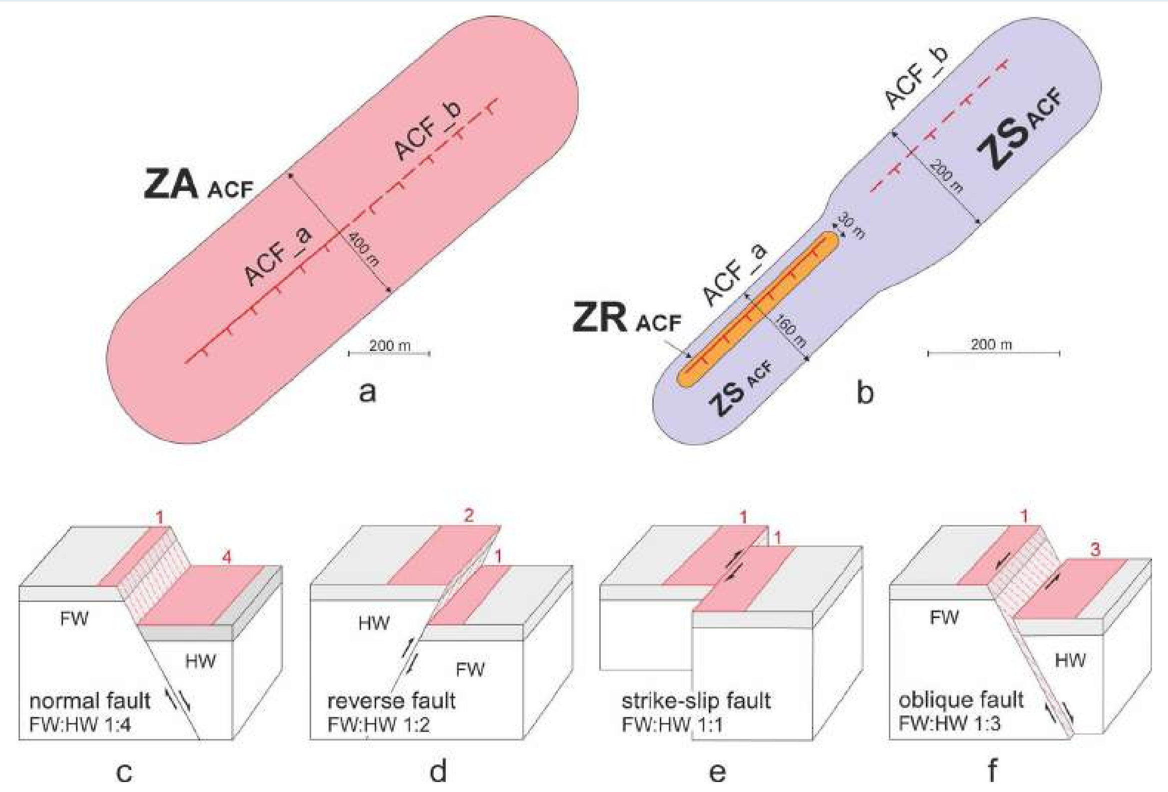

Figure 4. *a) Scheme to identify the Zone of Attention (ZA_{FAC}). b) Susceptibility (ZS_{FAC}) and Respect (ZR_{FAC}) around a defined (ACF_a) or hypothesized (ACF_b) active and capable fault. c-f) An extension of homogeneous microzones in seismic prospecting is based on the footwall/hanging-wall (FW/HW) ratio. In the case of strike-slip faults, the hanging wall and footwall were not detected.*

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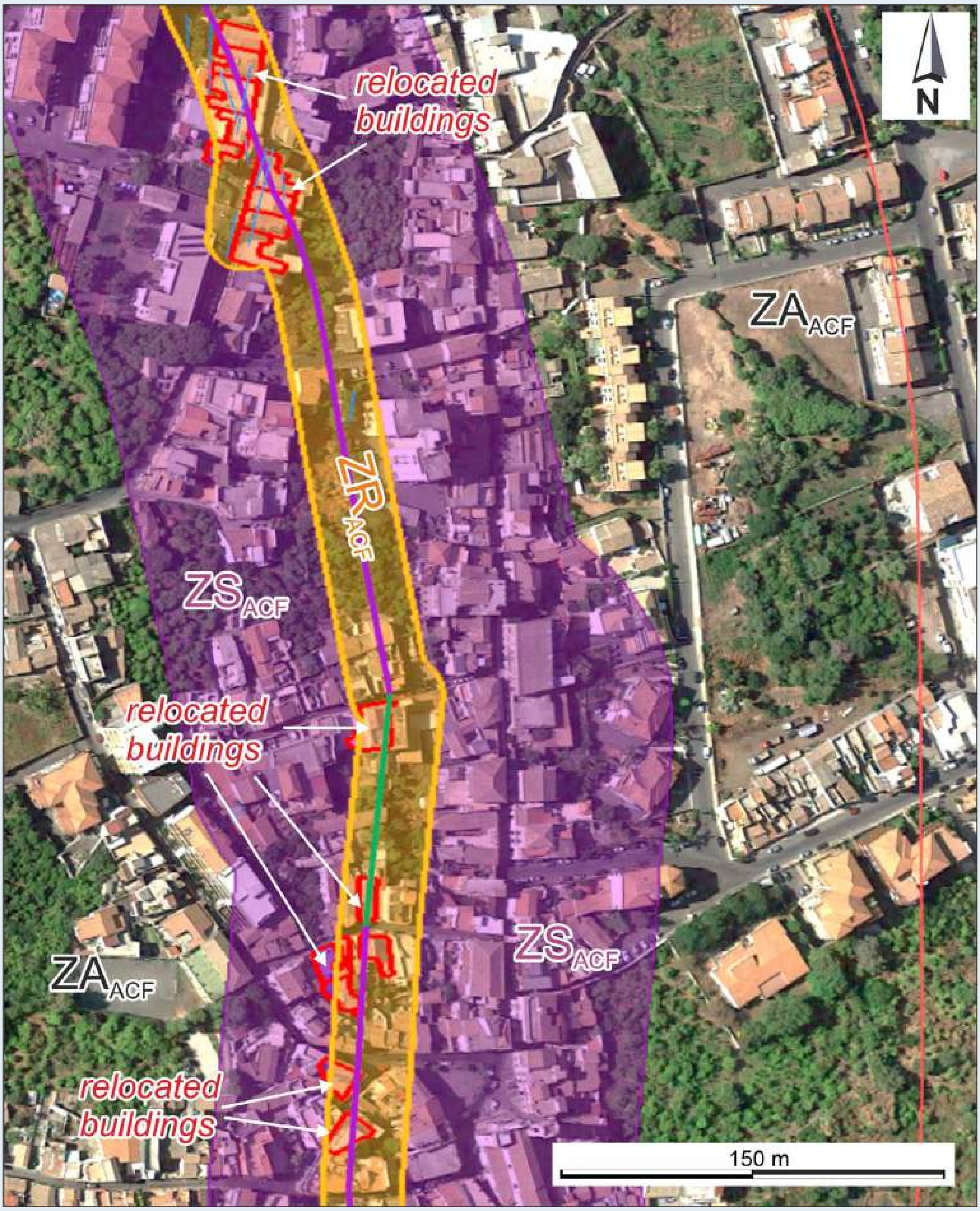

Figure 5. *Extract from the maps of homogeneous microzones and relocated buildings (in red) in the area of Aci Platani. ZR_{ACF} = Zone of Respect; ZS_{ACF} = Zone of Susceptibility; ZA_{ACF} = Zone of Attention. Green and purple lines = normal and transtensive faults, respectively.*

The ZS_{ACF} is the area where both the main fault plane and secondary fractures are located, as well as the transition areas between different fault segments. The ZS_{ACF} was identified for both certain (ACF_a) and uncertain (ACF_b) faults (Figure 4a-b), assuming a minimum width of 160 m across the main fault plane. The ZS_{ACF} was defined asymmetrically with respect to the fault plane, covering the hanging wall (HW) and footwall (FW) blocks according to the kinematics (see scheme in Figure 4c-f).

A Zone of Respect (ZR_{ACF}) with a minimum width of 30 m was established around certain defined active and capable faults (ACF_a) (Figure 5). As with previous cases, the ZR_{ACF} may be asymmetrical with respect to the fault trace, depending on its kinematics. If a footprint of an edifice is even partially situated within the buffer zone, it has been deemed as a potential candidate for relocation. Conversely, the land surrounding the building's footprint does not fall within the ZR_{FAC}. The full details of the relocation policy applied in the 2018 earthquake reconstruction process are set out in Ordinanza n. 18 [2020].

5. The principles of geoethics informed the reconstruction and relocation plans

Once the map of homogeneous microzones was created, the commissioner's regulations for rebuilding were prepared. These were described as follows.

In the areas not directly affected by the surface fault, i.e. outside the zone of attention, private citizens and public institutions were immediately able to present projects accompanied by geological studies that enhanced their understanding of the terrain in the specific project area. These studies were conducted in accordance with the technical standards currently in force in Italy [NTC, 2018].

A more profound comprehension of the geological substrate was imperative within the Zone of Attention (ZA_{ACF}) to preclude the potential presence of faults within the footprint of the building or in its proximate vicinity (up to 30 metres). In instances where the geological investigations unveiled the existence of conspicuous faults and fractures within the geological substrate of the building, the repair or reconstruction of the building was not permitted. Instead, the feasibility of relocating the building in accordance with the specified methods was considered. It is evident that these edifices are particularly vulnerable to substantial structural damage or even collapse in the event of a future seismic event. As demonstrated in the map created by Neri et al. [2020], the edifices most susceptible to this specific risk are located within the Zone of Respect (ZR_{ACF}), which spans approximately 0.3 km^2 and encompasses five of the nine municipalities affected by the 2018 earthquake: Trecastagni, Zafferana Etnea, Acireale, Aci Sant'Antonio, and Aci Catena. The edifices situated within the Zone of Respect (ZR_{ACF}) are positioned in a distinct geological environment. They are subject to not only the seismic tremors generated by the displacement of the fault plane but also to the fracturing (faulting) of the ground beneath their foundations (see example in Figure 6).

Figure 6. *The building has been displaced by the action of the ACF. The damage is selective in nature, with the reinforced concrete columns failing at the junctions with the first floor (red arrows) in the section of the building constructed above the fault (black dotted lines, bottom). As one moves away from the fault line to the left, the columns exhibit less damage (yellow arrow) or no damage at all (white arrow).*

If seismic vibrations are effectively absorbed by sufficiently robust and/or elastic structures, the faulting of the ground will result in a permanent displacement of the substrate, which may subsequently lead to significant structural damage to the building. This may manifest as a loss of verticality, rotational displacement, or, in the most severe cases, complete collapse. These conditions were considered in the reconstruction design, which involved the relocation of citizens from the most hazardous zones. This strategy was implemented to ensure public safety and to prevent the expenditure of funds on the reconstruction of buildings that are likely to sustain further damage or collapse within a few years. In light of the aforementioned considerations, a relocation plan has been devised for all edifices rendered inoperable by the seismic event and situated within the Zone of Respect (ZR_{ACF}). This plan also applies to those edifices where comprehensive geological investigations have revealed the existence of an active and capable fault beneath the building and in its adjacent vicinity (less than 30 metres) (see Figure 7).

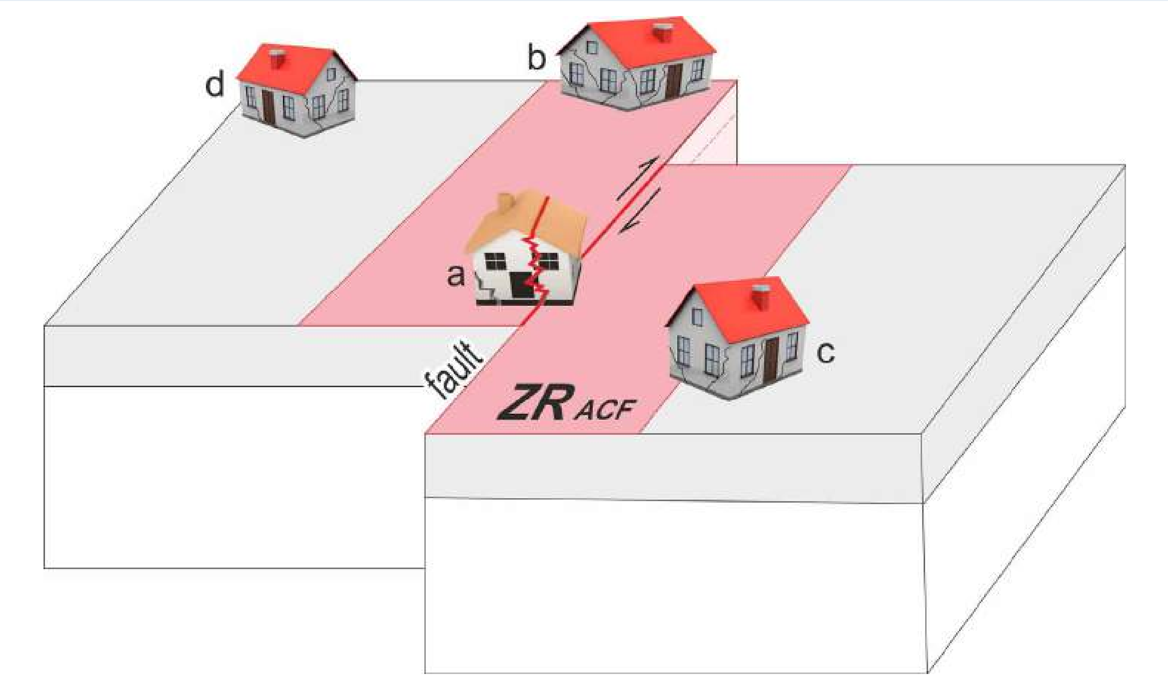

Figure 7. *a, b, c) It is not permissible to repair buildings situated within the Zone of Respect (ZR_{ACF}). Instead, they must be relocated to a safer location. With regard to buildings located in the vicinity of the Zone of Respect d), it is possible to proceed with repairs, provided that projects are accompanied by comprehensive geological studies demonstrating the absence of faults within a distance of at least 30 metres from the building.*

It is crucial to underscore that the relocation process is characterised as "voluntary", meaning that citizens with property located within the designated buffer zone have the option either to take advantage of the provisions of the Relocation Plan, supported by financial contributions from the Italian government, or to remain in their current location. In the second case, no financial contribution will be provided. In cases where there is uncertainty regarding the location of a fault within a 30-metre radius of the building, the professional geologist commissioned by the owner carries out comprehensive investigations, financed by the Commissioner, to ascertain or exclude the location of a fault. If these investigations confirm the presence of a fault, the citizen, through their appointed technician, submits a proposal for relocating their house, which is then reviewed by a Technical Table. This Table is coordinated by the Geology Area of the Commissioner's Structure and is composed of numerous bodies, including Genio Civile, Superintendence of Cultural and Environmental Heritage, Municipality, Etna Park, and others. The Technical Table then decides whether to admit or reject the request.

The Government Commissioner's plan indicates that 58 buildings are to be relocated, a small fraction of the approximately 3,000 buildings estimated to have been damaged by the earthquake. Furthermore, the relocation plan allowed us to estimate the economic needs (approximately 33 million euros) associated with their relocation to safer areas.

Once the economic feasibility of the intervention had been verified, Commissioner's Ordinance n.18, dated 21 December 2020, was enacted, which regulates the relocation process (see Figure 8 for an illustrative example). The ordinance provided that owners of properties that had sustained damage and were situated within the designated buffer zone (ZR_{ACF}) would be granted an economic contribution equivalent to the total area of the property to be relocated. Following the demolition of the aforementioned building, the owners were offered the option of either purchasing an existing property or purchasing land and constructing a new building in an area deemed to be seismically safer. In either case, the existing property and the new building were required to be situated within the boundaries of one of the nine municipalities that had been affected by the 2018 earthquake. This was done to prevent the unjustified depopulation of the area, which would have been a consequence of the new construction. The relocation of buildings originally located within urbanised areas forces entire households to "emigrate". This is perceived by the community as a loss of economic and social value, which must therefore be limited. In any case, this aspect represents a critical issue for the population, which has been forcibly displaced from the territory in which it may have lived for generations. Indeed, in the case of numerically small communities, as exemplified by the villages of Fleri and Aci Platani, which have been particularly affected by the delocalisation process, the loss of tens of family units can therefore represent a significant social challenge.

It is also noteworthy that the redevelopment of the area has involved the restoration of areas that were previously cleared of rubble following the removal of buildings.

These areas, which were acquired by the local authorities, are now being used for a variety of purposes, including the creation of parks and green spaces, playgrounds, squares, and parking lots. The objective of this initiative is to enhance the urban fabric and restore its historical memory, thereby facilitating a transition to a more sustainable urban environment.

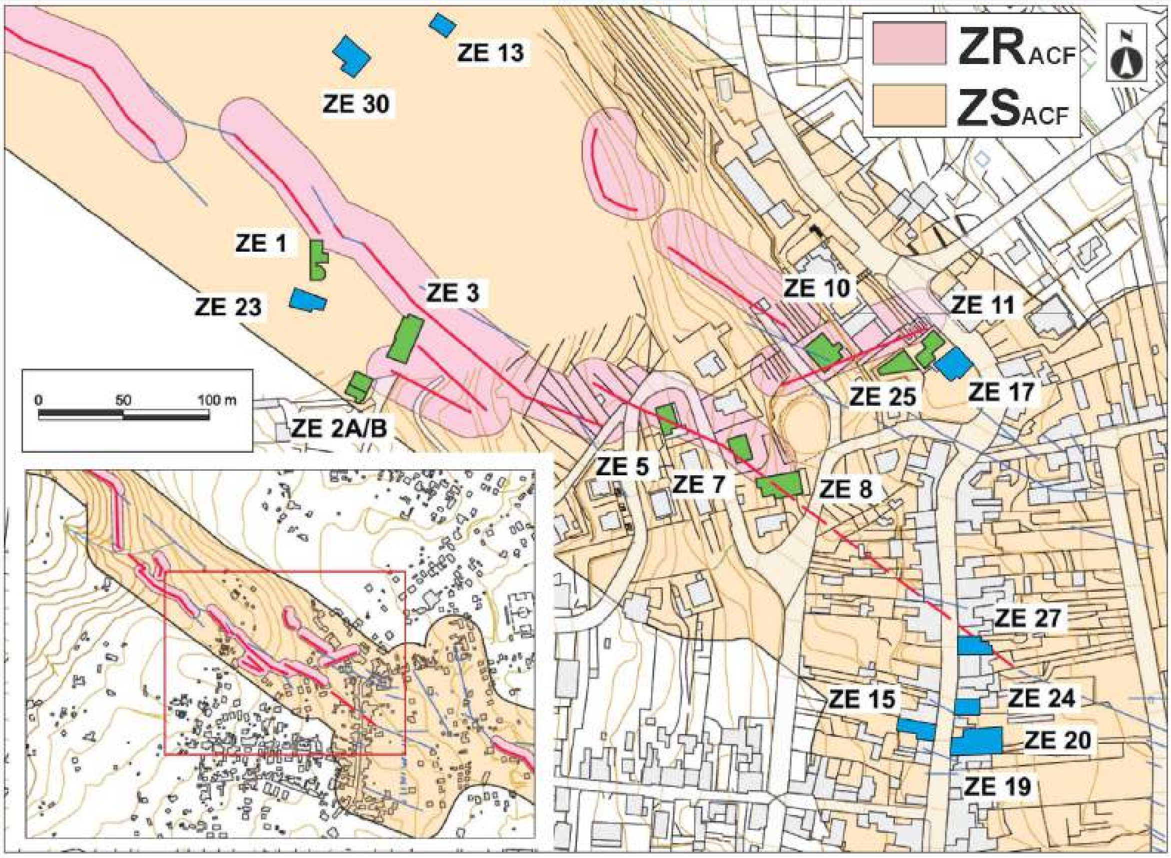

Figure 8. *The map illustrates a portion of the proposed relocation plan, delineating the buildings designated for relocation (ZE) (green) and those situated above a potential fault line (blue). For the latter, more comprehensive geological investigations are necessary to substantiate the necessity of the relocation.* ZR_{ACF}*=Zone of Respect;* ZS_{ACF}*=Zone of Susceptibility.*

6. Discussion

6.1. Planning for earthquake recovery using geoethical principles

The reconstruction of areas affected by a catastrophic earthquake is a process aimed at enabling the citizens to return to their homes in a timely manner and in accordance with technically acceptable safety standards. It is unethical to allow unjustified delays in the reconstruction process, given the severe psychological and social distress suffered by earthquake victims who have been uprooted from their homes and forced to live away from them for years. It is important to note that the average timeframe for post-earthquake reconstruction in Italy exceeds ten years, with some cases taking significantly longer. Furthermore, it is in the interest of the State to limit the expenditure of public funds intended for independent housing contributions while waiting for citizens to be able to return to their homes. The Italian State provides financial support known as the "contributo di autonoma sistemazione" (autonomous accommodation contribution), which is calculated based on the number of members in each household forced to evacuate during reconstruction. In the case of the 2018 Etna earthquake, this contribution ranged from approximately 700 to 1,800 Euros/month per family. As a result, longer reconstruction periods require greater financial resources for this contribution, increasing the burden on the State.
Furthermore, a recently emerging necessity must be acknowledged, namely that of not using public funds for the reconstruction of buildings situated in regions characterized by elevated seismic and geological risks. In particular, the term "high seismic and geological risk" is here used to describe areas where surface faulting results in the permanent displacement of soil, leading to irreparable damage to any artefact. This is a crucial aspect that has been largely overlooked in the past, yet it is now imperative to integrate it into the reconstruction process. The aforementioned considerations have been instrumental in guiding the reconstruction process currently underway in the region devastated by a 4.9-magnitude earthquake on the night of 26 December 2018 (Ordinanza n.18 [2020]). The earthquake caused significant damage across nine municipalities on the southeastern flank of Etna, exposing a pronounced band of superficial fractures spanning at least ten kilometres and traversing several urban centres. It is also noteworthy that analogous principles for the protection of citizens' health were adopted by other Extraordinary Commissioners in central Italy (2016 earthquake) and in Ischia (2017 earthquake). In the former case, the Ordinanza n.119 [2021] governed interventions in areas affected by active and capable faults and other hydrogeomorphological instability. In Ischia, the Ordinanza n.24 [2023] concerned the relocation of buildings involved in a large landslide movement. These regulatory acts illustrate a heightened awareness of the importance of land use. In

contrast to previous practices, which involved rebuilding structures in identical configurations to those that existed prior to the disaster, modern reconstruction procedures require a preliminary assessment of the geological and geo-structural risks associated with the site. This assessment determines the eligibility or otherwise of the reconstruction of areas considered to be at high risk.

At the time of the earthquake, the affected area had not undergone in-depth seismic microzonation studies. In order to facilitate the safe and expedient return of citizens to their homes, the government commission responsible for reconstruction established a technical table comprising representatives from various public authorities, including the Genio Civile (Department of the Sicilian Region), the national agency Invitalia, and the National Institute of Geophysics and Volcanology. This was the first occasion on which a number of state institutions had collaborated with one another in order to obtain, free of charge and in a relatively short period of time (4-8 months), a geostructural knowledge framework of the territory, which would prove useful for post-disaster reconstruction. This has resulted in a comprehensive scientific and technical investigation of the faults that were activated during the earthquake, and the delineation of the most seismically vulnerable areas in their vicinity. The availability of these maps enabled the commencement of reconstruction in a very short time. The first reconstruction commissioner's ordinance was issued a mere five months after the Extraordinary Commissioner's team assumed office, on 25 May 2020 (Ordinanza n.7 [2020]). Subsequently, the regions requiring reconstruction were identified, and in-depth geological and geophysical studies were conducted for each project. The intensity of these studies was tailored to the specific morpho-structural criticalities of each site.

A specific category of cases pertains to persons who are compelled to relocate their residences as a consequence of the impact of the earthquake. In accordance with the provisions set forth in the Zone of Respect (ZR_{ACF}) regulations, citizens whose residences are situated within the designated area, which encompasses regions most vulnerable to the destructive potential of surface faults in the future, may opt to voluntarily relocate their buildings. In such instances, citizens will be provided with an economic contribution corresponding to the value of their property. This is with the objective of enabling them to purchase an equivalent property in a location that is safer from a geological and seismic perspective, or to rebuild their home in an area that is less susceptible to such risks. This approach is designed to guarantee the safety of citizens and to ensure the durability of the houses constructed with public contributions.

Nevertheless, not all citizens who were involved in the relocation of their homes reacted favourably, at least initially. Some of them, for various reasons were opposed to the relocation of their homes. Consequently, a technical and dialectical dialogue was initiated with the population, during which the geologists of the government structure explained the logic, practicality and safety reasons for the process of relocation.

6.2. What was the response of the population to the proposed relocation plan?

The initial objective was to ascertain the rationale behind the decision of some individuals to construct buildings in locations that are potentially or evidently hazardous. Such locations include areas in proximity to seismic faults or regions susceptible to lava flows. It became evident that, on occasion, this decision may be predicated on a lack of comprehensive information, which may result in an incomplete understanding of the subject matter. It is possible that some people are unaware of the intrinsic complexities of the Italian geological landscape, particularly in the Sicilian and Etna regions. Alternatively, despite awareness of the inherent risks, people may choose to establish their residences in areas deemed high-risk.
In order to explain this behaviour, a number of hypotheses can be formulated. Earthquakes and eruptions are frequently abrupt and sporadic occurrences. Consequently, the associated threat is not readily apparent, yet it is a concrete and pervasive danger that is not readily discernible. In the context of such events as well as other types of crises, individuals may exhibit a range of responses, two of which are particularly prevalent. These are a) minimising the perceived severity of the situation and b) denying its existence. In the first case, the individual, unable to cope with the emotional impact of the information, attempts to reduce its significance in order to align it with their psychological, emotional, and cognitive capabilities. Those involved in the construction of the house can reassure themselves with the statement: "We will construct a house that can withstand an earthquake. There is no cause for concern if such an event occurs." In the second case, the individual refutes the existence of the problem, effectively erasing it from their consciousness and failing to consider it. This can occur for the same reasons as in the previous example, indicating that personal resources are even more limited than in the first example. The person might think, "What about a small earthquake?"
It is possible that some individuals may not adhere to scientific principles and instead adhere to alternative beliefs or experiences that do not reflect actual potential outcomes [Risen, 2016]. One illustrative example is the conviction that an individual's past experience of being spared from an earthquake will inevitably be replicated in the future. These coping behaviours have been extensively documented in human beings and can be applied, to varying degrees of

consciousness, in situations of distress [Folkman and Lazarus, 1988; Lingiardi and Madeddu, 2002]. Furthermore, it is crucial to consider an alternative response to the issue, namely the fear reaction, which has the potential to reach exceedingly high levels. This represents a reversal of the prevailing view. It is not uncommon for individuals to have a tendency to envisage the most adverse scenarios following the disclosure of a potential or probable threat. This can result in an unjustified magnification of their concerns, rather than a realistic assessment of the situation. The psychological distress experienced by these individuals as a result of their contemplation of a potential disaster can have a significant impact on their daily lives. For instance, despite having taken the necessary precautions, individuals may still experience apprehension and exhibit elevated anxiety regarding seismic events, even if they reside in a structurally sound building situated at a considerable distance from seismic faults or have relocated their residence to a more secure location. It is important to note that the behaviours in question do not necessarily indicate the presence of pathology. Rather, they represent defensive strategies that people utilise in order to cope with situations that are perceived as uncomfortable or that force them to leave their comfort zone, that is to say, their safe place, which is represented by the house and/or neighbourhood in which they live [Van Der Kolk, 2015]. In particular, the concept of a safe place is represented by the home and/or neighbourhood in which the individual resides.

It is clear that the psychological impact of relocation can be significant and adverse, particularly for those who are emotionally vulnerable and/or have a history of emotional distress. Furthermore, the subjective meanings attributed to one's home are also implicated in such dynamics. For example, consider the following example and attempt to envisage implications: one might consider an individual who has invested a significant amount of effort into the construction of their own residence. This individual has demonstrated unwavering commitment to the project, made considerable personal sacrifices, and dedicated years, if not decades, to the endeavour. Then, in an unexpected turn of events, an earthquake causes irreparable damage to the structure, effectively erasing the value of their years of labour in a matter of seconds. It is reasonable to conclude that someone in this situation would experience a profound sense of loss and sadness.

Such individuals may experience a sense of disorientation, lacking a clear point of reference, and confrontation with the stark reality of the destruction of a place they previously perceived as secure and welcoming. It is commonly assumed that the most fundamental human needs are the provision of a roof over one's head and a hot meal. The loss of fundamental security for the lives of all of us is a significant consequence of such events. It should be noted that reactions may vary subjectively, based on an individual's life experience, cognitive abilities, and cultural resources [Van Der Kolk, 2015]. Nevertheless, such experiences can be classified as "biographical shock," a term used to describe a moment in an individual's history that tests their resilience, including from a psychological perspective.

For all these reasons, relocating one's home can be a challenging decision to make. It is possible that people may employ strategies comparable to those previously outlined, even going so far as to disavow the evidence and insist that their home be rebuilt on the same site or in close proximity to the destroyed home, thereby placing it in a highly vulnerable location. Conversely, people who display excessive fear may request frequent and repeated inspections of the new structure, which has been constructed in a safer location. Alternatively, they may experience prolonged periods of insomnia due to their apprehension about the potential for future traumatic experiences associated with the catastrophic event [Van Der Kolk, 2015]. One might be inclined to conclude that these individuals are not mentally healthy. However, a more accurate assessment would be that they are merely experiencing difficulty in accepting the situation and coping with it to the best of their abilities with the resources available [Van Der Kolk, 2015]. The question of whether this strategy is useful or scientifically sound is, of course, a separate matter for consideration.

Another noteworthy finding from our research is the prevalence of difficulties in seeking assistance. In such instances, individuals tend to resort to self-medication, which can be defined as the pursuit of readily accessible and socially accepted instruments within their immediate environment to cope with challenging circumstances. These instruments, which may include drugs, alcohol, or other substances, are often perceived as a means of managing distress. Whereas self-medication may be a useful strategy in extreme cases for a limited period of time, it cannot become a structural part of the healthy management of each individual difficulty.

It is evident that mere knowledge is insufficient, at least according to our perspective. This phenomenon can be attributed to the fact that individuals are capable of engaging in self-deception and even the distortion of reality when such actions serve to protect them from emotions and thoughts that they find unbearable. This analysis highlights the importance of considering comprehensive psychological assistance as a crucial element of support for populations affected by natural disasters. In providing psychological assistance, it is essential to diversify the approach in accordance with the specific characteristics of the disaster in question, the anticipated time frame for recovery, and the planned interventions. It is of the utmost importance to emphasise the necessity of providing psychological assistance without delay following a disaster event. Furthermore, a comprehensive and long-term intervention plan must be devised, which is tailored to the specific type of disaster and affected population. In this regard, we posit that integrating the expertise of a psychologist into the intervention care plans would be highly beneficial. It is therefore evident that the scope of support should extend beyond mere economic assistance. Instead, it should aim to help people overcome the difficulties they face in the immediate aftermath of the tragedy, as well as the discouragement caused by the loss, which is sometimes irreparable, of basic reference points for their existence. The ongoing dialogue between government commissioners and the affected population, particularly those involved in relocation, represents a significant initial step in comprehending the multifaceted nature of the support required, extending beyond mere economic assistance.

7. Conclusions

The reconstruction of the Etna area affected by the 26 December 2018 earthquake has demonstrated that a successful strategy necessitates collaboration between various state agencies, all of which are dedicated to the shared objective of ensuring expeditious and technically sound reconstruction of the earthquake-stricken regions. It is always advantageous to have a productive collaboration between the various stakeholders involved in the reconstruction process. These include the government commission, civil protection agencies, regional technical offices with engineering, architectural and environmental expertise, nature parks technicians, local municipalities and authorities, research institutions and universities, technical designers, and citizens. The establishment of memoranda of understanding between public entities has facilitated the streamlining of bureaucratic procedures and the acceleration of authorisation processes.

With regard to the territory in question, it became evident that a comprehensive understanding of the geology of the region was of crucial importance for the effective implementation of post-earthquake reconstruction strategies. The Guidelines for the Study of Active and Capable Faults have become a fundamental reference point for the planning and secure execution of reconstruction projects. Indeed, in regions where volcanic activity is ongoing, such as Etna, it is of the utmost importance that reconstruction planners possess a comprehensive understanding of seismogenic and volcano-tectonic processes. It is not a realistic proposition to rebuild in all areas affected by a disaster. In the aftermath of an earthquake, for instance, it is essential to identify locations with high geological and seismic risks, prompting the relocation of structures situated in these areas and reducing the urban density in the most severely affected regions. It is, however, of the utmost importance that local residents are made aware of the geologic context in which they live and the measures that can be taken to mitigate the negative effects of potential natural disasters. In order to facilitate the acceptance of planning choices, it is imperative that government authorities responsible for the reconstruction of disaster-stricken areas communicate empathetically with the affected populations, elucidating the rationale behind their reconstruction planning choices.

It is clear that the reconstruction of damaged houses and infrastructure is a pivotal phase following a catastrophic earthquake. However, it is not the only aspect that necessitates attention. The promotion of social recovery is also essential to prevent the depopulation of severely affected regions. Furthermore, it is vital to provide assistance to the affected population, taking into account the significant psychological challenges they are facing. This study highlights the critical need for timely psychological assistance as an essential part of support for individuals and communities affected by natural disasters. We contend that integrating psychological expertise into intervention plans would be highly beneficial. It is therefore evident that the scope of support should extend beyond mere economic assistance. Instead, the objective should be to assist individuals in overcoming the challenges they encounter in the immediate aftermath of the tragedy, as well as the discouragement caused by the irreparable loss of fundamental reference points for their existence. The ongoing dialogue between the team of government commissioner and the affected population, particularly those involved in relocation, represents a significant initial step in understanding the multifaceted nature of the support required, which extends beyond mere economic assistance. It is also noteworthy that the methodology developed in the Etna region for the treatment of buildings exposed to significant geological and seismic risks has subsequently been adopted and applied, with specific modifications to account for the different regulations and geological characteristics of the area, to the reconstruction of other regions affected by earthquakes in central Italy (2016-2017 earthquakes). This represents a contemporary, logical, and morally defensible approach to the reconstruction of urban areas affected by extensive surface faulting phenomena in Italy and worldwide.

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