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Sustainable management of demolition waste in post-quake recovery processes: The Italian experience

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ABSTRACT

Disasters may have a severe impact on the environment and can generate huge amounts of building waste. The post-disaster recovery and reconstruction phases should be performed with special care, in particular when dealing with damaged cultural heritage. This study presents the positive experience of building waste management in the town of Venzone, Friuli-Venezia Giulia (north-eastern Italy) after an earthquake of M_w 6.46, in which historical buildings were almost completely damaged. Forty years after the event, it is possible to state that the recycling program - the first case of sustainable disaster management planning in Italy - was successfully conducted, and the cultural heritage of the town was fully recovered in its pre-event configuration. Considering the alternative forms of disposal, significant environmental impact was avoided, mainly related to land use and non-renewable resources exploitation. From this experience, some suggestions about how to conduct a sustainable disaster debris management policy can be obtained, particularly when dealing with cultural heritage.

1. Introduction

Construction and demolition waste (C & DW) is one of the most voluminous waste streams produced in Europe, accounting for about 25–30% in mass of all waste produced in Europe [30]. Its management is one of the most important challenges of modern society: indeed, the European Union has set a minimum target for recycling non-hazardous C & DW at 70% by 2020 [22]. Currently, in many States of the Union (e.g. Denmark, Estonia, Netherlands), it is already feasible to recycle up to 80–90% of the total amount of C & DW [20,32,45]. However, in some other countries (e.g. Czech Republic, Latvia, Poland) this limit is far from the official statistics on recycling, and C & DW is still largely disposed in inert landfills [20,25]. Abundant literature is available on C & DW recycling for producing recycled aggregates in many civil engineering works, including structural [21,24] and non-structural applications [1,37]. In normal conditions, the quantification of C & DW volume can be carried out using predictive models, able to define the waste volume in both new constructions and demolition projects [42], also taking into account the expected service life of aging masonry and reinforced concrete structures [13]. In this circumstance, the composition of the waste involves both masonry and concrete elements, as well as metals, wood, plastics, plasterboard, glass, etc., depending on the original structural types. When a devastating event occurs, huge amounts of construction waste can be generated in a very short time, thus requiring special management policies. As an indication, one single event may be responsible for about 5–15 times the annual amount of waste generation [41], with peak values that may be much higher. For instance, Hurricane Katrina in Louisiana produced about 40 million m^3 of debris. Together with Hurricane Rita, those two events severely damaged or destroyed over 275,000 homes, which correspond to more than the total number of residential units demolished in an entire year across the United States. Another relevant example relates to the Tohoku tsunami, triggered by the M_w 9.0 2011 Great East Japan earthquake, which hit the Pacific Coast of Japan's Oshika Peninsula. This event was responsible for 23 million tonnes of disaster waste found on land, in addition to the amount washed into the ocean. In the city of Ishinomaki, this tsunami produced approximately about 6.15 million tonnes of debris, equivalent to more than 100 years of solid waste production in that city in normal circumstances [44]. Those great volumes of waste deriving from disasters require dedicated management policies, as their potential impact may substantially affect the sustainability of an entire region. Additionally, the composition of the waste depends highly on the structural type affected by the disaster, and by the event itself: waste generated by hurricanes are usually quite mixed, whereas waste produced by an earthquake in a historic center is principally made up of stone or brick masonry.

Financial issues can also influence the selection of the disaster waste management strategy: for instance, when dealing with damaged modern buildings without significant architectural features, the demolition and reconstruction of new structures seems the optimal solution.

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On the contrary, for masonry buildings located in historic centers (i.e. most small Italian towns) of high cultural heritage value, an alternative strategy based on full recovery of the initial built environment can be implemented.

Hence, in this context, the aim of achieving a sustainable solid waste management system has substantial importance, considering at the same time economic optimization, environmental gains and social acceptability. Four main criteria can be applied for assessing the sustainability of waste management systems [15]:

- environmental desirability, referring to the effects on public health and the environment;
- economic optimization, regarding the cost-effectiveness and economic soundness of the management strategy;
- social acceptability and equity, relating to how receptive and supportive the local community is of the waste management plan, also taking into account potential indirect losses due to the strategy adopted;
- administrative diligence, which concerns the administrative capacity to adequately ensure that the policies can be carried out continuously in the long term.

Disasters can be typically classified as natural or man-made and technological (Fig. 1): both can have severe social, economic and environmental impacts, often resulting in permanent changes to human societies and ecosystems. Natural disasters usually include earthquakes, tornadoes, volcanoes, tsunamis, etc., whereas man-made and technological ones are due to the actions of human beings. When dealing with disaster management, it is possible to identify the following three main phases: the pre-disaster phase, the event itself, and the post-disaster phase (Fig. 2). All the activities aimed at preparing the society for a disaster are carried out in the pre-disaster phase, including risk mitigation. The warning phase immediately anticipates the event, which can in some cases be predicted by monitoring specific indicators. After a disaster strikes, disaster management activities constitute the post-disaster phase, which can be subdivided into short-term actions (e.g. rescue operations and lifeline restoration) and long-term programs (e.g. building rehabilitation and reconstruction). In particular, the emergency phase has priority of importance, as it represents the immediate response to the threats due to an event, e.g. debris management for facilitating rescue actions, meeting humanitarian needs and providing services (food, shelter, clothing, public health, safety), cleanup, damage assessment, and the start of resource distribution.

In this context, proper disaster waste management plays a key role, as it affects many emergency activities: Kobayashi [31] reported that after the M_w 6.9 1995 Great Hanshin-Awaji earthquake in Japan, many lifelines were interrupted, and this prevented survivors from being reached inside several buildings. Some recent studies have proposed methodologies for assessing potential critical damage to urban road networks in historic centers in the event of an earthquake [2,46].

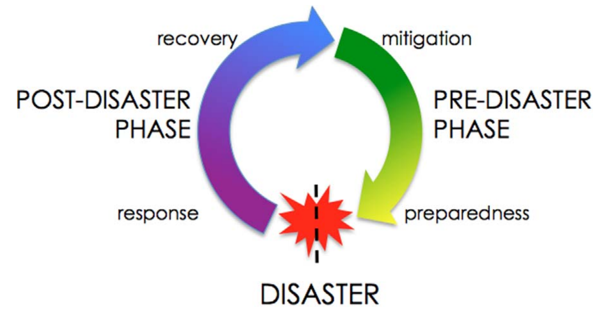

Fig. 2. Disaster management cycle (adapted from Cutter [17]).

Furthermore, the presence of waste constitutes a potential public health risk [10], not only in the short-term, but also in the long-term [43]. Long-term consequences of poor disaster waste management may also affect the recovery (restoring lifelines and building demolition) and rebuilding processes. Disaster waste management operations impact the environment, economy and society, and they should be minimized through proper planning and benchmarking. Efficiency of disaster waste management programs should hence be evaluated after an adequate time window, able to examine not only the immediate response to the event, but also potential long-term impacts.

In this paper, the experience of disaster waste management after the M_w 6.46 1976 Friuli earthquake in the town of Venzone is reported. After 40 years, it is possible to identify the success of the first debris waste recycling plan in Italy. Full recovery of the town was achieved, and almost all of its historical buildings were rebuilt using the *anastylosis* reconstruction technique, employing a large amount of the original materials. Debris was also used in river engineering applications, leading to almost total recycling of the construction waste. The recycling operations helped avoid a significant environmental impact, especially when compared with the alternative of landfill disposal of the materials, as occurred following other Italian earthquakes. Finally, due to the preservation of its architectural-cultural heritage, Venzone is currently visited by about 130,000 tourists a year [36], thus giving a significant boost to the local economy.

2. The 1976 Friuli earthquake

2.1. The event

On May 6, 1976 a M_w 6.46 earthquake struck an area of about 5700 km^2 in central Friuli (north-eastern Italy), causing 989 deaths, leaving more than 100,000 people homeless, with 43,000 buildings declared unusable (more than 70,000 inspected) and damage totaling around 4.5 billion Italian lire (at the 1976 value; corresponding to about 20 billion € in 2016 terms), across 137 municipalities affected [12].

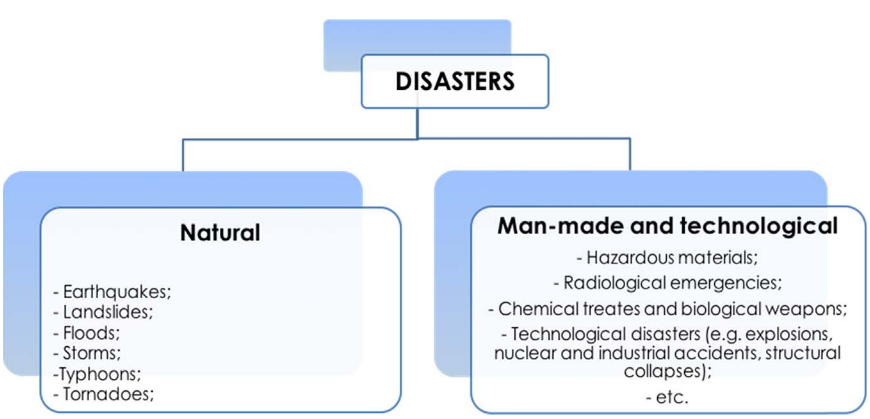

Fig. 1. Classification of disasters' typologies.