XLI CONFERENZA ITALIANA DI SCIENZE REGIONALI

SEISMIC RISK MANAGEMENT IN HISTORIC CENTRES. INTEGRATED LARGE-SCALE MODELLING FOR A SCENARIO-BASED METHODOLOGY

Francesca Giuliani[1]

ABSTRACT

Italian historic centres have been facing a process of decline and deterioration whose impact has been irreversibly accelerated by a great number of hazardous events. Among others, earthquakes have affected many settlements highlighting the necessity to improve their seismic risk management strategy and planning methods. In these highly vulnerable areas, prevention is paramount to preserve the authenticity of cultural heritage and to limit the loss of social, economic, and physical values. Conversely, today Italian planning policies in historic centres are limited to listing conservation interventions allowed for buildings, while little attention is devoted to safety from an urban perspective.

This contribution explores the theoretical, methodological and practical issues of developing seismic risk analyses and management plans in historic centres. It moves from a discussion on the current Italian strategy for risk reduction and the achievements in the fields of civil protection and urban planning, with a focus on the differences between the national, regional, and local levels. The review of current land use and emergency planning regulations underlines the fragmentation of knowledge, competencies and responsibilities within institutions. In fact, civil protection plans are not spatial plans and are often non-harmonised one another, although they should be concurrent and coordinated. Then, the contribution focuses on the building-street interface combining the vulnerability assessment of buildings' façades with the prediction of human flows during the emergency. The novelty is in the adoption of an interdisciplinary approach that links the data collection and analysis to the decision-making process. This task is achieved by applying a set of instruments for the development of a fit-for-purpose platform. Particularly, Geographic Information Systems (GIS) and Space Syntax analysis are employed to inform and support the development of mitigation strategies. The main advantages of GIS mapping lay in the database adaptability and extensibility for a variety of uses and data detail. Nonetheless, the need for a standard practice for risk management in historic centres led to the definition of an optimal result-oriented organisation. As a result, this approach develops large-scale data-driven intervention priorities and site-specific measures aimed at mitigating the impact of future earthquakes as well as assisting early recovery and reconstruction activities.

[1] Department of Energy, Systems, Territory and Construction Engineering, University of Pisa, Largo Lucio Lazzarino 1, Pisa, Italy, e-mail: francesca.giuliani@ing.unipi.it

1. Introduction

Italy is characterised by a seismically active territory and a great number of earthquakes have caused considerable casualties and damage to the built environment. The highest seismicity is concentrated in the south-central part of the peninsula, along the Apennines, from Tuscany to Calabria, as well as in Sicily and in some northern areas, such as Friuli, Veneto, and the western part of Liguria. These areas have been urbanised in ancient times and today host a number of borgoes and historic settlements with unique assets that contribute to their integrity and heritage values. Among the most recent events, the L'Aquila (2009), Emilia Romagna (2012) and Central Italy (from 2016) earthquakes have damaged or even destroyed many historic centres, affecting their cultural, economic and social values. Moreover, the high vulnerability of the local infrastructure and the presence of a vulnerable buildings stock resulted in a great number of casualties and homeless. These hazardous events produced large-scale impacts and losses of tangible and intangible assets whose recovery is still challenging.

In the last decade, several researchers and international agencies acknowledged the importance of cultural heritage in building resilience to disasters thanks to its ability to foster the post-event response and recovery of communities (Jigyasu, 2016; UNISDR, 2013). Besides, risk reduction is encouraged by UNESCO (2007) within the "Strategy for Reducing Risk at World Heritage Properties" that, among other actions, calls for building a culture of disaster prevention and promotes risk assessment activities for cultural sites. Moreover, the UN's Sendai Framework for Disaster Risk Reduction 2015-2030 promotes the identification of strategies for risk assessment and disaster management in cultural properties (UNISDR, 2015). Since 2016, the World Bank promoted a program on resilient cultural heritage (Stanton-Geddes and Soz, 2017) through the Global Facility for Disaster Risk and Recovery (GFDRR). In this framework, several initiatives have been launched to improve the Disaster Risk Management (DRM) in cultural properties, especially in low-mid income countries (Minguez Garcia, 2019). The European Commission (2018) is contributing to the development of good practices to integrate cultural heritage into national disaster and risk reduction strategies developed by EU Member States. The EU report officially recognizes that cultural heritage is a strategic resource because it embeds cultural, environmental, social and economic values of great significance for societies.

The evaluation of risk in built-up areas is the potential occurrence of negative impacts due to an event with a certain intensity on a fixed site (UNISDR, 2009). It depends on three main measures: the hazard of the site (e.g. earthquakes); the vulnerability of people, buildings, and infrastructure that make them susceptible to the damaging; and exposure that refers to people, property, systems, or other elements into hazard zones that can be lost (UNISDR, 2009). As highlighted by past events, Italian historic centres present high seismic risk due to the presence of a broad range of specific vulnerable conditions and exposed elements associated to the characteristics of the built environment and the current living conditions. Vulnerability is affected by the great and diffuse presence of historic buildings and by the morphological evolution of the urban structure resulting from centuries-old processes of transformation (Giuffrè, 1999). The higher liability to damaging is related to a series of practices processed over generations, such as unmanaged stratifications, change of use in buildings and aggregates, lack of maintenance, mixed construction types with a misuse of modern constructive materials on vernacular architecture. Italian historic centres are characterized by a great presence of unreinforced masonry buildings, each one having a specific structural evolution that hinders the confident survey of the extent and quality of components and materials. From an urban perspective, further vulnerabilities depend on the presence of narrow, winding streets and the lack of open spaces. Moreover, historic settlements present an elderly resident population and a high concentration of tourists (ANCSA, 2017) that can be exposed to risk. The lack of preparedness and risk awareness affects the coping capacity of communities and poses challenges for DRM and Disaster Risk Reduction (DRR) in historic centres.

The awareness of the vulnerabilities and the exposure to seismic hazards in Italy fostered the research of methodologies for the risk assessment and management in such complex systems. The methodologies are mostly sector-centred, pertaining to single disciplines (seismic engineering, risk analysis, urban planning, heritage studies) and specific scales (national, territorial, urban, single building). Only a limited number of studies have focused on historic centres and they mainly concern the vulnerability of historical building in

the domain of civil engineering. The fragmentation of competencies and knowledge affects the SRM in historic centres and hinders the implementation of large-scale risk reduction policies (Haigh and Amaratunga, 2010), thus posing great challenges in these fragile areas. As a consequence of such deficiencies, anytime an earthquake occurs, historic centres are subject to a sort of 'architectural Darwinism' in which only a few safer buildings survive the ground motion, with significant loss of human life, resources and heritage values, both tangible and intangible.

This paper presents part of the results of the PhD research conducted by the author (Giuliani, 2020) at the Department of Energy, Systems, Territory and Construction Engineering, University of Pisa, under the supervision of prof. Anna De Falco and prof. Valerio Cutini. The project aimed at developing and validating of an interdisciplinary methodology to reduce and manage seismic risk in Italian historic centres. The main challenge was the creation of a link between disciplines without neglecting the achievements and drawbacks of the single disciplinary approaches. This paper examines historic centres in Italy expanding upon the regulatory framework and guidelines regarding their preservation and management within the disciplines of heritage studies and urban planning. Then, it focuses on the existing proposals to assess and manage seismic risk, discussing the main achievements and possibilities for improvement. Starting from this framework, the paper proposes a scenario-based methodology to SRM that combines functional, structural and configurational analyses into the planning phase. Preserving the compatibility with existing proposals, the formulation aims to overcome the current sector-based fragmented vision on SRM. To achieve this goal, the model integrates different approaches and establishes a direct correlation between preventive planning and emergency management in Italian historic centres. The development of a fit-for-purpose Geographic Information System (GIS)-based platform offers an automatized management of large-scale data from multiple sources.

2. Italian historic centres: the preservation-safety nexus

2.1 A history of preservation

The inherited and traditional attitude towards the preservation of cultural assets in Italy led to the presence of a large number of lively historic centres throughout the territory. Their urban fabric, architecture, community structure and boundaries progressively evolved over the centuries, and the present-day complex morphology is the natural result of a processes of aggregation, space saturation and adaptation to the territory. In the past, the preservation of historical settlements or districts has stimulated a long-standing debate in heritage studies and urban planning. Starting from the Athens Chart (1933) and the first Code of Cultural Heritage and Landscape (1936), the preservation of historical assets has become central for Italy leading to the adoption of specific regulations and charters that promote the conservation of monuments into historic centres, rejecting any invasive intervention (e.g. the Gubbio Charter, 1960). A large body of literature has examined the development of the notion of historic centres in Italy, identifying several phases in the planning history of the last fifty years (Cervellati and Scannavini, 1973; Cialdini and Falini, 1978). By and large, the concept of conservation evolved from monument restorations in the 1960s to the concept of cultural landscape and cities as living heritage in the 21st century (fig. 1).

The earliest approach to the issue has been defined as "urban conservation" (Nasser, 2003), pinpointing the passage from an object-centred science of conservation to a wider perspective dealing with districts and urban contexts. Between the Seventies and the Eighties, historic centres have also been considered as places needing for regeneration because the historical building stock could provide affordable dwellings to compensate the growing housing demand in urban areas. The rediscovery of the existing building stock fostered the research on conservation policies and reuse strategies with a consequent emphasis on the role of urban cultural heritage, which was originally defined as the set of tangible assets that preserved the original morphological and structural configuration and appearance (Cialdini and Falini, 1978, p.119). The boundaries of the historical city were set with the introduction of homogeneous zones 'A' (*zona omogenea A*) into the General Urban Development Plan (GUDP) (*Piano Regolatore Generale*), according to the Law 765/1967 (the so-called Legge Ponte). The physical and institutional designation of these areas brought to

the introduction of a strict binding legislation on buildings within the boundaries. Since 1972, the Restoration Charter addressed the discussion towards the urban nature of the historic centres by specifically referring to the set of buildings, open public spaces (e.g. streets, squares), private spaces (e.g. gardens, courtyards), and natural territorial assets (water resources, geomorphological features).

In the early Nineties, the previous boundary-centred notion of historic centre was revised because of the weak criteria for setting their limits and of the tendency to preserve only the assets within that conventional boundary (Gabrielli and Cervellati, 1993). The same boundary-centred tendency to work on target areas can be found in Gasparrini (1994) who analyses cities by means of two dichotomous categories: the ‘historic’ is opposed to the ‘non-historic’, and ‘preservation’ is seen as the contrary of ‘development’. In the last decades, the debate around this dual perspective in historic centres has become increasingly important: on the one hand, there is the necessity to foster the development of a living area, giving access to amenities and basic public services; on the other, there is the necessity to preserve the traditional uses and architectural features as expressions of local identity. Overtime, these two visions gained alternatively more attention, never to reach a shared and integrated orientation. However, the Code of the Cultural Heritage and Landscape (known also as Codice Urbani) (Legislative Decree 42/2004) recognised the historic centres are “*complex urban structures and settlements*” and not merely a sum or composition of single heritage buildings. Hence, the boundaries set within the GUDP could be revised and updated considering this wider vision. Besides, the legal designation of landscape heritage ensures a large-scale protection of the values, which is different from the architectural heritage designation applied to monuments and buildings. The interventions in the area under landscape protection are generally subject to authorisation by the local Office for Heritage Protection (*Soprintendenza,* in Italian), except for some listed cases that regrettably change according to politics. The more recent Law 98/2013 (“decreto del fare”), Law 164/2014 (“sblocca Italia”) and DPR 31/2017 modified the type of interventions that are allowed within the zone. In particular, the changes affected the categories of “ordinary maintenance” and “extraordinary maintenance” on buildings that are not under the status of architectural heritage, allowing for fewer restrictions on private initiatives.

Today, the main challenges for local governments concern the possibility of balancing these different aspects: development, safety, and preservation of identity and functions. Paradoxically, the long periods during which disastrous earthquakes in Italy does not occur make settlements even weaker because of the tendency to underestimate or even remove the possibility of a new disaster (Petrei, 2015). This tendency results in insufficient prevention activities and emergency preparedness throughout the country which is worsened by the great distance between National authorities and Local Governments on the topic. The lack of specific resources for seismic risk reduction in historic centres and the poor planning against disasters is a source of institutional vulnerability. Therefore, it is necessary to extend the current discussion in heritage conservation to risk assessment and management, including other disciplines into the problem.

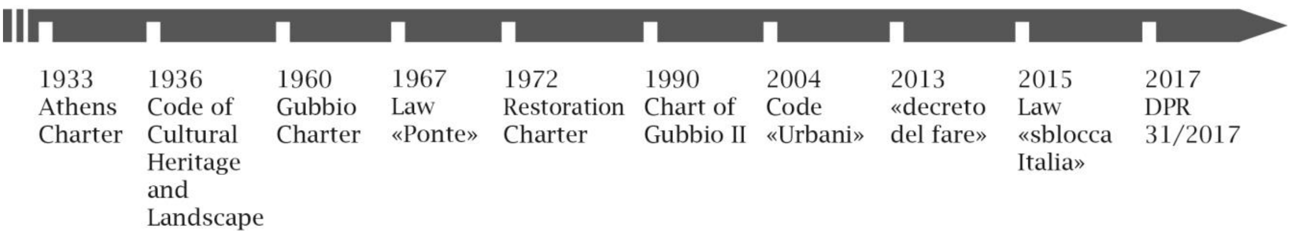

Figure 1 - The main legal steps and achievements regarding historic centres in Italy.

2.2 A framework for seismic risk management

Whilst the effects of earthquakes have received considerable attention from sector-based perspectives (particularly seismic engineering, risk analysis, urban planning), relatively little research has involved and integrated all disciplines into a comprehensive framework. So far efforts aimed at improving knowledge on seismic hazard on the whole national territory (Crowley et al., 2009) even by means of microzonation studies

(Bramerini et al., 2015) and studying seismic vulnerabilities of historical masonry buildings (Calvi et al., 2006; RELUIS, 2010; Dolce 2012). Besides, the emergency management has been strengthened by introducing the notion of Limit Condition for Emergency (LCE) (CTMS, 2016), which ensures the operability of urban streets and strategic functions during and after an earthquake. Additionally, funds have been provided for the retrofitting of strategic and critical buildings, while private owners can access to financial incentives to intervene on their properties for seismic strengthening (Cosenza, 2018). All these actions have been promoted by the Italian Department of Civil Protection (DCP) at national level and are not specifically targeted on historic centres.

In the context of urban and territorial planning, there is a peculiar asymmetry in the contents of Italian urban plans with reference to different hazards (Fabietti, 2013). Territorial planning and regulations devote particular attention to hydrogeological risks (Di Giovanni, 2016), as evidenced by River Basin Management plans (*Piani di Bacino and Piani Stralcio,* in Italian) and Landscape Plans (*Piani Paesistici*, *Piani dei Parchi*, in Italian). On the contrary, seismic risk is considered only within the knowledge framework of the territory, and there is no planning tool addressing urban development toward the reduction of the consequences of earthquakes. The asymmetry is motivated by the tendency to leave the topic to seismic engineering, hence traditionally referring to buildings and neglecting the complex response of the whole urban system to earthquakes. As a direct consequence, interventions have always been targeted on the structural units rather than large-scale systems. Overtime, only a few proposals on seismic risk included the multiple sources of vulnerability into urban studies (Fera, 1991; Menoni et al., 2012). Fera (1991) considers physical vulnerability of spatial systems, which depends on the liability to damage of the single units (e.g. buildings, streets), functional vulnerability, which is the partial or complete disruption of a set of functions within the urban system independently from the damage to constructions, and socio-economic vulnerability, intended as the capacity of the inhabitants to deal with an emergency in social, psychological and financial terms. Although this model is interesting, it has not escaped criticism due to the difficulties in gathering reliable data on every component of urban vulnerability (De Paoli, 2012; Cremonini, 1994). Menoni et al (2012) identify a set of specific parameters that describe the vulnerability of the subsystems which are part of regional systems, as well as social and economic vulnerabilities. The main advantage of the method lies in its ability to qualitatively assess several aspects of vulnerabilities at the urban scale, but it may become too simplistic when dealing with the historical urban fabric. In fact, historical buildings present diverse types, configurations, materials, and level of maintenance, which affect the vulnerability of structural and non-structural elements and require to be investigated by means of calibrated models (Calvi, 2006).

Further investigations on the topic led to the two proposals: the ‘Struttura Urbana Minima’ (SUM), or Strategic Urban Structure (Fabietti, 1999, 2001; Pizzo and Fabietti, 2014), and the ‘Vulnerabilità dei Sistemi Urbani’ (VSU), or Vulnerability of the Urban System (Cremonini, 1994; Olivieri, 2004a). The SUM is both an analytical and normative tool whose aim is not the vulnerability assessment but the identification of strategic elements for the emergency and recovery of the urban system. Although it is a flexible tool that allows for being integrated with Civil Protection Plan, its main weakness lies in neglecting the physical vulnerability of existing buildings that instead is extremely important in historic centres. The VSU is a further approach developed in cooperation with the Emilia-Romagna Region and aims at the definition of urban preventive plans based on priority interventions (Cremonini, 1994; Olivieri, 2004). The methodology is based on standard forms that allow for collecting statistical and qualitative data regarding the urban environment. The VSU methodology draws attention to historical settlements, stressing the correlation between morphology, construction techniques and typologies in existing masonry buildings. However, it does not consider the spatial location of functions and services for civil protection.

As a matter of fact, a wide-ranging interdisciplinary approach to SRM in Italian historic centres is still missing and the sector-centred strategy tends to be largely ineffective for the implementation of large-scale mitigation policies. The latter are paramount in heritage-centred risk-related problems because prevention is the only strategy that can guarantee the preservation of cultural assets, while mitigating the impact of hazardous events. On the contrary, approaches to the study of Italian cultural heritage and particularly historic centres have mainly focused on their conservation with little consideration for their safeguard from

disasters. According to Italian regulations, conservation is ensured to monuments, landscapes and collections, in application of the Code of Cultural Heritage and Landscape (Legislative Decree 42/2004). Historical buildings or monuments are listed as architectural heritage (*vincolo architettonico*, in Italian), while historic centres and natural landscapes are under large-scale protection thanks to the notion of landscape heritage (*vincolo paesaggistico,* in Italian). While the object of conservation was extended to larger environmental contexts, in the same decades, authority over the management of historic centres has fallen under the residual power of Regions (ANCSA, 2017), with the consequent limit in the role of National Government. This fragmentation of competencies regarding historic centres rewards virtuous Regions and penalises those that lack of competencies, particularly since the procedures for SRM are not unitary. To conclude, the current response system to earthquakes presents several strengths, as well as shortcomings and possibilities for improving by means of multidisciplinary approaches able to offer a richer toolbox to those working on historic centres and SRM.

3. Datasets and methods

The methodology builds on existing knowledge in the single disciplines and is the result of a preliminary critical selection of the most suitable analysis in each disciplinary field. The selection is oriented by the scope of the research, considering the drawbacks of a large-scale problem and accounting for both the limited knowledge and the a priori difficulty of ranking the various components of the systems. The underlying idea is that the overall seismic performance of historic centres depends on the response of historical buildings in aggregates, as well as on the characteristics of the road network. During and soon after an earthquake, the most important aspects are the autonomous evacuation of people along safe routes, the prompt operability of strategic functions and the access of emergency services. So that the emergency response is more effective if a number of routes are safe and free from debris or fallen obstacles. In order to avoid the blockage of roads, the facing buildings or their façades are requested to be safe. These emergency routes should be preventively identified considering accessibility and damage scenarios. In this study, accessibility scenarios are based on the location of strategic functions and on the results of the configurational analysis of the historical settlements. Instead, damage scenarios depend on the urban vulnerability assessment conducted through empirical methods.

3.1 Data collection and elaboration

Preliminary to the analytical investigations, the historic centres are subject to extensive research regarding the location of emergency facilities and areas (functional aspects), the characteristics of buildings and aggregates, such as material, time of construction, basic plan geometry, number of stories, transformations undergone during their lifetime (structural aspects), and finally the features of open spaces and roads (configurational aspects). The data regarding the historic centres can be retrieved from the Regional Technical Map (*Carta Tecnica Regionale*, in Italian), the Structural Plan of the Municipality, and the Emergency Plan. The latter specifically contains information on the emergency management system. Furthermore, several institutional databases provide secondary statistical data on the built environment (e.g. height of the buildings, age of construction), demographic distribution (residents, activities) and cultural heritage. Official repositories are provided by the National Institute of Statistic (ISTAT) and the most recent open-source data date back to 2011. Then, on-site surveys are conducted in order to verify the consistency of secondary data and maps and to gather further information regarding land uses and buildings. Other than the investigations on structural elements, the surveys allow for mapping the non-structural deficiencies that can potentially cause road obstruction. These are infilled panels, chimneys, cantilevers, cornices, and other heavy elements on façades, that are dangerous in case of fall. In fact, the majority of losses in an earthquake are associated to the damage or collapse of non-structural components (P-58-5, 2018; Cremen and Baker, 2019). Table 1 summarizes the datasets and their use in this work, with specific reference to the Tuscany Regional databases where the case study is located. Several data are retrieved from open source databases and are therefore available for planners and disaster managers to conduct a data-driven strategic decision-making.

Table 1 - Datasets of the research with reference to Tuscany.

Data	*Data type*	*Data sources*	*Source type*	*Actions and scopes*
Land uses	Vector	Regional databases: Geoscopio[2] Municipal Structural Plan	Open	Map land uses and urban functions; identify empty areas
Population	Raster	Regional databases: Geoscopio National repositories: ISTAT	Open	Map human exposure
Cultural heritage	Vector	National database: Vincoli in rete[3] Regional database: Geoscopio	Open	Map cultural values and exposure
Land uses for emergency	Raster	Territorial and Municipal Emergency Plan	Open	Map strategic functions and emergency areas
Age of constructions	Vector	Regional database: Geoscopio National repositories: ISTAT	Open	Characterisation of physical vulnerabilities
Height of buildings	Raster	Regional database: Geoscopio National repositories: ISTAT	Open	Characterisation of physical vulnerabilities
Typologies	-	On-site survey Historical data	Direct	Characterisation of physical vulnerabilities
Features of the building	-	On-site survey Historical data	Direct	Map physical vulnerabilities
Street network	Vector	CTR On-site survey	Open, direct	Edit maps Space Syntax analysis

Data are collected and elaborated by means of a GIS-based platform. The advantage of GIS is in the possibility to connect data to spatial georeferenced digital entities by associating a set of project-related attribute tables. Other than collecting data on the built environment for a critical overview, GIS tools can also support the analytical phase. In fact, the results of the analyses and their output data can be directly accessed and combined by processing queries and operations between columns and layers. Moreover, the creation of a single platform enables a multidimensional study of the historic centres in which functional, structural and configurational issues regarding buildings and streets are considered as different layers of information. In this research, the analysis is conducted by mapping and discussing all outputs by means of the free and open-source software QGIS 3.6.1.

3.2 Accessibility scenarios

Accessibility scenarios are identified by combining functional and configurational analyses with the objective to support the emergency response into the historic centre. With respect to the LCE, the investigation proposes to map the strategic and critical facilities, the emergency areas and their interconnecting routes (CTMS, 2016). Strategic facilities are those hosting operation, coordination and healthcare centres, namely town halls, municipal offices, hospitals. Additionally, critical facilities (e.g. schools, libraries, gym) are also identified because they are potentially crowded or can host vulnerable groups of people. It is important to underline that emergency facilities have often been relocated and are usually in safer areas, commonly outside the historic centre. Nevertheless, several emergency functions are still hosted in heritage buildings within the historical districts. The relief system accounts for different types of emergency areas (Galanti, 1997; Legislative Decree, 2018): (i) safe meeting points, namely free areas or safe buildings (e.g. schools, gyms, halls) to host the population in the earliest post-event phases; or (ii) recovery areas for first-aid to population and shelters; and (iii) service areas where rescue teams and material resources can be located during the emergency operations. A preventive location of such spaces could improve the intervention and increase the preparedness of services and citizens (Galanti, 1997). Due to the informal pattern of development previously described, open spaces are generally rare in historic centres, therefore we rely on existing emergency areas next to the settlement and the internal public areas that respect a simple geometric criterion. In particular, we can consider squares that are larger than the height of the

[2] http://www.regione.toscana.it/-/geoscopio
[3] http://vincoliinretegeo.beniculturali.it/vir/vir/vir.html

facing buildings, to be on safety side. This simplified geometrical approach derives from the first applications of the LCE (CTMS, 2016) that assumes a building-street interference is caused by an out-of-plane collapse of the façade whose debris width (w_d) is equal to the height of the building (h_b). The procedure considers that the blockage occurs if the debris width is equal to the road width (w_r), namely $w_d = h_b = w_r$.

Another key aspect in the accessibility scenario is the evacuation of people and the efficient route-finding decision-making, which can be modelled by applying space syntax analysis. It consists in a robust set of techniques concerned with the topological description and investigation of spatial layouts or configurations (Hillier and Hanson, 1984). According to the theory, the urban grid has a primary role in urban dynamics and the topology of the network influences the distribution of 'natural movement' (Hillier et al., 1993). In recent years, space syntax research emphasised the correlation between the spatial properties and the concept of resilience, paving the way towards disaster risk management (Cutini, 2013; Koch and Miranda Carranza, 2013; Maureira and Karimi, 2017; Cutini et al., 2019; Giuliani et al., 2020). The studies conduct disaster simulations relying on Graph Theory and Network Analysis to derive useful measures, such as the 'Degree Centrality', 'Closeness Centrality' and 'Betweenness Centrality'. In space syntax analysis equivalent metrics are known as 'Connectivity', 'Integration' and 'Choice' indices. Connectivity is the number of directly connected elements and highlights the local hubs in the system. Integration represents the level of accessibility of a road and higher values identify to a condition of centrality, corresponding to spaces that are on an average closer to all the others. For this reason, roads with higher integration are usually those where people tend to direct intentionally or not, when moving into the city, highlighting the places with a higher rate of social and economic activities. Choice reproduces the potentials of a spatial element to be on the shortest paths connecting all the others and is associated to the concentration of flows during the movement. The segments with highest choice and integration values identify the so-called cores that represent the two form of centralities.

The spatial indices can be interpreted according to the aim of this work. In fact, high connectivity values are associated to local hubs or hotspots whose blockage can potentially alter the pattern of movement in the historic centre, thus affecting the emergency management. Instead, the segments with highest integration values are adopted to assess the accessibility of emergency areas and relief resources and to address mitigation by including socio-economic factors (i.e. location of retail activities and density of social encounters). Finally, the segments with highest choice values provide the critical routes, namely the ones that could host great flows and lead to a dangerous scenario for the evacuation if alternative routes are missing. These three configurational-based situations require the implementation of proper strategies aimed at reducing the closure probability along central spaces, avoiding the isolation of streets or districts.

In this study, the three indices derive from the Angular Segment Analysis (ASA) that converts open spaces and streets into intersecting segments, thus obtaining a network that completely describes the urban layout. With respect to the other types of configurational analyses, ASA presents an improved capacity to evaluate the pattern of movement because spatial indices account for angular variations among the segments (Turner, 2001a; Hillier and Iida, 2005). This aspect is particularly relevant in the analysis of historic centres that are characterized by narrow and winding streets with a wide variation in the segments' cumulative angle. The analysis has been implemented into the software Depthmap that produces the segment maps and calculates the spatial indices (Turner 2001b). Finally, the integration and choice indices are normalised between 0 and 1 in order to enable cross scale comparisons between different systems - or graphs with different sizes. A normalisation procedure has been introduced by Hillier et al. (2012) so that the NAIN (Normalised Angular Integration) and the NACH (Normalised Angular Choice) are used to illustrate the results of the ASA.

3.3 Damage scenarios

The estimation of damage in historic centres during a seismic event is a challenging task because of the large number of buildings - most of them are URM structures - and the lack of information, especially if structural alterations have not been recorded and documented. The vulnerability of the historical building

stock can be evaluated with different methods having different levels or investigation, knowledge and accuracy. Among the several methodologies for a large-scale vulnerability assessment (first level approach), this study applies empirical approaches that are based on expert judgements that account for a limited - but uniform - knowledge level of the built environment. Useful information derives from previous post-earthquake damage assessments (Dolce and Di Bucci, 2017; Bracchi et al., 2012; RELUIS, 2010; Giuliani et al., 2019). Common damage induced by earthquakes to masonry buildings concern façade walls and the internal parts of the buildings. Façades usually show cracks in load bearing vertical walls and lintels, associated to in-plane response. In the interior, the major damage is in the thin brick vaults and it increases in the upper levels, where walls are commonly thinner and vertical loads are lower. The occurrence of out-of-plane failure modes can be related to the presence of thrusting roofs, pounding beams, poor connections to wall edges, combinations of large wall slenderness or unrestrained wall lengths, and structural irregularity (Andreini et al., 2014). A large part of masonry buildings exhibits the collapse of chimneys, pinnacles, decorations, and sliding of the roof tiles (Carocci, 2012). Past events highlighted that the seismic vulnerability depends also on the poor state of conservation and maintenance of constructions, as well as on the presence and effectiveness of seismic reinforcements (i.e. ties, buttresses in masonry buildings) (Dolce and Di Bucci, 2017). These considerations provide an interesting catalogue of typical damage patterns that can inform the vulnerability assessment and definition of damage scenarios.

In this study, the vulnerability has been evaluated with simplified expert-based methods that entail a uniform knowledge of the historic centre. The assessment is guided by the scope of the research, in fact the potential interfering elements along the roadsides have been identified in order to improve the emergency response. In particular, the non-structural that can cause obstructions are infilled panels, chimneys, cantilevers, cornices, and other heavy elements on façades, dangerous in case of fall. Besides, the urban scale of the problem requires the adoption of a wider perspective so that other vulnerable elements can be towers and vertical elements (i.e. water tanks), retaining walls, small bridges and underpasses (De Paoli 2012).

4. The historic centre of Lucignano as case study

The historic centre of Lucignano is located in Tuscany and it is characterized by a peculiar configuration in elliptic shape with concentric rings of narrow streets and several radial roads that connect the outer to the top of the hill (fig. 2). The urban structure shows the typical imprint of medieval settlements whose layout follows the orography of the terrain. The perimeter of the historic centre is clearly visible even though the city walls have been progressively incorporated into private houses and historical buildings. Four accesses allow to reach the centre: three of them coincide with the historic gates, while the north-east passage has been realised with the demolition of a portion of the city walls.

Nowadays, the historic centre is vulnerable to disasters and prone to several hazards, particularly seismic hazard that is higher in areas near the Apennines. The area is classified as seismic zone 3, characterized by a maximum Peak Ground Acceleration (PGA) of 0.15 g. It corresponds to the maximum expected acceleration at the foundation interface on rigid soil, corresponding to a 10% probability of exceedance in 50 years (Ultimate Limit State) (NTC, 2018).

4.1 Data collection and elaboration

The evaluation starts from the classification of the land uses and the features of buildings into the historic centre, according to the Structural Plan of the Municipality, Regional repositories, ISTAT statistical data (year 2011) and on-site surveys. Data have been elaborated and analysed by means of QGIS. The geodatabase architecture has been developed for the research scope, and the application to the case study of Lucignano provides a parallel validation. There are 248 buildings into the historic centres and their use is summarised in tab. 2 in terms of number of units and percentage distribution. The prevalent uses of units are church, commercial, deposit/garage, public service, residential, residential/annex, tourism (fig. 3). Private properties are the majority and about the 87% of them are dwellings. Only a small percentage of the building

Figure 2 - Lucignano. Geographical location and orthophoto of the historic centre.

stock is public (regional, municipal, or church properties), and it comprises administrative offices, schools, a library, churches and healthcare services. Statistical data show that all the buildings, both private and public, are made of unreinforced masonry, and this information is corroborated by on-site surveys. Besides, the 87% of them was constructed before 1919. The distribution of the number of highlights that almost the 95% of the masonry buildings have less than three stories, with a great predominance of 3-storey constructions (64 % over the total number of buildings).

Table 2 - Historic centre of Lucignano: present-day distribution of buildings according to their use (elaborated from ISTAT statistical data).

	Number	*Distribution (%)*
Total number of buildings	248	100.00
Building with a function	246	99.19
Residential buildings	215	86.69
Productive buildings	14	5.65
Public buildings	17	6.85

During the survey, the architectural features of the historic centres have been examined and documented. The masonry typologies are extremely varied with a prevalence of irregular textures made of mixed materials (bricks and stones) and ashlars roughly worked rubble masonry. There are frequent signs of interventions and sometimes the reuse of earlier materials is evident. Stone elements are often fragmented and varying greatly in size, arranged with interlaying bricks: the use of two different components witnesses the difficulty in finding raw materials, and the fragmentary adoption of bricks is a clear sign of reuse. The roofing system is commonly wooden, and a limited number of units has been modified with the insertion of concrete roofs. Construction typologies are classified in several categories: annex, irregular block, isolated, linear, regular block, row building, specialistic, and tower (fig. 3). The prevalent typological organisation is in rows, with a linear, terraced, and concentric distribution on the slopes.

The most up-to-date open source data regarding demographic distribution are provided by ISTAT and date back to 2011. The census data report that the population into the historic centre counts 479 people over a total of 3609 in the whole city of Lucignano. Population age and density are two important for risk

Figure 3 - GIS elaboration of data. On the left, map of the land uses; on the right, typologies.

management because they affect the response capacity and rescue operations. In the historic centre under investigation, the population tends to be homogeneously distributed among the age ranges, with a consistent number of people being more than 70 years old (%27 of the total). Children under 10 registered into the historic centre are the 9% of the population, but the parameters do not account for daily movements towards the school located into the area. The number of families is 223 of which 93 are composed of only 1 person, 62 have 2 members, 39 present 3 members, 26 are composed of 5 or 6 people, and 3 have more than 6 members. Finally, the 10% of the population living in Lucignano comes from a foreign country.

Although useful, these data are affected by a great uncertainty and variability associated to the daily movements, to the unknown number of second residences and to the seasonal use of properties. Many houses into the historic centre are rented and the registers might not be consistent with the actual presence of people. Touristic flows during Summertime and special events increases the demographic counter whereas many aged people spend the Winter in nearby cities with amenities. Moreover, wider institutional databases refer to the whole Municipality - not only the historic centre. Hence, further investigations by institutional stakeholders would allow for refining the investigation and planning phases.

4.2 Accessibility scenario

Due to the limited dimensions of the city, Lucignano is included in the Valdichiana Emergency Plan (Protezione Civile di Arezzo, 2017) and the emergency system is coordinated by the Territorial Operation Centre in the nearby Municipality of Monte San Savino. Instead, the Municipal Operation Centre (MOC) is hosted in the Town Hall and in a delocalised building (fig. 4a). The Municipal Emergency Plan reports the location of emergency areas and strategic facilities, but neglects critical facilities (e.g. schools, libraries, theatres) that are not identified. Currently, the referral hospital and fire department are in Arezzo and Cortona, respectively, which are approximately 30 min away from Lucignano in normal traffic conditions. For this reason, the territorial connections between the historic centre and the emergency services should be preserved by means of efficient logistics and road infrastructure. Five emergency areas are placed nearby the historic centre, two of which are directly connected to two gates. Several emergency facilities are located within the boundaries of the historic centre of Lucignano (fig. 4a). The town hall (TH) is hosted in an ancient building and is part of a complex-shaped aggregate that includes a heritage-listed church, as well as a

primary and secondary school (S) (fig. 4b). Other strategic uses for the emergency management are the police station (P) and a small healthcare centre (H).

With reference to the LCE, the geometrical approach provides the streets that would remain free - or partially free - from debris if the condition $w_d = h_b = w_r$ is not satisfied, hence if the road width (w_r) is greater than the height of the buildings (h_b). The average width of the streets in the centre is 5,80 m, while the 94% of the buildings has more than two stories therefore the condition is rarely satisfied. Only squares and wider open spaces could be identified as temporary emergency areas and meeting points to gather the population, especially vulnerable groups. Nevertheless, the outer street ring of the historic centre may be a strategic route on account of its ability to link all the gates in the centre and some of the strategic/critical functions (fig. 4b). Additionally, a further strategic route is introduced to connect the town hall with the previous path.

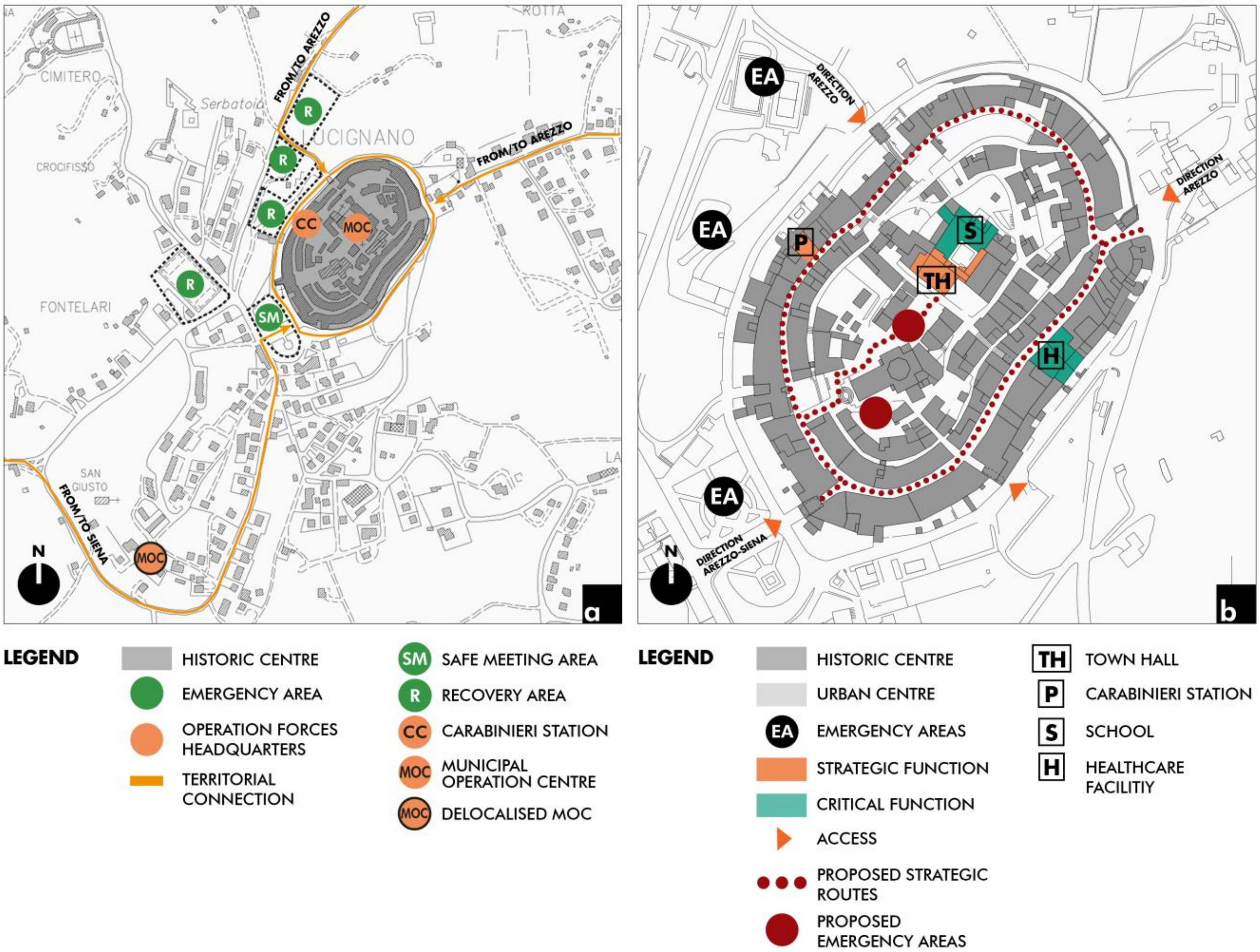

Figure 4 - Functional analysis of Lucignano. Figure a: current emergency plan of Lucignano. Figure b: integration of functions aspects for the identification of potential strategic routes and emergency areas.

The configurational indices are obtained with the application of the ASA to the segment map of the historic centre. The base map is composed of 158 segments and it has been constructed including all the accessible spaces so that the network internalises the presence of slopes or stairs but excludes existing obstacles. The software Depthmap computes the numerical values and provides a chromatic representation of the configurational indices: high values are highlighted by the red hues, low values by the blue ones.

The segments with highest connectivity (C_{max}=4-5) and are located next to the most important gates that can be considered as local hubs for the systems. The global choice analysis provides a through-movement indication and allows for selecting the strategic routes from a configurational perspective. The paths with the highest choice values (fig. 5, in red) differ from the strategic emergency routes selected in compliance with

the LCE (fig. 4b). The integration analysis shows that there is a core in the south-eastern area; the western part is more segregated and presents a lower potential of accessibility. The areas with lower integration values are mainly located in the north-west of the historic centre, and they are characterized by a residential land use.

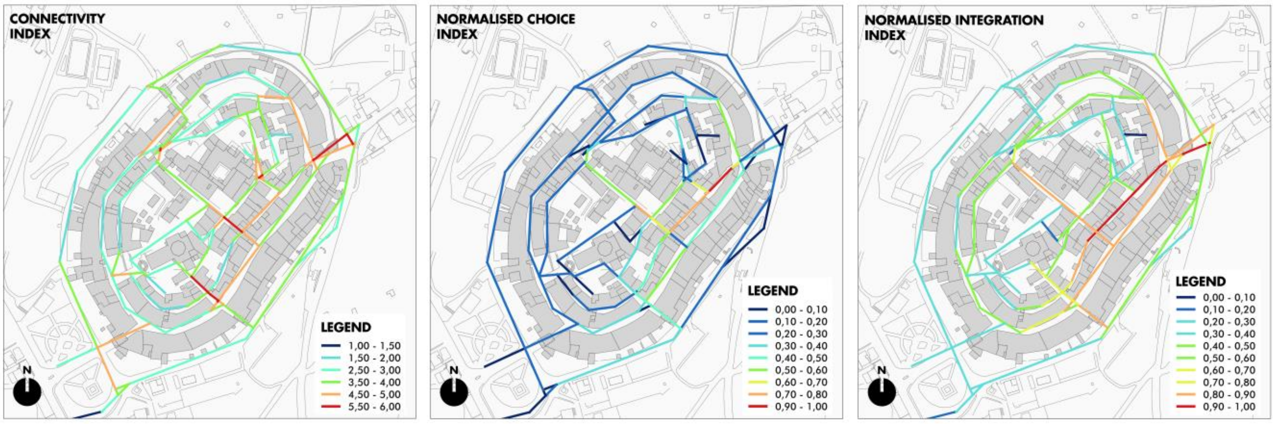

Figure 5 - Thematic colour maps representing the spatial distributions of centralities in Lucignano. From right, the normalised connectivity, choice and integration indices.

4.3 Damage scenario

The vulnerability of the historical building stock is preliminarily evaluated with empirical methods based on site surveys conducted from the roadside. In fact, detailed inspections are difficult due to the presence of a great number of private properties and to logistic issues. The analysis includes an expert-driven survey and GIS mapping of the elements that can induce damage and produce debris on the streets (fig. 6), such as towers, retaining walls, porches, underpasses, and non-structural elements like balconies and chimneys. This map can address the definition of disruption scenarios associated to the collapse of one or more vulnerable elements, considering the likelihood of streets closure. In this regards, walled cities present inherent vulnerabilities associated to the limited number of gateways and the impossibility to guarantee alternative exit from the historic centre. Consequently, gates are both constraints and interferences, and their collapse can significantly impact on the emergency capacity. As shown in figs. 6a-6b, interferences can derive from the poor state of conservation of contrast arches and even from the location of towers next to critical functions.

Furthermore, the preliminary investigation on the vulnerability of the masonry façades within the historic centre of Lucignano (Giuliani et al., 2019) showed that several obstructions may occur in relation to different macro-seismic intensity levels. The procedure has been implemented on QGIS that allows for elaborating and visualising the results. The parameters included into the evaluation form concern four groups, namely the façade geometry and openings, the masonry materials and conservation, the connection efficiency to other structural elements, and finally other elements connected with the façade wall. In this way, it is possible to identify vulnerable façades and assume the occurrence of induced damage on the facing streets. The spatial comparison between the location of strategic routes and the potential debris formation areas can inform decision-making by prioritizing structural interventions into the historic centre.

5. Conclusions

Italian historic centres present varied urban fabrics and layouts, depending on history, orography, traditional uses, dimensions, population. In this context, critical aspects of the emergency management can be recognised in the presence of obstructions along the streets due to local or global collapses of parts of

Figure 6 – Thematic map representing local vulnerabilities in Lucignano. Photos: a) underpass defined by a contrast arch in poor state of conservation; b) physical relationship between the school (on the left) and the isolated tower (on the right).

buildings along the roadside. In order to improve the emergency response of the historic centre, intervention measures can be designed on the basis of the combination of accessibility and damage scenarios.

This paper presented a scenario-based methodology scenario-based methodology to investigate the impact of earthquakes on the operability of the street network into Italian historic centres. It introduced a procedure developing accessibility and damage scenarios based on functional, configurational and vulnerability evaluations of historic centres. Critical aspects are related to the data collection on the buildings and urban fabric and to the lack of information on past interventions and structural changes. Moreover, municipal urban plans do not include information on the disaster relief system that instead is under the responsibility of the DCP. One of the main difficulties of the data collection phase regards the broad range of data deriving from diverse sources. For this reason, information has been collected into a GIS database that provide easy access to stored layers and ensures adaptability and flexibility for a variety of specific requirements and increased detail of data.

Starting from the results on the case study, it is possible to discuss several aspects of the research having wider and general validity. The proposed methodological framework provides indications on the selection of evacuation routes on the basis of mathematical and non-arbitrary evaluations. The choice-based road network considerably differs from the function-based one underlying the LCE. By overlapping these two grids, we can discuss the efficiency of the two approaches and the potentialities of their combination. On the one hand, a strategy based only on the connection of emergency areas and facilities is not sufficient for the emergency management because it neglects routes that are important from a configurational perspective, namely the ones that describe the behaviour of people and the human-environment interaction. Conversely, the configurational approach does not consider the location of strategic facilities that are paramount in crisis situations. SRM should promote a higher correspondence between the natural movement system (choice-based routes) and the emergency system (function-based routes) into the evacuation planning. Assuming that the evacuation process is performed autonomously and in a short time, an increased correspondence between the two routes systems would reduce uncertainties in the route-finding decisions during the earthquake. This

is even more relevant for historic centres due to the peculiar vulnerability and exposure that hinder the implementation of large-scale interventions. As such, a combined approach for the route-finding decision making offers a prioritization criterion to target preventive interventions on a limited set of streets, but simultaneously considering the evacuation of people, the access of emergency services and the connection with the strategic facilities.

The more integrated routes identify the spaces with greater presence of people, retail activities and social encounters. These routes are important for the daily life of the historic centre and can foster the recovery of the site in the post-earthquake phase. For this reason, the preservation of buildings along integrated routes should address the preventive planning and inform the SRM. Besides, the location of emergency areas (open spaces and squares serving as meeting points) along the more integrated paths may potentially offer a safe destination while moving into a historic centre. Whereas this condition is verified, the emergency response of the system is expected to be more effective during and immediately after the event. If people can reach a meeting point safely and autonomously, then emergency services can intervene and aid in the post-disaster phase.

In conclusion, the methodology offers an approach based on the integration urban and spatial planning, risk analysis and seismic engineering. The results are encouraging and suggest that scenario-based analyses can be a valid tool to support the definition of integrated risk reduction and emergency plans. Intervention measures can be designed starting from the identification of strategic routes, the location of strategic facilities and areas, and the evaluation of critical scenarios in terms of configuration. Proper risk mitigation actions should be adopted to guarantee the street safety, starting from strategical ones. Efforts should aim to remove vulnerabilities, retrofitting façades and vertical elements, and to place restrictions on the minimum street width free of furniture and vehicles. These risk mitigation measures can contribute to increase resilience of the historic centres, not only by ensuring the operability of the emergency system but most importantly by preserving the built environment and the socio-economic assets. In fact, when some elements of the historical fabric are damaged or even destroyed, the ability of local communities to function – economically and socially – may be severely disrupted. On such basis, spatial analysis is vital to guide the implementation of risk reduction policies at a large-scale, overcoming the current building-focused approaches through a strategy that is inherently interdisciplinary. By linking the methodological innovation proposed in this work to formal and informal instruments of urban development, the project will contribute to strengthening both the institutional and planning tools for a forward-looking seismic risk management.

6. Acknowledgments

I wish to express my deep gratitude to my supervisors Prof. Anna De Falco and Prof. Valerio Cutini for the support and the encouragement constantly provided during the PhD. Their different background and perspectives contributed to this research.

7. References

ANCSA (Associazione Nazionale Centri Storico Artistici). (2017). *Centri storici e futuro del paese. Indagine nazionale sulla situazione dei Centri Storici*. Associazione Nazionale Centri Storico Artistici, Centro Ricerche Economiche e Sociali del Mercato dell'Edilizia.

Andreini M., De Falco A., Giresini L., Sassu M. (2014). Structural damage in the cities of Reggiolo and Carpi after the earthquake on May 2012 in Emilia Romagna. *Bull. Earthq. Eng*. 12, 2445–2480. https://doi.org/10.1007/s10518-014-9660-7.

Bosher L., Kim D., Okubo T., Chmutina K., and Jigyasu R. (2019). Dealing with multiple hazards and threats on cultural heritage sites: an assessment of 80 case studies. *Disaster Prevention and Management* 29(1): 109-128. DOI: 10.1108/DPM-08-2018-0245.

Bracchi S., Da Porto F., Galasco A., Graziotti A., Magenes G., Mandirola M., Manzini C., Masiani R., Morandi P., Palmieri M., et al. (2012). Comportamento degli edifici in muratura nella sequenza sismica del 2012 in Emilia. *Progettazione Sismica*.

Bramerini F., Castenetto S., Naso G. (2015). *Guidelines for seismic microzonation*. (english ed.). Seismic Microzonation Working Group, Conference of Regions and Autonomous Provinces of Italy – Civil Protection Department, Rome. URL: http://www.protezionecivile.gov.it/httpdocs/cms/attach_extra/GuidelinesForSeismicMicrozonation.pdf.

Calvi G.M., Pinho R., Magenes G., Bommer J.J., Restrepo-Vélez L.F., Crowley H., 2006. Development of seismic vulnerability assessment methodologies over the past 30 years. *ISET Journal of Earthquake Technology* 43, 75–104.

Carocci C.F. (2012). Small centres damaged by 2009 L'Aquila earthquake: on site analyses of historical masonry aggregates. *Bull. Earthq. Eng.* 10, 45–71. doi: 10.1007/s10518-011-9284-0.

Cervellati P. L., Scannavini R. (1973). *Bologna: politica e metodologia del restauro nei centri storici, volume 1*. Società editrice il Mulino.

Cialdini F., Falini P. (1978). *I centri storici. Politica urbanistica e programmi di intervento pubblico: Bergamo, Bologna, Brescia, Como, Gubbio, Pesaro, Vicenza*. Milan: Mazzotta.

Cosenza E., Del Vecchio C., Di Ludovico M., Dolce M., Moroni C., Prota A., Renzi E. (2018). The Italian guidelines for seismic risk classification of constructions: technical principles and validation. *Bulletin of Earthquake Engineering* 16, 5905–5935.

Cremen G., Baker J.W. (2019). Improving FEMA P-58 non-structural component fragility functions and loss predictions. *Bull. Earthq. Eng*. 17, 1941–1960. https://doi.org/10.1007/s10518-018-00535-7.

Cremonini, I. (1994). Rischio sismico e pianificazione nei centri storici: metodologie ed esperienze in Emilia-Romagna, Volume 6 di INU, Istituto Nazionale di Urbanistica. Alinea Editrice.

Crowley H., Colombi M., Borzi B., Faravelli M., Onida M., Lopez M., Polli D., Meroni F., Pinho R. (2009). A comparison of seismic risk maps for Italy. *Bulletin of Earthquake Engineering* 7, 149–180. doi:10.1007/s10518-008-9100-7.

CTMS (Commissione Tecnica per la Microzonazione Sismica). (2016). Manuale per l'analisi della Condizione Limite per l'Emergenza (CLE) dell'insediamento urbano. Versione 1.1. BetMultimedia, Rome. Italian.

Cutini V. (2013). The city when it trembles. Earthquake destructions, post-earthquake reconstructions and grid configuration." *Proceedings of the 9th Space Syntax Symposium*. Sejong University Press.

Cutini V., De Falco A., Giuliani F. (2019). Urban grid and seismic prevention. a configurational approach to the emergency management of Italian historic centres. In: *Proceedings of the 12th Space Syntax Symposium*. Beijing, China.

De Paoli R. G. (2012). Urban spaces and safety. *TeMA - Journal of Land Use, Mobility and Environment*, 5(3):119–131.

Di Giovanni G. (2016). Cities at risk: status of Italian planning system in reducing seismic and hydrogeological risks. *TeMA – Journal of Land Use, Mobility and Environment* 9, 43–62. doi:10.6092/ 1970-9870/3726.

Dolce M. (2012). The Italian national seismic prevention program. In *15th world conference in earthquake engineering, Lisbon*.

Dolce M., Di Bucci D. (2017). Comparing recent Italian earthquakes. *Bull. Earthq. Eng*. 15, 497–533. doi: 10.1007/s10518-015-9773-7.

European Commission. (2018). *Safeguarding Cultural Heritage from Natural and Man-Made Disasters - A comparative analysis of risk management in the EU.* Luxembourg: Publications Office of the European Union.

Fabietti V. (1999). *Vulnerabilità e trasformazione dello spazio urbano*. Alinea Editrice.

Fabietti V. (2001). *Linee guida per la riduzione urbanistica del rischio sismico. Il recupero dei centri storici di Rosarno e Melicucc*o. Edizioni INU, Roma.

Fabietti V. 2013. Dalla CLE alla SUM: i contenuti urbanistici della protezione dai rischi. Strategie di mitigazione del rischio sismico e pianificazione CLE: condizione limite per l'emergenza. *Urbanistica Dossier*, 130:38–39.

Fera G. (1991). *La città antisismica*. Gangemi, Roma.

Gabrielli B., Cervellati P. L. (1993). *Il recupero della città esistente: saggi 1968-1992*. Etas libri.

Galanti E. (1997). *Il metodo Augustus, supplemento a dpcinforma*. Dipartimento della Protezione Civile, Roma, 2(4):1–35.

Gasparrini C. (1994). *L'attualità dell'urbanistica: dal piano al progetto, dal progetto al piano*. Etas libri.

Giuliani F. (2020). *Seismic risk management in historic centres. Integrated large-scale modelling for a scenario-based methodology*. PhD Thesis. University of Pisa. URN: etd-03182020-145019.

Giuliani F., De Falco A., Cutini V. (2020). The role of urban configuration during disasters. a scenario-based methodology for the post-earthquake emergency management of Italian historic centres. *Safety science*, *127*, 104700. doi: 10.1016/j.ssci.2020.104700.

Giuliani F., De Falco A., Sevieri G., Cutini, V. (2019). Managing emergency into historic centres in Italy: seismic vulnerability evaluation at urban scale. In: Papadrakakis M., Fragiadakis M. (Eds.), *COMPDYN 2019 - 7th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering*, Crete, Greece, 24–26 June 2019.

Giuffré A. (1999). *Letture sulla meccanica delle murature storiche*. Protagon Editori Toscani.

Haigh, R., Amaratunga, D. (2010). An integrative review of the built environment discipline's role in the development of society's resilience to disasters, *International Journal of Disaster Resilience in the Built Environment*, Vol. 1 No. 1, pp. 11-24. doi: 10.1108/17595901011026454.

Hillier B., Hanson J. (1984). *The Social Logic of Space*, Cambridge University.

Hillier B., Penn A., Hanson J., Grajewski T., Xu J. (1993). Natural movement: or, configuration and attraction in urban pedestrian movement. *Environment and Planning B: planning and design*, 1993, 20.1: 29-66.

Hillier B., Iida S. (2005). *Network and psychological effects in urban movement*. In: Cohn, A.G., Mark, D.M. (Eds.), Spatial Information Theory. Springer, Berlin, Heidelberg, pp. 475–490.

Koch D., Miranda Carranza P. (2013). Syntactic resilience. *Proceedings of the 9th International Space Syntax Symposium, Seoul Sejong University 2013*. Sejong University Press, 2013. p. 54:1-54:16.

Legislative Decree 42/2004. *Codice dei beni culturali e del paesaggio, ai sensi dell'articolo 10 della legge 6 luglio 2002, n. 137*. Decreto Legislativo n.42 del 22 gennaio 2004. Pubblicato su GU n.45 del 24 febbraio 2004 - Suppl. Ordinario n. 28.

Legislative Decree 1/2018. *Codice della protezione civile*. Decreto Legislativo n.1 del 2 gennaio 2018. Pubblicato nella Gazzetta Ufficiale n.17 del 22 gennaio 2018.

Maureira V. M., Karimi K. A. Y. V. A. N. (2017). The everyday and the post-disaster urban systems as one thing: A configurational approach to enhance the recovery and resilience of cities affected by tsunamis. *Proceedings of the 11th International Space Syntax Symposium*. Vol. 11. Instituto Superior Técnico, Portugal.

Minguez Garcia B. (2019). Resilient cultural heritage: from global to national levels – the case of Bhutan. *Disaster Prevention and Management* 29(1): 36-46. DOI: 10.1108/DPM-08-2018-0285.

Menoni S., Molinari D., Parker D., Ballio F., Tapsell S. (2012). Assessing Multifaceted Vulnerability and Resilience in order to Design Risk-Mitigation Strategies. *Natural Hazards, 64*(3), 2057-2082.

Nasser N. (2003). Planning for Urban Heritage Places: Reconciling Conservation, Tourism, and Sustainable Development. *Journal of Planning Literature*, 17(4):467–479.

NTC (2018). *Aggiornamento delle "Norme Tecniche per le Costruzioni". Decreto 17/01/2012 del Ministero delle Infrastrutture*. Pubblicata su G.U. n. 42 del 20 febbraio 2018.

Olivieri M. (2004). *Vulnerabilità urbana e prevenzione urbanistica degli effetti del sisma: il caso di Nocera Umbra*. INU Edizioni, Roma.

P-58-5, A.A.T.C.F. (2018). *Seismic Performance Assessment of Buildings. Volume 5 –Expected Seismic Performance of Code-Conforming Buildings*. Washington, D.C.: Federal Emergency Management Agency.

Pizzo B., Fabietti V. (2014). Environmental risk prevention, postseismic interventions and the reconstruction of the public space as a planning challenge. an introduction. *Italian Journal of Planning Practice*, 3(1).

Protezione Civile di Arezzo (2017). *Piano provinciale integrato di protezione civile della provincia di Arezzo. Parte generale*. URL: www.protezionecivile.provincia. arezzo.it/upload/files/USERFILE42906_3836111.pdf.

RELUIS (Rete dei Laboratori Universitari di Ingegneria Sismica). (2010). *Linee guida per il rilievo, l'analisi ed il progetto di interventi di riparazione e rafforzamento di edifici in aggregato*.

Stanton-Geddes Z., Soz S.A. (2017). *Promoting Disaster Resilient Cultural Heritage*. Washington DC: World Bank. Accessed March 16, 2020. https://openknowledge.worldbank.org/handle/10986/28955.

Turner A. (2001a). Angular analysis. In: *Proceedings of the 3rd international symposium on space syntax*. Georgia Institute of Technology Atlanta, GA. pp. 30.1–30.11.

Turner A. (2001b). Depthmap: a program to perform visibility graph analysis. In: *Proceedings of the 3rd International Symposium on Space Syntax*, pp. 31–12.

UNESCO. (2007*). Strategy for Reducing Risks from Disasters at World Heritage properties*. World Heritage Committee thirty first Session in Christchurch, New Zealand 23 June – 2 July 2007, UNESCO World Heritage Centre. Accessed March 18, 2020. https://whc.unesco.org/archive/2007/whc07-31com-72e.pdf

UNESCO. (2011). *Recommendation on The Historic Urban Landscape*. Paris: UNESCO World Heritage Centre. Accessed March 16, 2020. https://whc.unesco.org/uploads/activities/documents/activity-638-98.pdf

UNESCO. (2016). *The HUL Guidebook: Managing Heritage in Dynamic and Constantly Changing Urban Environments; A Practical Guide to UNESCO's Recommendation on the Historic Urban Landscape.* WHITRAP and City of Ballarat. Accessed Apr 7, 2020. http://historicurbanlandscape.com/themes/196/userfiles/download/2016/6/7/wirey5prpznidqx.pdf

UNISDR. (2009). *UNISDR Terminology on Disaster Risk Reduction*. Geneva: United Nations International Strategy for Disaster Reduction. Accessed: https://www.unisdr.org/we/inform/publications/7817.

UNISDR. (2015). *Sendai Framework for Disaster Risk Reduction*. Geneva: United Nations International Strategy for Disaster Reduction.