WP 1 – BE and SUOD: State of the Art (SoA), risks and human behavior

T1.2 - SoA of earthquake (SUOD) impact on BE and related earthquake-induced modifications due to building/aggregate and aggregate/public spaces interfering conditions. Current risk-reduction strategies analysis. Definition of human behavior including crowding conditions by combining SoA data and real-world events analysis.

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Abstract

The Disaster Risk Reduction (DRR), with the objective of anticipating-reducing risk, and Disaster Risk Management (DRM), concerning the actions that aim to reduce risk, are the main areas while deepening the study of SUdden Onset Disasters (SUOD) and their impact to the Built Environment (BE). Disaster risk reduction strategies and policies define goals and objectives across different timescales and with appropriate targets, indicators, and time frames. In line with the Sendai Framework for Disaster Risk Reduction 2015-2030, these should be aimed at preventing the creation of disaster risk, the reduction of existing risk, and the strengthening of economic, social, health, and environmental resilience. This report aims to conduct a systematic review of the literature to gain insight into how DRR can be improved in urban areas. When dealing with earthquakes, it is possible to identify two main categories of seismic risk mitigation strategies focusing on the: Reduction of the Vulnerability and/or the Exposure (RVE); or Improvement of the Emergency Response (IER). These strategies can then be applied through a series of measures distinguishable into structural and non-structural measures. A more specific focus on documents with quantitative indicators for the DRR has been realized. From the analysis of the results, the research was mainly carried out with 4 areas of attention for the indicators: a holistic approach that combines social or management factors, the urban form, and morphology, the role of open spaces, the analysis methods of the city's paths network.

Keywords

SUOD; Built Environment (BE); open space; disaster risk reduction; disaster risk management; DRR; DRM; seismic resilience; seismic risk; earthquake; risk management; reduction strategies;

Approvals

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0.1	10.04.2020	Conclusion improvements and integrations to Section 4	Quagliarini Enrico, Gabriele Bernardini	UNIVPM
0.2	08.05.2020	Minor revision, i.e. requests on the discussion organization	Quagliarini Enrico, Gabriele Bernardini	UNIVPM
1.0	25.05.2020	Minor revision, language proofreading and editing	Quagliarini Enrico, Gabriele Bernardini	UNIVPM

Summary

1. Introduction

The policy objective of anticipating and reducing risk is called Disaster Risk Reduction (**DRR**). Although often used interchangeably with DRR, Disaster Risk Management (**DRM**) can be thought of as the implementation of DRR, since it describes the actions that aim to achieve the objective of reducing risk (PreventionWeb - UNDRR). UNDRR (UNISDR 2009) give a clear definition of the two terms:

- DRM - Disaster risk management:
  "The systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies, and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster.
  This term is an extension of the more general term "risk management" to address the specific issue of disaster risks. Disaster risk management aims to avoid, lessen, or transfer the adverse effects of hazards through activities and measures for prevention, mitigation and preparedness."
- DRR - Disaster risk reduction:
  "The concept and practice of reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events."

The Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR 2015) represents the most important actual worldwide shared document in the DRR field. The Framework was adopted at the Third UN World Conference on Disaster Risk Reduction in Sendai, Japan, on March 18, 2015, and aims to achieve the substantial reduction of disaster risk and losses in lives, livelihoods and health as well as in the economic, physical, social, cultural and environmental assets of people, businesses, communities and countries over the next 15 years. In the document 4 "Priorities" for DRR are defined. Taking into account the experience gained through the implementation of the Hyogo Framework for Action, and in pursuance of the expected outcome and goal, focused action are needed within and across sectors by States at local, national, regional and global levels in the following four priority areas:

- Priority 1: Understanding disaster risk.
- Priority 2: Strengthening disaster risk governance to manage disaster risk.
- Priority 3: Investing in disaster risk reduction for resilience.
- Priority 4: Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.

Disaster risk reduction strategies and policies define goals and objectives across different timescales and with concrete targets, indicators and time frames. In line with the Sendai Framework for Disaster Risk Reduction 2015-2030, these should be aimed at preventing the creation of disaster risk, the reduction of existing risk and the strengthening of economic, social, health and environmental resilience. DRR strategies are planning tools that provide the vision and long-term perspective, identify goals and actions decided by a high-level authority at the national or local level or a multi-stakeholder mechanism with the appropriate authority, building on the country context (governance structure, political and economic priorities) on an understanding of disaster risk (prevailing hazards, risk vulnerability, exposure, perception of risk and existing coping capacities of society) and an evaluation of current DRR systems and capacities at country level. DRR strategies should be closely linked with development plans so that underlying factors of risk and resilience-building can be fully addressed (UNDRR 2019).

Among SUODs events, with a specific focus on seismic disasters, risk mitigation encompasses a suite of approaches to reduce the impact on our society. Allen (Allen 2007) affirms that since the development of earthquake seismology and earthquake engineering at the beginning of the XX century, the probability that any one person dies in an earthquake has been reduced by a factor of 3. Different risk mitigation strategies have been applied through the years. Earthquake prediction, while often seen as a solution by the general public, does not represent a practical mitigation tool. In the category of long-term mitigation techniques, earthquake-resistant buildings have been most effective in the past (Allen 2007).

The mitigation options have been classified above according to what they involve, they can be categorized according to when they occur, as follows:

- reduction (i.e., identifying and reducing risks via infrastructure improvement);
- readiness (i.e., training civil defence staff and installing warning systems);
- response (i.e., reacting to emergency phases in the short term);
- recovery (i.e., minimizing the socio-economic impacts in the long term).

These 4 phases represent the 4 traditional part of DLC (Disaster Life Cycle). The first and last two categories involve activities before and after a disaster, respectively. Reduction options (e.g., improving component reliability and network configuration, undertaking regular preventive maintenance) have been the primary focus of mitigation effort in the past (Nicholson 2007), but there has recently been a shift towards:

- readiness options (including deploying standby components for activation after degradation of the original component);
- response options (e.g., monitoring critical components and advising users of degradation and alternatives travel options);
- recovery options (e.g., identifying priorities for repairing degraded components to minimize socio-economic impacts).

Recent natural disasters have exposed the direct consequence of damage and impact upon the built environment. It appears that one of the biggest challenges to natural risk mitigation is how to improve the performance of older building and infrastructure to enhance their ability to withstand natural disasters. By improving their performance, the risk associated with buildings and infrastructure against natural hazards can be mitigated. As highlighted by Foo and Davenport (Foo and Davenport 2003), within the context of risk management of buildings against earthquakes, the general practice is to follow a three-step process, namely screening, evaluation and mitigation. Screening constitutes a preliminary evaluation process and sets the priority for detailed evaluation. The evaluation compares a built environment with code requirements for new construction and sets the priority for mitigation. Mitigation can be achieved using retrofit or replacement. Retrofit is intended to improve the performance of the built environment as required. The replacement may be the only viable solution when economical, technical and environmental considerations are account for.

In the specificity of seismic risk management, DRR strategies are generally aimed to reduce building seismic vulnerability, working on structural features and not considering that the concept of vulnerability can be adopted also referring to the whole urban system. This is fundamental especially in historical urban contexts, where the urban system is consolidated with the evolution of the urban fabric morphology, the activities that populate it, the open spaces of the local identity and the elements of the cultural heritage that characterize it. Considering all these elements, it is strategic to identify before a disastrous event strikes, which of these have prior importance after the event, to guarantee a rapid response and the reestablishment of normal conditions: this means identifying the resilient city (Tilio et al. 2012).

1.1 DRR and DRM for Cultural Heritage in Urban Areas

Urban areas undoubtedly require a specific approach to disaster risk reduction given the complexity of the systemic components of the city organism to be considered, the exponential rate of urbanization and the inherent risks that are faced by dense urban areas. The case of areas belonging to the cultural heritage category covers an area of even more particular attention in the field of DRR and DRM such as the specificity of the Italian and European historical and artistic centres. A recent report entitled "Disaster Risk Management of Cultural Heritage in Urban Areas" and published by ICCROM and UNESCO, in collaboration with the World Heritage Center, analyzes the topic in an interesting way (Jigyasu and Arora 2014).

Cultural heritage, in both its tangible and intangible manifestations, is essential for a city's cultural identity. Jigyasu and Arora affirm the importance of the comprehensive disaster risk management plans that need to be formulated relying on the specific characteristics of cultural heritage and nature of hazards within a regional context. These plans should take into account the principles of risk management, response to historic, aesthetic and other values of cultural heritage, and, at the same time, address greater urban development challenges. Such planning requires skilled professionals, administrators and policymakers who can take into consideration various aspects for developing risk management plans in regard to cultural heritage.

The traditional DLC (Disaster Life Cycle) divided into 4 areas (Preparedness, Response, Recovery and Mitigation), is reworked by Jigyasu and Arora (Jigyasu and Arora 2014) in 3 sectors: before, during and after the disaster to face the specificities of cultural heritage sites (Figure 1). Before a disaster, the main activities include risk assessment, prevention and mitigation methods and warning systems for specific hazards. Planning for emergency evacuation and response procedures are all activities which should be undertaken in advance for responding during the disaster situation, which is generally defined as a period extending for the first three days after an incident. Activities initiated after the disaster include damage assessment, treatment of damaged components of the heritage property through interventions such as repairs, restoration and retrofitting and recovery or rehabilitation activities. At this stage, the effectiveness of the previous stages can also be evaluated, and them, once again, it becomes possible to prepare for any successive event.

Figure 1: Disaster Risk Management Cycle for Cultural Heritage Sites (Jigyasu and Arora 2014)

Analyzing local specificity, Italy is one of the countries with the highest seismic risk in the Mediterranean area. Historical cities and towns of Italian territory are a valid example of resilience in a seismic context, and earthquakes have profoundly influenced their typological and constructional evolution. The close correlation between the seismic history of our country and the evolution of the building construction technique, of typologies and morphologies in the historic Italian city, can be an important point in the analysis and definition of urban resilience to reduce the disaster risk, in particular regarding the role of the built environment (D'Amico and Currà 2018). The origin and the historical process of formation of each settlement are crucial for understanding today's values and identity to be preserved. The present-day compact form of the Italian cities derives from a century-old intensification of constructions with consequent reduction of open space (Giuliani et al. 2020). The main changes concerned changes in the conformation of existing buildings, as well as the aggregation of individual units into more complex structures (Carocci 2001). These processes result from today in specific configurational, structural and functional issues that are strictly interrelated (Figure 2).

The configurational approach is well described by Giuliani et al. (Giuliani et al. 2020). They assume that the urban layout has a primary role in urban dynamics and is based on the conversion of the continuous open space into a connected set of discrete lines whose topology is conditioned by the shape of the BE in reference to the urban fabric. It evaluates the relations between the spaces of the system through Space Syntax (or spatial) analysis that provides a mathematical and non-arbitrary model of urban space on account of its capacity to internalize irregularities. As largely discussed by spatial research, human behaviour and experience depend on the shape and configuration of the built environment. Therefore, the spatial analysis of the road network can contribute to emergency planning by providing information on the distribution of people's movement within the urban fabric and "urban centralities" (Giuliani et al. 2020). It is important to underline how the cultural heritage of our cities is therefore composed not only of historical building but also of the morphological aspects that determine its shape and a series of "urban centralities" such as i.e. archaeological sites, open spaces and identity elements, sights, cultural heritage collections (all the museum material in open spaces or inside suitable built spaces, as in Figure 2) and which represent places of aggregation of people (both tourists and inhabitants), with the possibility of increasing the exposure factors.

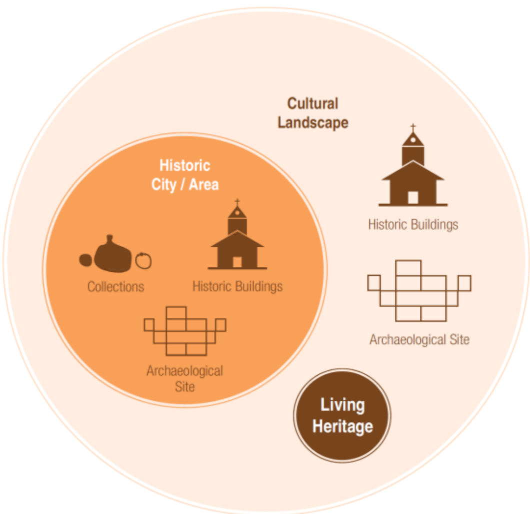

Figure 2: A diagrammatic representation of the realm of cultural heritage and interconnectedness of various components in an urban environment. Source: Rohit Jigyasu (Jigyasu and Arora 2014).

The historical process of growth, typical of historical centres, has been a natural infilling of free areas determining different building typologies, structural characteristics and thus specific damage patterns. In this regard, literature distinguishes between direct and induced vulnerabilities analyzed in detail in report D.1.2.3. The first type originates from the structural characteristics of each building in the block; the second derives from the mutual interactions between adjacent buildings, from any damaging effect induced from a structural component to another or that affect the safety of the nearby open spaces (Carocci 2001).

Beyond this complexity, the overall seismic performance of urban centres depends on the response of buildings in aggregates, as well as on the characteristics of the road network, infrastructures and lifelines (Giuliani et al. 2020). The compact urban fabric and the richness of the cultural legacy of historical cities create a peculiar situation in which multiple functions coexist in a limited area. Most of the times, the administrative and public functions are still hosted into historic centres due to the symbolic values of monumental buildings (see the general issues in D1.1.2).

Therefore, it seems clear how complex it is to act on the hazard component in the historical city, while it is possible and must work on vulnerability and exposure in order to be able to reduce the seismic risk In light of these important initial reflections, it is clear that it is not possible to guarantee a maximum level of security on the entire cultural heritage of the historic city and therefore it is necessary to operate through a series of strategies aimed at reducing the disaster risk in a targeted manner according to a series of intervention priorities and differentiated with respect to the elements of the built environment to be assessed.

This report aims at conducting a systematic review of the literature in order to gain insight into how DRR can be improved in urban areas to support the improvement of BE in the response and emergency phase (Figure 3). In support of this aim, the research has three primary objectives:

- Consolidate existing literature on the research for DRR for seismic risk reduction in the specific contest of urban areas;
- Analyze the literature on DRR to identify strategies and measure to adopt;
- Identify indicators able to be used in DRR scenarios to improve seismic-prone BE, with a focus on public open spaces.

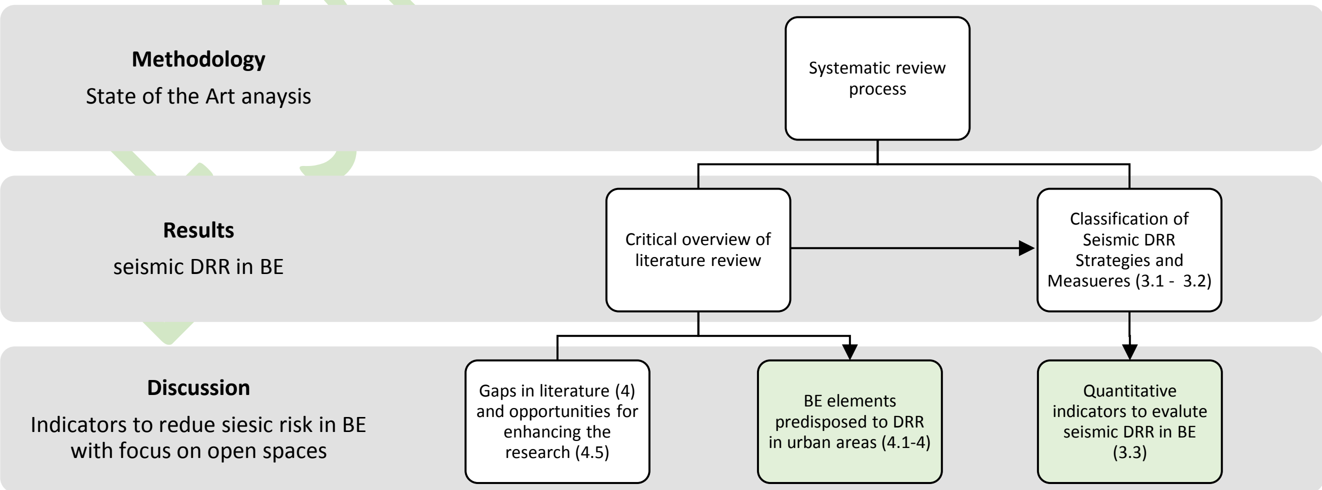

Figure 3: Synthesis of structure of the report and his contributions (in brackets, references to the sections below are reported).

2. Methodology

The research related to BE earthquake risk management and reduction strategies pass through various scales of analysis and different approaches according to many disciplines. Research review methods are able to recognize patterns and trends across a wide range of literature, and are a critical first step in the identification of DRR strategies that could improve the response of BE to earthquakes (Malalgoda et al. 2010; Newman et al. 2017; French et al. 2019; Ivčević et al. 2019). At the same time, it is important to understand the global scenario in which we are operating after the Sendai Framework for action (UNISDR 2015) and learning lesson from actual strategies adopted worldwide (Amaratunga et al. 2018; Faivre et al. 2018; Ivčević et al. 2019; UNDRR 2019).

The systematic review of the literature is an ideal approach to identify DRR strategies, approaches and measure related to seismic risk in the built environment. This process appears to be fundamental to locate, summarize and consolidate research results in a manner that is both transparent and replicable (Torgerson 2003).

As highlighted by French (French et al. 2019), there is no single method for conducting a systematic review and a number of guidelines exist that detail preferred review methods (Palermo 2013). Although the effectiveness of systematic reviews is proven in some research field such as the medical one (Torgerson 2003), the use of this method is spreading and developing also in other thematic areas such as in conservation and environmental management (Pullin and Stewart 2006). Several systematic reviews have been taken into consideration in the elaboration of this contribution, expressly inherent to the field of DRR (Malalgoda et al. 2010; Newman et al. 2017; Ivčević et al. 2019) and urban resilience to disasters (French et al. 2019; Sharifi 2019a), which have shown how it is possible to systematize the current lines of research developed on the subject.

It is significative to be specified that in the current field of research it is important not to limit the systematic review to indexed scientific production, but also to understand what are monographs, books, working papers and documents produced by governmental and non-governmental organizations that work on the topic, what is defined “grey literature”.

2.1 Search strategy

According to French (French et al. 2019), both grey literature and peer-reviewed academic papers were included in the systematic review. For this study, grey literature included also building codes expressly referring to the implementation of resilience or risk reduction (Moullier and Sakoda 2018).

Electronic searches were carried out on the 1st of April 2020, using the following databases:

- Science Direct[1]
- Scopus[2]

[1] Science Direct - 2808 results: https://www-sciencedirect-com.ezproxy.uniroma1.it/search/advanced?qs=open%20space%3B%20built%20environment%3B%20earthquake%20risk%20reduction&show=100

[2] Scopus - 393 results: https://www-scopus-com.ezproxy.uniroma1.it/results/results.uri?sort=plf-f&src=s&sid=18dfdfca3917391254e3a43d9fb252d0&sot=a&sdt=a&cluster=scolang%2c%22English%22%2ct&sl=238&s=TITLE-ABS-KEY+%28%28risk+reduction*+or+risk+mitigation*%29+and+%28earthquake*+or+seismic*%29+and+%28%22open+space%22+or+%22public+space%22+or+%22urban+area%22+or+road*+or+lane*+or+street*+or+square*+or+park*+or+access+or+%22historic+cent*%22+or+%22built+environment%22%29%29&origin=searchadvanced&editSaveSearch=&txGid=2d9d40c957ada30264a4501554abb2fb

The search strategy has been refined in an iterative way and the keywords have been refined as the authors proceeded in the initial steps of the process. For the Science direct database, the following keywords were used: built environment; earthquake; risk reduction; strategies; open spaces. For the Scopus database, a more detailed search strategy has been applied. The keywords were refined by the study authors and grouped into categories, which encapsulated the research question: keywords of disaster management, type of disaster, types of BE space and relevant disciplines (see Table 1: Search Terms). Search strings that combined terms from the four categories were then used to locate literature. Referring to Table 1**Errore. L'origine riferimento non è stata trovata.**, the search code was composed using the operator “AND” among the main columns (Disaster Management, Disaster Space type) and the operator “OR” among the row. Discipline column highlights the thematic areas considered in the search.

Table 1: Search terms.

Disaster Management terms	Disaster Type	Space type	Discipline
Risk reduction	earthquake	urban area	Emergency Management
Risk mitigation	seismic	open space	Landscape Architecture
strategies		public space	Urban Planning
		road	Urban Design
		lane	Structural Engineering
		street	Infrastructural Engineering
		square	
		park	
		access	
		historic center	
		built environment	

TITLE-ABS-KEY ((*risk* AND *reduction** OR *risk* AND *mitigation**) AND (*earthquake** OR *seismic**) AND (*"open space"* OR *"public space"* OR *"urban area"* OR *road** OR *lane** OR *street** OR *square** OR *park** OR *access* OR *"historic cent*"* OR *"built environment"*)) AND (LIMIT-TO (LANGUAGE , *"English"*))

2.2 Study selection

The systematic review was based on consolidated methods (Torgerson 2003; Palermo 2013) and starting from the organized approach of two recent articles that developed bibliographic reviews similar to that presented in this report (French et al. 2019; Ivčević et al. 2019).

Stage 0: Title and keywords Review

The research initially produced a total of 3201 documents from the two electronic databases, skimmed on the basis of the Title and the keywords actually provided by the authors.

According to method presented by French et al. 2 stages were elaborated (French et al. 2019). Articles were required to meet the following criteria for inclusion:

Stage 1: Title and Abstract Review

- *Academic Literature: Terms from the Search Terms list appear in the title, abstract or keywords.*

- *"Grey" Literature: Terms from the Search Terms list appear in the title, executive summary, first two paragraphs of text and/or the database has located a search term embedded within the document.*
- *Full text is available in English or Italian, (referred to the application to national case studies, see D1.1.2 and D1.2.1).*

In this phase, articles relating to other types of disaster (not expressly seismic or not having a multi-hazard approach), and related topics mainly related to the social sphere (i.e. participatory planning processes and gender vulnerability) have been eliminated.

Stage 2: Full-Text Review

- *Documents must specifically address elements of DRR strategies and management. Research focused on strategies, approaches and measures to reduce the risk of earthquake disaster with particular attention to the effects on the built environment in urban areas*
- *Academic literature and grey literature have been analyzed in the structure of the document, paying attention to the presence of indicators and quantitative parameters*

Lastly, bibliographic information from articles that met the criteria was entered into the citation manager Mendeley. The bibliography of selected documents has been analyzed and relevant sources that were not identified in previous searches were incorporated.

Final article selection: Full-Text Review

In total 143 elements from stage 2 were filed and 41 significant elements were identified for in-depth analysis (see Figure 5, for study selection).

The documents was first summarized, and key data compiled according to a purpose-built database that identified the authors, year of publication, type of publication (literature review or case study), scale of analysis, part of BE analyzed, if focused on Open Space the distinction between Areal Space (AS) and Linear Space (LS) according to report D.1.1.2. of the PRIN Research, hazard(s), interactions with sections of OS survey according to report D.1.1.2. of the PRIN Research and type of resource.

As the literature was reviewed, common sub-themes were identified, especially for the identification of DRR strategies types. Modifying themes is a necessary part of the review process as new data is added (French et al. 2019). Themes were further refined as the review progressed and during the writing phase.

2.3 Analysis of results

A bibliometric analysis based on the co-occurrence of the keywords was also conducted using VosViewer software (van Eck and Waltman 2010). The result is a neural network where the size of individual elements represents the recurrence of a single term (the larger the size, the greater the recurrence), while the links between the elements represent the relationships between the terms in the documents analyzed. The process was repeated both on the initial research deriving from the Scopus database and on the selection of documents (393 results) from the final stage (41 results). The authors chose keywords with a minimum occurrence of 2 (in terms of keywords), performed data cleaning merging variants of similar terms, and delete geographical indication and a few minor terms (i.e. localities of case studies, plural/singular terms, and similar terms like "disaster risk reduction" and "risk reduction"). The analysis has been developed through the use of a bibliometric database in .ris format (Research Information Systems) exported from Mendeley collection of the analyzed bibliography. The data cleaning has been developed through a specific “thesaurus file”[3] elaborated by the authors and processed in the VosViewer software. The settings of the bibliometric analysis are shown in Figure 4.

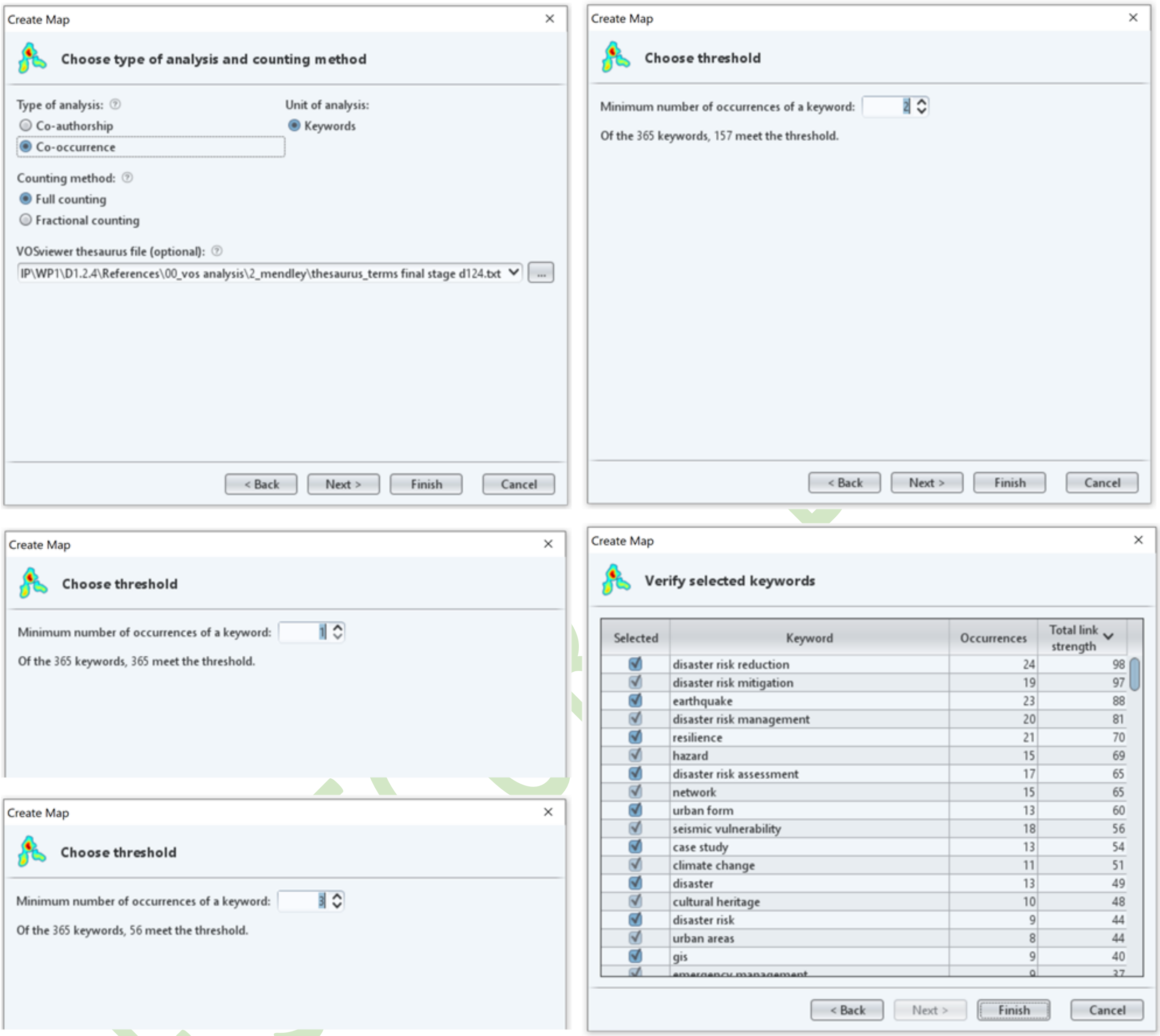

Figure 4: VosViewer’s settings, from top left: 1 (top-left). Type of analysis and import of thesaurus file; 2 (top-right). The choice of the minimum numbers of occurrences of the papers' keywords for the analysis; 3-4 (bottom-left). Attempting using occurrences of 1 (excluded since too wide) and of 3 (excluded since not enough significant); 5 (bottom-right). Final check of the included keywords.

[3] Link to the “thesaurus file” elaborated by the authors for the data cleaning of the keywords used in the final stage of the systematic review: https://univpm.sharepoint.com/:t:/r/sites/be.s2ecure/Documenti%20condivisi/WP1/T1.2/DELIVERABLE%201.2.4/thesaurus_terms%20final%20stage%20d124.txt?csf=1&web=1&e=iH906W

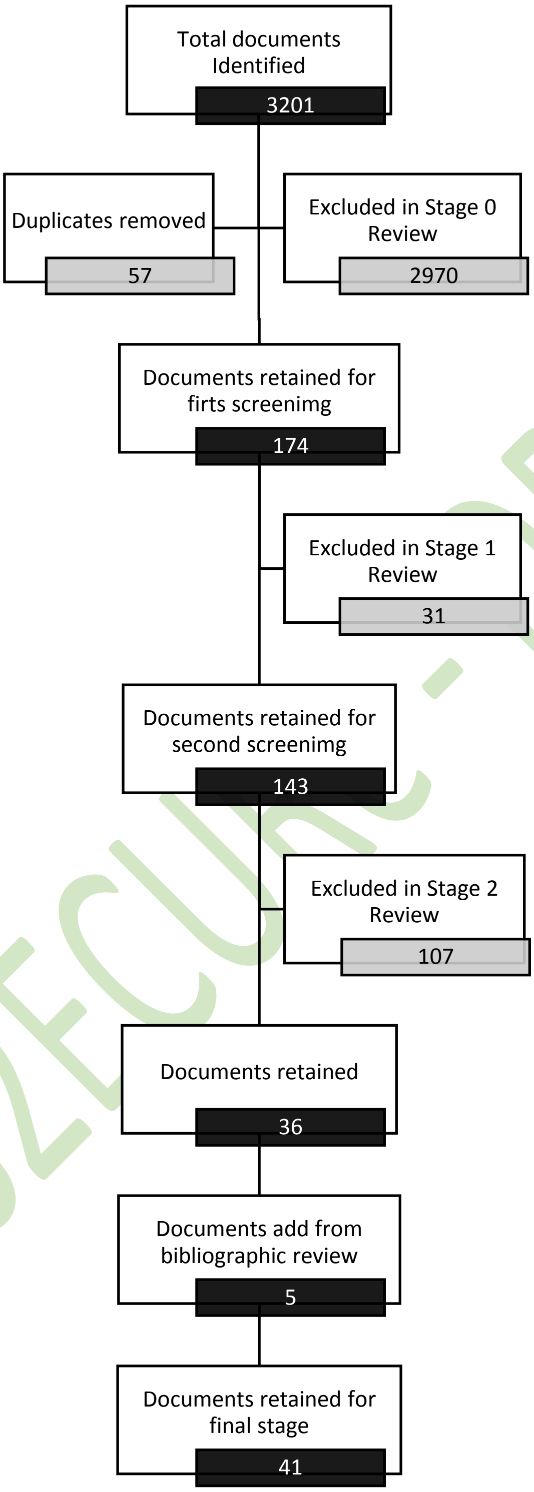

Figure 5: Systematic review study selection

3. Results

The systematic review has highlighted an important increase in publications on the topic of DRR in the last decade (Figure 6). Although the theme is not new, there are systematizations in tackling it, new approaches, and in general greater attention to the aspects of disaster reduction and implementation of resilience. The approaches provided by the UNDRR following the global Hyogo and Sendai meetings were certainly significant (UNISDR 2015). The total of documents retained for stage 2 screening is analyzed in the following graphs.

From the analyzed documents it is also possible to highlight the scale of attention (Figure 7), not only strictly construction, but rather mainly on an urban scale. It is also possible to identify a series of contributions that insert the aggregate scale between those of analysis.

the type of resource analyzed in the review is also significant (Figure 7). most of the documents come from papers published in journals (112), but there is an interesting portion also deriving from grey literature, books and conferences.

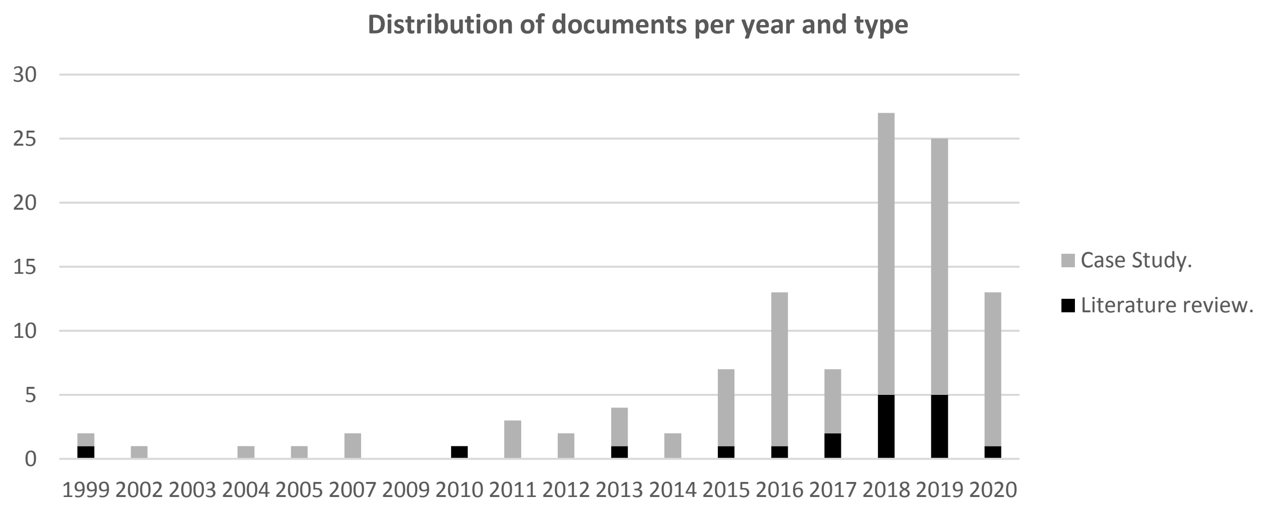

Figure 6: Graph of distribution of documents per year and type. Documents from stage 2 were analyzed

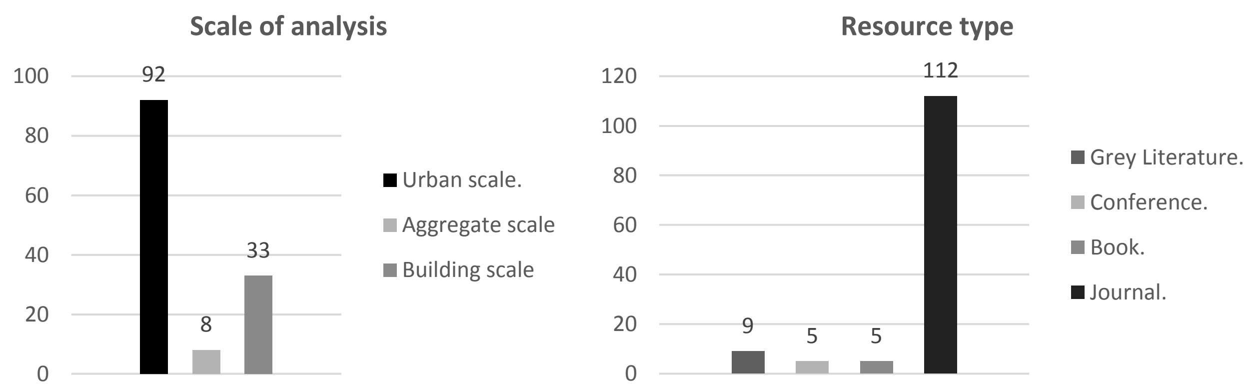

Figure 7: Graphs of distribution of documents per scale of analysis (on the left) and resource type (on the right). Documents from stage 2 were analyzed

3.1 Definitions of Disaster Risk Reduction (DRR) Strategies

The first important result of the review had to be necessarily linked to the identification and definition of the types of DRR strategies and related measures adopted. This first step is structured as a prerequisite for the analysis of subsequent results.

According to Giuliani et al. (Giuliani et al. 2020), common risk reduction actions aim at reducing the causal factors of disasters. When dealing with earthquakes, it is impossible either to reduce the hazard or to predict the timing and impacts of a shock. It is possible to identify two main categories of **seismic risk mitigation strategies** focusing on the:

- Reduction of the Vulnerability and/or the Exposure **(RVE)** that aims at limiting the impacts of an event;
- Improvement of the Emergency Response **(IER)** that entails preventive planning for evacuation patterns and access of emergency services.

Alongside these two main categories, it is possible to identify an approach expressly linked to intervention on ecosystems, which differs from engineering approaches. Hinzpeter and Sandholz (Hinzpeter and Sandholz 2018), focused on the ecosystems and natural part of the environment, defining **Ecosystem-based disaster risk reduction (Eco-DRR)** as “the sustainable management, conservation, and restoration of ecosystems to reduce disaster risk, to achieve sustainable and resilient development”.

Finally, it is possible to identify a holistic approach to some research, in which although it is still possible to trace one of the two strategies identified, we read a search for a broader vision of implementing resilience.

It is evident that the assessment of vulnerability and exposure in urban areas, and especially in historic centres, is of complex definition. For this reason, some research focuses on deepening the first strategy (RVE) (Foo and Davenport 2003; Jayakody et al. 2018), while others believe it is more effective to intervene on the second (IER) (Ahn et al. 2011; Giuliani et al. 2020). Other documents still present characteristics attributable to both strategies dividing the work phases (Nicholson 2007; Yücel et al. 2018).

Having defined the strategies, it is necessary to understand that there are a series of measures (UNISDR 2009) that apply the aforementioned strategies, which can be divided into:

- **Structural measures**: *Any physical construction to reduce or avoid possible impacts of hazards, or application of engineering techniques to achieve hazard- resistance and resilience in structures or systems;*
- **Non-structural measures**: *Any measure not involving physical construction that uses knowledge, practice or agreement to reduce risks and impacts, in particular through policies and laws, public awareness-raising, training and education*

As highlighted by Giuliani et al. (Giuliani et al. 2020) the first refers to all of the engineering solutions that aim to limit the expected impacts of hazards; the second refers to actions that do not concern physical constructions, such as policies, laws, public awareness-raising and capacity building.

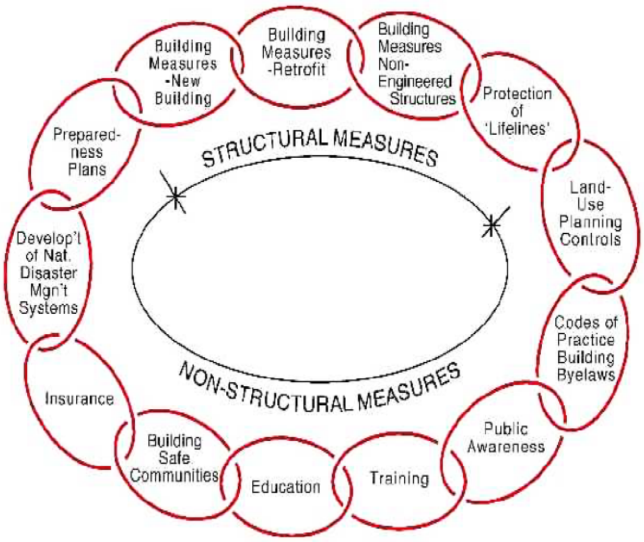

Figure 8: The Seismic Safety Chain. Elaborated from (Davis 2004a)

Ian Davis (Davis 2004a) introduces an interesting concept when describing Structural and Non-Structural Measures, with the image in Figure 8: *"The imagery may be particularly appropriate for earthquake engineers with its similarity to a ring-beam. Each link in the chain can represent an element within an integrated risk reduction strategy".*

This approach divides so the measures in:

1. Structural Protection Measures:
 1.2 building measures: new buildings and infrastructure
 1.3 building measures: existing buildings and infrastructure (retrofit)
 1.4 protection of non-engineered structures
 1.5 protection of lifelines/critical facilities (including disaster plans for each facility)
2. Non-Structural Mitigation:
 2.2 legislative framework:
  2.2.1 land use planning controls
  2.2.2 codes of practice/ building bye laws
 2.3 human resource development (HRD):
  2.3.1 public awareness
  2.3.2 training
  2.3.3 education
 2.4 public-private partnerships:
  2.4.1 building safe communities (this refers to the initiative within the USA developed by the Federal Emergency Management Agency (FEMA) now called 'Project Impact'
  2.4.2 insurance
 2.5 risk reduction planning:
  2.5.1 development of national disaster management systems
  2.5.2 preparedness plans

In summary, in the DRR it is possible to identify two main strategies that are implemented with a series of structural and non-structural measures. The theory exposed is represented in Figure 9.

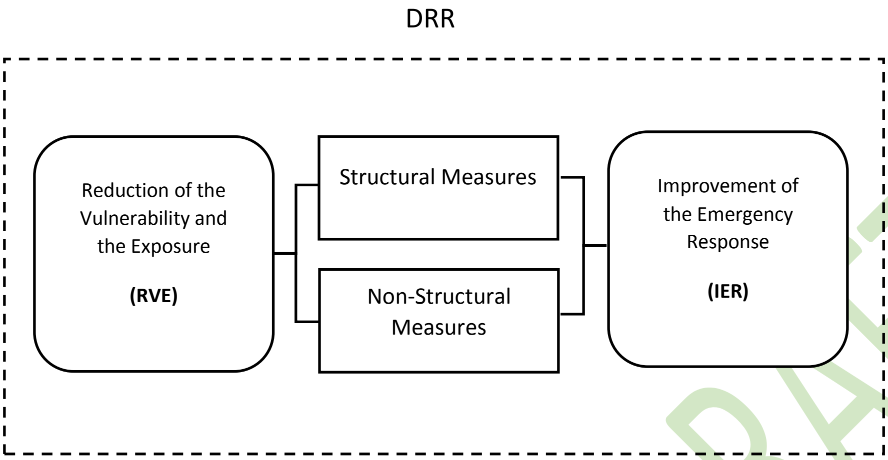

Figure 9: Explanatory diagram of the relationship between Strategies and Measures

The documents analyzed in stage 2 and filed in the database were divided according to the strategy followed and the highlighted measures (Figure 10). 78 documents report the first strategy (RVE), 47 documents the second strategy (IER), and in 7 cases we have an overlapping of the 2 identified strategies. IN the graph, the individual structural measures have been made explicit.

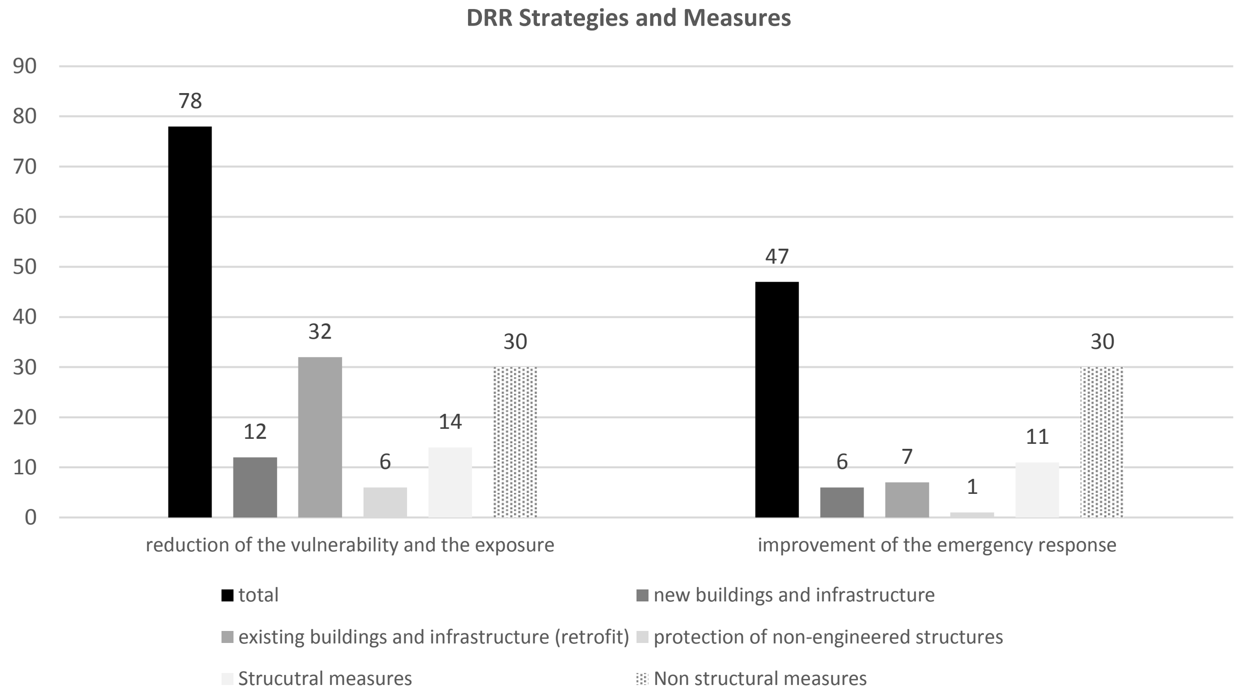

Figure 10: Graph of distribution of documents per DRR strategy and measure. Documents from stage 2 were analyzed

3.2 Classification of the strategies for seismic risk reduction

The detailed analysis for the identification of the measures adopted focused on the selection of the 41 documents deemed significant during the systematic review. The documents have been filed according to the author, the type of resource, if specifically referring to the seismic or multihazard disaster, which part of the BE they analyze, the DRR strategy that can be found, and what type of measures they highlight (Table 2Table 2: Final article summary.).

The first series of documents considered fundamental is the one that makes a point of the research situation in specific subfields. These documents do not necessarily deal with a single type of strategy or measure but are considered fundamental to create the elaborated framework. Amaratunga et al. (Amaratunga et al. 2018) realize a good review of some practices that have been tested and implemented by different cities around the world to aid knowledge-sharing opportunities for future disaster risk reduction. In their paper they use uses the ten essentials identified by the United Nations International Strategy for Disaster Reduction (UNISDR) in 2010 to illustrate some of the risk reduction work that has been undertaken across the world. Davis (Davis 2004b) explores the capability of performance Targets to measure the effectiveness of the elements in a seismic safety strategy. He elaborates his theory based on the division of structural and non-structural measures and the fundamental characteristics of resilience (i.e. redundancy). Etinay et al. (Etinay et al. 2018) investigate the historical emergence of DRM and DRR in pre-and-post the year 2015. The outcomes of their study show the absence of indicators to monitor progress on evolving disasters and underlying risk drivers. Malalgoda et al. (Malalgoda et al. 2010) focus on the various definitions of disasters and explains the literature on disaster management. Disaster risk reduction measures can be employed in both pre-disaster planning and post-disaster recovery stages of the disaster management cycle. They analyze the disaster risk reduction in the built environment where the relationship of the disasters and the built environment, especially with a focus on the role of the construction industry and the built environment disciplines in disaster risk reduction. Ivčević et al. (Ivčević et al. 2019) discuss the spatial and temporal scale at which indicators of risk management can be applicable, to what extent they should be physically oriented and if they can fit the needs of the governance framework. Maio et al. (Maio et al. 2018) provide a comprehensive review of the disaster risk mitigation of urban cultural heritage assets located in historical centres, by providing a holistic framework on the features of such a complex system.

Then there are the documents strictly relative to the two different DRR strategies.

3.2.1 RVE: Reduction of the Vulnerability and/or the Exposure

Documents elaborated according to RVE strategy are prevalent related to mitigation on buildings and built part of BE. Atrachali et al. (Atrachali et al. 2019) develop an indicator system to quantify the seismic resilience in urban areas, with an interesting view on the BE. Bostenaru Dan (Bostenaru Dan 2005) investigates the building design according to urbanistic zoning and seismic micro-zonation. Boukri et al. (Boukri et al. 2018) integrated framework for seismic damage assessment at the urban scale, aimed to take adequate preventive measures and develop appropriate mitigation strategies, i.e. crisis prevention and management plans to reduce the losses. Cerè et al. (Cerè et al. 2019) develop a qualitative characterization of resilience for buildings on an urban scale of analysis. The system analyzes the categories of Environment, Governance & Planning, Utility Services, Infrastructures, Emergency & Rescue systems, Economy, Land use & urban morphology with a mix of structural and non-structural measures. Foo et al. (Foo and Davenport 2003) present a series of measure for seismic hazard mitigation for buildings, highlighting the general practice to follow a three-step process, namely screening, evaluation and mitigation to support decision in cost-efficiency for DRR.

Table 2: Final article summary.

#	Reference	Resource Type	Hazard		Part of BE analyzed			DRR strategies		Measures	
			Earthquake	Multihazard	Buildings	Open Space		RVE	IER	Str	Non-Str
						AS	LS				
1	(Ahn et al. 2011)	Journal	X				X		X	X	
2	(Amaratunga et al. 2018)	Journal	X	X				X	X	X	X
3	(Atrachali et al. 2019)	Journal	X		X	X	X	X			X
4	(Bostenaru Dan 2005)	Journal	X	X	X			X			X
5	(Boukri et al. 2018)	Journal	X		X			X			X
6	(Cara et al. 2018)	Journal	X				X	X	X	X	
7	(Cerè et al. 2019)	Journal	X	X	X	X	X	X			X
8	(Davis 2004b)	Conference	X	X						X	X
9	(Etinay et al. 2018)	Journal	X	X				X		X	X
10	(Faivre et al. 2018)	Journal	X	X		X	X	X			X
11	(Foo and Davenport 2003)	Journal	X		X			X		X	
12	(French et al. 2019)	Journal	X	X		X	X		X	X	X
13	(Giuliani et al. 2020)	Journal	X			X	X	X	X		X
14	(Guardiola-Víllora and Basset-Salom 2013)	Conference	X		X			X		X	
15	(Hinzpeter and Sandholz 2018)	Journal	X	X		X	X	X		X	
16	(Ivčević et al. 2019)	Journal	X	X				X	X		X
17	(Jayakody et al. 2018)	Journal	X	X		X	X	X			X
18	(Li and Zhou 2020)	Journal	X				X		X	X	
19	(Liu et al. 2019)	Journal	X		X			X			X
20	(Maio et al. 2018)	Journal	X		X	X		X		X	
21	(Malalgoda et al. 2010)	Conference	X	X				X		X	X
22	(Marshall 2020)	Journal	X	X	X			X			X
23	(Martins et al. 2018)	Journal	X	X	X	X	X	X			X
24	(Moullier and Sakoda 2018)	Grey literature	X	X	X			X		X	X
25	(Newman et al. 2017)	Journal	X	X				X			X
26	(Nicholson 2007)	Journal	X	X			X	X	X	X	
27	(Platt and Drinkwater 2016)	Journal	X		X	X	X		X		X
28	(Quagliarini et al. 2018)	Journal	X			X	X		X	X	
29	(Quagliarini et al. 2019)	Journal	X		X			X		X	
30	(Rapone et al. 2018)	Journal	X		X			X		X	X
31	(Rus et al. 2018)	Journal	X	X	X	X		X			X
32	(Sharifi 2019b)	Journal	X	X		X	X		X		X
33	(Sharifi 2019a)	Journal	X	X			X		X	X	
34	(Shrestha et al. 2018)	Journal	X			X	X		X		X
35	(Srinurak et al. 2016)	Journal	X				X		X	X	X
36	(Villagra-Islas and Alves 2016)	Journal	X			X			X		X
37	(Wei et al. 2016)	Journal	X		X			X		X	
38	(Xu and Xue 2017)	Journal	X	X	X	X		X		X	X
39	(Ye et al. 2012)	Journal	X			X	X		X		X
40	(Yücel et al. 2018)	Journal	X				X	X	X	X	X

41	(Zhang and Wang 2016)	Journal	X	X			X	X	X

Open Space: AS - Areal Space; LS - Linear Space
Seismic risk mitigation strategies: RVE - reduction of the vulnerability and the exposure; IER - improvement of the emergency response;
Measures: Str – Structural measures; Non-Str - Non-structural measures

Guardiola-Víllora and Basset-Salom (Guardiola-Víllora and Basset-Salom 2013) aim to identify the determinant factors that have prevented or increased the damage after a strong earthquake struck Lorca in 2011. Results obtained should influence the intervention for seismic risk mitigation in unreinforced masonry buildings in similar historical centres, sharing the same construction techniques. Liu et al. (Liu et al. 2020) an integrated approach for a macroseismic vulnerability assessment composed of data mining methods and GIScience technology. Martins et al. (Martins et al. 2018) investigate identifies the exposure of the built heritage of Lisbon Downtown to natural hazards and the potential impacts that these may have had on the ability of the city's fabric performance. Moullier and Sakoda (Moullier and Sakoda 2018) elaborate on the building regulation expressly referring to the implementation of resilience or risk reduction for the case of Japan, evaluating structural and non-structural measures. Quagliarini et al. (Quagliarini et al. 2019) propose a rapid and easy-to-apply approach to inquire about the vulnerability of buildings aggregate starting from vulnerability indexes of single structural units that composes it. Rapone (Rapone et al. 2018) a predictive model for the seismic vulnerability assessment of old Italian historic centres. The potentiality of the method in DRR is in providing likely damage scenarios, also with the support of GIS-based representations. Xu and Xue (Xu and Xue 2017) face the question of the complex urban public spaces (CUPSs) with multi-layer structure integrated into three-dimensional space that has been constructed in many cities, such as the integrated railway transport hub, airport terminal, and commercial complex. Some documents focus on the Eco-DRR approach. Faivre et al. (Faivre et al. 2018) focus on Eco-DRR affirming that ecosystems themselves can offer sustainable solutions for the reduction of disaster risks and the severity of their impacts while adapting to global changes. Nature-Based Solutions, Ecosystem-based Adaptation, Green Infrastructure and Natural Water Retention Measures are examples of ecosystem-based initiatives. Hinzpeter and Sandholz (Hinzpeter and Sandholz 2018) face the field of risk reduction measures regarding their consideration of ecosystem-based approaches. Jayakody et al. (Jayakody et al. 2018)in their study aim to find out the innovative planning and designing methods, integrated with disaster management strategies to plan and design Public Open Space in cities. Another interesting point of view on the theme is the risk perception, the decision support systems, and lifecycle assessments. Marshall (Marshall 2020) investigate the relationship between risk perception and disaster risk reduction (DRR). Newman et al. (Newman et al. 2017) discuss of decision support systems (DSSs) for natural hazard risk reduction (NHRR). Finally, Wei et al. (Wei et al. 2016) propose a lifecycle assessment (LCA) framework that can incorporate building damage due to hazards and convert these data into quantifiable environmental metrics.

3.2.2 IEV: Improvement of the Emergency Response

The second type of DRR strategies focuses predominantly on networks, roads, and evacuation paths for urban areas, or on design and management of open spaces. Ahn et al. (Ahn et al. 2011) examine the function of the road networks connecting cultural heritages and their bases for disaster mitigation at the time of the disaster occurrence, from the viewpoint of protecting cultural heritages and their surrounding urban areas comprehensively. Li and Zhou (Li and Zhou 2020) use an empirical predictive model of debris obstruction of collapsed buildings to calculate link connectivity probability, the Monte Carlo simulation method to calculate post-earthquake road network accessibility based on the results of link connectivity reliability and propose an optimal risk mitigation investment model in order to maximize post-earthquake network accessibility with different government budgets. Quagliarini et al. (Quagliarini et al. 2018) present an analysis of factors influencing the seismic risk of evacuation paths and consequent evaluation of their safety during the emergency are thus desirable. Sharifi (Sharifi 2019a) discuss the relationships between urban resilience and different centrality and connectivity measures related to network topology. The focus is on the design and orientation category that explores the possible effects of street width, street edges, street canyon geometry, and street layout and orientation on the resilience of cities. According to this research, all topology and design measures have implications for urban resilience and so on DRR. In a second paper (Sharifi 2019b) he focuses on morphological parameters related to the following urban form elements: neighbourhoods, blocks, lots, and open spaces. Srinurak et al. (Srinurak et al. 2016) focus on egress points and accessibility of urban network, to act as evacuation network investigated by space syntax analysis combined with GIS as a primary tool. Results show how the risk of bottlenecks in the evacuation network is mainly caused by the street narrowness, especially concerning the numerosity of the egress points (i.e. the ratio between the narrowness and the egress point number). As a consequence, the urban morphology is a key element for the evacuation plan definition. Ye et al. (Ye et al. 2012) develop a systematical methodology for occupant evacuation against earthquakes on community-scale by employing spatial analysis techniques of Geographical Information System (GIS) Based on the present layout of evacuation facilities and shelters as well as the evacuation demands in urban communities. Some of the analyzed documents focus on the importance of open spaces. French et al. (French et al. 2019) focus on the function of public open spaces to become hubs for both short-term disaster response efforts and support longer-term recovery needs. Platt and Drinkwater (Platt and Drinkwater 2016) face the DRR in terms of decision making for post-earthquake recovery in Turkey, with attention to multiple aspects of the urban scale. Rus et al (Rus et al. 2018) elaborate a review to determine how to best assess the resilience of urban systems as a whole, taking into account all of their components, i.e. both the physical components (i.e. of buildings, infrastructure, and open spaces) and the social components (i.e. of the community), as well as the dynamic interactions between them. Then a probabilistic fragility analysis for each physical element a complex network approach (graph theory) for the assessment of the resilience of urban systems as a whole is presented. Shrestha et al. (Shrestha et al. 2018) investigate the important relationship between perceived risks and open spaces. Villagra-Islas and Alves (Villagra-Islas and Alves 2016) explored the different uses of the open space in two scenarios: emergency (in case of an earthquake) and non-emergency.

3.2.3 Combination of RVE and IEV

In the end, there is a small group of documents where is possible to identify a combination of the two enounced strategies. Cara et al. (Cara et al. 2018) focus on the identification of the most vulnerable buildings whose collapse may hinder the operationality of strategic urban roadways after the occurrence of an earthquake, up to the proposal of proper interventions to improve their functionality. The research elaborated by Giuliani et al. (Giuliani et al. 2020) aims at implementing the spatial-configurational aspects into the post-seismic emergency management of Italian historic centres. The application of a scenario-based method offers a predictive approach to emergencies which embeds the uncertainties of the effects of earthquakes. The methodology is based on the development of road network's scenarios and their analysis by means of space syntax techniques, with attention to building vulnerably reduction. Nicholson (Nicholson 2007) discusses the sources of unreliability, and the relative merits of alternative measures of reliability and models for predicting reliability for urban-roads. (Zhang and Wang 2016) introduce a novel metric based on system reliability and network connectivity to measure the resilience-based performance of a road transportation network. The formulation of this resilience-based performance metric (referred in the paper as WIPW), systematically integrates the network topology, redundancy level, traffic patterns, structural reliability of network components (i.e. roads and bridge) and functionality of the network during community's post-disaster recovery, and permits risk mitigation alternatives for improving transportation network resilience to be compared on a common basis. Yücel et al. (Yücel et al. 2018) propose a new dependency model for random link failures to predict the post-disaster status of the network, then estimate an accessibility measure, namely, the expected weighted average distance between supply and demand points by checking pre-generated short and dissimilar paths in the sample.

3.3 Focus on quantitative indicators for DRR

A more detailed focus on documents with quantitative indicators has been realized. A total of 75 documents from the second stage were expressly reported analyzes related to buildings (39) or open spaces (36), only 6 documents presented both the part of BE analyzed (Figure 11). Of these documents, only a small part had a quantitative approach with evaluation indicators (33 in total). The analysis of the documents from the final stage reports a smaller group of documents, in a total of 35 documents, 7 of which are interested in both buildings and open spaces. In the end, an analysis of distribution per DRR strategy and measure were performed divided for Buildings and Open Spaces theme (Figure 12).

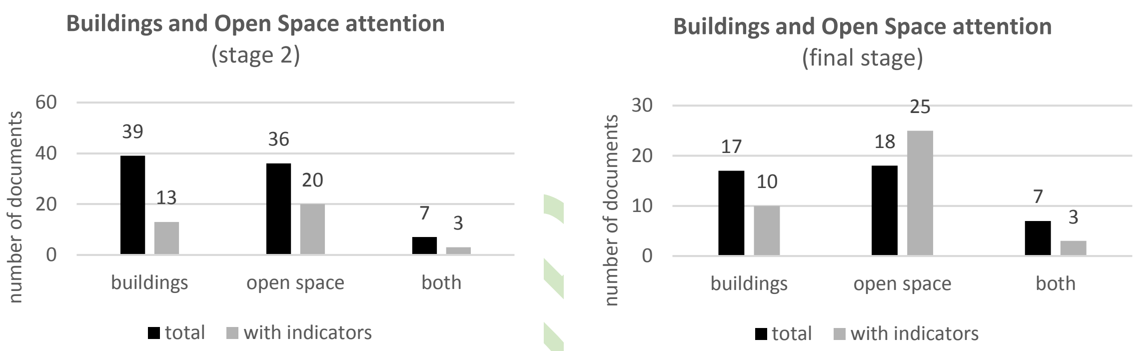

Figure 11: Graphs of distribution of documents per Building or Open Space attention, with the explanation of those with quantitative indices. Documents from stage 2 were analyzed on the left and documents from the final stage on the right.

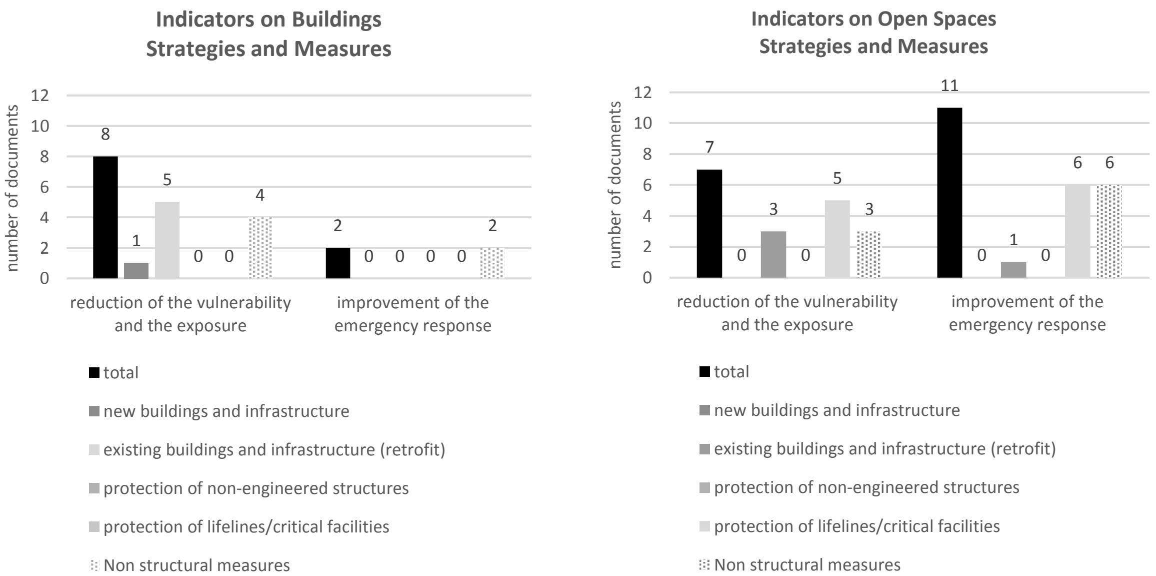

Figure 12: Graph of distribution per DRR strategy and measure of documents for focuses on indicators divided for Buildings and Open Spaces. Documents from the final stage were analyzed.

In Table 3 is possible to see the documents analyzed, selected from the final stage of the review, with the focus on indicators where the type of document, the hazard, the part of BE investigated, and a description of indicators are reported. Besides, a possible intersection with the sections of the expeditious evaluation form for public spaces developed in deliverable D1.1.2 has been reported.

Table 3: Studies specifically using indicators. "Section of interaction with BE Open Space classification" are derived from D1.1.2 report; all the acronyms and codes are defined below.

#	Reference	Case study/review	Hazard		Part of BE analyzed			Type of indicators used	Section of interaction with BE Open Space classification				
			Earthquake	Multihazard	Buildings	Open Space AS	Open Space LS		1	2	3	4	5
1	(Ahn et al. 2011)	Case Study	X				X	Road passage rate, calculated for each important road section; the rate is connected to road blockage, to condition of buildings along the roads and the spread of fire.	X	X			
2	(Atrachali et al. 2019)	Case Study	X		X			Urban Resilience, structural and non-structural indicators. 37 indicators, 13 thematic areas and 5 sectors has been developed.					
3	(Boukri et al. 2018)	Case Study	X		X			Damage estimation indicators among buildings characteristics.					
4	(Cara et al. 2018)	Case Study	X				X	Index to rate vulnerability of buildings and aggregates connected to the main roads		X	X		
5	(Cerè et al. 2019)	Case Study	X	X	X			Environmental, Governance & planning, Utility services, Infrastructural, Emergenc y & rescue services, Economy, Land use & urban morphology criteria.,				X	
6	(Quagliarini et al. 2018)	Case Study	X			X	X	The analyzed criteria are connected to safety influencing factors path use and exposure; geometric features; physical-structural features; extrinsic vulnerability; seismic hazard.					

7	(Foo and Davenport 2003)		X		X			Vulnerability index regarding buildings characteristics. Sismic Priority Index.			X	
8	(Giuliani et al. 2020)	Case Study	X			X	X	Vulnerability index of build heritage connected to transport system				
10	(Li and Zhou 2020)	Case Study	X				X	Post-earthquake link connectivity reliability study and road network reliability	X	X		
12	(Marshall 2020)	Literature Review	X				X	Risk perception index to offer a beneficial approach to DRR (Disaster Risk Reduction)				
13	(Srinurak et al. 2016)	Case Study	X				X	Urban network accessibility criteria during earthquakes				
14	(Nicholson 2007)	Case Study	X	X	X			Linear Spaces indicators for road transport network reliability.				
15	(Quagliarini et al. 2019)	Case Study	X		X			Vulnerability criteria influencing assessment of building heritage				
16	(Rapone et al. 2018)	Case Study	X		X			Criteria connected to building heritage vulnerability				
17	(Rus et al. 2018)	Case Study	X	X	X	X	X	Urban resilience criteria in a holistic perspective				
18	(Sharifi 2019b)	Literature Review	X	X			X	Urban resilience criteria connected to street and streets network	X	X		
19	(Shrestha et al. 2018)	Case Study	X			X	X	Risk Perception Index connected to escape behavior				
20	(Wei et al. 2016)	Case Study	X		X			Lifecycle criteria analyses				
21	(Ye et al. 2012)	Case Study	X			X	X	Evacuation and escape index to build scenario				X
22	(Zhang and Wang 2016)	Case Study	X	X			X	Transportation network vulnerability index	X	X		

Open Space: AS - Areal Space; LS - Linear Space
1 - Main type; 2 - Characteristics of geometry and space; 3 - Constructive characteristics; 4 - Characteristics of use; 5 - Environmental characteristics

4. Discussion

The bibliometric analysis based, on the co-occurrence of the keywords and conducted using VosViewer software (van Eck and Waltman 2010), has been fundamental to categorize areas of intervention of DRR strategies. The process was repeated both on the initial research deriving from the Scopus database and on the selection of documents from the second stage. The figures (Figure 13 and Figure 14) compare the two networks, highlighting in the second's one, the greater relevance to the systematic review, as well as better defined clusters on DDR and open space. For the first neural map, among the 477 Keywords of the 143 relevant elements of the final stage, those with an occurrence of at least 2 (234 out of 477) were processed. In this map, the themes interpenetrate in a chaotic way, the terms used are redundant and non-specific (they are the keywords used by the authors of the documents), and it is not possible to identify well-defined clusters. While, for the final stage documents, among the keywords, we chose the ones with a minimum occurrence of 2 (40 out of 61). The map elaborated in this way helps to read the results and to individuate 4 clusters which shown thematic grouping around BE elements predisposed to DRR in urban areas, identified by the different colours. The discussion of the results, specifically of the documents containing reference indicators for the DRR, is articulated according to these 4 clusters:

- A first area inherent a **holistic approach** that seeks to combine social or management factors with risk reduction in the built environment (4.1);
- A second with a focus on **urban shape and morphology** (4.2);
- A third mainly oriented to **open spaces**, to planning and understanding the perception of risk (4.3);
- Finally, a quarter focuses attention on the **roads and paths** with analysis methods of the city's network. (4.4)

Documents are discussed in detail in the following paragraphs.

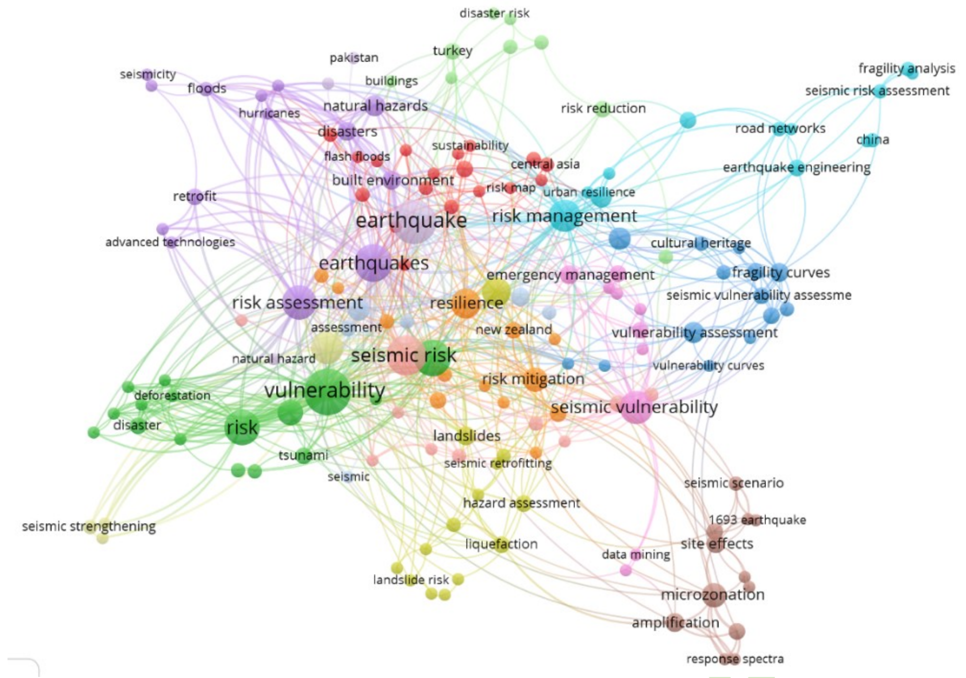

Figure 13: Neural network of recurring keywords in scientific literature documents examined through the VOSviewer software. The documents produced by the bibliographic research on Scopus are analyzed here

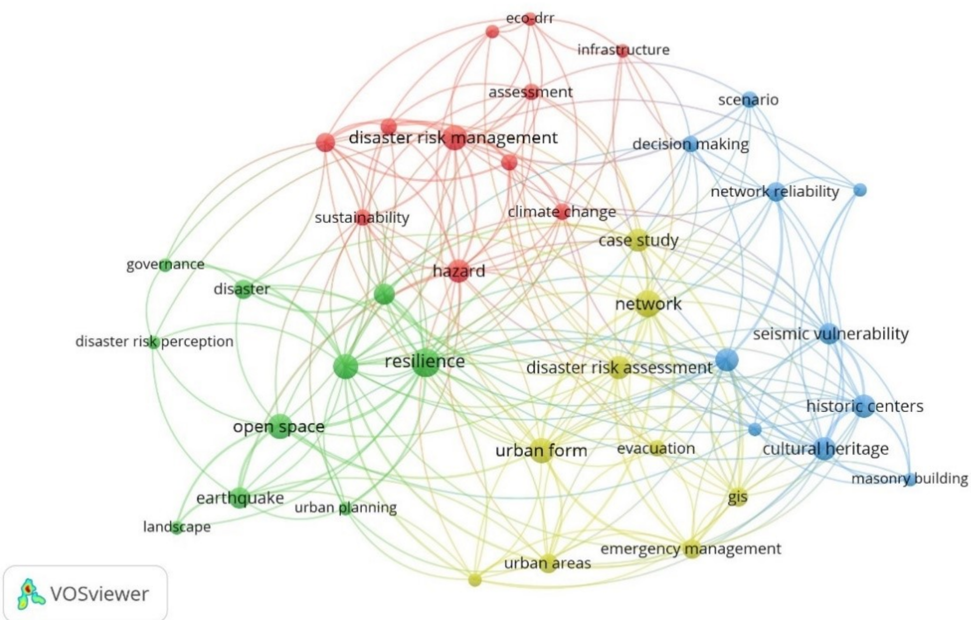

Figure 14: Neural network of recurring keywords in scientific literature documents examined through the VOSviewer software. The documents from final stage of the review are analyzed here

4.1 Holistic approach

The documents analyzed in this paragraph present a common holistic approach to the concept of resilience and the DDR in the urban context. These researches assume that the urban organism, as a complex system, is difficult to schematize in the summation of characteristics of the individual elements, albeit fundamental to evaluate, and the real difficulty is represented by the analysis of the relationships that exist between the individual components. The studies all present a variety of indices divided into various reference sectors, always considering also the social and management aspects, as well as the physical aspects of the built environment.

The main objective of Atrachali et al. study (Atrachali et al. 2019) is the definition of a quantitative procedure to define resilience (Figure 15), this is "first step" of a complex approach to analyze seismic resilience in the area studied in this paper, Iran. The specific aims of the study can be outlined as follows:

1. To provide a resilience indicator system compatible with localized features of urban fabrics;
2. To define the relative importance of the indicators (weighting process);
3. To define the key urban seismic resilience components and methods for their assessment;
4. To model the quantitative urban resilience;
5. To define the most important parameters of the indicators;
6. To evaluate urban seismic resilience in two selected divisions as the applicability test of the model.

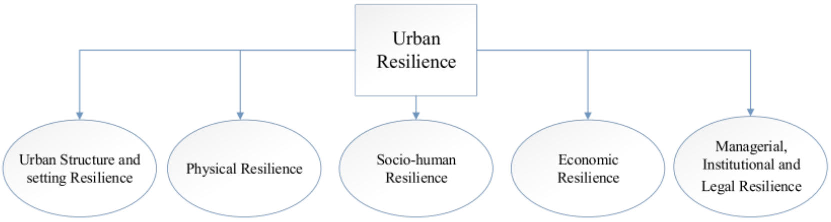

Figure 15: Main covered area by the indicator system (Atrachali et al. 2019).

These factors are classified in 5 categories: Urban structure; Physical resilience; Socio-human resilience; Economic Resilience; Managerial, Institutional and Legal Resilience (Figure 16).

Proposed resilience indicator system.

Sectors	Weight factors	Thematic areas	Weight factors	Indicators	Weight factors
Urban Structure and setting Resilience	0.19	Urban development commensurate with the level of hazard	0.63	I_{F1}=Compatibility of development and construction with the level of hazard	0.57
				I_{F2}=Comprehensive urban development plan	0.43
		Form and overall structure of the city	0.37	I_{F3}=Ratio of buildings height to streets width	0.14
				I_{F4}=Access to outdoor	0.24
				I_{F5}=City pattern	0.25
				I_{F6}=Time-worn urban textures	0.37
Physical Resilience	0.34	Buildings	0.39	I_{P1}=Vulnerability (structure type, age, No. of floors)	0.80
				I_{P2} = Usage	0.20
		Physical infrastructures for disaster management	0.30	I_{P3} = Fire stations	0.28
				I_{P4} = Hospitals	0.36
				I_{P5} = Rescuers access	0.36
		Urban infrastructures	0.31	I_{P6} = Water conveying network	0.19
				I_{P7} = Gas transmission system	0.23
				I_{P8} = Power distribution system	0.21
				I_{P9} = Telecommunication system	0.12
				I_{P10} = Road network	0.25
Socio – human Resilience	0.18	Understanding the disaster risk	0.22	I_{S1}=Level of people's awareness and sensitivity	0.61
				I_{S2}=Local risk management/emergency response team	0.39
		Human development index	0.22	I_{S3}=Trust and communication among people, officials and experts	0.21
				I_{S4}=Level of health	0.17
				I_{S5}=Level of education and training	0.29
				I_{S6}=Age	0.16
				I_{S7}=The relative welfare and hope to life	0.17
		Social contribution	0.21	I_{S8}=Collaboration	0.38
				I_{S9}=Existence and activities of NGOs	0.32
				I_{S10}=Holding emergency response drills	0.30
		Human vulnerability	0.35	I_{S11}=The level of population vulnerability in earthquakes (penetration rate of specific preparedness programs on earthquake)	0.45
				I_{S12}=Population density	0.55
Economic Resilience	0.15	Economic potential	0.63	I_{E1}=Financial capacity to implement policies and responding to the effects of the crisis	0.37
				I_{E2}=Ability to physical and economic recovery and reconstruction	0.37
				I_{E3}=Job	0.26
		Income	0.37	I_{E4}=Economic welfare	0.69
				I_{E5}=GDP per capita	0.31
Managerial, Institutional and Legal Resilience	0.14	Administrative and legal capacities of city	0.57	I_{M1}=Existence of disaster-oriented regulations	0.28
				I_{M2}=Enforcement and rule of laws	0.72
		Emergency management	0.43	I_{M3}=Early warning systems	0.49
				I_{M4}=Ability to manage delivery of resources to the most vulnerable populations and optimum use of existing resources	0.51

Figure 16: Proposed resilience indicator system *(Atrachali et al. 2019)*

This model combines the indicators and their weight factors linearly (Equation 1). One of the crucial parts of this model is the quantification of indicators. A qualitative method of assessment based on a five-level scale has been used. Each indicator can range from 0 to 1, and this range is divided into five equally separated levels (0.2-0.4-0.6-0.8-1.0). Final formula of resilience assessment from (Atrachali et al. 2019) (1) shows the 5 indices, and their weights, corresponds to the 5 thematic areas highlighted in Figure 15:

$$\textbf{Total Resilience} = (\mathbf{W}'_F \,.\, \mathbf{R}_F) + (\mathbf{W}'_P \,.\, \mathbf{R}_P) + (\mathbf{W}'_S \,.\, \mathbf{R}_S) + (\mathbf{W}'_E \,.\, \mathbf{R}_E) + (\mathbf{W}'_M .\, \mathbf{R}_M) \quad (1)$$

The process of "indicator selection" has been done with high care, because each selected indicator should be quantifiable and the required data for quantification should be accessible. The logic behind the development of the present model is based on the simulation of the different sectors of a city to serial springs. Hence, the final effect of an earthquake on a city can be considered as the summation of the individual effect of different sectors of a city.

Cerè et al. (Cerè et al. 2019) present a qualitative characterization of resilience for the built environment on an urban scale of analysis. The initial set of criteria consisted of 40 indicators, increasing to 48 at the end of the survey. The different criteria are clustered into seven categories, ranging from environmental to socio-organizational and technical (Governance & planning; Infrastructural; Utility services, Emergency & rescue services; Economy; Land use & urban morphology; Environmental) the most relevant for this study are reported (Figure 17).

Governance & planning criteria consensuses, *(IQR): interquartile range.

	First round	Mean	St.Dev.	IQR*
13	Scale of hazard governance strategy (e.g., flood prevention strategies at local, regional and national level)	4.61	0.739	1
14	Level of compliance to existing regulatory landscape	3.86	0.640	0.75
15	Presence of data sensing and acquisition for hazard forecasting	3.91	1.342	2
16	Education (from elementary or secondary school), training and communication	4.05	0.999	1.75
	Second round			
14	Scale of hazard governance strategy for hazard prevention and recovery (i.e., post-disaster reconstruction)	4.43	0.746	1
15	Effectiveness of previous disaster governance strategies	4.75	0.500	0.5
16	Level of compliance to existing regulatory landscape	3.76	0.831	1
17	Presence of monitoring and data collection (i.e., early warning systems)	4.13	1.170	1

Infrastructural criteria consensuses, *(IQR): interquartile range.

	First round	Mean	St.Dev.	IQR*
25	Presence of structural health monitoring systems of critical infrastructures (e.g., reservoirs, dams)	4.36	0.902	1
26	Connectivity level of transportation networks (e.g., railway stations, airports)	4.32	0.716	1
27	Level of maintenance regime of public infrastructures	4.05	0.722	0.75
	Second round			
28	Presence of structural health monitoring systems of critical infrastructures (e.g., reservoirs, dams)	4.33	0.856	1
29	Connectivity level of transportation networks (e.g., railway stations, airports)	4.33	0.796	1
30	Level of maintenance regime of public infrastructures	3.95	0.973	1.25
31	Accessibility and transport network proximity to emergency services	4.63	0.644	0.75

Emergency & rescue services criteria consensuses, *(IQR): interquartile range.

	First round	Mean	St.Dev.	IQR*
28	Redundancy of critical infrastructures (e.g., hospitals)	4.45	0.671	1
29	Spatial distribution of critical infrastructures	4.32	0.716	1
30	Emergency communications, access to warning systems and evacuation information	4.64	0.581	1
31	Availability and update of contingency plans (e.g., evacuation strategies, traffic management)	4.41	0.666	1
	Second round	**Mean**	**St.Dev.**	**IQR***
32	Redundancy of critical infrastructures (e.g., hospitals)	4.48	0.750	1
33	Spatial distribution of critical infrastructures	4.24	0.700	1
34	Emergency communications, access to warning systems and evacuation information	4.52	0.680	1
35	Availability and update of contingency plans (e.g., evacuation strategies, traffic management)	4.38	0.740	1

Land use & urban morphology criteria consensuses, *(IQR): interquartile range.

	First round	Mean	St.Dev.	IQR*
36	Urban fabric and development pattern	3.45	0.963	1
37	Population density (i.e., concentration of people per square kilometre)	4.41	0.590	1
38	Floor area ratio (FAR) on an urban scale (i.e., ratio between the sum of the buildings' floor surfaces and the urban centre area)	3.68	0.839	1
39	Building coverage ratio (BCR) on an urban scale (i.e., ratio between the sum of building external footprints and the urban area)	3.68	0.945	1.75
40	Buildings' height profile (e.g., Digital Surface Models techniques)	3.32	0.995	1
	Second round			
43	Urban fabric and development pattern	3.33	0.796	1
44	Population density (i.e., concentration of people per square kilometre)	4.38	0.669	1
45	Floor area ratio (FAR) on an urban scale (i.e., ratio between the sum of the buildings' floor surfaces and the urban centre area)	3.71	0.845	1
46	Building coverage ratio (BCR) on an urban scale (i.e., ratio between the sum of building external footprints and the urban area) based on satellite imageries and GIS techniques	3.69	0.814	1
47	Buildings' height profile (e.g., Digital Surface Models techniques)	3.52	1.167	1
48	Predominant Land use/type	3.71	0.916	0.5

Environmental criteria consensuses, *(IQR): interquartile range.

	First round	Mean	St.Dev.	IQR*
1	Single hazard (e.g., flood, earthquake, landslide, tsunami) vs multiple hazard occurrence (e.g., flood-earthquake, landslides- earthquake, earthquake- tsunami)	4.18	0.795	1
2	Geographical scale of hazard(s) (e.g., local, regional, territorial)	4.18	0.958	1
3	Intensity of hazard(s)	4.82	0.395	0
4	Scenario probability (i.e., likelihood of occurrence of a specific disruptive condition)/identification of the most probable scenario	4.23	0.869	1.75
5	Site location (e.g., altitude, urban or country area, flat or mountainous site)	4.32	0.780	1
6	Local environmental factors (e.g., pollution, chemical aggressiveness, vibrations)	3.23	0.685	1
7	Geotechnical awareness of the area (e.g., drill cores, investigations, maps)	3.36	0.902	1
8	Ground typology (e.g., classification according Eurocodes)	2.91	0.971	2
9	Level of exposure to snow (according to Eurocodes)	2.50	0.859	1
10	Class of exposure to wind and terrain category (according to Eurocodes)	3.00	0.976	1.75
11	Level of engineering alterations with potential impact on the soil properties (e.g., mines, deforestation, fuel extraction)	3.36	0.902	1
12	Presence of hazardous industrial areas (e.g., nuclear plants)	3.77	1.307	2.75
	Second Round			
1	Number and specific typology of hazard(s) simultaneously occurring in the disaster scenario	4.33	0.730	1
2	Geographical scale of hazard(s) (e.g., local, regional, territorial)	4.24	0.831	1
3	Intensity/magnitude of hazard(s)	4.52	0.680	1
4	Hazard return period	4.10	0.831	1
5	Site location (e.g., altitude, urban or country area, flat or mountainous site)	4.29	0.644	1
6	Local amplification and environmental factors (e.g., pollution, chemical aggressiveness, vibrations)	3.10	0.831	0.25
7	Geotechnical awareness of the area (e.g., drill cores, investigations, maps)	3.86	1.153	2
8	Soil typology (e.g., classification according Eurocodes)	3.50	1.118	1
9	Level of exposure to snow (according to Eurocodes)	2.95	0.805	0.5
10	Class of exposure to wind and terrain category (according to Eurocodes)	3.19	0.602	1
11	Level of engineering alterations with potential impact on the soil properties (e.g., mines, deforestation, fuel extraction)	3.57	0.746	1
12	Presence of hazardous industrial areas for potential disaster chain occurrence (e.g., nuclear plants)	3.86	1.014	2
13	General climatic type according to Köppen classification (e.g., continental, temperate, tropical)	2.46	0.660	1

Figure 17: Indicators for qualitative characterization of resilience for the built environment (Cerè et al. 2019)

Noticing the relationship between risk perception and disaster risk reduction improved over time, Marshall (Marshall 2020) elaborate a more integrative framework that could explicitly combines the concepts of risk perception and safety culture. These can offer a beneficial approach to DRR. In this paper, risk perception and safety culture studies and their connection were highlighted. The approach used by Marshall to argue with these matters is to start from a review of risk as a natural problem, to define a global focus on reducing risk and on analyzing risk perception and safety culture, to use this knowledge to contribute to DRR in the following ways:

1. Facilitating the capturing and understanding of complex social interactions on safety behaviors along with the consideration of the spatial and temporal elements within society.
2. Facilitating the capturing of the risk perception and safety culture at a polycentric and multiscale - decision-maker, expert and layperson.
3. Providing an iterative tool that can be utilized for risk assessment. Its application within the risk assessment process contributes to deciding who might be harmed and how through the evaluation of risk perception and safety culture. Which then feeds into the prevention and mitigation stages of the disaster management cycle by addressing the findings of the evaluation.
4. Contributing to the explicit use of safety culture within the DRR context, through the determination of safety culture at the societal level.

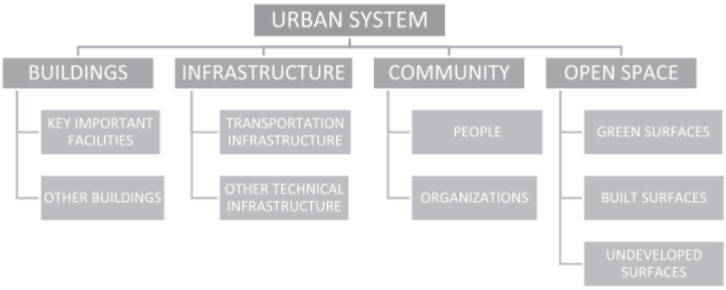

Figure 18: Division of the urban system (Rus et al. 2018)

Rus et al. (Rus et al. 2018) applies a holistic approach to the study of the “resilience assessment of complex urban systems to natural disasters”. Their concept consists of three different parts: a probabilistic fragility analysis for each physical element (i.e. a building or an infrastructure element), (ii) a composite index methodology for the measurement of community disaster resilience, and (iii) a complex network approach (graph theory) for the assessment of the resilience of urban systems as a whole. In the conclusion of the paper, the authors defined the division of an urban system (Figure 18) in subcomponents, as reported in Figure 21.

With a focus on the resilience assessment of urban systems as a whole, three main methodologies with some modifications within individual categories were recognized in the reviewed papers (Figure 19). Whereas the first two methods are related to system vulnerability and risk evaluation, the third method comprehensively assesses resilience, including all phases of preparedness, response, recovery, and adaptation.

Starting from their literature review based on the newly performed literature, the following findings can be made: only a few studies deal with the resilience assessment of an urban system as a whole (and the methodologies reviews are reported in Figure 19), taking into account the relationships and interactions between multiple urban components; there is a lack of studies of the system recovery phase; given the available metrics, time-dependency of the system resilience is often neglected; as a measure for system performance, only one figure-of-merit is usually used; in existing quantitative approaches to the resilience assessment of urban systems the social aspect is frequently considered in a very simplified or limited way, which means that some important issues may be neglected; open space and its potential are usually ignored in the case of studies about the quantitative assessment of the seismic resilience of urban systems.

Observed resilience phase	Resilience metric	Assessment technique	Application
Preparedness, response	$V = w_1 v_s + w_2 v_{12} + w_3 v_{22};\ \sum_{i=1}^{3} w_i = 1$	Weighted composite index, fragility analyses, GIS tools	Eskisehir, Turkey
Preparedness	$R_T = R_F(1 + F)$	Weighted composite index, fragility analyses, GIS tools, fuzzy set theory	Barcelona, Spain; Bogota, Colombia; Medellín, Colombia
Preparedness, response, recovery and adaptation	$R = \frac{\int_0^{C_{max}} y(C)dC}{C_{max}}$	Network and graph theory, fragility analyses, GIS tools	Accera, Italy; Sarno, Italy; hypothetical urban networks

Figure 19 The main methodologies used for the resilience assessment of urban systems as a whole (Rus et al. 2018)

Regarding Figure 19, the preparedness and response metric refers to an overall urban vulnerability index V, where v_s = the structural vulnerability index; v_{12}= the socio-economical vulnerability index; v_{22}= the vulnerability index for accessibility to critical services; and w_i= the wight of a vulnerability component *i* (*i* =

1,2,3). For preparedness the metric refers to R_T as the total risk index, R_F is the physical risk index and F is the aggravating coefficient. This coefficient is a composite indicator and depends on the weighted sum of a set of aggravating factors related to socio-economic fragility and a lack of resilience. The physical risk is calculated starting from a probabilistic risk scenario developed within the scope of the framework of the Risk-UE project. While for the aggravating coefficient F, Rus et al. (Rus et al. 2018) comment that most contribute are the population density and the number of public areas, respectively. The last metric concern the resilience of an urban system as the area under the recovery curve expressed from R equation in Figure 19, where C_{max} is the total number of people to be relocated after a certain event.

Wei et al. (Wei et al. 2016) explore the role of natural hazards from the perspective of building long-term environmental performance, as well as the environmental value of hazard mitigation. Accordingly, an innovative lifecycle assessment (LCA) framework is proposed that can incorporate building damage due to hazards and convert these data into quantifiable environmental metrics. Moreover, by incorporating buildings' environmental impacts attributable to hazards as derived from the LCA framework, a benefit-cost analysis (BCA) is achieved to justify the environmental desirability of hazard mitigation actions.

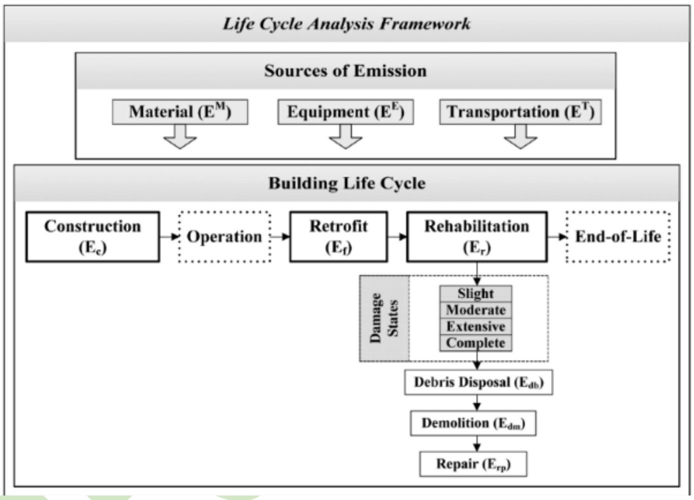

Figure 20: LCA framework (Wei et al. 2016)

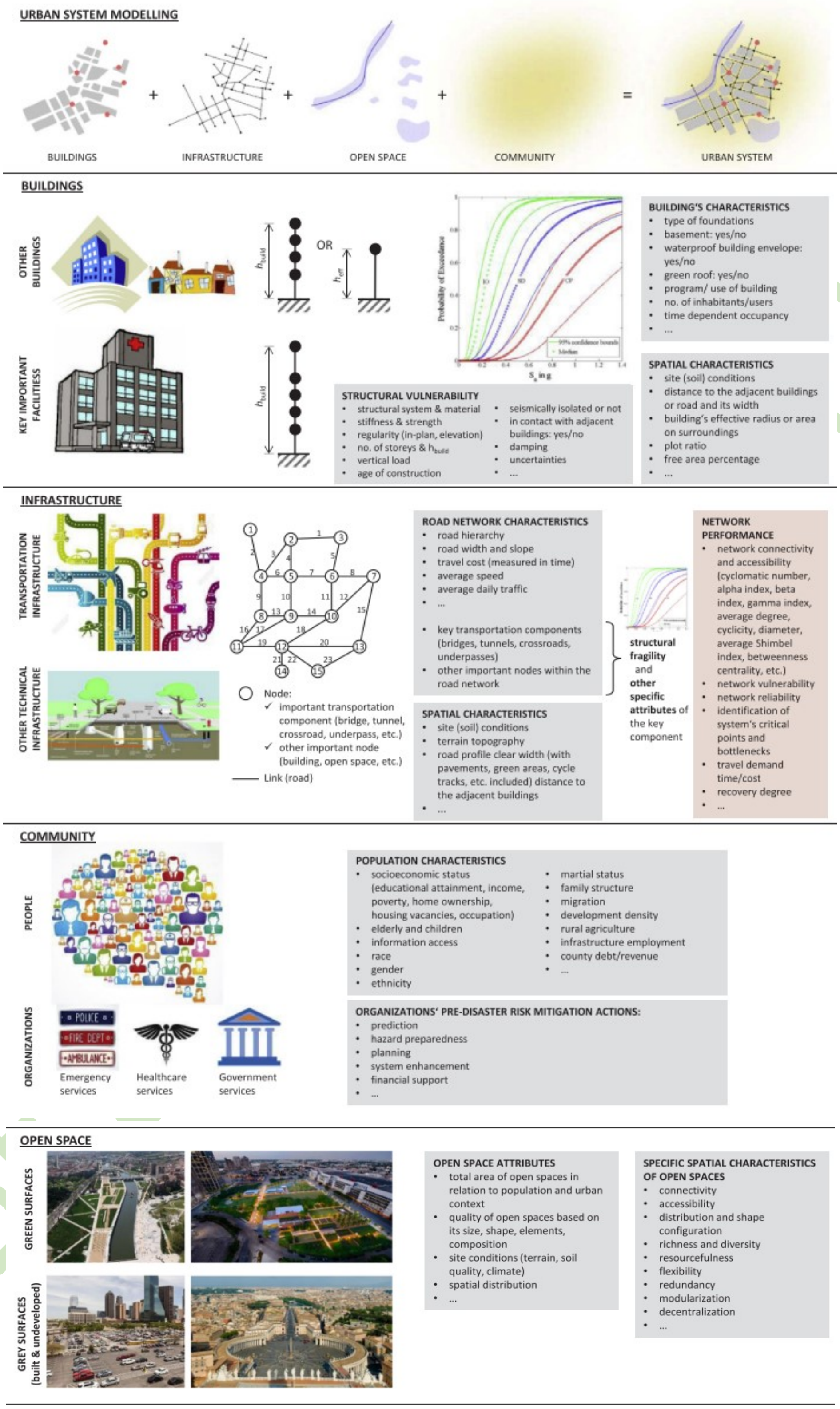

Figure 21: Concept of the modelling of an urban system, its (sub)components and their attributes (Rus et al. 2018).

The metric adopted affirm that, for a given building inventory at seismic risk, an E_p curve (Exceedance Probability) [%] is a probabilistic representation of a certain level of loss that will be exceeded in a given return period. The expected average annual benefits, in terms of emissions reduced by mitigation to a given portfolio, can be obtained by calculating the difference in average annual loss (AAL) [10^6 kg-CO_2] between as-built and retrofitted cases, as shown in the equation 2. Consequently, the total expected benefits over a building's entire service life can be obtained by multiplying the average annual benefit (AAB) [10^6 kg-CO_2] by service lifetime (T). Finally, the BCR (the Benefit-Cost Ratio in terms of CO_2 emission) can be arrived at by dividing the total expected benefit by the up-front cost of mitigation E_f [CO_2]. The hazard risk mitigation action can be seen as environmentally justified when the BCR is greater than 1 (Equation 2).

$$Ep_i = 1 - \prod_{j=1}^{i}(1 - p_i) \qquad \mathrm{AAB} = \mathrm{AAL}_{\text{as-built}} - \mathrm{AAL}_{\text{retrofitted}} \tag{2}$$

$$\mathrm{AAL} = \sum E(L_i) = \sum p_i \cdot L_i \qquad \mathrm{BCR} = \frac{\mathrm{AAB} \cdot T}{E_f}$$

4.2 Urban form and urban morphology

Boukri et al. (Boukri et al. 2018) elaborate a classification based on parameters that narrowly influence the observed damage during past earthquakes. These parameters are the building materials, building systems, applied seismic code, age, usage, and the number of stories. The scoring system proposed by Foo and Davenport (Foo and Davenport 2003) is made up of a structural index (SI) and a non-structural index (NSI). SI is related to the possible risk to the building structure and NSI is related to the risk of non-structural building components. The non-structural index (NSI) (Equation 3) and structural index (SI) (Equation 4), are dimensionless, refer to the indicators explicated in Figure 22, and calculated as follows:

$$\mathrm{NSI} = B \times E \times F \tag{3}$$

$$\mathrm{SI} = A \times B \times C \times D \times E \tag{4}$$

Where the letters correspond to different values of:

(A) Seismicity
(B) Soil condition
(C) Type of structure
(D) Building irregularities
(E) Building importance (occupancy)
(F) Non-structural hazards (life safety and operation requirement)

This challenge aims to define a method that includes all-hazard mitigation levels. The vulnerability index method (VIM) adopted by Liu et al. (Liu et al. 2019) to assess the seismic vulnerabilities of buildings in Urumqi is based on the RISK-UE project (starting from the studies of Lagomarsino and Giovinazzi), which was launched in 1999 and involved seven cities throughout Europe and around the Mediterranean Sea, namely, Barcelona (Spain), Bitola (Macedonia), Bucharest (Romania), Catania (Italy), Nice (France), Sofia (Bulgaria), and Thessaloniki (Greece). Due to its compatibility with the EMS-98 standard, the VIM has been widely applied to other areas worldwide. A building typology matrix (BTM) is a typological classification that reflects the differences among various types of structures that are expected to display similar seismic performances.

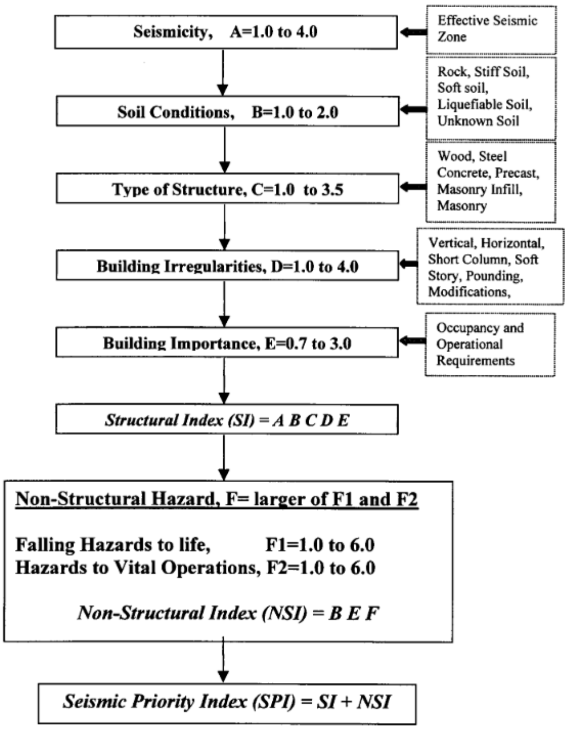

Figure 22: The process of definition of indicators (Boukri et al. 2018)

Basic vulnerability indices are attributed to each typology class corresponding to the median value $V^*_{I;\,BTM}$ and to the lower ($V^-_{I;\,BTM}$) and upper ($V^+_{I;BTM}$) bounds of the possible values of the vulnerability index. Modifier factors are then applied to V^*_I in consideration of various physical factors, including the height, irregularities, and position. The final vulnerability index is the sum of all possible factors as follows (Equation 5):

$$\overline{V_I} = V_I^* + \Delta V_R + \Delta V_m \qquad (5)$$

where V^*_I is the vulnerability index corresponding to the building classification, V_R is a regional vulnerability factor considering the characteristics of the region or building period, and V_m is the seismic behaviour modifier that includes all other aspects of the seismic performance.

The building vulnerability part of this method is analyzed more deeply in the report D1.2.1., while here is considered and studied the important aspect regarding the casualties that signify the main "damages". In fact, the objective of this report is focused on the reduction of them due to the organization of disaster risk mitigation plans.

Heavy damage or the collapse of structures is the main reason for casualties (deaths and important wounds) during an earthquake. During a study connected to the number of casualties the factors that are important to keep in the count are: the number of persons that are considered to be present inside these buildings, the number of damaged buildings. The number of people that are count into a building on both building class and time period (night or day) of occurrence of the seismic event were considered. The model proposed is and shown in Figure 23 is the one used by the RADIUS methodology, developed by Coburn et al. (Coburn et al. 1992; OYO Corporation 2000)

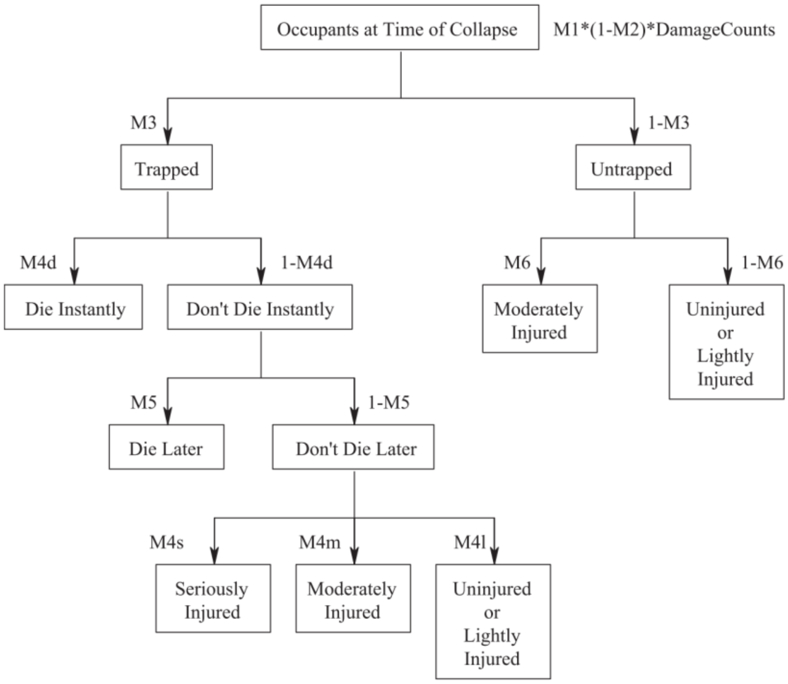

Figure 23: Flowchart of RADIUS methodology uses the model developed by Coburn et al. (Boukri et al. 2018). M1 is the number of people in each building; M2 represents the occupancy ratio at the time of the earthquake; M3 represents the number of people "unable to escape from under" the debris; M4d is the death ratio at the instant at which the building collapses; M5 represents the death ratio before the arrival of reliefs and rescue teams (number of people who did not die instantly); M6 represents the number of people moderately injured.

The objective of this method is to evaluate the number of deaths and injuries during an extreme event (moderate and severe). In the RADIUS methodology the following aspects are taken into account:

- Depending on the number of people present in the buildings during the earthquake, the percentage of those who cannot escape during the collapse is estimated;
- It is assumed that part of the people present in the building during the collapse will die instantly due to debris impacts and shocks from the falling of floors and roofs, or by suffocation;
- For people who will not die instantly, but cannot escape by themselves from under the debris, a number of them will die as time passes away;
- The success of relief operations depends mainly on time and speed of response and rescue. The percentage of persons rescued is almost null after 72 h because their majority will succumb under the debris.
- The number of victims per cell or area also depends on the buildings' class and the event occurrence time (day or night).

This is very interesting given the development of DRR strategies and for the drafting of emergency plans and the evaluation of appropriate risk reduction measures on an urban scale.

Rapone et al. (Rapone et al. 2018) study, moving from L'Aquila post-earthquake damage analysis, defined a method for seismic vulnerability assessment. L'Aquila case study was useful to calibrate the method. This method focuses in particular on building scale analyses as it can be seen from the table in which are reported Rapone's vulnerability parameter, analyzed in the D.1.2.1. report (Figure 24). Here we want to focus on the possibility of the application of the method to define potential damage scenarios for several earthquake intensities. The analysis of the scores, obtained by the inspections of the buildings, has allowed understanding, also with the support of GIS representations (Figure 25), which are the main sources of vulnerability that have to be faced employing proper mitigation measures. The method is based on the definition of the "fragility" and "protection" scores (v_{kf} and v_{kp}) distributions of the vulnerability parameters. These results could be profitably used for the evaluation of possible mitigation measures that could be adopted to reduce the seismic vulnerability of the center of Scanno. Vulnerability parameters presenting higher frequencies related to the score v_{kf}, or, rather, lower frequencies of scores v_{kp}, represent the main sources of fragility for which it is necessary to apply mitigation intervention prior.

Vulnerability Parameter	Vulnerability type	ρ_k
P_1	Position (in the cluster)	1.5
P_2	Number of storeys	1.5
P_3	1st mode mechanism	1.5
P_4	2nd mode mechanisms	1.0
P_5	Arches	1.0
P_6	Vaults	1.0
P_7	Slabs	1.0
P_8	Thrusting forces	0.8
P_9	Presence of added structures	0.5
P_{10}	Stairs	1.0
P_{11}	Non regularities	0.8
P_{12}	Non Structural elements	0.5
P_{13}	Site effects	1.5
P_{14}	Non Seismic external hazard	0.3

Figure 24: Vulnerability parametres (Rapone et al. 2018)

P3

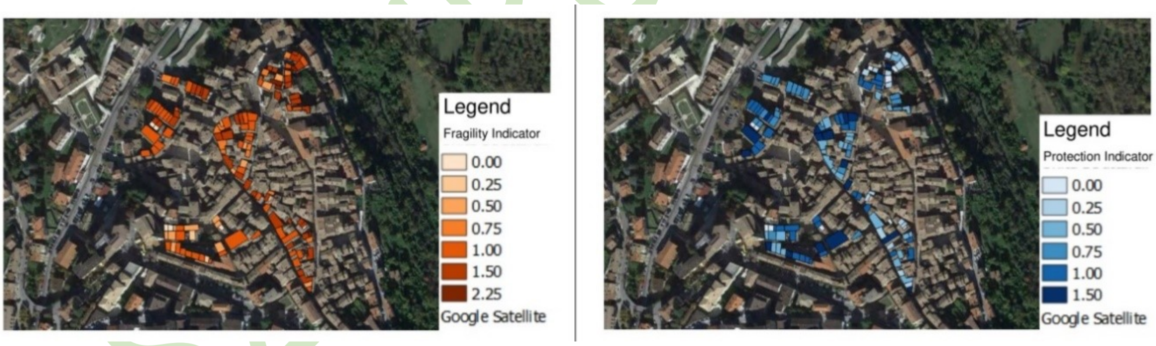

Figure 25: Example of GIS representation of the vkf and vkp scores for the studied buildings (Rapone et al. 2018)

The evacuation route in historical centers moving from the analyzes of urban morphology is assessed by (Srinurak et al. 2016). This research program is useful and central for the planning of urban mitigation strategies that are highly needed in the present day. According to Srinurak, historical accessibility character and its morphology are the objectives of studying urban fabrics. This study focuses in particular on urban networks, but other items connected to urban morphology, such as building usage, egress point, and its condition are also studied and consider as particular conditions. In this work, urban morphology is consider starting from their two fundamental aspects: one regarding spatial aspects and the other connected to human activities, this aspect regards how the network is chosen.

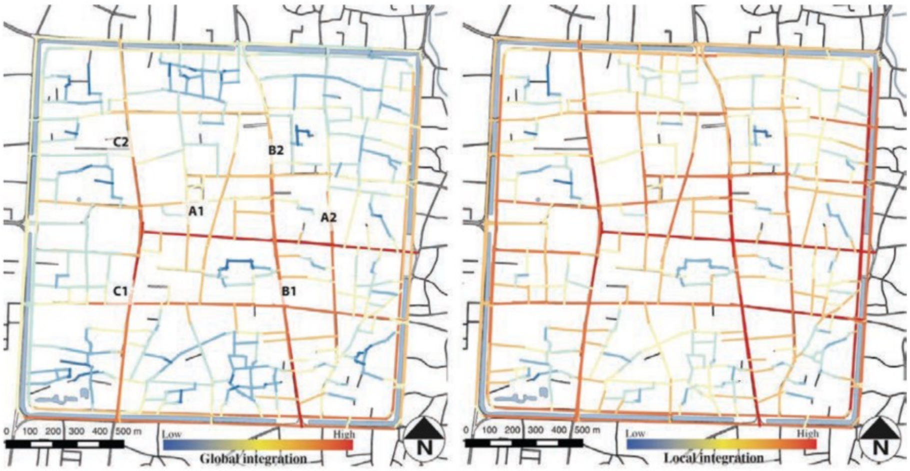

Figure 26 Global integration axial map and Local integration axial map (Srinurak et al. 2016)

According to the study conducted from Srinurak in Chiang Mai the Intelligibility coefficient value (R2=0.3478, Mean integrate=1.38) was low. It could interpret that spatial configuration may cause tourists or outsiders in a moderate incident of lostness. Primarily cause of lostness also showed in a syntactic map, it has complicated subnetwork. The coefficient identifies as the Synergy coefficient, presents the possibility to an integrated urban network to travel through (R2=0.75) due to involve of deform-grid and blocks of a residential area. Thus, coefficients could be explained: for outsiders or tourists, the extraordinary event is of course worst because of lostness due to labyrinth. Instead, for residents, it may be easy to move inside their city between the defined networks (Figure 26).

The egress point from buildings analysis had been define, from Srinurak and categorized in 5 types consist of:

1) Normal access; egress point from a building that had 1-5 meters width.
2) Large access; egress point that had more than 5 meters width.
3) Service access; egress point that origin from service access or secondary access to the building.
4) Fire-exit; egress point that determined to be emergency access
5) Un-use access; the unused access of buildings.

It is important to notice how narrow streets, may be unable to support the density of buildings in the present-day due to street character it can cause congestion when a disaster occurs.

Quagliarini et al (Quagliarini et al. 2019) elaborate on the application of an aggregate vulnerability assessment method following the conservative approach. Hence, missing information lead to apply the worst vulnerability conditions. In particular, parameters concerning “Construction age or last intervention date” and “Presence of buildings without box behavior” cannot be remotely retrieved without local surveys. So, this study always applies the worst conditions to such parameters (Figure 27). This work is structured in the following phases:

1. definition of a simplified methodology (and its related sources) for remote surveys and data collection techniques to be applied to two well-known and reliable MVAMs
2. application of the simplified MVAMs to a sample of buildings/aggregates affected by real-world earthquakes

3. comparison between the simplified MVAMs-based predicted and experimental damage degree coming from real cases observation are analyzed to validate the novel remote approach;
4. definition of an empirical formula to reach a MVAMs-based aggregate seismic vulnerability index from the MVAMs-based seismic vulnerability of each structural units composing the aggregate itself;
5. application of this formula to the same previous employed sample, to compare results to an already existing method (SISMA) for assessing the aggregate seismic vulnerability. This phase could be considered as a first attempt to prove the reliability of the proposed methodology.

	Parameters	Contribution range (v_p)	Weight (w_p)
1	Volumetric differences in elevation	0-0.6	1.0
2	Planar volumetric differences	0-0.6	1.0
3	Maximum differences between number of building floors and the average number of floors	0-1	0.6
4	Differences in materials and in constructive typologies	0-1	0.6
5	Construction age or last intervention date	0-1	0.6
6	Not aligned opening / staggered floor presence	0-1	0.6
7	Presence of buildings with non-box behaviour	0-1	0.4
8	Aggregate overall shape / planar symmetry	0-1	0.4
9	Conservation state / maintenance deficiency	0-1	0.6
10	Geomorphology of aggregate foundation	0-1	0.4

Figure 27: Vulnerability parametres (Quagliarini et al. 2019)

The vulnerability parameters of this document are analyzed in detail in the D.1.2.1 report, but here we want to analyze and focuses on the possibility of this approach to additionally permit to maintain a satisfying estimation of the damage grades suffered by historical buildings during earthquakes, intending to define urban scenarios modification induced by the earthquake. With this method, the vulnerability maps used could allow taking under control huge risky areas of historical centres. The representation of which elements are more critical safety situations is the base point to define a useful scale of priority for the interventions. Furthermore, as proposed by the authors, some rapid tools should be proposed to define risk reduction planning strategies to increase the inhabitants' safety level.

4.3 Open spaces

The relationship between the BE in an urban context and seismic risk perception is the object of Shrestha et al. (Shrestha et al. 2018) work. This study focuses on this relation connected to open spaces conducting a comparative study between two communities in Kathmandu in 2015 post-earthquake contest. Escape behaviour was examined, in relation to open spaces, by analyzing the correlation with a risk perception index (RPI) (Figure 28). This paper aimed to identify and analyses the relationship between open spaces and seismic perception of risk through an analysis of the actual response of people during and after the 2015 Nepal earthquake. The results indicate that open spaces are a key component of disaster response which directly or indirectly affects people's perception of seismic risk. It was found that medium-sized communal spaces are preferred within proximity of 200m as immediate safe destinations (example of analysis elaborated in Figure 29). The choices for such spaces are dependent on the built environment of the site given by its layout, landmarks, building density, and building height. For temporary shelters in the during-earthquake phase, the availability of necessary infrastructure and services is relevant whereas for long term shelter needs the ownership of the open spaces, economic capability as well as local institutions become more important.

S.N.	Indicators	Denotation of value	Rationale
1	Awareness of earthquake safety before the event	Yes: 0 No: 1	Awareness of earthquake safety enables people prepare for a seismic event and helps them for a safe response during an actual event
2	Perceived preparedness against earthquake before the event	Strongly agree: 1 Agree: 0.75 Neutral: 0.5 Disagree: 0.25 Strongly disagree: 0	People who view risks to be real are more like to act on them (Slovic, 2000). Thus a negative relation can be established between preparedness and perceived risk.
3	Perceived effect to personal life	Strongly disagree: 0 Disagree: 0.25 Neutral: 0.5 Agree: 0.75 Strongly agree: 1	People who have been strongly affected by the earthquake will perceive the risk to be higher as the risks have been realized and experienced.
4	Willingness to move away from the community (specifically asked in relation to the earthquake)	No: 0 Yes: 1 Unsure: 0.5	People's desire to move suggests an increase in perception of risk. For people who are unsure, the value is taken at the middle.
5	Anticipation of earthquake event in near future	No: 0 Yes: 1 Don't remember: 0.5	People who do not anticipate an earthquake means they were either in denial or did not expect one in the near future. This suggests they were also aloof of the risk and thus perceive it to be low. For people who do not remember, the value is taken at the middle.
6	Location of stay after 1st earthquake	Within community: 0 Outside community: 1	People will stay where they feel the safest during the disaster. Availability of water, food, shelter, electricity, toilets and community support are also some of the factors that affects this decision.
7	Location of stay after 2nd earthquake	Within community: 0 Outside community: 1	People would stay in locations where they feel the safest during the disaster. Availability of water, food, shelter, electricity, toilets and community support are also some of the factors that affects this decision.
8	Perceived safety within the community (safer)	Strongly disagree: 1 Disagree: 0.75 Neutral: 0.5 Agree: 0.25 Strongly agree: 0	People who felt safe within the community means they perceive the risk to be less or acceptable there.
9	Perception of community bond to be high	Strongly disagree: 1 Disagree: 0.75 Neutral: 0.5 Agree: 0.25 Strongly agree: 0	Strong community bonds will have a positive influence to risk perception because people have more trust among themselves.

Figure 28: Selected indicators for RPI (Shrestha et al. 2018)

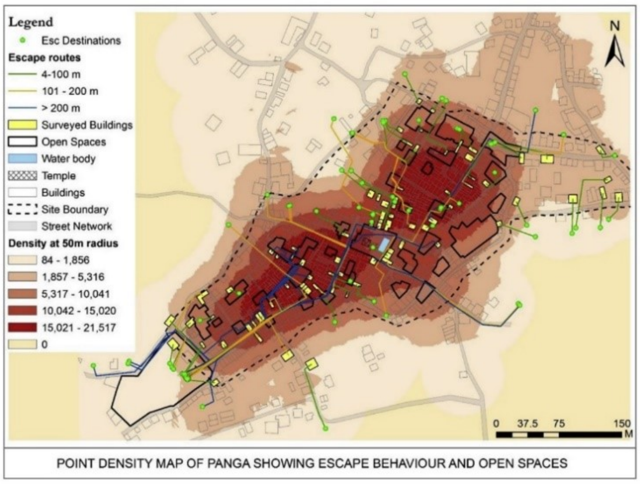

Figure 29 Escape behaviour and open spaces presented over point density map of Panga (Shrestha et al. 2018)

The work of (Quagliarini et al. 2018) aims to offer a preliminary and quick holistic method for seismic risk assessment and damage level estimation of possible evacuation paths. Firstly, data about safety influencing factors (i.e.: path use and exposure; geometric features; physical-structural features; extrinsic vulnerability; seismic hazard) are collected, associated to related weights and organized in risk indexes according to three calculation approaches, as shown in Figure 32 (Modified Cherubini's approach; Expert judgment; Analytical hierarchy process). According to a general risk assessment approach, the evacuation path risk depends on the combination between: hazard, mainly in terms of soil category, morphology and topography, local amplification phenomena also related to the position of the historical urban fabric (e.g.: on the top of a hill); vulnerability as a function of: intrinsic vulnerability, which relates to the elements composing the street itself, the related infrastructural elements (i.e.: street pavements, foundations, embankment, and lifelines) and the interfering elements, such as underground structures); extrinsic vulnerability, which refers to the elements that do not directly belong to the path itself but can compromise or block it (i.e.: buildings that can collapse by blocking facing streets because of debris formation) due to the typical scenario of historic city centers (i.e.: narrow streets with high facing buildings; network complexity); possible exposure conditions (i.e.: high density of citizen, tourists' presence, mass-gathering events). From this point of view, the proposal of a holistic risk index concerning evacuation paths network elements can help safety planners to understand which factors are effectively able to affect safety conditions (before/during the emergency); design proactive risk-reduction strategies (i.e.: interventions on buildings); design evacuation plans (i.e.: safest path choice) leading to efficient rescue operations' management in historical scenarios. Correlations between risk, event intensity, and earthquake-induced damages could be able to offer additional data for emergency scenario characterization. Dividing criteria in two macro groups made it possible to identify criteria connected to linear spaces and criteria connected to areal spaces (Figure 31). In this method, risk indices are assessed for each link and node. In order to graphically evidence the riskiest paths within the urban fabric, a Seismic Risk Map is proposed and an example is shown in Figure 30. This can be a tool for supporting emergency management directly obtained from the proposed methodology application (regardless of the calculation approach).

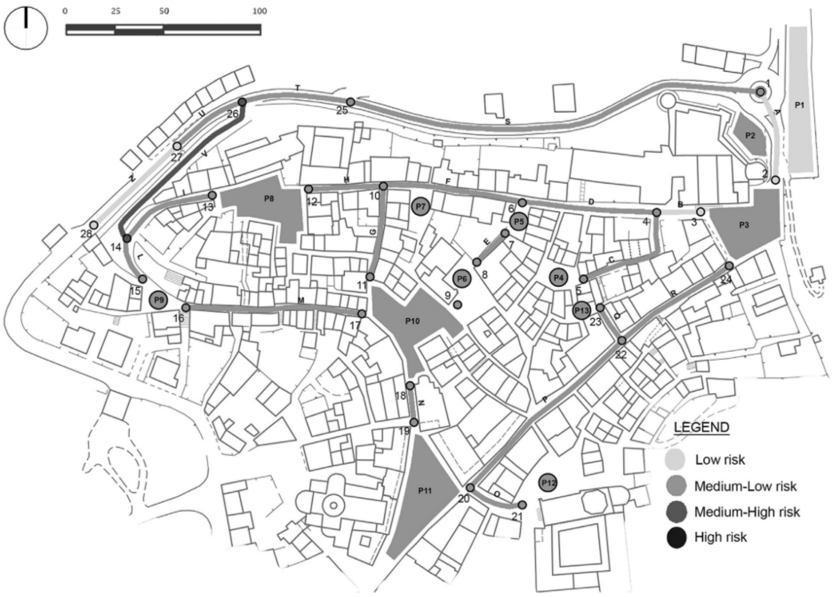

Figure 30 Seismic Risk Map of the selected part of Offida (AP) paths network (Quagliarini et al. 2018)

ID	Factors	ID	Parameters	Alternatives
A	Path analysis	A.1	Link code 1° Node code 2° Node code	– – –
		A.2	State	Clear Partially obstructed Obstructed
B	Exposure	B.1	Street type	Interconnection Access
		B.2	Direction of travel	Single Double
		B.3	Carriageway	Separated Unique
		B.4	Path type	Urban Suburban
		B.5	Average Flow	Low Medium High
C	Geometric features	C.1	Length (m)	$0 < L \leq 0.33\ L_{max}$ $0.33\ L_{max} < L \leq 0.67\ L_{max}$ $0.67\ L_{max} < L \leq L_{max}$
		C.2	Width (m)	$0.67\ W_{max} < W \leq W_{max}$ $0.33\ W_{max} < W \leq 0.67\ W_{max}$ $0 < W \leq 0.33\ W_{max}$
D	Physical-structural features	D.1	Finishing surface	Asphalted Paved Rough
		D.2	Potential landslides	No landslide, retaining walls in both sides Landslide, retaining walls in one side Landslide, no retaining walls
		D.3	Underground elements	Low-risk pipes High-risk pipes Caves, cisterns or cavities
		D.4	Conservation state	High Medium Low
		D.5	Street Typology	Level link Hillside link, with retaining walls Hillside link, without retaining walls Tunnel Bridge and viaduct
E	Extrinsic vulnerability	E.1	V_{Nlink}	$0 < V_{Nlink} \leq 25\%$ $25\% < V_{Nlink} \leq 50\%$ $50\% < V_{Nlink} \leq 75\%$ $75\% < V_{Nlink} \leq 100\%$
F	Seismic hazard	F.1	Design ground acceleration (a_g)	$a_g \leq 0.05\,g$ $0.05\,g < a_g \leq 0.15\,g$ $0.15\,g < a_g \leq 0.25\,g$ $a_g > 0.25\,g$
		F.2	Ground type	A B C D E
		F.3	Topographic amplification factor	T1 T2 T3 T4

ID	Factors	ID	Parameters	Alternatives
B	Exposure	B.1	Usage	Wide crossroad Pedestrians' zone Parking area
		B.2	Presence of obstacles	Absence Presence
		B.3	Square type	Urban Suburban
		B.4	Average Flow	Low Medium High
C	Geometric features	C.1		$0.67\ A_{max} < A \leq A_{max}$ $0.33\ A_{max} < A \leq 0.67\ A_{max}$ $0 < A \leq 0.33\ A_{max}$
D	Physical-structural features	D.2	Potential landslides	No landslide, retaining walls in more than one sides Landslide, retaining walls in one side Landslide, no retaining walls
		D.5	Square Typology	Level Square Hillside Square with retaining walls Hillside Square without retaining walls

Figure 31: Assessment for OS from Quagliarini, links on the left and squars on the right.

	[19]	Modified Cherubini's approach	Expert judgement	Analytical hierarchy process
Modified parameters and factors		Added the parameter "Underground elements" in Physical-structural features factor Added the factor "Extrinsic vulnerability" with a single parameter (*Vlink*) Added the factor "Seismic hazard" with following parameters: "Design ground acceleration", "Ground type" and "Topographic amplification factor"		
Values	Cherubini's approach	Values are given following Cherubini's approach	Values are given by the Expert judgement	Given through Analytical Hierarchy Process
Weights	Cherubini's approach	approach	Weights are given by the Expert judgement	Two sets of weights are given for each factor and parameters through the Analytical Hierarchy Process
$I_{R,j}$ calculation approach	The weighted sums are firstly normalized on factors maximum obtainable value and then on related weight for each factor	The weighted sum is firstly normalized on factors maximum obtainable value and then on related weight for each factor	The index is obtained through the sum of Sp_{iK} values weighted on related Wc_K for each factor	The calculation is given by a first weighted sum on Wi_K for each parameter and then on Wc_K for each factor
$I_{R,j}$ formulation	$\sum_{K=1}^{5}\left[\frac{(\sum_i Sp_{iK})}{(\sum_i Sp_{iK}^{MAX})}*Wc_K\right]$	$\sum_{K=1}^{5}\left[\frac{(\sum_i Sp_{iK})}{(\sum_i Sp_{iK}^{MAX})}*Wc_K\right]$	$\sum_{k=1}^{5}(\sum_i Sp_{iK}*Wc_K)$	$\sum_{k=1}^{5}((\sum_i Sp_{iK}*Wi_K)*Wc_K)$

Figure 32: Features of the three calculation approaches (Quagliarini et al. 2018)

4.4 Road and paths

(Ahn et al. 2011) work aim is to study the correlation between the number of road blockages. The main focus was connected to cultural heritage disaster mitigation in historical cities to build the capability of regional disaster mitigation in Kyoto. The first step is the identification of the important roads: the one that. connect the historical city centre and fire stations, as well as even roads that are frequently used are pointed out as significant roads. The following phase consists of evaluating the road passage rate at the time of disaster this is calculated for all important roads. In recent studies, it was also taken in count building conditions of the road identify as significant. Due to this study, a method to evaluate the road blockage rate is proposed. At least, the vulnerability of road sections is taking in count starting from the road passage rate calculated using the defined method.

The study verified that the probability distribution of the number of road blockages follows the Poisson distribution. The following model is built to represent the probability of road blockade in arbitrary link length according to road width. The Poisson distribution is generally expressed as follows (Equation 6):

$$p_k = \frac{m^k}{k!} \cdot e^{-m} \tag{6}$$

Where *k* is the number (integer) of road blockages per unit link length and *m* is the average of road blockages number per unit link length. It is thought that the factors shown in Figure 33 could affect the functional road obstacles caused by the collapse of buildings along the roads.

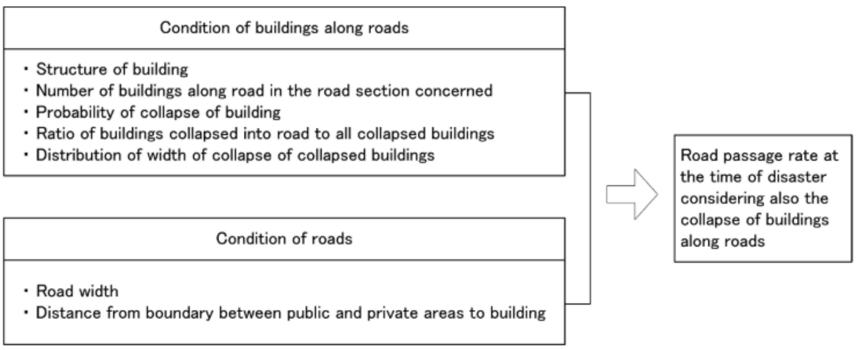

Figure 33 Factors affecting the probability of road passage (Ahn et al. 2011)

The factors studied by Ahn et al. refers to two main groups: one regarding the conditions of the buildings on the road the other connect to the particularities of the road itself. Although, road blockages due to the collapse of buildings along the road are divided into two types: blockages due to the collapse of buildings on one side of the road, and blockages due to the collapse of buildings on both sides.

A proposal for road network improvement to mitigate possible disaster is drafted, and the effectiveness of the proposal is examined through reliability analysis. The following is an outline of the concept of this plan:

i) Roads with a width of 12 m and over have little risk of becoming blocked even when disaster strikes. The area surrounded by a road 12 m wide and over is set as a unit district. Unit districts are shown in Fig. 7.

ii) The road network forming the framework in the unit district concerned is built not to produce any zone in which firefighting is difficult. To eliminate such zones, the unit districts have roads 7 m wide and wider, which are relatively resistant against earthquake disaster.

iii) The road connecting cultural heritages and roads 12 m wide and over are improved.
iv) The especially vulnerable sections of road in vulnerable urban areas are improved to reduce the risk of disaster.

Road network mitigation strategies are proposed moving from the reliability analyses that can study road networks in a simplified way; this phase aims to raise the disaster mitigation capability of the historical centre and the surroundings of the urban area in Kamigyo Ward, Kyoto. Considering the relation between the unit districts surrounded by roads 12 m wide or wider and that of areas in which firefighting is not problematic. For instance, a plan for the network's study is proposed: the ampliation of the roads to 7 m and a reinforcing of the buildings along the roads connected to this extension of the road (Figure 34).

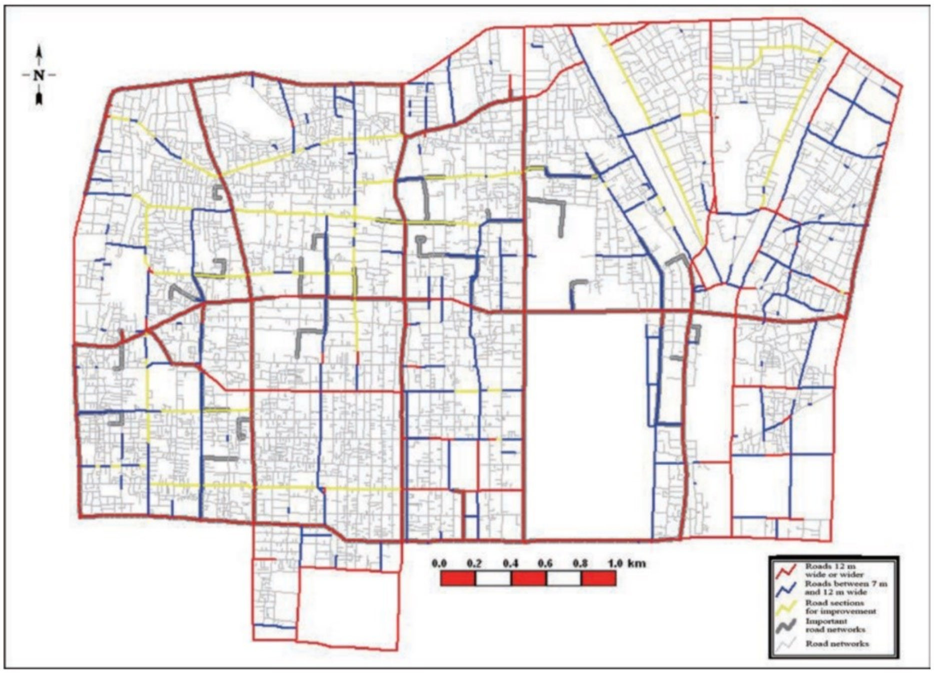

Figure 34: Plan for road network improvement to raise the capability of local disaster mitigation (Ahn et al. 2011)

(Cara et al. 2018) work deal with parameters connected to buildings and their interaction with main roads; the parameters that define the vulnerability of open spaces are deeply connected to masonry buildings, concrete buildings, and aggregates Figure 35. The proposed methodology considers multiple objectives, from the identification of the most vulnerable buildings whose collapse may hinder the operationality of strategic urban roadways after the occurrence of an earthquake, up to the proposal of proper interventions to improve their functionality. After the definition of the Emergency Limit Condition (ELC) system, based on the identification of the Minimum Urban Structure (MUS), the proposed methodology for seismic risk assessment has proved to be simple and effective.

	Parameter	Class C_{vi}				Weight w_i
		A	B	C	D	
P1	Type and organization of the resisting system	0	5	20	45	1.00
P2	Quality of the resisting system	0	5	25	45	0.25
P3	Conventional strength	0	5	25	45	1.50
P4	Building position and foundations	0	5	15	45	0.75
P5	Horizontal diaphragms	0	5	25	45	variable*
P6	Plan configuration	0	5	25	45	0.50
P7	Configuration in elevation	0	5	25	45	variable*
P8	Maximum distance between walls	0	5	25	45	0.25
P9	Roof	0	15	25	45	variable*
P10	Non-structural elements	0	0	25	45	0.25
P11	Current condition	0	5	25	45	1.00

* see CETE Méditerranée (2008)

	Parameter	Class C_{vi}				Weight w_i
		A	B	C	D	
P1	Type and organization of the resisting system	0	-1.00	-2.00	0	1.00
P2	Quality of the resisting system	0	-0.25	-0.50	0	1.00
P3	Conventional strength	0.25	0	-0.25	0	1.00
P4	Building position and foundations	0	-0.25	-0.50	0	1.00
P5	Horizontal diaphragms	0	-0.25	-0.50	0	1.00
P6	Plan configuration	0	-0.25	-0.50	0	1.00
P7	Configuration in elevation	0	-0.50	-1.50	0	1.00
P8	Connections and critical elements	0	-0.25	-0.50	0	1.00
P9	Low ductility elements	0	-0.25	-0.50	0	1.00
P10	Non-structural elements	0	-0.25	-0.50	0	1.00

Figure 35: Vulnerability parameters (Cara et al. 2018)

Seismic retrofitting strategies, normally used for masonry and RC buildings, were proposed to mitigate the vulnerability of the ELC system of the "Antiga Esquerra de l'Eixample". The objective was to reduce the seismic vulnerability if they are applied to a large scale, which can infect produce a significant effect on the urban seismic risk mitigation. The analysis of the standard structural vulnerabilities of the buildings permits the description of the criteria useful for the seismic retrofit interventions. For instance, the application of Textile Reinforced Mortar (TRM) is a retrofit intervention proposed; it as to be applied at both sides of the walls to increase their thickness and their in-plane and out-of-plane capability. This intervention is efficient, and it could be easily used in numerous urban buildings. The spread of the use of retrofit interventions in a particular area is central to permit seismic risk mitigation on the urban scale of both masonry and RC building concerning their structural typology. In the case study of Cara, the usefulness of the post-intervention ELC system was taken in count in order to understand the general urban mitigation effects. The reliability increases by 92% for I_{EMS-98} = VII, compared to 16% of the original ELC system.

(Giuliani et al. 2020) assume that the urban configuration and morphology of historic settlements have a key role in the definition of urban safety and resilience. By adopting an interdisciplinary approach, the research aims at implementing the spatial-configurational aspects into the post-seismic emergency management of Italian historic centres. The application of a scenario-based method offers a predictive approach to emergencies which embeds the uncertainties of the effects of earthquakes. The methodology is based on the development of the road network’s scenarios and their analysis using space syntax techniques. It starts from the evaluation of vulnerabilities and the mapping of the emergency system. Then, it analyses the road network in order to identify the more attractive routes of the configuration.

The methodology used for this work the following steps:

1. extensive investigation on the historic centre aimed at building a knowledge framework regarding: (i) the characteristics of the road network (configurational aspects); (ii) the location of emergency facilities and areas within the perimeter and in the immediate surroundings (functional aspects); and (iii) the buildings such as material, time of construction, basic plan geometry, number of stories, transformations undergone during its lifetime (structural aspects);
2. spatial analysis for the evaluation of the syntactic properties of the present-day layout. The step is paramount to address the route-finding decisions making and discuss the location of emergency facilities and emergency areas within the historic centre;
3. seismic vulnerability analysis of the building stock employing empirical methods that allow for a rapid large-scale assessment;
4. definition of scenarios based on the expected areas that are inaccessible by the evacuees and by the rescuers, , as well as the disruptions induced by the vulnerabilities of the built environment (phase 3);
5. analysis of the scenarios to evaluate their impact of the expected inaccessibility condition on the initial system.

The steps of this work and the data from the phase 1, 2, and 3 allow us to define the possible intervention and strategies for emergency planning. Instead, the scenario analyses (phases 4 and 5) permit to evaluate their impact on the system and therefore to study the priority of interventions.

Figure 36 summarizes the combination of factor took in the count and the scenario. Each of them refers to a particular combination of parameters:

1. Scenario 1: it takes into account the vehicular accessibility for trucks and emergency services, thus excluding narrow streets, stairways, low-covered, or cantilevered passages.
2. Scenario 2: it considers a grid tailored on the needs of elderly or disabled people, such as wheelchair users, that struggle to walk through the winding streets with changes in level.
3. Scenario 3: it considers the collapse of the vulnerable elements near the segments with higher connectivity index, while the internal road network is preserved. In particular, the third scenario is based on the collapse of the northern and southern gates, thus assuming that the two main accesses to the historic centres are blocked.
4. Scenario 4: it assumes that the underpasses and contrast arches are damaged by the earthquake and the streets are not accessible. This scenario alters the internal road network and the number of accesses.

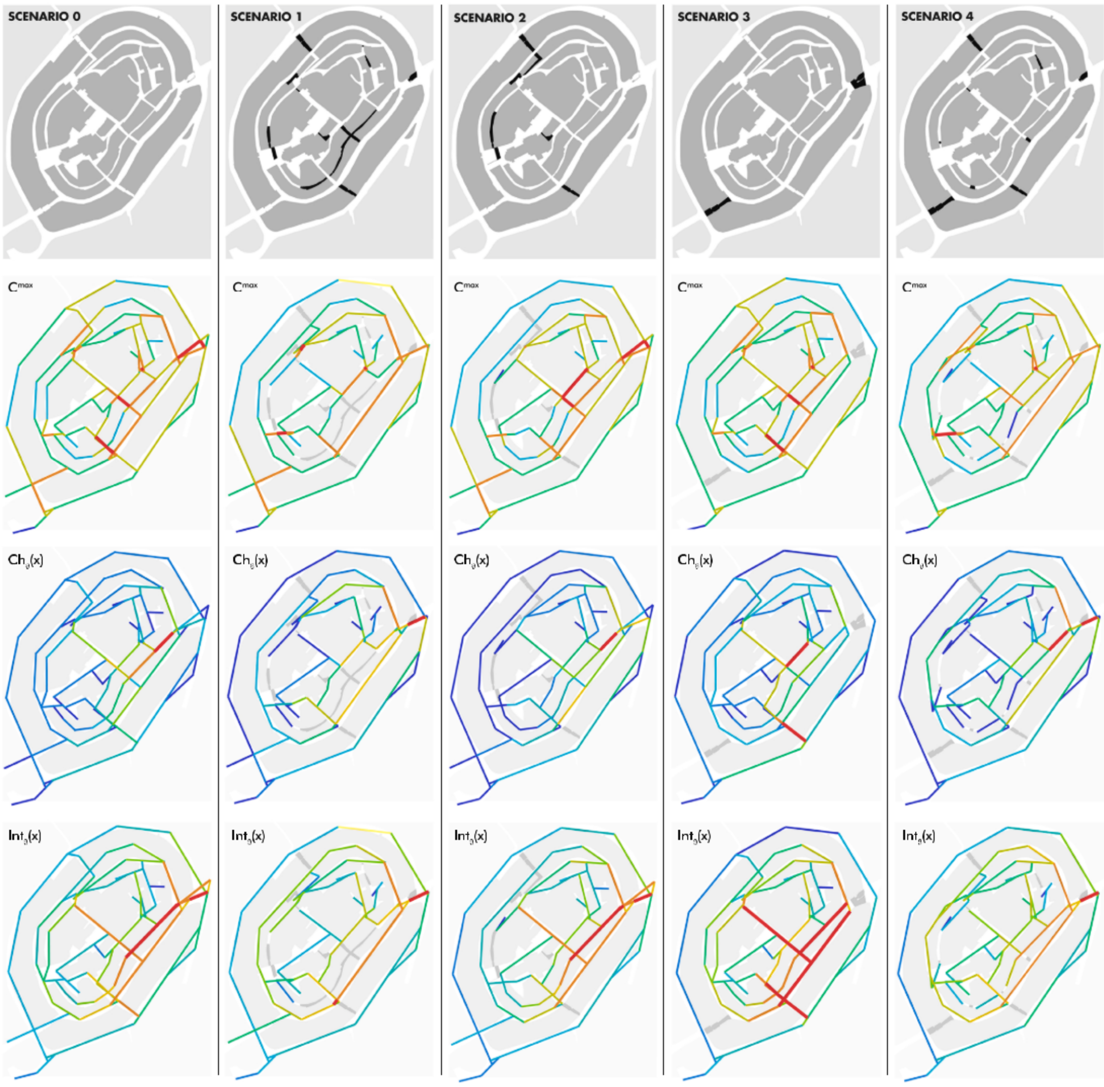

Figure 36 Scenario maps with their connectivity, choice, and integration indices (Giuliani et al. 2020).

In a second phase is possible to notice and propose some intervention moving from the data collected in the previous analyze:

1. Action 1. To ensure the operability of the strategic streets identified employing the functional and configurational approaches, combining the results of the LCE with the chosen measures. This task is achieved through different retrofit techniques of the façade walls such as the strengthening of the corners, the installation of wall-to-wall connections and ties, the provision of wall-to-floor, and wall-to-roof connections, and the improvement in the quality of masonry. Besides, further intervention measures pertain to the reinforcement of non-structural elements and the removal of obstacles in the streets.
2. Action 2. To strengthen and reinforce the southern gate and the buildings facing the northern passage. These two accesses are destined for pedestrian evacuation and access to emergency services and trucks.
3. Action 3. To identify and equip emergency areas within the integration core, and to communicate their location to people. In particular, the square on top of the hill is identified as a safe meeting area to

guarantee a compensation measure. It represents an important relief point for vulnerable groups whose evacuation towards the emergency areas located outside the historic centre is difficult.

4. Action 4. To preserve the streets with higher integration in which the economic and social activities are located. However, proper regulations should place restrictions on the minimum street width free of furniture and vehicles.
5. Action 5. To implement campaigns and programs to raise awareness and foster preparedness among citizens.
6. Action 6. To prepare local groups to monitor the compliance with the emergency plan and to rescue visitors and people with disabilities, conducting them along accessible routes to safe areas within the historic centre. Several studies investigated the vulnerability of older people to disasters arguing that community-based organizations are resources that can play a key role during emergencies.
7. Action 7. To inform non-Italian speakers tourists and foreigners on the emergency plan by integrating multi-language signs.

Li and Zhou (Li and Zhou 2020) proposed a practice-oriented method moving from the concept of post-earthquake road network resiliency. The objective was to find the optimal risk mitigation investment for improving the resilience of networks. According to Li and Zhou work, post-earthquake link connectivity reliability was calculated starting from the prediction model of debris blockage from the post-earthquake building collapse. For this reason, the prediction of connectivity probability of road is determined by types of buildings that are on the sides of the street and of course from the distribution range of the collapsed buildings. The authors divided the possible types of buildings along the road into bungalows (including walls), multi-story masonry brick buildings, and multi-story concrete frame buildings.

The work of Li and Zhou moves from world urban development as a field of study to public safety. According to DRR literature is possible to understand that disasters as earthquakes can cause huge damages; it in this framework that Liu focuses on the centrality of the urban road network. This is an important lifeline and its usefulness during an emergency moment is a fundamental feature.

First, some assumptions exist in the prediction model of the rubble blockage of post-earthquake building collapse:

- Rubble from the collapse is concentrated in the street.
- Rubble from the collapse is evenly distributed across the street.
- The volume of the collapsed building is equal to the volume of the rubble formed.
- Only the effects of two factors, the types of the buildings along with the street and distribution range of the collapsed buildings' rubbles, are considered on the calculation results.
- The distribution range of buildings is 2/3 of their height.

This work defines the parameters that mainly can affect the reliability of a road and connects it to three factors: high buildings and old houses along with the link, as well as narrow road widths.

w_r = Road width
w_d = Average distance from street building to the road
w_s = Sidewalk width
B_{ik} = Amount of rubble caused by k-th collapsing buildings in i-th lay
H_{ik} = Height of k-th building i-th floor from the ground
A_{ik} = k-th building area of i-th layer
B_k = Total amount of rubble caused by k-th collapsing buildings
J_k = Percentage of rubble caused by k-th collapsing buildings
Y_k = Severely damaged building area caused k-th collapsing buildings of the building area
D_k = Collapsed building area caused by k-th collapsing buildings of the building area
Ω = Total debris obstruction along the street

W = Effective section width
w_d = Average distance from street building to road
w_s = Sidewalk width
w_0 = Lane width
Q = Density of debris obstruction
Ω = Total debris obstruction of collapsed buildings along street
L = Length of the section unit
P_r = Link connectivity probability
Q_c = Critical value of debris obstruction density

Figure 37: Parametres of link connectivity reliability (Li and Zhou 2020)

In this study, post-earthquake link connectivity reliability was calculated based on the prediction model of rubble blockage from post-earthquake building collapse (Figure 37), and then the post-earthquake road network connectivity reliability was calculated via the Monte Carlo simulation method based on the link connectivity reliability. An optimal mitigation investment model was proposed in order to maximize post-earthquake network accessibility within the fixed government budget (Equation 7):

$$\max R' \qquad (7)$$

Subject to

$$s_i = \begin{cases} 1, & \textit{Reinforcement link } i \\ 0, & \textit{otherwise} \end{cases}$$

$$\sum_{i=1}^{M} s_i w_i < W_0$$

$$p'_{ri} = (1 - s_i)p_{ri} + s_i(d + p_{ri} - dp_{ri})$$

where

R' = Post-earthquake network accessibility with mitigation strategies
s_i = Reinforcement vector of link i
w_i = Cost of reinforcing link i
W_0 = Total cost of government investment
p'_{ri} = Connectivity probability of link i after reinforcement
p_{ri} = Connectivity probability of link i before reinforcement
d = Earthquake mitigation effect via reinforcement

Nicholson (Nicholson 2007) focuses on the use of standard risk evaluation and classical management methods. The first step moved was to identify the hazards, which were found to be:

- snow and ice formation
- volcanic events (i.e., ashfall on roads during eruptions or lahar damage to roads and bridges)
- earthquake damage to roads and bridges
- motor vehicle accidents.

For each hazard, the frequency distribution had to be studied using both historical information and an understanding of the generating mechanisms, plus Monte Carlo simulation. The objective of this work is to study the connection between hazard and road network and the impact that disasters can act on them.

The approach considered by Nicholson in assessing the reliability of the network is related to the extension of travel times for any interruption due to a natural disaster. The procedure of valuation of travel reliability improvement involves using the standard deviation of travel time (s) as the measure of travel time variability.

It is assumed that the standard deviation of travel time is related to the ratio of the volume (v) to the capacity (c) according to the following sigmoid-shaped relationship (Equation 8):

$$s = s_{\min} + \frac{(s_{\max} - s_{\min})}{1 + \exp[b\left(\frac{v}{c}\right) - a]} \quad (8)$$

where s_{min} and s_{max} are the minimum and maximum standard deviations of travel time (when v equals zero and c, respectively), and a and b are constants. The values of s_{min}, s_{max}, a and b vary according to the type of facility (e.g., motorway, urban arterial, rural highway, signalized intersection, unsignalized intersection).

(Sharifi 2019a) focuses on centrality and connection connectivity measures (Figure 38). The design and orientation category explore the possible effects of street width, street edges, street canyon geometry, and street layout and orientation on the resilience of cities. It is discussed that all topology and design measures have implications for urban resilience. The appropriate physical form of urban streets can contribute to urban resilience to analyze the contents, theoretical discussions, and empirical evidence related to each of the street elements that were extracted from the reviewed literature. In this paper, empirical evidence refers to any evidence reported based on real-world observations and/or simulation results. The labelled and categorized for the respective street elements. Additional categories were designed for any evidence that is related to interlinkages and trade-offs.

In this study, two synoptic schemes appear interesting that the author builds based on the analysis of literature (Figure 38). The first concerns the parameters most commonly used for centrality and connectivity measures. The second concerns the taxonomy of the different street patterns.

There is also a lack of research comparing the resilience of different street patterns. Street networks are complex and multiple permutations of street patterns can be observed in cities. He suggests that street patterns can be divided into five broad categories: linear, tree, radial, cellular, and hybrid (Figure 39). Various permutations can be identified under each of these categories. Analyzing these permutations using the measures described in this paper may bring new insights regarding their resilience.

Measure	Expression	Note
Centrality measures		
Degree centrality	(1) $C_i^D = \frac{\sum_{j=1,N} a_{ij}}{N-1} = \frac{k_i}{N-1}$	The larger the number of connections between a node and other nodes in the graph, the higher its importance in terms of degree centrality.
Closeness centrality	(2) $C_i^C = \frac{N-1}{\sum_{j=1;j\neq i}^{N} d_{ij}}$	Indicates how near an intersection (node) is to all other reachable intersections in the city along the shortest paths of the network. C_i^C of node i is the inverse average distance from it to all other nodes in the network.
Betweenness centrality	(3) $C_i^B = \frac{1}{(N-1)(N-2)} \sum_{j=1;k=1;j\neq k\neq i}^{N} \frac{n_{jk}(i)}{n_{jk}}$	Nodes that are traversed by a larger fraction of shortest paths between all pairs of nodes in the network exhibit higher betweenness centrality.[1]
Street network efficiency	(4) $E = \frac{1}{N(N-1)} \sum_{i,j\in N,\, i\neq j} \frac{d_{ij}^{eucl}}{d_{ij}}$	It is the average normalized efficiency of all possible couples of nodes in the network.
Straightness centrality	(5) $C_i^E = \frac{1}{N-1} \sum_{j=1;j\neq i} \frac{d_{ij}^{Eucl}}{d_{ij}}$	This measure is used to understand the extent of straightness of the shortest links between network nodes.
Information centrality	(6) $C_i^I = \frac{\Delta E}{E} = \frac{E[S]-E[S']}{E[S]}$	It can be utilized to understand how exclusion of a link(s) that is connected to a specific node(s) affects the functionality and efficiency of the street network.
Connectivity measures		
Characteristic path length	(7) $L = \frac{1}{N(N-1)} \sum_{i,j\in N,\, i\neq j} d_{ij}$	It is the average length of the shortest paths between all possible couples of nodes in the network.
Cyclomatic number	(8) $\mu = K - N + 1$	Representing the number of circuits in the network, it is an indication of the number of possible routes between two different points in the network.
Alpha index (also called 'meshedness coefficient')	(9) $\alpha = \frac{\mu}{2N-5}$	Related to the Cyclomatic number, it is defined as the ratio of number of circuits (loops) to the maximum possible number of circuits in a graph with the same number of nodes.[2]
Beta index	(10) $\beta = \frac{L}{N}$	It is a measure of frequency of connections and is defined as the ratio of the number of links to the number of nodes (intersections) in the street network.
Gamma index	(11) $\gamma = \frac{L}{3(N-2)}$	It is another measure of the frequency of links and is defined as the ratio between the number of links and the maximum possible number of links.

Note: C_i^D- degree centrality, C_i^C - closeness centrality, C_i^B- betweenness centrality, E-street network efficiency, C_i^I- the information centrality of node i, a_{ij} - indicates presence or absence of a link between nodes i and j (1 when there is a link and 0 otherwise), d_{ij} - the shortest distance between nodes i and j, d_{ij}^{eucl} - the Euclidian distance between nodes i and j, N- is the total number of nodes, k_i - is the number of nodes adjacent to i, n_{jk} - the total number of shortest paths between nodes/links j and k, n_{jk} (i) - the number of those shortest paths that traverse node/link i, $E[S]$- the efficiency of the street network with N nodes and K links that can be obtained from Equation 4, S'- the street network with N nodes and K-k_i links (following the link removal).

Figure 38: Major centrality and connectivity measures (Sharifi 2019a)

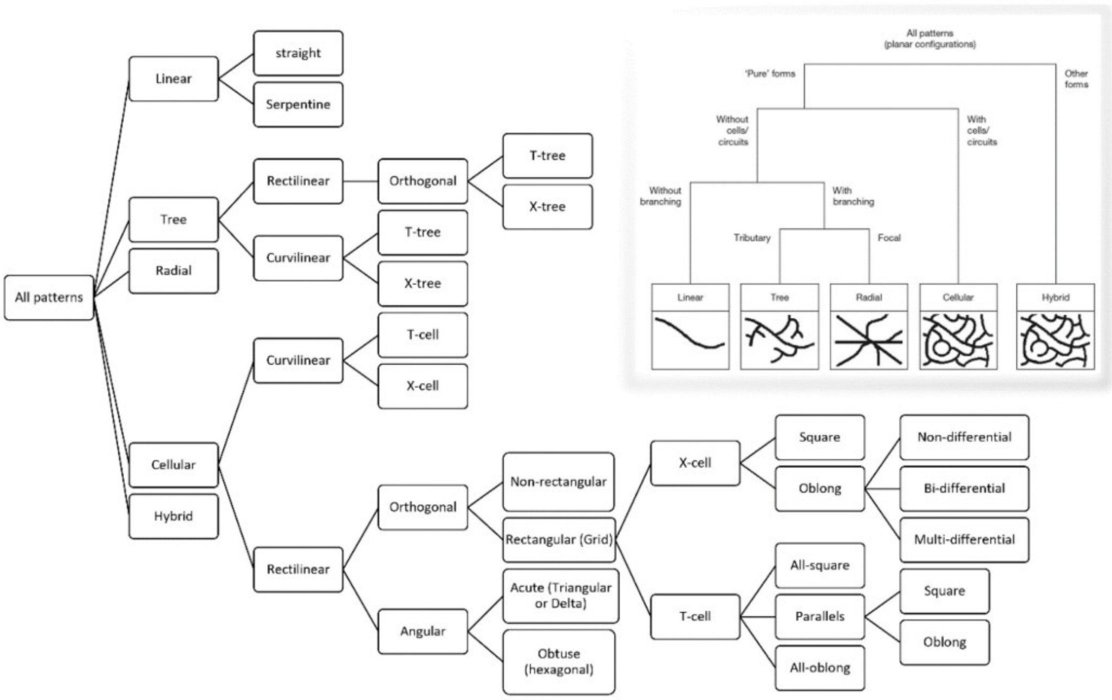

Figure 39 A general taxonomy of street patterns (Sharifi 2019a)

Ye et al. (Ye et al. 2012) focus on pre-disaster emergency evacuation zoning. This one has become an important topic of disaster prevention study and mitigation strategies research. The methodology included the following aspects: the distribution analysis of emergency evacuation demands, the calculation of shelter space accessibility, and the optimization of evacuation destinations. A systematical methodology for evacuation in earthquakes situation was developed by employing spatial analysis techniques of Geographical Information System (GIS). As well this paper focuses on a night-time scenario, when people are mainly distributed in residential areas; the following assumptions are considered:

- Consider the evacuation procedures when a devastating earthquake has not yet damaged the ground, or the earthquake is of a small magnitude.
- One single residential building is considered as the basic dwelling unit for evacuation. Assume that residents are all uniformly distributed in the assembly points (the entrances/exits of each dwelling unit) and begin to evacuate at the same moment.
- According to the guidance of emergency managers, residents are heading for the pre-specified destinations (shelters), which take the entrances/exits location into account.
- Residents are evacuated by foot along the designated routes without consideration blocked roads and travel speed variations.

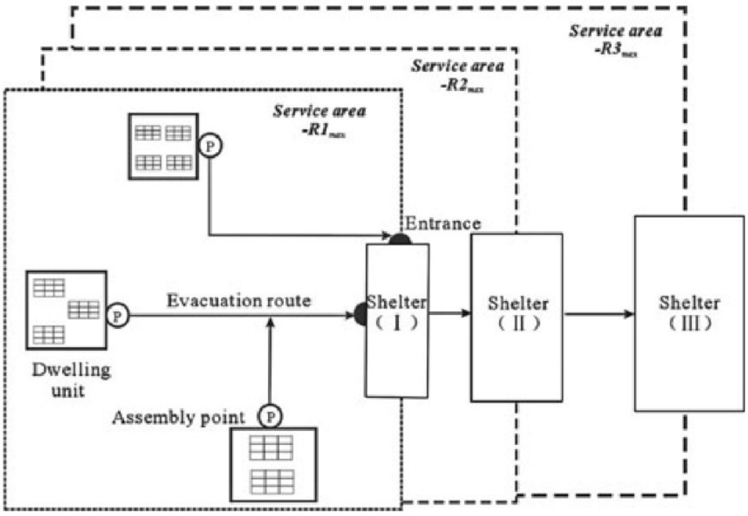

Figure 40 The concept map of occupant evacuation zoning against earthquakes in an urban community under a night-time scenario (Ye et al. 2012)

According to the assumptions, the concept map is constructed to represent the occupant evacuation zoning under a night-time scenario (Figure 40). Numerical evaluations are connected to the following formula (Equation 9):

$$S = \frac{S_T}{P_T} \tag{9}$$

$$P_i = \frac{N_i \times S_i}{S}$$

This formula refers to: ''i'' is defined as the identification of each dwelling unit; N_i is the number of floors; S_i is the vertical projection area of each dwelling unit; S_T is the total living space in the research region; P_T is the total population in the research region; S is the per capita living space; and P_i is the population of each dwelling unit.

Green parks, large squares, and other large open spaces were selected as the evacuation destinations (shelters) to analyze the space accessibility. To represent the output and study on the data collected. Ye study proposes to connect the numerical and theoretical considerations to a spatial visualization by ESRI ArcGIS9.3, a GIS software package.

In this paper, the use of scenario analysis was proposed as a new approach for evacuation demand calculation, and a new distance and capacity-constrained algorithm was proposed for the evacuation zoning problem. Existing even distribution approaches ignore people's space-time behavior characteristics. Since people participate in different social activities over different periods of the day, uneven distribution occurs at different time periods. To address the limitations, the evacuation demands were calculated according to people's activities and their locations at one time-period (Figure 41).

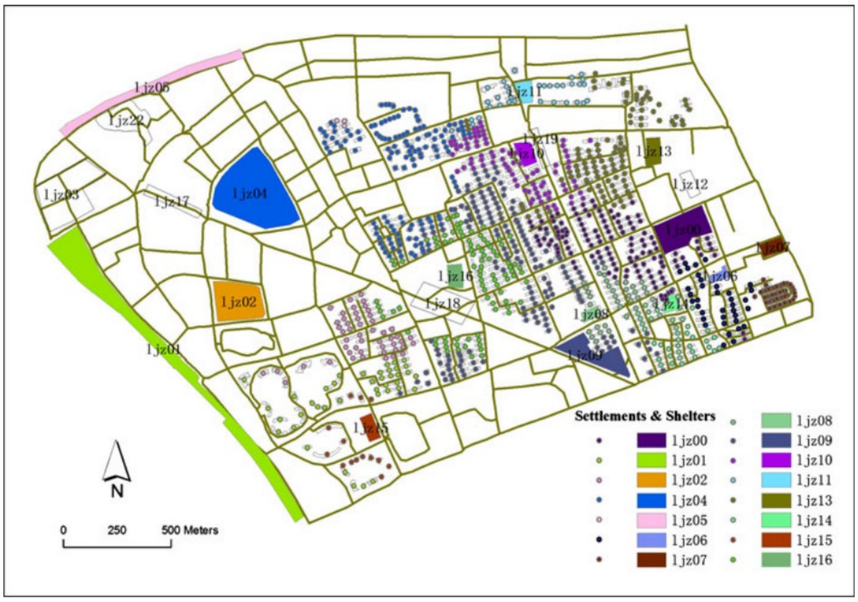

Figure 41: The optimal evacuation destination of each settlement (dwelling unit) (Ye et al. 2012)

(Zhang and Wang 2016), moving from the modern study among network themes, managed to introduce a novel metric based on system reliability and network connectivity. The objective was to measure the resilience-based performance of a road transportation network.

The formulation of this resilience-based performance value (referred in the paper as WIPW), depends on different factors: network topology, redundancy level, traffic patterns, structural reliability of network components (i.e. roads and bridge) and of course functionality of the network during community's post-disaster recovery.

Using the WIPW (Equation 10) as a network performance value to identifying and prioritizing transportation network retrofit projects that are important took to keep in the count for effective pre-disaster risk mitigation and resilience planning.

$$\mathrm{WIPW}(G) = \sum_{i=1}^{n} w_i r_i \tag{10}$$

The WIPW parameter methodically adds information's as: the network topology, traffic patterns, redundancy level, location of community emergency response facilities, as well as failure probability of individual bridges. When this is analyzed with risk mitigation decision analysis, risk mitigation interventions for improving the resilience of networks can be counted and studied on a common and rational basis.

Figure 42 shows the algorithm to proceed to evaluate WIPW. This factor can be used to study the transportation network performance and response, as well it can also be included in a framework for decision making. In this case, it has the objective to define a base from which to start to evaluate and study risk mitigation strategies moving from a common rational basis.

Possible pre-disaster risk mitigation strategies are connected to both road networks and links. In the following paragraph, the decision-making process proposed by Zhang and Wang aims to maximize the network performance WIPW and to minimize the associated cost.

In the following formulas, the X represents the risk mitigation strategy (or decision) that will develop the existing network system All the other parameters are defined function of X: their argument (e.g., WIPW(G(X)), wi(X), ri(X) and Pk(i, j|X)). Also, some of the parameters are not certain and for this reason, they can be treated as random variables. These variables will be represented with argument n. The first aim of the decision process is to maximize the network performance metric WIPW (Equation 11):

$$\max \mathrm{WIPW}(G(X,\xi)) = \sum_{i=1}^{n} w_i(X) r_i(X,\xi) \tag{11}$$

h(X) denotes the cost associated with decision X. The second formula wants to minimize the cost (Equation 12):

$$\min \theta(X,\xi) = \sum_{t=1}^{s} c_t(\xi) x_t \tag{12}$$

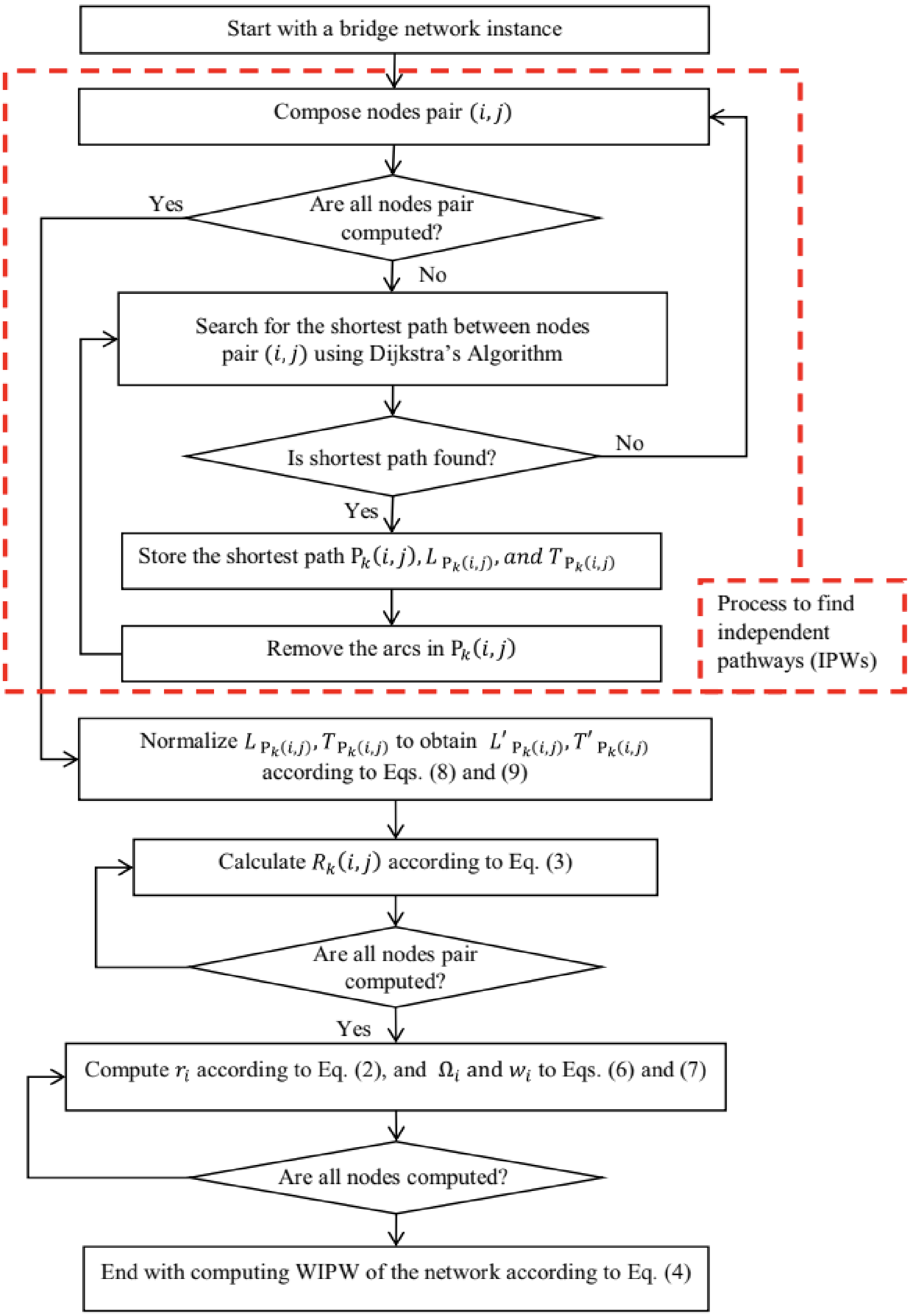

Figure 42: Evaluation of network resilience-based performance metric (Zhang and Wang 2016)

4.5 Final debate and opportunities for enhancing the research

The analysis carried out so far has analyzed numerous studies in detail, trying to understand approaches, strategies, and measures applied, in order to identify possible developments in existing researches. Among the four areas of interest deepened in the discussions (Holistic approach, urban form and urban morphology, open spaces, and roads and paths), a variation of the DRR strategies applied is certainly distinguishable. While the first two areas are mainly used in the REV strategy, focusing attention on the pre-disaster phase, risk mitigation, and implementation of resilience in the preventive phase; studies that focus on open spaces and the role of paths and roads are purely oriented towards the IEV strategy.

Some studies on the road networks investigate approaches that involve a combination of the two DRR strategies, systemizing a reduction in vulnerability or optimization of exposure analyzes in order to improve the emergency evacuation response of urban tissues.

At the same time, the measures implemented by the various researches are varied, by involving both structural and non-structural ones. Nevertheless, it is possible to find a prevalence of structural measures in research dealing with urban form and urban morphology, aiming to reduce the seismic vulnerability of constructions.

This final discussion aims to understand the directions of current research in the field of DRR, to evaluate whether some specific indices and topics are particularly interesting in reducing the seismic risk that can be integrated into ongoing research. In this sense, Figure 43 offers a scheme of these selected elements derived from the following discussion. According to the authors, these represent significative elements for research implementation and future improvement of the research project. In the following discussion, **bold and underlined** terms refer to the main elements to be focused in Figure 43, while bold terms to the related **keywords** in Figure 43**.**

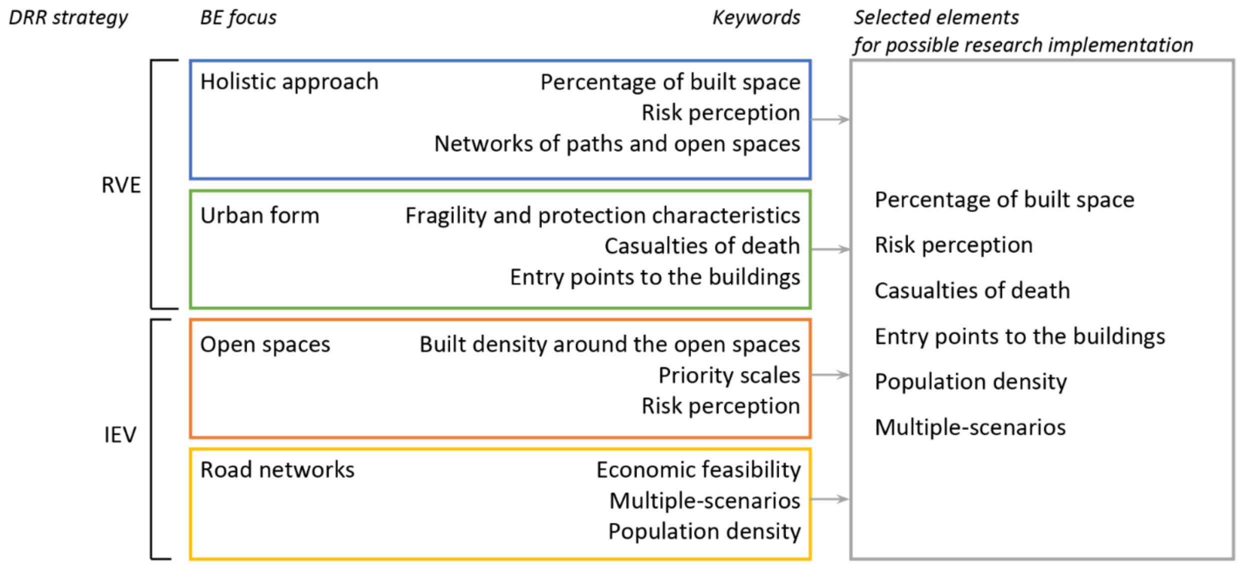

Figure 43: Scheme of selected elements for possible research implementation

Concerning REV strategies, the **holistic approaches** proposed by previous studies on resilience and DRR in the urban contexts focuses on the performance of the urban organism, whose overall behaviour is more complex than the sum of the individual parts of the BE that compose it, but derives from the relationships between the parts, and therefore on the difficulty of schematizing it. Since studies are very large and not focused on a single theme, the description of the individual indices remains not particularly analyzed in detail, although it is interesting to note the attention of three studies to the **aspects of the urban fabric**, the **networks of paths and open spaces** (Rus et al. 2018; Atrachali et al. 2019; Cerè et al. 2019). In this sense, the **percentages of space built** on the total of the urban space are defined to characterize such elements, by proposing, e.g. (Cerè et al. 2019):

1. Floor Area Ratio (FAR) on an urban scale (i.e., the ratio between the sum of the buildings floor surfaces and the urban centre area);
2. Building Coverage Ratio (BCR) on an urban scale (i.e. ratio between the sum of building external footprints and the urban area).

Similar concepts are referred to as "plot ratio parameters" and "percentage free area" by other works (Rus et al. 2018). About the open spaces, they instead mention the quality of the space based on the **shape**, the **size**, and their **composition**. (Atrachali et al. 2019) consider city pattern and form of the city parameters, without specifying their characteristics. In general, the other indices presented in these studies have a qualitative development or are divided into evaluation ranges.

The considerations on the **social aspects** are deepened by (Marshall 2020). The importance of **risk perception** in the population compared to disaster risk reduction is highlighted, underlining how the interactions between the elements of the BE placed in an urban system must also be considered in their spatial and temporal variation.

Finally, the approach of Wei et al. (Wei et al. 2016) results interesting in the metrics developed for the assessment of the feasibility of mitigation interventions concerning **a lifecycle assessment** (LCA) approach through a benefit-cost analysis (BCA). Among the researches considered, this last one is too partially focused on specific topics, and then it is less useful for our aims.

It is therefore interesting to note how holistic approaches, unfortunately, lose effectiveness in defining specific quantifications. They appear to be too immature in the current research phase to convey in all-inclusive evaluation systems. These systems aim to organize, schematize, classify indices and parameters in thematic areas often related to each other, risking the creation of partially redundant systems and for which each system offers different classifications as there is not yet a shared and consolidated framework. It is undoubtedly a very high goal to aim at, in order to bring about significant advances in research. On one hand, it will be necessary to continue, however, having more in-depth insights into the thematic areas (i.e. social resilience, physical resilience, etc.). On the other hand, these studies move towards the detection of parameters by expeditious evaluations as an interesting area for ongoing research. For instance, the overall shape of the built environment (that relates the percentages of built and open spaces) should be investigated in the point of view of comparative evaluations between analyzed case studies, to improve general indexes, and derive general rules for DRR. Another interesting point concerns the assessment of risk perception which could be integrated into the analyses of human behaviour during the emergency phase, which will be the subject of the next working packages of the research.

The studies concerning **urban form** are closely related to seismic vulnerability assessments. The vulnerability analysis concerns building systems survey and intervention, although the assessments are carried out on an urban scale. As reported in the debate of the contributions, the report D1.2.1 (§5.2) should be compared to refer for an in-depth analysis of the vulnerability assessment parameters, while here we are keen to analyze the effects that these contributions highlight in the DRR field. Most of these refer to applications in emergency and prevention planning. The territorial representations (that can facilitate the application of these methods) would allow highlighting risk scenarios aimed at identifying more or less vulnerable areas within the BE placed in the overall urban fabric (Srinurak et al. 2016; Rapone et al. 2018; Quagliarini et al. 2019). Among these, specific methodologies (Rapone et al. 2018) differentiate the **fragility and protection characteristics** of the individual elements considered. Among the metrics, the evaluation of the **casualties of death** of the population living in the BE (i.e. in buildings) is one of the most significant elements for the process of DRR proposal and assessment (Boukri et al. 2018). The morphological relationship, through space syntax, on the uses of buildings and the **entry points to the buildings** should be considered in this sense (Srinurak et al. 2016). Furthermore, the urban form plays a pivotal rule in the view of tourists/BE visitors, i.e. see the sense of lostness related to labyrinthic urban forms for people unfamiliar to the BE spaces during a disaster.

In these studies, the possibility of integration with territorial systems based on GIS appears clear and interesting, and the measures can be divided into two main areas: structural measures for the analysis of building vulnerability, and non-structural measures for the assessment of the exposure factors. In particular, the use of the RADIUS method (Coburn et al. 1992; OYO Corporation 2000) for the evaluation of causalities death linked to the study of the different time slots in which urban life is divided is significant. Certainly, this approach could bring added value to the analyzes envisaged by the research project.

Concerning IEV strategy, the contributions related to the specificity of the role of **open spaces** in the DRR are focused on the definition of escape routes in the disaster emergency phase and the immediate aftermath, by using the analysis of open spaces from the point of view: 1) of risk perception(Shrestha et al. 2018); 2) of the vulnerability of the built environment, of the hazard and the exposure (Quagliarini et al. 2018). Either the approaches have the aim of directing disaster risk reduction intervention strategies and develop evacuation scenarios for the emergency phase. The distinction made between open spaces is fundamental to this end. (Shrestha et al. 2018) classified five broad groups: courtyards, parks/playgrounds, agricultural lands (open fields), street (road) networks, and others (vacant land, private gardens, etc.). Open spaces were assessed against three attributes: number of open spaces, size of open spaces, and **built density around the open spaces**. Besides, this confirms and further validates what has been elaborated in the previous reports on the investigation and typing of open spaces (see report D1.1.2). Other studies (Quagliarini et al. 2018) divide the spaces into Link (linear spaces LS) and Squares (Areal spaces AS). Related methods have an interesting application in the identification of intervention **priority scales**, which can constitute supplementary maps to those shown in the analysis of the contribution. Further efforts to include the **perception of risk**-based approach into the Link/Squares oriented assessment approach should be performed. In this case, the risk perception assessment by the population is a fundamental element for the correct setting of possible emergency evacuation scenarios.

The part correlating the DRR measures to **road networks** consists of the largest number of analyzed documents. The main spillovers can be placed in the management of emergency planning. Thus, some studies refer to the protection and reinforcement of the ELC elements (Cara et al. 2018; Giuliani et al. 2020). Both of these studies propose typical interventions on some types of buildings to improve the safety of the roads contained within the ELC. Simplified methods (Cara et al. 2018) demonstrate good applicability to highlight the disaster risk mitigation measures to be assessed in emergency plans. Meanwhile, other methods (Giuliani et al. 2020) combines the analysis of the configuration of the road network with the morphological analysis of urban fabrics, underlining the importance of the **construction and evolutionary aspects of the aggregates**. The measures exposed for disaster mitigation are 7, both structural and non-structural. Among the former, several **generic retrofit strategies** applied to buildings are highlighted. The retrofit strategies are selected to be generically applicable to building systems ofbuildings having similar features, in a typical territorial-scale analysis. The non-structural ones include **campaigns of awareness and preparation programs among citizens**, as well as effective communication of the distribution of safe areas.

Another fundamental aspect of DRR strategies is related to their **economic feasibility** (Zhang and Wang 2016; Li and Zhou 2020). Resilience-based performance metric (WIPW) evaluation algorithm is proposed according to choices that can be shared with the stakeholders (Zhang and Wang 2016). The proposed strategy is based on non-structural measures to optimize costs and investments, aware that the best choice cannot be the one that brings the system's resilience to the maximum level and the cost to the minimum, but a compromise will have to be accepted. Interesting models of investment mitigation through **scenarios** based on two calculation methods are proposed (Li and Zhou 2020): first, link reliability on debris and then network on Montecarlo based on previous data. According to a similar perspective, the model developed by (Ahn et al. 2011) bases the road network interruption assessments on the **debris evaluation**, but adds to this an interesting relationship with the **fire risk following an earthquake**, as an added risk for the occlusion of the road network. The proposed disaster risk mitigation appears interesting and is divided into two structural measures: on the one hand, the widening of the road sections; on the other, the reduction of vulnerability of buildings on the street, which leads to an improvement equal to the enlargement of the first measure. The limited applicability of the first measure in the context of European historical cities is evident, where the impossibility of modifying the urban fabric in such a significant way does not allow an expansion of the road sections. Meanwhile, the second measure is more practicable, but it should be studied in depth in the equivalence dimension to widening the road. Other studies develop methods for improving the **reliability of the road network**. A **priority scale** can be defined according to the evaluation of the lengthening of travel times, analyzing the closure of some road sections following disasters (Nicholson 2007). Investigations on **the population density** of the various buildings can be provided to measure the escape routes and the locations of possible crowding of the emergency areas (Ye et al. 2012). The algorithm for optimizing evacuations according to the distribution of the population versus the proximity to safe areas poses interesting research developments in the assessment of exposure factors. Finally, (Sharifi 2019a) analyses the literature by developing two synoptic schemes. In this way, he puts the most used parameters in the studies concerned with **the resilience of the street pattern** and the forms that these can take in the cities into a system.

*Therefore, the researches analyzed the role of roads and paths from a DRR perspective, highlight a fundamental approach based on **multiple-scenarios**. This allows questioning the simulation choices, that inevitably bring with them a certain degree of uncertainty. The analysis for multiple scenarios allows basing a dialogue with all the stakeholders involved (administrations, inhabitants, technicians), in the view of a shared choice both from an economic and social point of view, that is a fundamental point for the application of the strategies by DRR. Future studies should include interviews with different stakeholders to justify their usage (Ivčević et al. 2019). Furthermore, indicators should be developed using a bottom-up approach to better adapt to the specificities of local case studies, while top-down approaches should neglecting these elements and better adapt to territorial scales*

5. Conclusions

In this report, we have analyzed the various DRR strategies and the applicable measures to achieve them with a view to mitigation, preparation, and response to seismic events. The systematic and bibliographic literature review has made it possible to identify some prevalent areas of research and current strategies and measures under development to reduce the impacts of earthquakes on the environment built specifically in urban areas and historic centres. Most of the ongoing research undoubtedly focuses on the vulnerability assessment of the built environment (both on buildings and infrastructures), through different evaluation methods. In general, these methods require a detailed inspection of the structural aspects. It is evident that developing the same activities in all the structures of an entire urban system would not be affordable in terms of time and costs. For this reason, the large-scale policies for urban seismic risk mitigation should be carefully planned in order to assess the feasibility of the intended actions, compare different alternatives, and optimize resources and time. With this in mind, researches that deal with the development of post-event investigation scenarios to define intervention priority scales are significantly increasing. At the same time, there is growing attention to approaches that combine physical and social aspects. If on one hand, the vulnerability of the built environment is undoubtedly a fundamental aspect, on the other one, the difference in housing density and social behaviour in the event of evacuation could prove to be fundamental parameters to be taken into consideration. Besides, the social contribution in terms of DRR appears significant since the strategies would have to be developed concerning the specific population that inhabits the disaster-prone places under analysis. Also, as every region is specific, based on its basic environmental and social characteristics, there is a rising need to increase the number of case studies based on fieldwork studies that would contribute to fundamental knowledge on natural risk management.

Defining which strategies are more meaningful and effective in "a priori" perspective, however, is an arduous and perhaps impossible task, it is possible to quantify the effectiveness of these approaches only after a concrete application following the disaster event. In this sense, researches and approaches that aim to develop multiple assessment scenarios are certainly preferred, including various levels of residual risk to evaluate as many configurations as possible and to tend towards the optimal, rather than the best. Given the uncertainty of risk-prediction (i.e. intensity of the disastrous event), and also of the simulations of scenarios (i.e. adequacy of parameters and reliability of the calculation metrics), it will always be necessary to remember that the optimal situation provides for a compromise between the physical, economic and social spheres.

Aware of these elements, the proposed research will be able to implement a multi-scenario approach and some fundamental elements for exposure factors:

- **the temporal and spatial variations in population density and use of urban space,**
- **the risk perception of the population that it can change its behaviour in the event of a calamitous post-event escape,**
- **the causalities deaths in the various scenarios.**

6. Abbreviations

AS - Areal Spaces

BE - Built Environment

DRM – Disaster Risk Management

DRR – Disaster Risk Reduction

IER - Improvement of the Emergency Response

ISDR - International Strategy for Disaster Reduction

LS - Linear Spaces

OS – Open Space

RVE - Reduction of the Vulnerability and/or the Exposure

UNDRR - UN Office for Disaster Risk Reduction

UNISDR - previous name of UNDRR

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