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

Open spaces in the urban Built Environment (BE) are key places in risk management of SUdden Onset Disasters (SUOD) and their vulnerability is strictly related to the BE characteristics (extrinsic or intrinsic). In literature, several studies identify specific aspects of risk in the BE open spaces, but there is a lack of synthetic or comparative studies in this field. The present report aims to support the definition of tools for a qualitative risk assessment of open spaces in BE, through the literature-based identification of specific factors influencing outdoor seismic risk, focusing only on intrinsic aspects. Accomplishing a systematic and bibliographic review of the literature – indexed (in Scopus databases) and no-indexed – the results confirm the five macro-areas for classification of BE, introduced in D1.1.1 and D1.1.2, and identify specific factors involved in the seismic risk of open spaces in BE. Moreover, the systematization of the whole parameters allows providing preliminary criteria for evaluating outdoor seismic risk in emergency conditions and to find any relevant literature gaps where enhancing future research. This study is a necessary step towards the characterization of open space in BE and its modelling in digital environments. The parameters defined in the present report will be summarized in the matrix of seismic risk conditions in BE, as discussed by D1.2.1.

Keywords

SUOD; Building Environment (BE); open space; seismic risk assessment; earthquake; outdoor BE; risk assessment; risk factors.

Approvals

Role	Name	Partner
Coordinator	Quagliarini Enrico	UNIPM
Task leader	Currà Edoardo	UNIRM

Revision versions

Revision	Date	Short summary of modifications	Name	Partner
0.1	21.05.2020	Minor revision	Quagliarini Enrico,Lucesoli Michele	UNIVPM
0.2	25.05.2020	Reply to the minor revision	Currà Edoardo	UNIRM
1.0	04.06.2020	Editing, language revision	Quagliarini Enrico, Gabriele Bernardini	UNIVPM

Summary

1. Introduction: focusing on intrinsic seismic risk of open spaces in BE

Open space system has been described as a network of streets, parks and squares that activates after disasters to satisfy survival needs to escape, gather together, and find safety and shelter (Allan et al. 2013; Koren and Rus 2019). In this sense, the amount and location of open spaces which are useful after a disaster become the main attention factor (Cutter 1996; Allan et al. 2013; Tumini et al. 2017). The urban development process may lead to a careful formalisation of urban space in BE, creating a vacuum in the frontiers between buildings. The creation of this architectural object, the urban space indeed, requires a reformulation of understanding methods and transmitting the outdoors space's form, which was caught in its urban dimension moving beyond the simple inclusion of outdoors spaces within the architecture project (Pereira 1982).

The belief that a complete and comprehensive assessment of the seismic risk in an area cannot be exclusively dedicated to the study of buildings, regardless of the analysis of the transport system, is becoming increasingly widespread (D'Andrea and Condorelli 2006). It is also related to the use of public buildings (e.g. churches, schools), particularly those safe from the effect of disturbances, which can be used as temporary shelters after disasters (Tumini et al. 2017).
(D'Andrea and Condorelli 2006) remark lifelines concept within the urban road network, which can guarantee help from outside to reach the equipped areas, shelter and storage inside the urban fabric. Lifelines are required to ensure adequate functionality and level of efficiency both in ordinary conditions and in post-seismic event phases, for the management of critical moments of the emergency. The affected population must reach, on foot, the nearest areas of hospitalization or massing, so as not to overload the network, perhaps reduced in efficiency, allowing free movement for emergency vehicles.

In this sense, as regards the extension of the concept of seismic risk from BE risk (extrinsic) to OS risk (intrinsic), various reasonings have been made (Tesoriere 1991; Tesoriere et al. 2001; Berdica 2002; D'Andrea and Condorelli 2006) which start from the extension to the OS of the 3 main risk factors, hazard, exposure and vulnerability.
The concept of seismic hazard remains unchanged because it is based on the study of elements commons to both BE and OS, i.e. the seismological and seismogenic characteristics ("macro-zonation") and the geological characteristics of the soils ("micro-zonation").
In the same way, the concept of exposure in BE and in OS is united by the fact of sharing the object exposed to risk: people and goods in general. The movement of the population across the territory represents a particularly important aspect in the context of a seismic risk assessment procedure on a road network, at the urban level. Indeed, the concept of population exposure can be defined from two distinct points of view: direct and indirect. Direct exposure is determined by users who, being on the road infrastructure, can suffer direct damage due to the failure of the structural elements (bridges, viaducts, tunnels, and trenches). Indeed, the concept of indirect exposure is oriented towards the assessment of the effects due to the earthquake after (not "contextually", or rather not "during") its occurrence. In this perspective, all the population in a specific area must be considered indirectly exposed to the earthquake, as they are potentially subject to damage resulting from the inefficiency of the road system.

Infrastructure engineering literature (Tesoriere 1991; Tesoriere et al. 2001; Berdica 2002), propose a differentiation between the BE extrinsic vulnerability and OS intrinsic vulnerability:

- **Intrinsic vulnerability**: refers to elements that compose the infrastructure, such as the flooring, the substrate, the embankment, the technological networks and the infrastructure elements (i.e. bridges, retaining walls);
- **Extrinsic vulnerability**: refers to elements that are not part of the road, but whose collapse would also damage the road itself. It essentially concerns the building, on an aggregate or single structural unit scale.

Both are part of the physical (or structural) vulnerability, because they refer to the structural characteristics of the road solid and the building facing it.

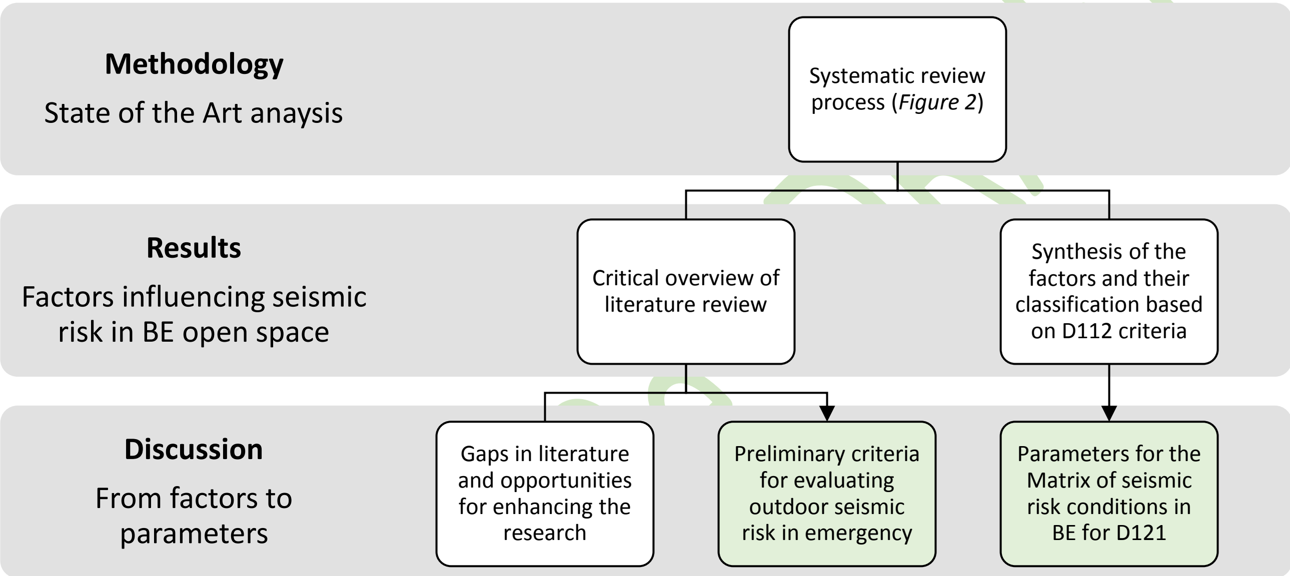

Figure 1: Synthesis of structure of the report and his contributions.

In the very recent literature, it is possible to find relevant systematic reviews concerning the role of open spaces in the BE (i.e. the one part of a urban context) connected to seismic events. (Koren and Rus 2019) accomplished a systematic review in the field of disaster management, about open space pre and post-disaster role in enhancing urban resilience. Based on the review, the research also proposes a conceptual evaluation model of the urban system - composed by buildings, infrastructures and open spaces - in order to identify and evaluate critical points in it. (French et al. 2019)'s review focused on the emergency phase, reporting the potential of open spaces during the short-term disaster response and long-term recovery needs. Among the results, the research identifies specific themes of interest to efficiently support the planning and the design process of seismic resilient open spaces. Both the studies highlight the importance of including the open spaces in urban system seismic performance assessment.

Despite the potential of BE open spaces is recognized, currently, there are no systematic studies in the literature about the factors influencing seismic risk in urban open spaces. Most of the earthquake risk assessment studies are mainly focused on building, structures and infrastructure performances. Considering the open spaces (i.e. squares, green area, streets) as one of the components influencing the risk assessment in the (urban) BE, the present report addresses the outdoor seismic risk, aiming to support and define parameters for his evaluation. The present report focuses on BE open spaces risk assessment, therefore originated from peculiar aspects such as morphology and typology, geometry of the space, materials and paving, peculiar elements into them, uses and users of the surrounding buildings over time, and accessibility condition, all influencing specific risk factor (Hazard, Exposure, Vulnerability). Using a systematic review process, it has been possible to gain a broad insight into how currently studies are facing the evaluation of risk factors in the BE open spaces, both in term of vulnerability and exposure. The systematization of the results has two main objectives:

- providing a critical state of the art based on a wide literature review and organized by major themes;
- and identifying factors, which influence seismic risk in BE open spaces, both for linear spaces (LS) and areal spaces (AS), as defined in D112.

Starting from these results, the report also contributes with specific parameters to the matrix of seismic risk conditions in BE (see D121) and provides preliminary criteria for evaluating outdoor seismic risk in emergency conditions (Figure 1).

2. Methodology

2.1 Systematic review of seismic risk in open space

As defined by (Cumpston et al. 2019), a systematic review is “a review of a formulated question that uses systematic and explicit methods to identify, select, and critically appraise relevant research, and to collect and analyze data from the studies that are included in the review. Statistical methods (meta-analysis) may or may not be used to analyze and summarize the results of the included studies”.
This definition suggests how the systematic review process is an ideal approach to find, analyze and summarize relevant findings in a broad range of publications. Recurring themes, approaches and results can be recognized with qualitative analysis and synthesis of data. Moreover, providing a transparent and organized procedure, the process of a systematic review can be replicate efficiently (Palermo 2013) and reduce biases and lacks in evidence (Petticrew and Roberts 2006).

2.1.1 Search strategy

Setting a balance between a broad and a narrow review is of primarily important in term of pertinence and relevance of the findings. A broad scope can provide a comprehensive summary of the data, but could also be time demanding and difficult to manage. A narrow scope instead will be easy to accomplish, thanks to the low numbers of contributes to be analysed, but the research question should be carefully set by the authors in order to avoid relevant lack in the results (Cumpston et al. 2019).

To achieve the define objectives, in the present systematic review the authors included journal papers, conference paper - both peer review - and book chapters, but exclude most of “grey” literature (e.g. thesis, preprints, working papers, technical reports, etc). Despite its significance was discussed in the literature (Pappas and Williams 2011; Haddaway and Bayliss 2015), for the aims of the present report it was not considered critical, leading a detrimental heterogeneity rather than increasing precision of the results.

The search was carried out using the Scopus database, in march 2020. To develop an effective search strategy the process of establishing the keywords to combine in a search code was iterative. A preliminary set of keywords (Table 1) was defined and grouped into categories, in order to represent and summarize the research question. Four categories are chosen: risk factors, disaster type, open space in BE, and data characterization. Referring to the Table 1, the search code was composed using the operator “AND” among the main columns (Risk factors, Disaster type, BE Open space, Data characterization) and the operator “OR” among the row. Using an iterative process, the authors refine the keywords, checking the impact in term of numbers and appropriateness of the results.

The final keywords are summarized in Table 2. Limiting the results only to English language and filtering documents for "subject area" (eliminate Immunology and Microbiology, Pharmacology, Toxicology and Pharmaceutics, Health Professions, Economics, Econometrics and Finance, and Nursing) and "document type" (limit to: Article, Conference Paper, Book Chapter, Review), the total preliminary documents identified in the databases have been 667.

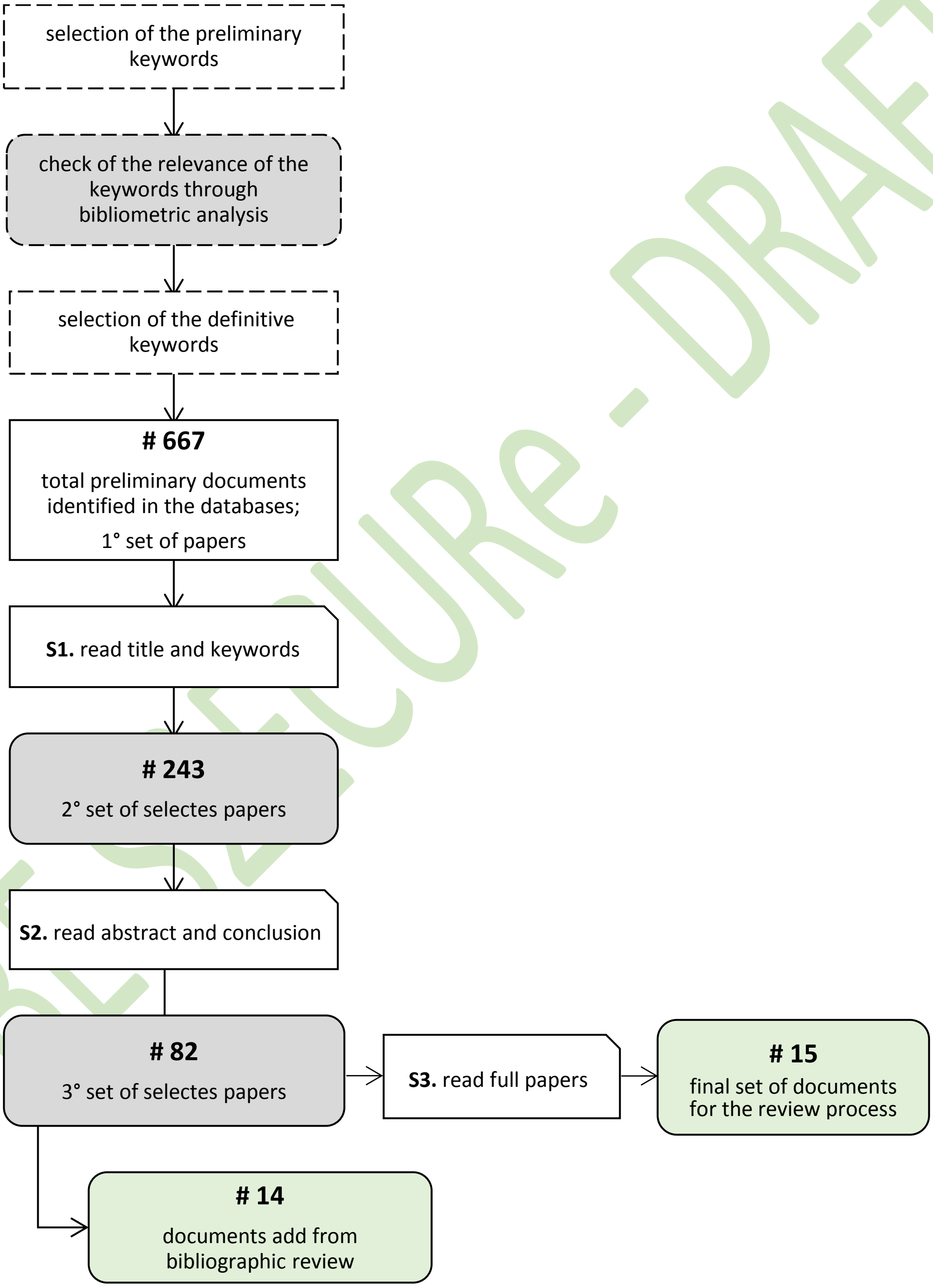

Figure 2: Workflow of the systematic review methodology applied in this report for the selection of documents.

Table 1: Preliminary keywords and search code selected.

Risk factors	Disaster type	BE Open space	Data characterization		
			Geometry and space charact.	**Constructive charact.**	**Use over time and space**
risk hazard vulnerability exposition exposure	earthquake seismic	open space public space urban area road lane street square park access historic center built env.	geometry classification canopy fountain monuments dehors obelisk statue quote differ. slope underg. cav.	constr. technique pavement ground obstacle	use pedestrian vehicular evacuation
TITLE-ABS-KEY ((risk* or hazard* or vulnerab* or exposition or exposure) 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 (classificat* or geometry or canopy or fontaine or monuments or obelisk or statu* or dehors or “urban furniture” or obstacle* or “underground cavities” or "construction technique" or pave* or slope or ground or “quote difference” or use* or evacu* or vehic* or pedestr*)) AND (LIMIT-TO (LANGUAGE,"English"))					
TOTAL Scopus’ results: 3136 documents					

Table 2: Final keywords and search code selected.

Risk factors	Disaster type	BE Open space	Data characterization		
			Geometry and space charact.	**Constructive charact.**	**Use over time and space**
risk vulnerability	earthquake seismic	open space public space urban area road square park access	morphology typology geometry slope underg. cav.	constr. technique pavement obstacle	pedestrian vehicular evacuation users
TITLE-ABS-KEY ((risk* OR vulnerab*) AND (earthquake* OR seismic*) AND ("open space" OR "public space" OR "urban area" OR road* OR square OR park* OR access) AND (morpholog* OR typolog* OR geometr* OR obstacle* OR "underground cavities" OR "construction technique" OR pave* OR slope OR evacu* OR vehic* OR pedestr* OR users)) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "ch") OR LIMIT-TO (DOCTYPE , "re")) AND (EXCLUDE (SUBJAREA , "HEAL") OR EXCLUDE (SUBJAREA , "PHAR") OR EXCLUDE (SUBJAREA , "IMMU")) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (SUBJAREA , "NURS")) AND (EXCLUDE (SUBJAREA , "ECON"))					
TOTAL Scopus’ results: 667 documents					

2.1.2 Selection of the studies

To reduce the number of studies avoiding the loss of significative contributions, the process of selection was divided into three consecutive stages. As summarized in Table 3, each stage involves a defined action and took into account different eligibility criteria, which were chosen to be appropriate in relation to the actions. The eligibility criteria encompass the key aspects of the research question: risk assessment as the core field of this research, earthquakes as disaster type, the intrinsic vulnerability of open spaces, and the identification of risk factors.

The first selection was conducted evaluating title and keywords (both author and index keywords). The eligibility of the papers was therefore controlled checking the global pertinence of the keywords, the research fields, the object of the case studies, and the types of disasters considered. Moreover, in this first stage was also excluded the irrelevant documents.

The second sorting process involved the reading of abstract and conclusions of each document previously included. In this case, the authors verified the pertinence of the objectives and the results, searching for studies which address intrinsic risk assessment of open spaces.

The third stage encompasses the reading of the full text, in order to exclude those documents which do not provide any explicit risk factors formulation.

Table 3: Summary of the criteria applied for the selection process.

Selection Stage	Actions	Eligibility criteria	No.
Stage 1	Title and keywords evaluation	Keywords: · global pertinence of the keywords; Research fields: · excluded: risk reduction; · included: risk assessment, emergency management, disaster preparedness, and evacuation strategies; Case studies: · excluded: viaducts, highway, dams, recent cities; Disaster/Hazard type: · included: multi-hazards studies; · included: earthquakes induced by other hazards studies, if the effect on open spaces was considered; Excluded: irrelevant documents.	667 ↓ 243
Stage 2	Abstract and conclusion evaluation	Objectives of research: · excluded: risk assessment of building and aggregates itself; · included: risk assessment of monuments and historic elements; Results: · included: intrinsic vulnerability of open spaces; · excluded: extrinsic vulnerability of open spaces.	243 ↓ 82
Stage 3	Full-text reading	Results: · included: explicit formulation of risk factors; · excluded: without any evaluation of the effects on BE open spaces.	82 ↓ 15

2.1.3 Final documents selection

In order to include relevant documents not identified with the described procedure, a final snowball search among the references of the selected papers was conducted. In total, 29 documents were selected for in-dept analysis and critical review (Table 4): 15 identified with the systematic process, 14 added with a traditional bibliographic search.

The whole final documents were catalogued, highlighting: type of source, hazard type considered, locations of the case studies (CS), risk factor involved (hazard, vulnerability, exposure), and BE open spaces interested (Areal Spaces or Linear Spaces). This preliminary classification was useful to control the subject of the selected documents and organize the following review steps.

Table 4: Summary of the final documents selected for the in-dept review.

	Documents	Type	Hazard	CS location	Risk factor			BE op. sp.	
					H	V	E	AS	LS
1	(Adafer and Bensaibi 2015)	Conference	Earthquake	Tipaza, Algeria	x	x			x
2	(Adafer and Bensaibi 2017)	Conference	Earthquake	-	x	x			x
3	(Álvarez et al. 2018)	Journal	Tsunami	Iquique, Chile		x	x		x
4	(Anhorn and Khazai 2015)	Journal	Earthquake	Kathmandu, Nepal	x	x	x		x
5	(Cunha et al. 2017)	Conference	General	Lisbon, Portugal	x	x		x	x
6	(Cremonini 1993)	Book	Earthquake	-	x	x	x	x	x
7	(Dan et al. 2017)	Journal	General	-		x		x	x
8	(D'Andrea and Condorelli 2006)	Conference	Earthquake	Catania, Italy		x	x		x
9	(Ertugay et al. 2016)	Journal	Earthquake	Thessaloniki, Greek					x
10	(Evans and McGhie 2011)	Conference	Earthquake	Maule, Chile		x		x	x
11	(FEMA 2013)	GL	Multi-hazard	-	x	x	x	x	x
12	(Ferreira et al. 2014)	Journal	Earthquake	-		x		x	x
13	(FHWA 2017)	GL	General	-		x		x	x
14	(Fischer et al. 2018)	Journal	General	-		x		x	x
15	(Fischer et al. 2019)	Journal	General	-		x		x	x
16	(Goretti and Sarli 2006)	Journal	Earthquake	Potenza, Italy		x	x		x
17	(Lancioni et al. 2014)	Journal	Earthquake	-	x	x		x	x
18	(León and March 2014)	Journal	Tsunami	Talcahuano, Chile		x	x		x
19	(León et al. 2019)	Journal	Tsunami	Viña del Mar, Chile		x	x		x
20	(Menoni 2001)	Journal	Earthquake	Kobe, Japan		x		x	x
21	(Pérez et al. 2017)	Journal	Earthquake	-	x	x		x	x
22	(Quagliarini et al. 2018)	Journal	Earthquake	Offida, Italy	x	x	x	x	x
23	(Santarelli et al. 2018)	Journal	Earthquake	Civitanova M., Italy	x	x			x
24	(Sarhosis et al. 2017)	Conference	Earthquake	-		x		x	x
25	(Tumini et al. 2017)	Journal	Tsunami	Chile	x	x			x
26	(Utami and Nurhadi 2018)	Conference	Earthquake	Indonesia		x		x	x
27	(Pereira 1982)	Book	General	-	x	x	x	x	x
28	(Yin and Xu 2010)	Conference	General	-		x			x
29	(Zhang et al. 2015)	Journal	Multi-hazard	Beijing, Cina		x	x		x

Risk factors: H - Hazard, V - Vulnerability, E - Exposure;
BE open spaces: AS - Areal Spaces, LS - Linear Spaces.

2.2 Analysis of results

A bibliometric analysis based on the co-occurrence of the keywords was conducted using VosViewer software (Van Eck and Waltman 2007, 2018), both on the first (667 results) and the second (243 results) set of documents.

VosViewer help to visualize the recurrence and correlation among the keywords in selected literature through a network data map, where the size of the elements shows the recurrence of a single term, while the links between the elements show the relationships among the terms.

The authors imported the .ris file (Research Information Systems), downloading it from Scopus database, selected a minimum occurrence of 2 for a keyword, and performed a data cleaning, both merging variant of similar terms with a thesaurus file wrote on purpose and deleting geographical indication and a few minor terms (Figure 3).

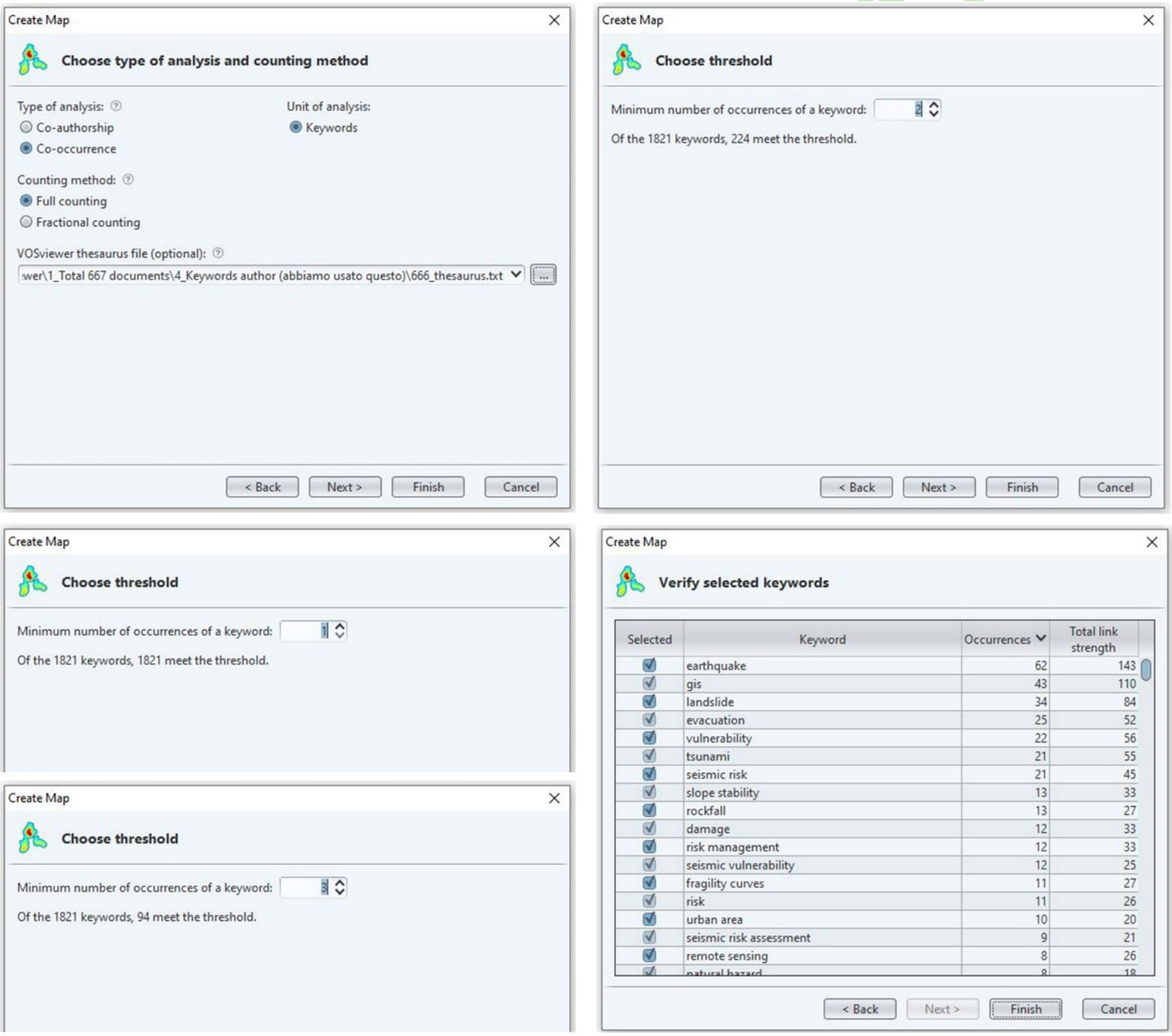

Figure 3: VosViewer's settings, from top left: 1. Type of analysis and import of thesaurus file; 2. The choice of the minimum numbers of occurrences of the papers' keywords for the analysis; 3-4. Attempting using occurrences of 1 (excluded since too wide) and of 3 (excluded since not enough significant);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

3. Results

3.1 Review of the selected literature

In the previous deliverables (D1.1.1 and D1.1.2), OS in BE have been classified in 2 main morphological systems, emerged as the most representative for the compact historic town: Areal Space (AS) and Linear Space (LS). The investigation of criteria for OS in BE classification concerns several features of the historical urban centres. The following results are focused on the content of OS features, classified according to 5 macro areas that could be identified according to the literature selected in Section 2.1.3:

- **Morpho-typological characteristics (Section 3.1.1)**: identification of features for morphological and typological system classification;
- **Characteristics of geometry and space (Section 3.1.2)**: identification of geometric-dimensional features of the main elements contained in open spaces;
- **Constructive characteristics (Section 3.1.3)**: definition of the constructive characters of elements characterizing the open spaces;
- **Characteristics of use (Section 3.1.4)**: description of space occupation (temporal and spatial);
- **Environmental characteristics (Section 0)**: definition of the context in which the open space is located from an environmental, climatic, infrastructural and hazard point of view.

3.1.1 Morpho-typological characteristics

In this section, literature approach concerning the relationship between the town concept and its physical expression, as well as the form characteristics that will be established in urban plans (Caniggia and Maffei 2001; Mandolesi and Ferrero 2001; Oliveri 2004) are pointed out. The influence of elements defining the morphology of the BE placed in existing urban settlement is expressed through the identification of space among physical barriers, also definable as content among frontier established between OS with different characteristics, which have an implication on the general infrastructure system with an emphasis on the road network (Pereira 1982).

(Fischer et al. 2018, 2019) assess different morphologies for the urban context, with consideration of multiple adverse events, like terrorist attacks or earthquakes (SEE 3.1.5), and multiple buildings. In the study, each defined urban object includes a certain number of attributes, like the object use, the construction type, the time-dependent number of persons, to derive different indicators.

(Tumini et al. 2017) propose an urban morphology analysis framework by comparing urban morphology resilience assessment of the case studies, before and after a disaster. The urban morphology framework is based on 8 indicators (Figure 4) addressing open space system, the use of public buildings and the proximity to open and built elements.

3.1.2 Characteristics of geometry and space

Among all geometrical factors influencing urban risk, the reference legislation (FEMA 2013; Italian technical commission for seismic micro-zoning 2014) focuses on large-scale expeditious approaches, for an efficient definition of the expected emergency scenario.

Several researches and experimental studies remark that road width is very influencing in case of an evacuation because wider roads show the larger carrying capability for pedestrian, directly determining the evacuation time (D'Andrea and Condorelli 2006; AA.VV. 2013; Quagliarini et al. 2016; Utami and Nurhadi 2018).

(Zhang et al. 2015) used Kirchhoff's law applied to urban seismic risk assessment to introduce a road resistor coefficient, that depends on road length and road width, to reflect the difficulty of evacuation. Furthermore, they point out a node degree parameter that expresses the accessibility of road and it quantifies the number of roads linked in the intersection, highlighting that evacuees prefer to choose crossroads than T-junction roads or the roads without any branches.

Indicator	Description		Relation with resilience	References	Data source
Population density (PD) [inh./ha]	This measures the population density in urban areas as *PD = (Tot. inh./area)*	−	> Density in tsunami flood area > Economic and human losses < Resilience	Cutter et al. (2014)	INE, Census
Balance Index (BI) [m²/m²]	This indicates the provision of open areas for emerging activities (useful areas) in the city; calculated as *BI = (Σunbuilt useful areas/Σbuilt areas)*	+	> Unbuilt area < Density > Recovery Area > Resilience	Cervero and Duncan (2003), Chou et al. (2013)	Municipal maps, Orthophoto Urban Planning documents
Temporary secure open space (SOS) [m²/inh.]	This evaluates the provision of secure evacuation areas in the city; calculated as *SOS = (ΣSOS areas/inh.)*	+	SOS ≥ 4 m² > Resilience	The Sphere Project (2011), Chou et al. (2013), Villagra et al. (2014)	INE, Census ONEMI OSS identification
Community Amenities Index (CAI) [m²/inh.]	This measures the provision of community amenities per inhabitant in urban areas *CAI = (Σ amenities area/ inh.)*	+	>CAI ≥ 45 m² > Resilience	The Sphere Project (2011), Chou et al. (2013)	INE, Census, Municipal maps
Evacuation Route Index (ERI) [n°/ inh.]	This evaluates the provision of secure evacuation routes in urban areas, calculated as *ERI = (Σn°Evacuation Route/(inh./100))*	+	> Escape Route > Redundancy > Resilience	Norris et al. (2008); Allan et al. (2013)	INE, Census ONEMI Emergency Map
Evacuation Route Distance (ERD) [m]	This measures the distance of evacuation routes from the farthest point in Euclidean Distance	−	> 600 m or 10-min walk (Euclidean Distance) < Resilience	Rueda (2006), Norris et al. (2008)	Municipal maps, Orthophoto ONEMI Emergency Map
Walkability Index (WI) [% m/m]	This measures the mobility and accessibility for pedestrians *WI = (Walkways length/Tot. streets length)* × 100	+	> Pedestrian streets > connectivity > resilience ≥ 75 %	Rueda (2006), Marín Cots (2012)	Municipal maps, Orthophoto, Information about streets
Proximity Index (PI) [%]	This measures the proximity and accessibility to basic services, such as food supply, education, health, sport or cultural calculated as *PI = (Inh. near basic services/Tot. inh.)* × 100	+	> Proximity services > social interaction > social capital > resilience	Rueda (2006), Marín Cots (2012)	INE, Census Localization of basic services

Figure 4: Resilience indicators for urban morphology analysis (Tumini et al. 2017).

(Utami and Nurhadi 2018) take into account road safety, road width and road accessibility, combining them with factors as high building density, narrow road network, limited availability of space, population density and high number of vulnerable groups.

With a geometric-spatial approach, taking into account high construction inside OS like bell towers or obelisk, (Sarhosis et al. 2017) introduce a simplified computation less fitting formula to predict the vulnerability of existing masonry towers. The needed input data are the main geometrical parameters, namely slenderness and cross shear area. The final formula has been derived conducting a sensitivity analysis on several idealized towers without any irregularity and with different slenderness and shear area.

The study by (Adafer and Bensaibi 2015) develops a vulnerability index (VI) method for road networks, where the most important parameters influencing roads seismic behaviour are identified, based on the worldwide seismic feedback experience, as synthesized on the left in *Figure 5*. Then a Multi-Criterion Decision-Making (MCDM) method is used to derive the relative importance between parameters with an assigned score (in the centre of *Figure 5*) and an Analytical Hierarchy Process (AHP) allows the determination of weighting coefficients for each defined parameter (on the right of *Figure 5*). In this way, the vulnerability index VI is calculated using Equation 1:

$$VI = \sum_{i=1}^{2} W_i \sum_{j=1}^{3or4} W_{ij} \sum_{k=1}^{2or3} W_{ijk} C_{ijkl} \quad (1)$$

Where Wi the weighting coefficient of structural or hazard parameters, Wij the weighting coefficient of items, Wijk the weighting coefficient of factors, where Wijk = 1 if i = 2 and Cijkl the score of categories, where l = 2 or 3 or 4 or 5. Furthermore, according to the value obtained for the vulnerability index, (Adafer and Bensaibi 2017) proposed three vulnerability ranges VR1 ($10<Vi<20$), VR2 ($20<Vi<35$) and VR3 ($35<Vi<50$).

3.1.3 Constructive characteristics

Several publications (Ertugay et al. 2016; Bernardini et al. 2018; Santarelli et al. 2018; Currà et al. 2019) characterizes all the road segments that present a blockage risk by a closure probability score. In (Ertugay et al. 2016) the road closures are attributed, in addition to the extrinsic vulnerability feature concerning the collapses of buildings adjacent to road edges, to ground failure, damage to bridges and damage to overpasses.

In (FEMA 2013) the road closure probabilities due to ground failure, bridge and overpass damage are based on fragility curves function of peak ground acceleration (PGA) (Tsionis and Fardis 2013). In the case of road pavements, the fragility curves provided in HAZUS (FEMA 2013) are used to estimate closure due to permanent ground deformation induced by soil liquefaction.

HAZUS (FEMA 2013) provides pieces of information also about pavement type, based on the FHWA classification, but it has no bearing on the computation of results. On the contrary, direct publications of FHWA (FHWA 2017) reports significant, balanced and comprehensive pavement condition rating systems, based on the two types of pavement conditions, both functional (based on ride quality and safety, skid resistance and rut depth) and structural (based on cracking and rut depth or faulting).

In this context, (Dan et al. 2017) focus on the quantitative relation between weather condition and pavement skid resistance. They measured skid resistance of asphalt pavement under various slippery conditions (wet, dry, icing, loose snow, water ponding, rime pavement) with pendulum friction coefficient tester, through simulating different pavement conditions in the freezing laboratory. Skid resistance values in (Dan et al. 2017) refer to vehicle tyre on an asphaltic slab, in terms of British pendulum number (BPN) expressing the friction performance of pavements (Figure 6).

(León and March 2014)propose an agent-based analysis of the evacuation route in the city of Talcahuano (Chile) to quantify the reduction of total evacuation time with the introduction of proposed urban design modifications. The developed model characterizes the evacuation route according to traffic condition, evacuee density and terrain slope, as shown by the literature.

Parameter	Item	Factor	Category
Structural	Pavement (1)	Number of lanes	> 2 lanes
			≤ 2 lanes
		Pavement Type	Paved
			Unpaved
	Embankment (2)	Height	H ≤ 2m
			2m < H ≤ 5m
			5m < H ≤ 8m
			H > 8m
		Compaction quality	Compliant with standards
			Compliant with technical provisions
			Other
		Slope	< 2/3
			= 2/3
			> 2/3
	Ground conditions (3)	Ground type	Rock
			Hard soil
			Soft soil
			Very soft soil
		Landslides potential	Low
			Medium
			High
	Maintenance conditions (4)	Pavement conditions	High
			Medium
			Low
		Slope protection measures	Compliant with standards
			Compliant with technical provisions
			Without any protections
Hazard	Seismic intensity (5)	-	C1*
			C2*
			C3*
			C4*
			C5*
	Liquefaction potential (6)	-	0 ≤ PL < 5
			5 ≤ PL < 15

* With: C1: MMI < VIII, C2: VIII ≤ MMI < IX, C3: IX ≤ MMI < X, C4: X ≤ MMI < XI and C5: XI ≤ MMI.

Parameter	Factor	Category	Scores
Structural	Number of lanes	> 2 lanes	20
		≤ 2 lanes	40
	Pavement Type	Paved	20
		Unpaved	50
	Height	H ≤ 2m	10
		2m < H ≤ 5m	30
		5m < H ≤ 8m	40
		H > 8m	50
	Compaction quality	Compliant with standards	10
		Compliant with technical provisions	30
		Other	40
	Slope	< 2/3	10
		= 2/3	30
		> 2/3	50
	Ground type	Rock	0
		Hard soil	10
		Soft soil	40
		Very soft soil	50
	Landslides potential	Low	10
		Medium	30
		High	50
	Pavement conditions	High	10
		Medium	20
		Low	40
	Slope protection measures	Compliant with standards	20
		Compliant with technical provisions	30
		Without any protections	50
Hazard	-	MMI < VIII	10
		VIII ≤ MMI < IX	20
		IX ≤ MMI < X	30
		X ≤ MMI < XI	40
		XI ≤ MMI	50
	-	0 ≤ PL < 5	10
		5 ≤ PL < 15	30
		15 < PL	50
	-	No intersection	10
		Intersection	40

Parameter	W*	Item	W*	Factor	W*
Structural	0.250	(1)	0.108	Number of lanes	0.667
				Pavement Type	0.333
		(2)	0.283	Height	0.648
				Compaction quality	0.122
				Slope	0.230
		(3)	0.561	Ground type	0.200
				Landslides potential	0.800
		(4)	0.048	Pavement conditions	0.667
				Slope protection measures	0.333
Hazard	0.750	(5)	0.633	-	-
		(6)	0.106	-	-
		(7)	0.261	-	-

* Weight.

Figure 5: Hierarchy of parameter, assigned scores and weighting factors for evaluation of intrinsic vulnerability (Adafer and Bensaibi 2015).

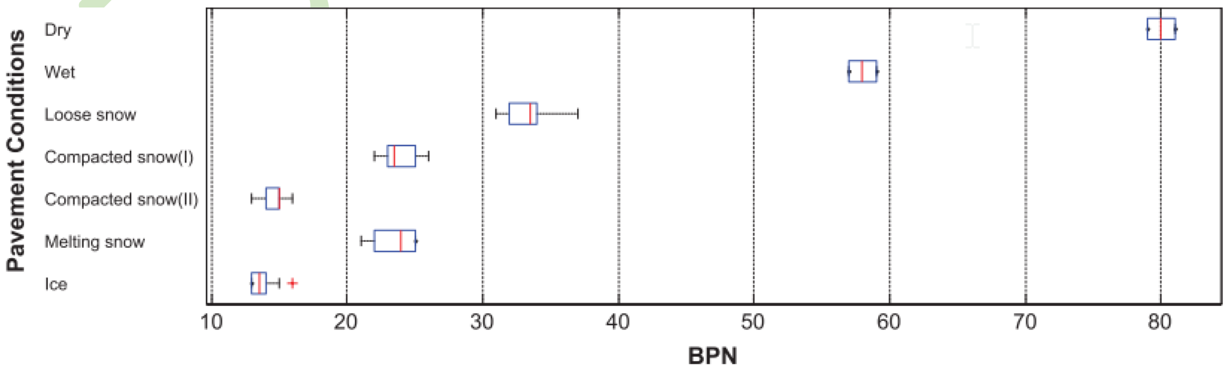

Figure 6: Data deviation analysis for various pavement conditions in terms of British pendulum number (BPN) expressing the friction performance of pavements (Dan et al. 2017).

An important in-depth study on direct damage to non-structural building components is estimated in HAZUS (FEMA 2013). Aspects related to Non-structural building include building mechanical/electrical systems and architectural components such as partition walls, ceilings, windows and exterior cladding but could be extended to outdoor spaces elements as slope/quote difference protections measure, decorative elements, monuments and obstacles in general. Some non-structural components (partition walls and windows) tend to crack and tear apart from structural elements during the earthquake. In the methodology, this element is called drift-sensitive non-structural damage. Other non-structural components such mechanical equipment tend to get damaged by falling over or being torn from their supports due to the acceleration component. In the methodology, this element is called acceleration-sensitive non-structural damage. Of course, many non-structural components are affected by both acceleration and drift, but for simplification, components are identified with one or the other as summarized in Figure 7.

Type of Non-structural Damage

Drift Sensitive	Acceleration Sensitive
• wall partitions	• suspended ceilings
• exterior wall panels and cladding	• mechanical and electrical equipment
• glass	• piping and ducts
• ornamentation	• elevators

Figure 7: Difference among Non-structural component damage (FEMA 2013).

The presence of obstacles along safe evacuation routes is a topic especially considered in those studies involve tsunami hazard. In their study on evacuation route for tsunami events in Iquique (Chile), (Álvarez et al. 2018) use the term "micro-vulnerability" to define the whole obstacle encountered in a street during a rapid evacuation. Those elements, constituting the micro-vulnerabilities, can be defined as a function of the inappropriate use of the public space (e.g. temporary occupation by restaurants), the poor maintenance of the space (e.g. broken sidewalk) and problems of design conception of the space itself (e.g. narrowing).
The identification of these micro-vulnerabilities can be done through direct diagnoses along the roads or through GIS tools. In the cited study, the authors inspected 45 km of urban roads in the city of Iquique (Chile) with the aim of developing evacuation models. The most common micro-vulnerabilities found were: the presence of parked cars on sidewalks, narrowing of sidewalks to make space for parking, use of sidewalks to extend the service area of restaurants (only during the day and evening), use of public spaces for informal commerce, and road works.
To assess the impact of the presence of these micro-vulnerability elements, Equations 2 and 3 are proposed:

$$i\% = \frac{\sum_j S_{mj} \propto_j}{S_r} 100 \quad (2)$$

$$\propto_j = 1 - SCV_j \quad (3)$$

where
i[%] is an index represents the proportion of the area of an evacuation route that is occupied by the micro-vulnerabilities existing on it;
S_m is the surface area of the micro-vulnerability associated with an evacuation route;
S_r is the surface area of the analyzed evacuation route;

α_i is the speed reduction factor associated with each micro-vulnerability;
SCV in the speed conservation value (for the evaluation of SCV refer to Figure 8).
As it can be seen, the factor α_i is the complement of the magnitude defined as speed conservation value (SCV) which represents the percentage of the maximum speed that can be maintained on a given surface. To this end, each micro-vulnerability was classified according to one of these categories: blocking or decrease in spaces available for evacuation, abrupt surface-level changes, and noticeable changes in surface roughness. Where the maximum speed is reached on a compacted and flat ground such as street pavement and sidewalks, speed is completely conserved and SCV is 1.

Speed conservation value (SCV)			
Blockages (0)		Level changes (0.5501)	Surface roughness (0.9091)
Barriers	Narrowings	Manhole covers	Cracked sidewalks
Basement entrances	Objects	Stairs	Green areas
Bus stops	Parking spaces	Uneven surfaces	
Cars	Public telephones		
Debris	Restaurants		
Electrical boxes	Road separators		
Electricity pole	Road works		
Fences	Sculptures		
Fire hydrants	Seats		
Garbage cans	Signs		
Gas stations	Trees		
Informal commerce	Walls		
Kiosks			

Figure 8: Speed conservation values (SCV) of micro-vulnerabilities present on evacuation routes (Álvarez 2018).

(Pereira 1982) focus on obstacles in an urban BE, that hinder the evacuants from freely move in OS, addressing not only the parked vehicles presence, but also lighting, urban furniture, sidewalk treatment, and types of vegetable species

The obstacles factor was also considered in (Zhang et al. 2015) already mentioned. They introduce an illegal vehicle parking parameter, that could be extended to poorly designed parking, directly influenced the evacuation because, if the road is occupied by parked vehicles, evacuees could not occupy the entire path.

(León et al. 2019) presents a macro and micro-scale analysis of a tsunami scenario affecting the city of Viña del Mar (Chile), using an approach which combines computer-based models and fieldwork. The authors considered the obstacles and the pavement condition along the evacuation route, assuming specific values to each types of micro-vulnerability affecting the walking speed from the literature.

3.1.4 Characteristics of use

Starting from morphological concepts (Pereira 1982) (see 3.1.1 Morpho-typological characteristics), analyses and divides the outdoors space into two categories in terms of use, because it has serious implications on its form. Therefore we must consider circulation space and outdoor meeting space. From the one hand, circulation space refers to the circulation scheme for vehicles and pedestrians, analysed in terms of spatial formal expression as well as its access relations. It concerns road circulation hierarchy and access to activities, type of access network connecting the roads, their relation with the buildings and outdoor meeting spaces. From the other hand, outdoor meeting space is the urban social spaces. It is analysed based on dimensional categories related to the type of private or public permanence as well as how they are linked with the buildings and the spatial circulation system. The analysed categories in these outdoors meeting spaces are those of paved and non-paved (green areas) spaces (see 3.1.3 Constructive characteristics), as well as public and private spaces.

In (D'Andrea and Condorelli 2006) the main aspect of global seismic risk assessment is considering the exposure of the transport network user population, in addition to the "classical" exposure of the resident population. Highways, roads, railways, stations are infrastructures where a large number of people are at risk, in case of the seismic event, as much as those inside buildings. An effective way to predict possible crowding/vehicle traffic is the study of traffic flow data obtained from real-time (Zhang et al. 2015) or recorded (Bernardini et al. 2018) monitoring.

(Anhorn and Khazai 2015) synthesize in an "Open Space Suitability Index" (OSSI) a qualitative (suitability and manageability of open spaces to be used as shelter sites) and qualitative (GIS-based accessibility and capacity measure based on network analysis) evaluation criterion to rank the suitability of open spaces for planning in the aftermath of an extreme event. The final suitability index OSSI consists of two factors: first, an expert-based weighting procedure of SI and second a measure. In these terms, access to basic utility supply systems and critical infrastructure such as hospitals need to be considered as part of site suitability. The proximity to medical services has also found wide acceptance as an important factor (FEMA 2013). Hospitals are particularly important due to high numbers of injuries incurring during an earthquake and to prevent high numbers of post-event "fade-away" people (Coburn and Spence 1992; Cutter 1996).

In this sense, urban seismic vulnerability is understood as the attitude to the physical and functional damage of BE that does not depend only on the degree of vulnerability of the individual buildings, but also on the functional organization of the systems that ensure the urban effect (current operating standards and the role of the individual physical elements in the overall functioning of the system) and their spatial organization (concentration of territorial diffusion and the relationship between systems and the physical environment) (Cremonini 1994). Morover, in (Cremonini 1993) a qualitative reading methodology through which to intervene on the whole city at different scale, considering factors of urban and building vulnerability, physical, geomorphological factors reading the single aggregate in its entirety, also analyzing the voids and relevance spaces.

3.1.5 Environmental Characteristics

According to (D'Andrea and Condorelli 2006), a more effective seismic risk management cannot be separated from the analysis of transport infrastructures conditions, and in particular of road, in the awareness of being able to reduce the extent of the damage only maintaining even a minimum functionality of road network for the emergency vehicles in the post-event emergency. In a functional point of view, (Pereira 1982) describes road network hierarchies as an indicator of the relation to be established between the road and the immediately close buildings (gap, access delimitation, parking, landscaping...) and it defines the degree of tissue accessibility for all types of residents. In this context, (Zhang et al. 2015) define a node degree parameter that expresses the accessibility of road intersections and it shows how many roads are linked with the intersection. The high node degree distribution reflects that the road network has high network rate, less dead ends, and relatively high reliability.

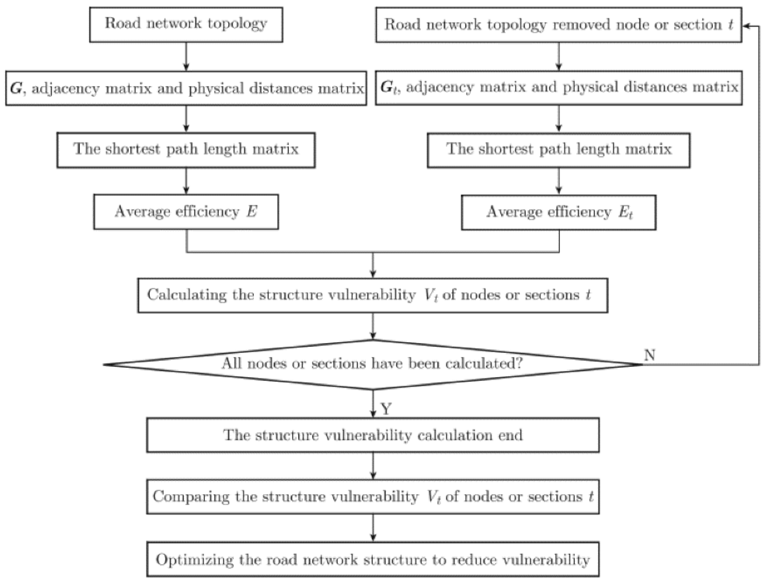

Figure 9: Framework of road network structure vulnerability measurement and improvement model (Yin and Xu 2010).

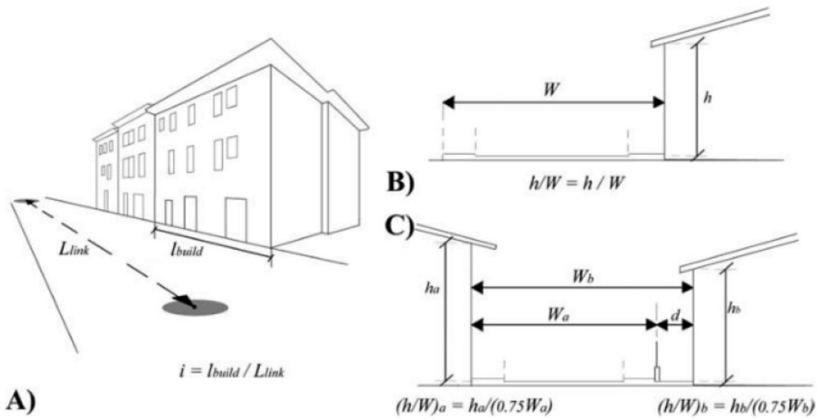

Figure 10: Calculating parameters of each building along with each link: (A) the incidence i; h/W in cases of (B) one built street side or (C) contemporary two built street sides (facing buildings). From (Santarelli et al. 2018).

Also (Goretti and Sarli 2006) underline that the interaction of road network, buildings and emergency services on network urban level is significant, but only for seismic intensities higher than IMCS=IX-X. For smaller intensities, the limited number of heavily damaged buildings makes the problem shift on other indicators.

(Berdica 2002; Yin and Xu 2010) define network structural vulnerability in the road transportation system as a susceptibility to incidents that can considerably reduce road network serviceability (Figure 9).

(Santarelli 2018; Santarelli et al. 2018) proposes a quick methodology for paths network vulnerability assessment, applicable to historical scenarios, including the effects of possible obstacles for evacuation procedures. They present a network schematization where the urban fabric is composed of nodes (control points or safe zones) and links (connections between 2 different nodes). In particular for links, they take into consideration the intrinsic vulnerability aspect of section decreases due to boundary limits (i.e. gates, walls, open pit canals, embankments), quantified in a street width reduction of 25% (Figure 10).

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)	$0 < L \le 0.33\ L_{max}$ $0.33\ L_{max} < L \le 0.67\ L_{max}$ $0.67\ L_{max} < L \le L_{max}$
		C.2	Width (m)	$0.67\ W_{max} < W \le W_{max}$ $0.33\ W_{max} < W \le 0.67\ W_{max}$ $0 < W \le 0.33\ W_{max}$
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}	$0 < V_{Nlink} \le 25\%$ $25\% < V_{Nlink} \le 50\%$ $50\% < V_{Nlink} \le 75\%$ $75\% < V_{Nlink} \le 100\%$
F	Seismic hazard	F.1	Design ground acceleration (a_g)	$a_g \le 0.05\,g$ $0.05\,g < a_g \le 0.15\,g$ $0.15\,g < a_g \le 0.25\,g$ $a_g > 0.25\,g$
		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		$0.67\ A_{max} < A \le A_{max}$ $0.33\ A_{max} < A \le 0.67\ A_{max}$ $0 < A \le 0.33\ A_{max}$
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 11: Factors, parameters and associated alternatives for links and nodes, reported to evaluate the risk-influencing aspects of links within the urban path network. From (Quagliarini et al. 2018).

Also in (Quagliarini et al. 2018) the urban fabric is composed of links and nodes and the definition of the holistic path risk assessment methodology based on the influencing factors is developed. The article proposes several influencing factors for links and nodes exposure, geometrical features and physical-structural features, subsoil conditions and vulnerability of facing buildings as reported in Figure 11. Each parameter can be characterized by different alternatives conditions. A particular focus is reserved to squares, defined as nodes where building facades projections do not entirely cover the square's area itself. For this reason, squares can hold people during the emergency and need ad hoc evaluation.

Both (Quagliarini et al. 2018; Santarelli et al. 2018) propose the application of the proposed methodology to real-world samples in order to offer a preliminary validation.

Taking into account the infrastructural network, (Pérez et al. 2017) propose a general application method to evaluate the typology of the linear hydraulic infrastructure that allows correlating the behaviour of the soils and the possible affectation in the potable water pipes. Referring to (FEMA Seismic Guidelines for Water pipelines 2005), the authors proposed parameters to estimate the damage to linear infrastructures of drinking water (potentially extendible to another infrastructural network), referring to physical characterization (type and material of the pipe, type of join, length of the pipe, conditions and definition of the elements of protection against corrosion…), operational characterization, hydrological definition, geological and geotechnical characterization, complementary aspects.

HAZUS (FEMA 2013) provides information concerning the probability of an expected level of permanent ground deformations (PGD) defined as liquefaction, landsliding and surface fault rupture. PGD are important in estimating losses to and functionality of lifelines.

(Dan et al. 2017) point out a direct link between weather condition (temperature) and pavement slipperiness. For example, skid resistance of icing pavement under the wet and low-temperature conditions declines sharply compared with dry and wet pavement. Dry pavement, instead, develops an adhesive surface due to asphalt properties when the temperature is high.

(Evans and McGhie 2011) conducted a fieldwork research on the seismic performance of lifeline utilities after the earthquake and tsunami in Chile in 2010. His paper considers the system network (electricity, water, gas and tele-communications) and the infrastructures (roads, bridges, ports, and airports), reporting qualitatively how they responded to the devastation.

Analyzing the Kobe earthquake of 1995 (Menoni 2001) deals with the seismic vulnerability of lifeline utilities. That experience shows how the physical event is only the trigger, which causes physical damage (to vulnerable structures), but which also reveals the organizational and managerial failures of the prevention phase that make the environment subject to systemic damage. (Menoni 2001) highlights the relationships between the different elements of an urban system which, in the event of an earthquake, presents interconnected effects.

The possibility of defining a disruption index (DI) to measure the level of unease for the population due to damage to public structures and service networks (lifeline utilities), is found in (Ferreira et al. 2014). In this case, too, the study is addressed at the urban scale and the goal is still to plan the prevention phases in the best way through a holistic vision of the problem of seismic vulnerability of urban systems.

3.2 Definition of the factors influencing seismic risk in BE open space

After highlighting the main themes of papers selected by bibliometric analysis, we have identified several recurring factors within each category of characteristics presented (morpho-typological characteristics, characteristics of geometry and space, constructive characteristics, characteristics of use, environmental characteristics). For the definition of each factor refer to the Appendix, §8.1.

Table 5: Summary of the whole factors influencing OS in BE Intrinsic Risk (content) in literature, grouping by type according to D1.1.2.

	SECTION 1 Morpho-typ. character.				SECTION 2 Characteristics of space				SECTION 3 Constructive characteristics				SECTION 4 Characteristics of use						SECTION 5 Environmental Characteristics						
Authors/ Year	**Morpho-typology**	**Dimension of OS**	**Numbers of lane**	**OS balance**	**Quote difference**	**Slope**	**Slope/quote diff protections**	**Monuments (i.e. statues)**	**Pavement type**	**Pavement conditions**	**Fixed obstacles**	**Temporary obstacles**	**Special uses of OS**	**Building facing OS special uses**	**Vehicles (parking)**	**Accessibility for vehicle**	**Accessibility for pedestrian**	**Crowding**	**Seismic intensity**	**Multi-hazard potential**	**Ground type**	**Lifeline utilities**	**OS interconnection**	**Underground cavities**	**Climate conditions**
(Adafer and Bensaibi 2015)			×			×	×		×	×									×	×	×				
(Adafer and Bensaibi 2017)			×			×	×		×	×									×	×	×				
(Álvarez et al. 2018)										×	×	×			×										
(Anhorn and Khazai 2015)		×		×											×	×	×		×	×			×		
(Cunha et al. 2017)																					×			×	
(Cremonini 1993)	×	×											×						×			×	×		
(Dan et al. 2017)									×	×														×	×
(D'Andrea and Condorelli 2006)		×		×												×	×			×		×	×		
(Ertugay et al. 2016)									×	×													×		
(Evans and McGhie 2011)																						×			
(FEMA 2013)									×	×								×	×	×	×	×	×		
(Ferreira et al. 2014)																						×			
(FHWA 2017)									×	×															
(Fischer et al. 2018)	×												×							×			×		
(Fischer et al. 2019)	×												×							×			×		
(Goretti and Sarli 2006)									×	×													×		
(Lancioni et al. 2014)																			×		×	×		×	
(León and March 2014)	×		×			×									×			×							
(León et al. 2019)	×	×			×					×	×	×			×			×					×		
(Menoni 2001)																						×			
(Pérez et al. 2017)																				×	×	×			
(Quagliarini et al. 2018)	×	×	×		×	×	×		×	×	×	×			×	×	×	×	×	×	×	×	×	×	
(Santarelli et al. 2018)	×	×		×							×								×				×		
(Sarhosis et al. 2017)	×							×																	
(Tumini et al. 2017)	×	×		×													×	×							
(Utami and Nurhadi 2018)		×																					×		
(Pereira 1982)	×	×			×	×		×	×		×	×	×	×	×	×	×						×		
(Yin and Xu 2010)		×																					×		
(Zhang et al. 2015)	×	×									×					×	×	×					×		

4. Discussion

4.1 Analysis of results and relevant literature gaps

A general increase in the number of publications about risk assessment of open spaces can be observed in the last twenty years (Figure 12). Focusing in particular on the contributions more related to historic urban context (for the whole selection criteria see Table 3), it can be noted a similar trend in the growing rate of publications, but a different starting point, approximately in the last decade (2008: 5; 2009: 7; 2010: 8; 2011: 11; 2012: 22; 2013: 19; 2014: 10; 2015: 29; 2016: 29; 2017: 27; 2018: 13; 2019: 30; 2020: 10). Despite the attention on the risk assessment of the open spaces is relatively recent, the graphic in Figure 12 depicts clearly the rising interest in the field, confirming the trend already shown by (Koren and Rus 2019) for open spaces resilience.

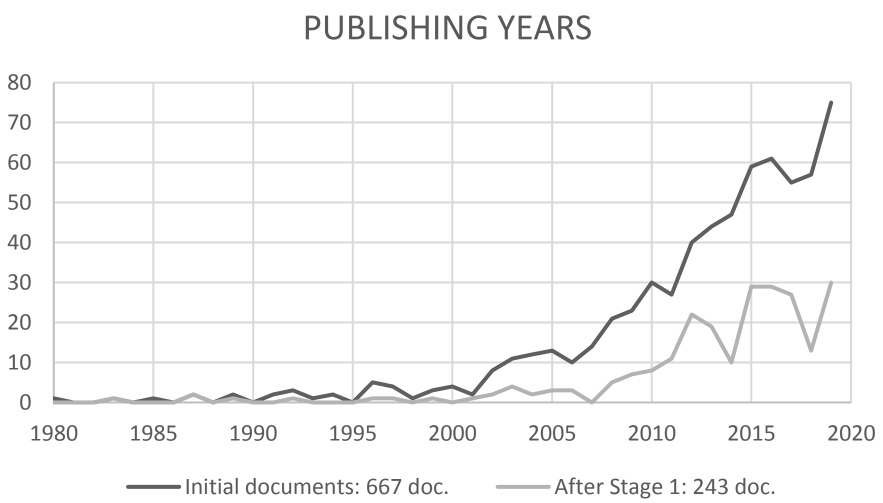

Figure 12: Publishing years of both initial set of documents (667) and after stage 1 of selection process (243).

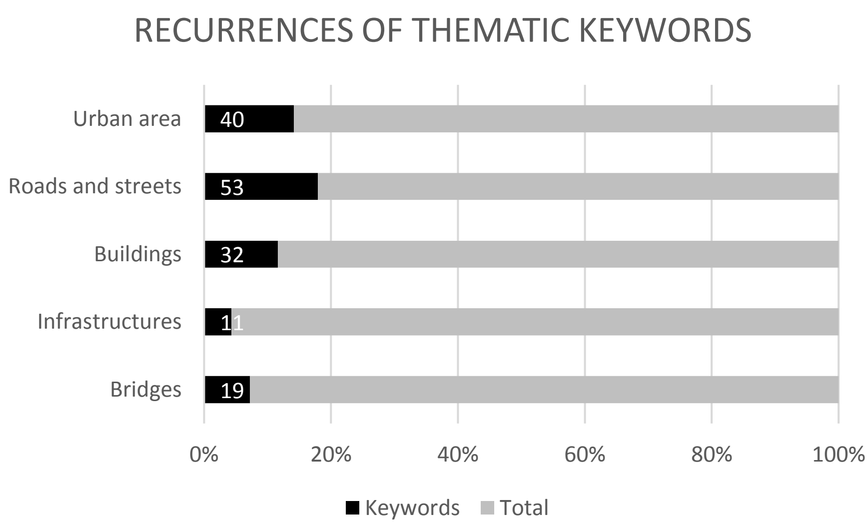

Figure 13: Recurrences of thematic keywords in the second set (243); on the bar the numbers of papers with the related keywords.

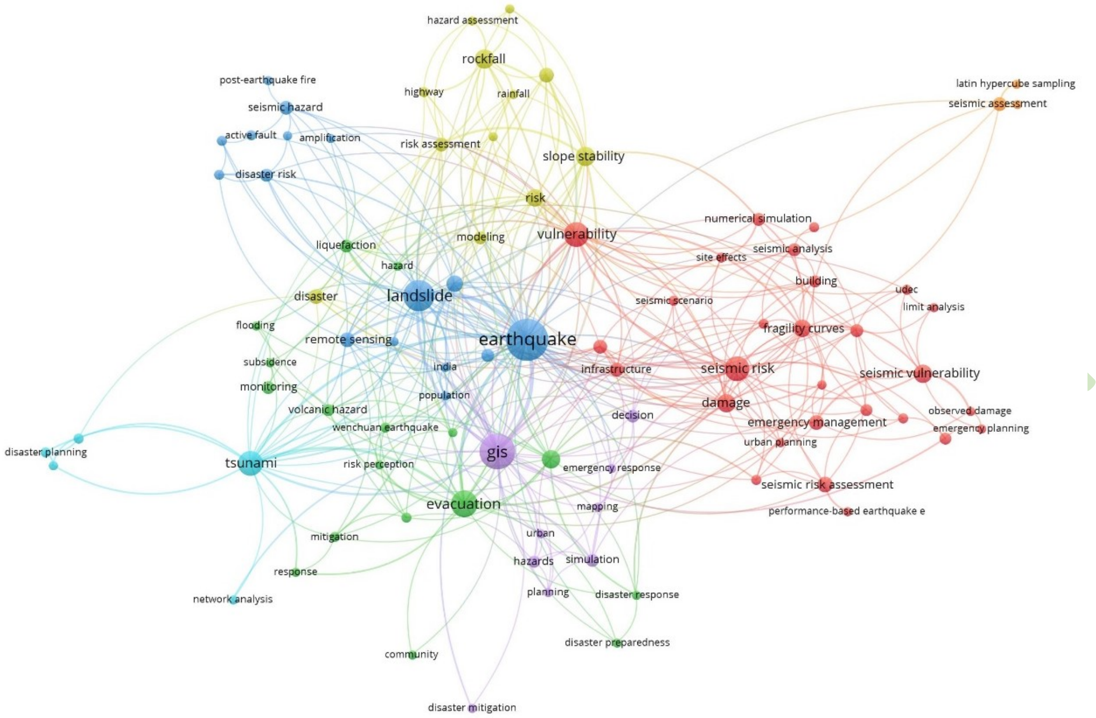

Figure 14: Neural map of the keywords' recurrence in the first set of documents (667 papers) found in Scopus (VosViewer).

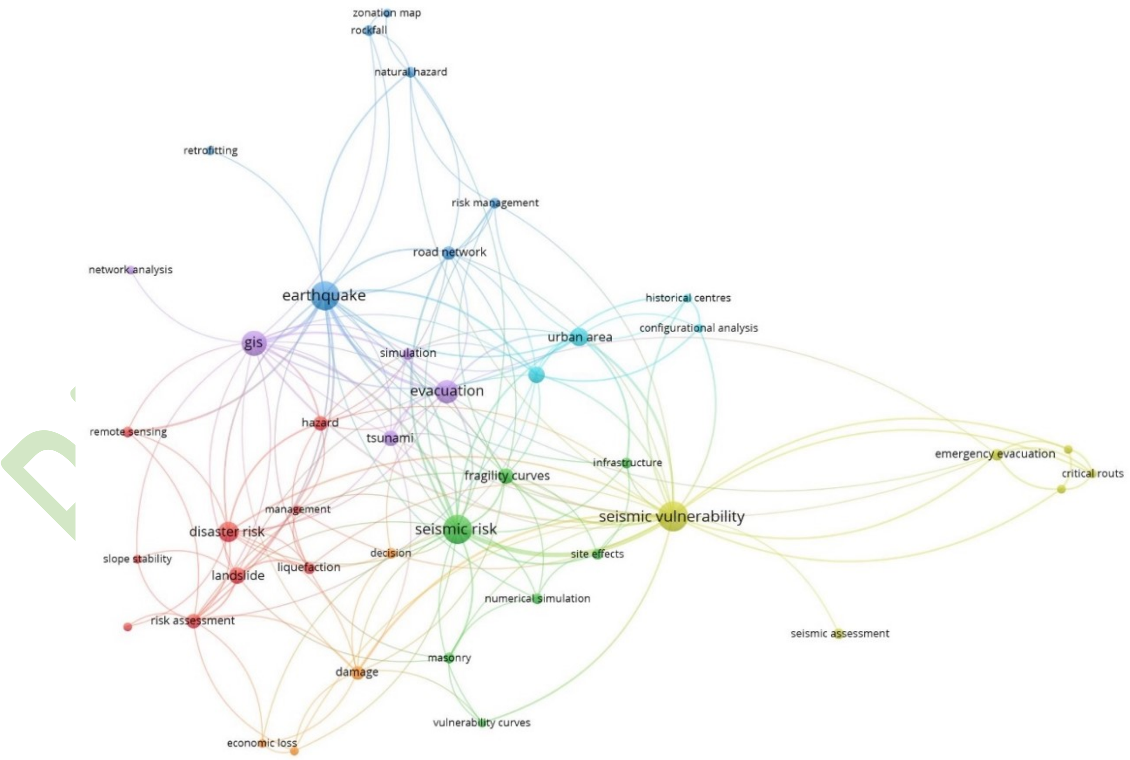

Figure 15: Neural map of the keywords' recurrence in the second set of documents (243 papers), selected during Stage 1 (VosViewer).

The second set of papers, with 234 publications, encompass a total of 93 documents about open spaces in the BE and the urban context (53 for Roads and streets; 40 for Urban area), 30 documents about infrastructures (19 for Bridges and 11 for Infrastructures in general), and 32 documents about buildings (Figure 13). The remaining papers do not include keywords on specific urban components. For effectively counting the keywords of the urban components some merging was done among similar classes of keywords. Each keyword includes the following:

- **Urban area**: Urban areas, Urban area;
- **Roads and streets**: Roads and streets, Road, Road Network, Urban Road Networks, Transportation Network;
- **Buildings**: Building, Buildings, Historical Buildings;
- **Infrastructures**: Infrastructure, Transportation infrastructures;
- **Bridges**: Bridges, Arch Bridges, Masonry Arch Bridges.

Removing the duplications, the papers encompassing the amount of the listed keywords to 100 elements, representing the 41% of results of the second set. Among the 40 results for Urban Area, 9 are specifically focused on risk assessment, 9 on the evacuation routes, and 4 involve morphological aspects.

A bibliometric analysis based on the co-occurrence of the keywords was also conducted using VosViewer software, both on the first (667 results) and the second (243 results) set of documents. The authors chose a minimum occurrence of 2, performed data cleaning merging variant of similar terms, and delete geographical indication and a few minor terms.
For the first set of documents, the final neural map includes 100 terms (Figure 14). The circle's size represents the occurrence of a term, the links instead represents the co-occurrence. The colors identify different clusters, that represent groups of keywords more related to each other. In Figure 14, it is possible to observe 7 clusters, which shown thematic grouping around a different type of hazard (earthquake, landslide, volcanic activities, tsunami).
For the second set of documents, the final neural map includes 50 terms (Figure 15). The 7 clusters identified highlight some interesting correlation, emerged also during the review process: "road network", "network analysis" and "configurational analysis" are recurrent subjects connected to evacuation strategies in urban areas; the not negligible role of the "evacuation" studies in relation to the risk factors; "GIS" and "numerical simulations" as tools frequently used; and the effect of the "liquefaction" phenomenon on the paving in the studies concern multi-hazard.

Besides the analysis on recurrent keywords and themes in the first and second set of selected documents, the authors conducted some estimation also on the final set, consisting of 29 papers. Among them, the sources of the documents are distributed as follow: 16 from journals, 9 from conferences, 2 from books, and 2 from grey literature (Figure 16). The analysis of risk factors involved in the studies has shown a prevalence of research connected to the vulnerability assessment for each type of disasters (Figure 17). Finally, the correlation among the type of open spaces and level of results are highlighted in Figure 18. The data indicates a prevalence in the number of studies involving linear spaces and qualitative results. It is relevant to note that the studies often do not focus specifically on the areal spaces, suggesting this could be a seminal subject for further research.

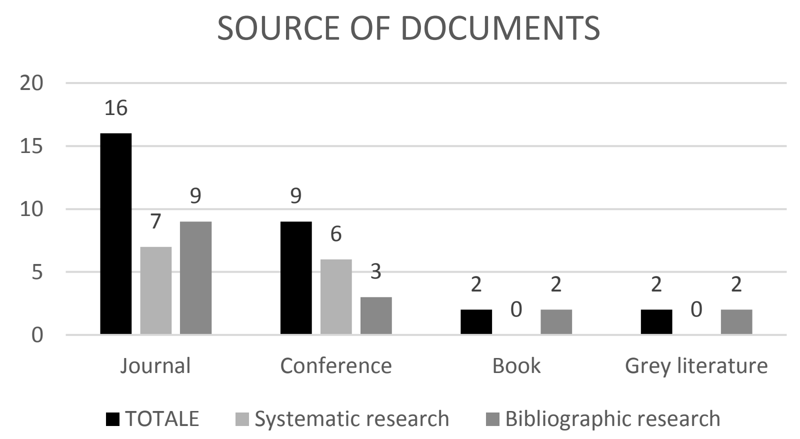

Figure 16: Type of publication of the final documents selected for the review process.

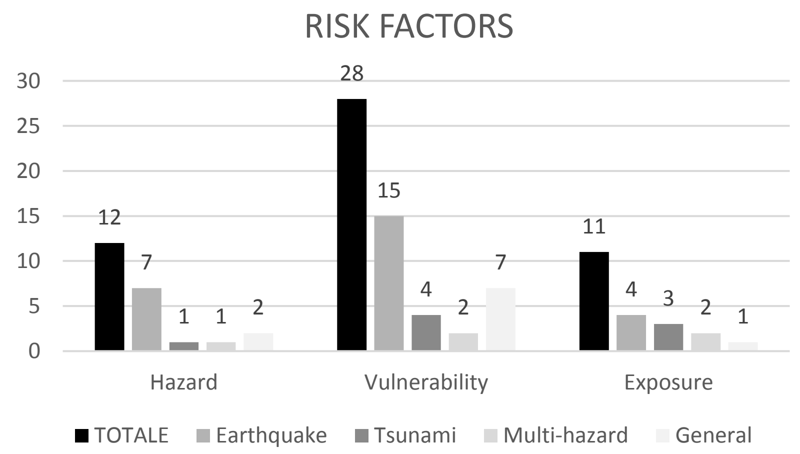

Figure 17: Type of risk factor studied and affected disasters.

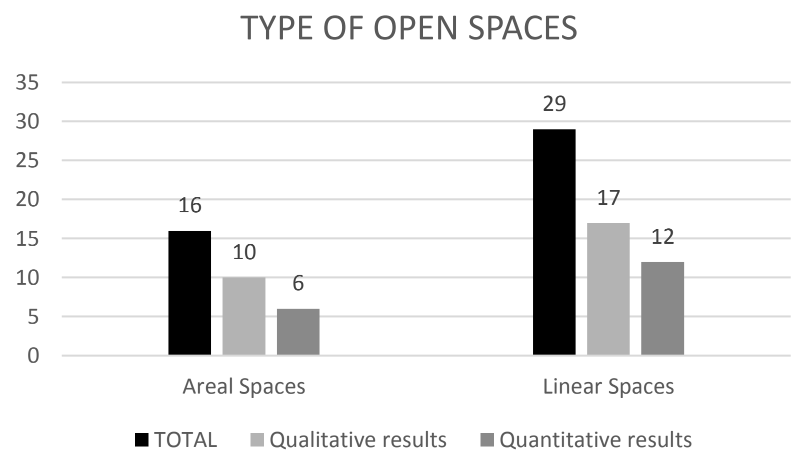

Figure 18: Correlation among type of Open Spaces and level of results.

4.2 From risk factors to parameters classification

This report identifies specific factors to support a qualitative and quantitative global risk assessment of open spaces in BE. As it was shown, papers as (Cremonini 1993; FEMA 2013; Lancioni et al. 2014; Adafer and Bensaibi 2015, 2017; Zhang et al. 2015; Dan et al. 2017; Quagliarini et al. 2018; Santarelli et al. 2018; Álvarez et al. 2018) have a distinctive quantitative approach, presenting original indicators and equations to evaluate the safety level of different aspects of BE open spaces. Among them, (Lancioni et al. 2014; Dan et al. 2017) focus on quantifying specific factor that the research herein presented judge a dutiful deepening.
The other papers selected, i.e. (D'Andrea and Condorelli 2006; Goretti and Sarli 2006; Yin and Xu 2010; Anhorn and Khazai 2015; Ertugay et al. 2016; Cunha et al. 2017; FHWA 2017; Pérez et al. 2017; Sarhosis et al. 2017; León et al. 2019), provide semi-quantitative evaluation, at least for the OS influencing aspect, considering parameters or evaluation methods aiming at defining quick methods for risk assessment.
Finally, papers with a qualitative approach as (Pereira 1982; León and March 2014; Tumini et al. 2017; Utami and Nurhadi 2018) have an important guidance contribution defining research possible directions. They introduce an interesting and innovative point of view on OS risk assessment, also presenting strong research motivations about OS focus.

The distribution of the risk factors found in the analyzed literature is summarized in Figure 19. The Environmental Characteristics records the higher number of occurrences (53), followed by the Morpho-typological Characteristics (30), the Constructive Characteristics (29), the Characteristics of use (28), and finally, the Characteristics of space (13).

Considering the recurrence of the factors in each section (Figure 20), it is possible to highlight which ones have been taken into account mostly. In Section 1, Morpho-typology and Dimension of OS recur 11 times. In Section 2 the recurrence distribution is rather uniform, with a slight prevalence of the Slope (5). In Section 3, the Paving type and the Pavement condition record 9 and 10 recurrences, while the less presence of the Fixed (6) and Temporary obstacles (4) factors highlighting the micro-vulnerability as one of most significant research areas for further research. Section 4 shows a rather uniform distribution, except for the factor about the Special uses of the building facing the OS (1). Section 5 shows a strong predominance of the OS interconnection factor (15), followed by the Lifelines utilities and the Multi-hazard potential (9), seismic intensity (8), the Ground type (7); the Climate condition factor seems to be actually of minor importance, although further research should be done to verify the real impact of this factor.

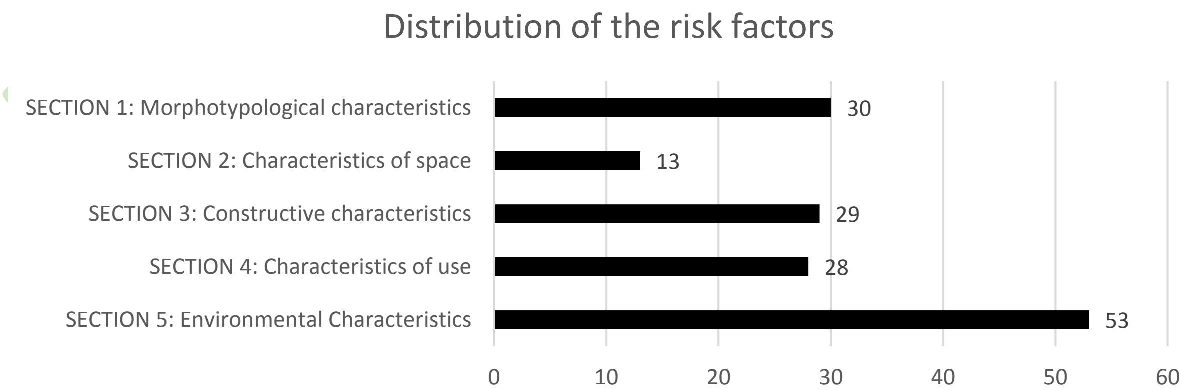

Figure 19: Distribution of the risk factors in the analyzed literature. The values indicate the number of occurrences.

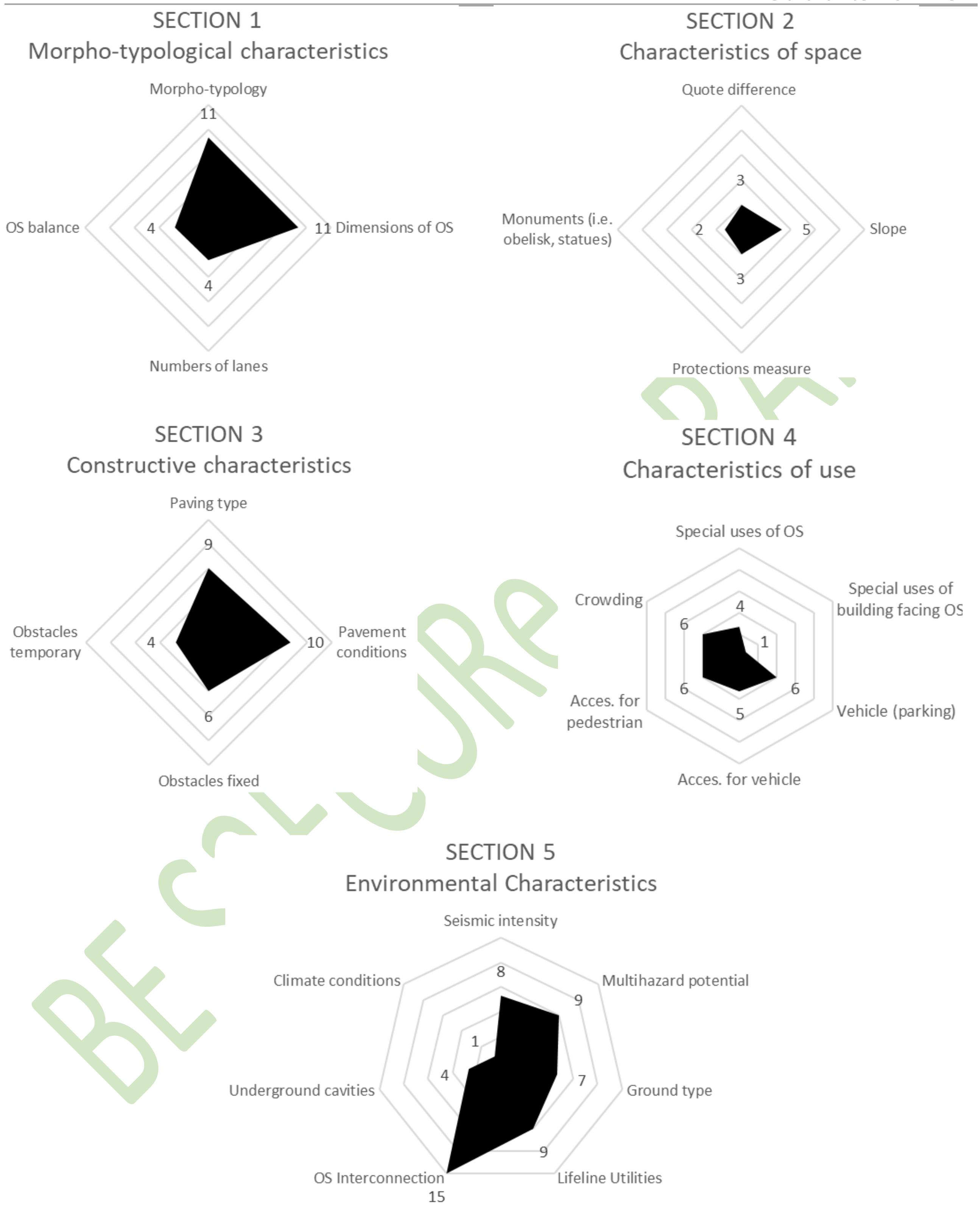

Figure 20: Recurrence of the factors influencing seismic risk in OS in the analyzed literature, groped in the 5 macro-areas.

5. Conclusions

The importance of open spaces in the BE is critical for the overall safety of the BE and its hosted users. Considering the open spaces (i.e. squares, green area, streets) as one of the components influencing the risk assessment in BE and in the related urban system where the BE is placed, the present report identifies specific aspects of risk in the BE open spaces, that will be summarized in the matrix of seismic risk conditions in BE, as discussed by D1.2.1.

Through both a systematic and bibliographic literature review on intrinsic seismic risk on BE open spaces, the authors identified 29 significant publications which address the disaster risk assessment in BE open spaces. Particular attention was paid on papers which express risk factor through a quantitative approach. After highlighting the main themes of each contribution, the authors identified recurring factors and grouped them according to the five macro-area characterizing the BE presented in D1.1.2, §2.1 (1. morpho-typological characteristics, 2. characteristics of geometry and space, 3. constructive characteristics, 4. characteristics of use, 5. environmental characteristics).

Moreover, the systematization of the whole factors in Table 5 and the analysis of the results in §4 allowed to provide preliminary criteria and parameters for evaluating outdoor seismic risk in emergency conditions and to find any relevant literature gaps where enhancing future research in quantifying each factor influence in seismic risk assessment.

6. Abbreviations

AS - Areal Spaces

BE - Built Environment

CS – Case Studies

LS - Linear Spaces

OS – Open Spaces

SUOD - Sudden-onset disasters

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8. Appendix

8.1 Definitions of risk factors

SECTION 1 Morphotypological characteristics

Morpho-typological characteristics: Direct influence of different urban forms and urban footprints (Fischer et al. 2018).
Dimensions of OS: Influence of geometric dimensions of OS (i.e. length and width of AS or LS).
Numbers of lanes: Influence of the number of lanes in a LS.
OS balance: Influence of the sum of OS in an urban centre.

SECTION 2 Characteristics of space

Quote difference: Presence of views, overhangs, cliffs and difference in altitude with a break of continuity between OS and a generic lower altitude / presence of walls against the ground for containing parts of cities at a higher altitude than the OS.
Slope: Presence of ramp, uphill climb without break in continuity between OS and a generic lower altitude.
Slope/quote diff protections measure: Presence of protection measure (i.e. railings, handrail…) for quote difference and slope.
Monuments: Presence of sculpture, or decorative architecture, which is placed in public areas to celebrate illustrious people or in memory of glorious events.

SECTION 3 Constructive characteristics

Paving type: type of materials used for OS pavement and lying (specifying if it is marble, travertine, etc.).
Pavement conditions: state of preservation of OS pavement surface, so to provide sufficient friction and avoid slipperiness (Dan et al. 2017), specifying if they are slick, compact, disjointed, etc.
Obstacles fixed: Presence of diffuse obstacles in the OS that can interfere with the evacuation of people during an emergency (i.e. benches, bumps, poles, flowerpot, railings, bike rack…).
Obstacles temporary: Presence of temporary obstacles in the OS that can interfere with the evacuation of people during an emergency (i.e. dehors, tables, stalls, carousel…).

SECTION 4 Characteristics of use

Special uses of OS: Presence of special use of OS (i.e. concert, fair, exhibition…) with attention to people distribution in a day depending on such activities.
Special uses of building facing OS: Presence of special use of buildings facing OS (i.e. museum, theatre, disco…) with attention to people distribution in a day depending on such activities.
Vehicle (parking): Presence of vehicle parked in OS.
Accessibility for vehicle: Possibility for vehicle to pass through OS.
Accessibility for pedestrian: Possibility for people to pass through and rest in OS.
Crowding: Attention to abnormal people distribution in a specific period of a day depending on special uses of OS and of building facing OS.

SECTION 5 Environmental Characteristics

Seismic intensity: Direct influence of effects of an earthquake on OS risk assessment.
Multihazard potential: Potential of OS to be subjected to others hazard during an earthquake.
Ground type: Type of soil under OS.

Lifeline Utilities: presence of infrastructure that can interfere with BE during hazard, i.e. primary urbanization, uncovered pipes, high tension wire, etc.
OS Interconnection: specify if the OS is part of a particular road network that define a specific system in BE.
Underground cavities: influence of natural or men made underground space (i.e. quarry, parking).
Climate conditions: Direct influence of climatic condition on OS material and indirect behavioural influence.

8.2 Selected literature and factors influencing seismic risk in open spaces

	Type of research		Scale			Risk factor			Open Space		SECTION 1 Morph. charact.				SECTION 2 Characteristics of space				SECTION 4 Characteristics of use				SECTION 5 Environmental Characteristics						SECTION 5 Environmental characteristics								Source				
Authors/Year	Literature review	Case Study	Building scale (US)	Aggregate scale (AS)	Urban scale	Hazard	Vulnerability	Exposure	Areal Space	Linear Space	Morpho-Typology	Dimensions of OS	Numbers of lanes	OS balance	Quote difference	Slope	Slope/quote diff protections measure	Monuments (i.e. obelisk, statues)	Paving type	Pavement conditions	Fixed obstacles	Temporary obstacles	Special uses of OS	Special uses of building facing OS	Vehicles (parking)	Accessibility for vehicle	Accessibility for pedestrian	Crowding	Seismic intensity	Multi-hazard potential	Ground type	Lifeline utilities	OS interconnection	Underground cavities	Climate conditions	Presence of indicators	Journal	Conference	Book	Grey Literature	Snowball
(Adafer and Bensaibi 2015)					×	×	×			×			×			×	×		×	×									×	×	×					×		×			
(Adafer and Bensaibi 2017)		×			×	×	×			×			×			×	×		×	×									×	×	×					×		×			
(Álvarez et al. 2018)		×	×	×	×		×	×		×										×	×	×			×											×	×				
(Anhorn and Khazai 2015)		×			×	×	×	×		×		×		×												×	×		×	×			×				×				
(Cunha et al. 2017)		×			×	×	×																								×			×				×			
(Cremonini 1993)					×	×	×	×	×	×	×	×											×									×	×			×			×		×
(Dan et al. 2017)							×								×	×																		×	×	×	×				×
(D'Andrea and Condorelli 2006)					×		×	×		×		×		×												×	×			×		×	×					×			×
(Ertugay et al. 2016)		×			×					×									×	×													×				×				
(Evans and McGhie 2011)		×			×		×		×	×																						×				×		×			×
(FEMA 2013)			×	×	×	×	×	×	×	×									×	×								×	×	×	×	×	×			×				×	×
(Ferreira et al. 2014)					×		×		×	×																						×				×	×				×
(FHWA 2017)					×		×												×	×																				×	×
(Fischer et al. 2018)		×			×		×				×												×							×			×				×				
(Fischer et al. 2019)		×			×		×				×												×							×			×					×			×
(Goretti and Sarli 2006)		×			×		×	×		×									×	×													×				×				×

(Lancioni et al. 2014)		×	×	×	×	×		×	×																		×		×	×		×		×	×				×
(León and March 2014)	×	×	×	×		×	×		×	×		×			×									×			×								×	×				×
(León et al. 2019)	×	×	×	×		×	×		×	×	×			×					×	×	×			×			×					×			×	×				×
(Menoni 2001)	×			×		×		×	×																						×				×	×				
(Pérez et al. 2017)				×	×	×																							×	×	×					×				
(Quagliarini et al. 2018)	×	×	×	×	×	×	×	×	×	×	×	×		×	×	×		×	×	×	×			×	×	×	×	×	×	×	×	×	×		×	×				
(Santarelli et al. 2018)	×	×	×	×	×	×			×	×	×		×							×								×				×			×	×				
(Sarhosis et al. 2017)		×				×				×							×																				×			
(Tumini et al. 2017)	×			×	×	×			×	×	×		×													×	×									×				
(Utami and Nurhadi 2018)	×			×		×		×	×		×																					×					×			
(Pereira 1982)				×	×	×	×	×	×	×	×			×	×		×	×		×	×	×	×	×	×	×						×						×		×
(Yin and Xu 2010)	×			×		×			×		×																					×					×			
(Zhang et al. 2015)	×			×		×	×		×	×	×									×				×	×	×	×					×				×				