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CONSTRUCTION AND BUILDING PERFORMANCE

BUILDING AND DESIGN TECHNOLOGIES

A SURVEY FORM FOR THE CHARACTERIZATION OF THE HISTORICAL BUILT ENVIRONMENT PRONE TO MULTI-RISKS

Alessandro D'Amico, Martina Russo, Letizia Bernabei, Marco Angelosanti, Elena Cantatore, Gabriele Bernardini, Fabio Fatiguso, Graziano Salvalai, Giovanni Mochi, Enrico Quagliarini, Edoardo Currà

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Abstract

The Historical Built Environment (HBE) is constantly prone to many risks causing sudden (e.g., earthquakes and terrorist attacks) or slow (e.g., climate change-related and environmental pollution) onset of emergency conditions. Morphological, physical, and constructive characteristics are critically linked to system vulnerability and users' exposure. In particular, Open Spaces (OSs) in the HBE represent typical attractors for the community in urban areas for leisure and touristic purposes and critical scenarios in case of a disaster. In fact, besides daily and hourly temporalities in everyday use, OSs also play a pivotal role in the immediate disaster response phases, considering sudden-onset events. Understanding which scenarios characterize OSs is critical to evaluate them from a multi-risk perspective and to propose effective mitigation strategies in multiple critical situations. To this end, this work offers a survey form template of the OSs within the HBE according to a holistic but quick-to-apply approach. Placed in the context of the Project of Relevant National Interest (PRIN) BE S²ECURe, the survey form assesses the relationships between frontier elements and those contained in the OSs, focusing on literature-based identification of vulnerability, exposure, and hazard factors affecting risk. These factors are organized into five sections as the basis for classification criteria of OSs: (1) morpho-typological, (2) geometrical-spatial, (3) constructive, (4) use, and (5) context. The application to eight case studies contributes to the validation of the survey, showing its ability to trace both the level of complexity and the main characteristics of the analyzed scenario. Furthermore, the survey form can be properly and quickly applied by non-specialized technicians, such as local authorities, thus representing the first step to support planners in data collection and risk assessment of historical OSs.

Keywords

Built Environment, Open Spaces, Disasters, Multi-hazard, Safety.

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1. INTRODUCTION

1.1. MULTI-RISK APPROACH AND SAFETY OF THE BUILT ENVIRONMENT

The performance of the built environment (BE) to face disaster risk and the safety of its users during emergencies depends on the system of connections between tangible and intangible elements that are activated in response to the disastrous events that may arise in the man-made space [1, 2]. Given the complexity of the urban system, consisting of urban fabrics, specialized buildings, and connecting networks, and the vulnerabilities that characterize it, both the risk assessment and the proposal of mitigation strategies must be based on a multi-disciplinary and multi-risk perspective. The assumption of the BE as a system of open spaces (OSs), buildings facing them, connection infrastructures, and users who gravitate within these spaces plays a decisive role in defining the resilience of the city and its users in response to catastrophic events [2, 3]. The resilience of the BE describes the system's ability to withstand shocks and preserve the structure of essential services and strategic functions for hosted users [4], as well as to absorb and adapt to the impacts of disturbing events. Human and social aspects act in concert to define the resilience of a BE, also respect to mutual interference that could determine other conditions of risk during the occurrence of catastrophic events. The morphology of the BE is one of the main factors in assessing the onset of demanding risk conditions and the consequent ability to respond to catastrophic events [5]. The resilience of the urban organism also depends on the fragility and ability of social agents (e.g., population, public and private service operators, local authorities, civil protection, and rescue organizations) to absorb the stresses and take action in advance to regulate the changes caused by unexpected catastrophic events. These aspects, related to the user preparation in response to disasters, are influenced and limited by both access to existing resources and emergency management systems set up within the built urban organism. A BE that can be considered resilient has a substantial number of characteristics to be evaluated from a holistic perspective, especially considering urban contexts which feature a high concentration of exposed users and high morphological and constructional complexity [2, 3, 6, 7]. In this sense, urban historical scenarios represent an emblematic case.

The meso-scale elements of the BE (e.g., blocks, OSs, and streets) help define the resilience of the urban system as a whole and ensure the safety of its users [1]. The specific morpho-typological characteristics and the urban layout, both players in the genesis and evolution of urban fabrics, substantially influence the system's ability to ensure the desired level of safety through strategic functions and services during all the phases of the catastrophic event. In this sense, OSs, defined as linear spaces (LS; e.g., streets) and areal spaces (AS; e.g., squares), play a fundamental role in the emergency management phase [12]: the roads allow the connection between the various elements of the BE, guaranteeing the evacuation process and the rescue operations, while the squares act as "safe" outdoor waiting areas for users affected by the sudden event. The value of these elements largely depends on the specific risk, the critical issues related to the functions they contain, and the use of such spaces made by users (e.g., becoming catalysts of attendance) [3]. Consequently, the safety conditions must be assessed by taking into account the interactions between different aspects: (i) morphological and constructive characteristics of the external spaces and the buildings facing them; (ii) their intended use and the variable presence of users over time both in the external areas and in the internal environments; (iii) the combined impacts of disastrous events on emergency and evacuation conditions, which essentially depend on the potential damage level for each risk [8]–[10]. Similar to other fields, such as urban energy behavior, these characteristics represent a higher level of building behavior: a meso-scale performance.

Regarding the definition of these risks, the scientific literature provides categorizations of disasters based on distinct criteria that define their causes and/or impacts. According to the World Health Organization [11], disasters are distinguished based on the temporal onset conditions of the consequences of the event on the BE and its users:

- SLow-Onset Disasters (SLODs): events whose effects are gradually recorded over time and are caused by anthropogenic factors, such as air pollution and the heat island effect resulting in higher temperatures than outlying areas;

- SUdden-Onset Disasters (SUODs): sudden and unexpected events with natural origins, such as earthquakes, and human-made, such as terrorist acts, whose effects have an immediate impact.

Although the development of analysis tools for BE and its risks is generally divided to date, previous studies have shown how a multi-risk approach allowed for the development of a set of mitigation strategies. These particularly concern the criticalities determined by the coexistence and mutual interaction of risks, conditions that could otherwise compromise the effectiveness of the adopted measures [12].

1.2. FROM RAPID SURVEY TO IDEAL SCENARIOS ASSESSMENT

Several national and international research activities have investigated the built heritage and documented its main typological and morphological characteristics in order to create extensive databases to develop study catalogs and/or risk assessments. In Italy, this need arises because the databases used for the building stock inventory refers essentially to the ISTAT (Istituto Nazionale di Statistica – Italian National Institute of Statistics) census data, whose information on the BE characteristics (e.g., construction period, number of floors, and structural material) is scarce [13]. The definition of rapid surveys is closely related to this study's objective. In the scientific literature, research activities aimed at the investigation of OSs can be identified on a regional basis, such as the one conducted by Mandolesi and Ferrero [14], or aimed at structural-typological characterization of buildings, such as those conducted for example by Zuccaro et al. [13] or from Gentile et al. [15]. Mandolesi and Ferrero investigated every OSs in the Piceno Area of the Marche Region of Italy, defining recurring typologies of this type of BEs [13]. Zuccaro et al. [13] looked for the definition of a rapid survey form for the typological-structural characterization of urban areas consisting of ordinary buildings (CARTIS), also based on previous experiences such as the definition of the AeDES form (Accessibility and damage in the seismic emergency) used starting from the Umbria-Marche earthquake in 1997 and all subsequent seismic events. This research is part of the ReLUIS three-year project, "Network of University Laboratories of Seismic Engineering" 2014-2016, and funded by the Department of Civil Protection, Line "Inventory of existing structural and building types, Thematic Area "Territorial themes", to develop a systematic methodology for the assessment of exposure at a territorial scale based on the typological-structural characteristics of ordinary buildings and the creation of a database in order to deepen the knowledge on seismic vulnerability, first of all, and towards other natural phenomena, such as volcanic eruptions and hydrogeological events. Similarly, Gentili et al. [15] focused on the risk for school buildings in the UK by defining, through the use of rapid-visual survey (RVS) forms, the INSPIRE seismic risk index. Those research activities were performed by rapid surveys focusing on macro-scales, whose methods mainly referred to seismic vulnerability, which, in some countries, might not be enough for the development of a rational, multi-hazard prioritization scheme. As highlighted by Gentili et al. [15], this approach required a domain expansion in terms of the type of risks and type of buildings to ensure further applicability to the whole BE.

Multi-risk scenarios can be developed starting from these approaches, working on the idealization of the BE. Other examples oriented towards risk assessment and simulation application (i.e., mainly in SUODs, such as floods), based on the analysis and classification of real-world scenarios into typical conditions through quick assessment methods (e.g., geometry-based), have been proposed in previous works. Such cited research activities selected case studies to elaborate on the idealization of BE in different ways, according to relevant parameters considered.

1.3. AIM OF THE PAPER

This contribution, therefore, intends to take a first step towards the creation of multi-risk scenarios in OSs through the definition and validation of a rapid survey form. This approach considers the multiplicity of factors involved and the complexity linked to the characterization of the BE. Specifically, the authors will examine the morphological, geometric, constructive, and use characteristics of the elements of the external space and of the frontier elements that can influence and/or determine the impact of disastrous events on present users. The use of rapid survey techniques allows for the replicability of application, even by subjects with limited specific knowledge, thus making the form usable for local administrations and non-specialized technicians.

The activity is part of the actions carried out for the PRIN project BE S^{2}ECURe – "(make) Built Environment Safer in Slow and Emergency Conditions through behavioral assessed/designed Resilient solutions", funded by MIUR, the Ministry of Education, University and Research. This project intends to develop methods, tools, and guidelines to assess the resilience of the BE, promote the design of risk mitigation strategies, and increase risk awareness using a holistic and multi-risk approach focused on user behavior during an emergency.

2. METHODOLOGY

The survey form for the characterization of both the BE with a multi-risk approach and the safety of its users in urban OSs was developed starting with critically analyzing the literature for both SUODs and SLODs risks (e.g., vulnerability, exposure, and hazard factors) and the interfering elements of the BE, up to defining multi-risk scenarios. Subsequently, the form was validated by applying it to eight case studies in the context of Italian historical centers. The validation process both evaluated the ability of the form to describe the peculiar aspects of the chosen OSs, and indicated the first recurrence of these characteristics. The form provided an operational tool for expeditious investigations on the OSs of an entire urban environment, especially in complex contexts such as historical centers. These contexts typically consist of compact and critical urban fabric due to the fragility of the existing building heritage. The form has been developed to consider all the aspects of risk (i.e., vulnerability, exposure, and hazard) with a multi-risk approach and consists of 5 sections (Fig. 1). The first three sections mainly focused on vulnerability issues by investigating the morpho-typological characteristics of OSs, the geometric-spatial and construction characteristics, both elements present within the OS (i.e., content), and those that define the perimeter (i.e., frontier). The fourth section focused on the exposure aspects through the space-use characterization and the elements that most influenced users and their possible behavior in case of disaster. The fifth and last section collected information on the hazard, defining the characteristics of the context.

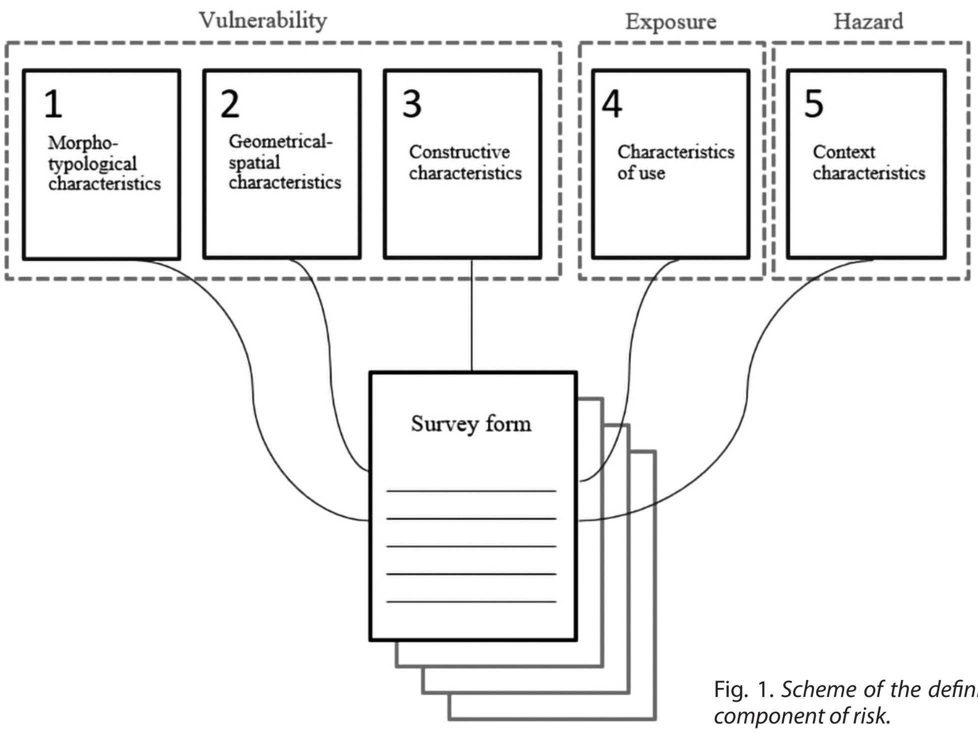

Fig. 1. *Scheme of the definition of the survey form considering the component of risk.*

2.1. AREAS OF INVESTIGATION FOR THE CONSTRUCTION OF THE FORM

According to the literature concerning the OSs [5], [9] there has been an ever-increasing interest in urban resilience and its assessment. Experience obtained in recent extreme events (in particular, earthquakes and floods, two main morphological systems were identified:

- ASs (e.g., squares, parks, parking areas) were defined as OSs partially or entirely surrounded by buildings and were characterized by different functions based on social uses (e.g., places of aggregation) or types of buildings along their frontiers (e.g., civil, religious, administrative, monuments). They could be completely free or partially occupied by urban furniture and/or other elements;
- LSs (e.g., roads, streets, alleys) were defined as OSs bordered by buildings along two sides and characterized mainly by the function of connecting different AS within the urban fabric, thereby allowing and supporting the movement, rather than the aggregation, of people and vehicles.

The survey form was composed of five sections that described a variety of features characterizing the OSs, considering both their frontier (e.g., the buildings facing the OS) and their content elements (e.g., the urban furniture, monuments). Each section comprised a list of principal parameters and detailed sub-parameters related to SUODs and SLODs considerations (Fig. 1). The first section focused on identifying the morpho-typological characteristics of the OSs. Based on morphological approaches [5], six categories for the ASs and four categories for the LSs were proposed in relation to both the evacuation difficulties for the SUODs and the environmental factors for the SLODs. The second section focused on the characteristics of geometry and space of the OSs, describing both the frontiers composition, in terms of architectonical and structural aspects [16] (e.g., structural aggregates and unit, special buildings, porches) and the content elements, regarding the micro vulnerabilities (e.g., obstacles and quote differences) and the environmental mitigation components (i.e., greenery and water bodies) [17]. The third section focused on constructive characteristics of the OSs' pavement (e.g., material, lying, and finishing) and the buildings along the frontiers (e.g., construction techniques and age), which are both involved in the user's safety during an evacuation process [16] and affect the environmental performance [17].The fourth section was concerned with the exposure factors linked to the characteristics of the uses and users. It defines the potential levels of crowding over time, vehicular and pedestrian accessibility, and the type of user [16]. The fifth section focused on the characteristics of the considered OSs' context [12]. These factors are related to the peculiarity of the site, reporting the SLODs hazard level (e.g., climate and environmental factors), and the evaluation of probable SUODs and multi-hazard potential.

2.2. APPLICATION TO AREAL SPACE CASE STUDIES

Given the BE S[2]ECURe project's main application context was the wide variety of construction culture of the Italian historical centers, the survey form to describe the complexity of their several peculiar aspects was evaluated using 8 case studies belonging to ASs typology (Fig. 2). The selected case studies represented various layout configurations of ASs in the Italian territory by geographical locations, types, dimensions, and populations. The eight squares belong to both medium-sized (between 5,000 and 50,000 inhabitants) and small cities (less than 5,000 inhabitants), which represented more than 90% of the total Italian municipalities and about 70% of the national resident population [7]. These ASs were located in cities representing different historical-architectural and construction traditions, with various geometric (e.g., dimension and position of the access), spatial (e.g., building along the frontier and peculiar element in the content), and uses-related features (e.g., principal and temporary function of the space and crowding level). The data collected for each parameter were analyzed to verify the ability of the form to describe recurring multi-risk conditions. For each case study, the complexity was evaluated as the sum of the present parameters from the application of the form to highlight a preliminary selection of case studies representative of multi-risk conditions on which to deepen the research.

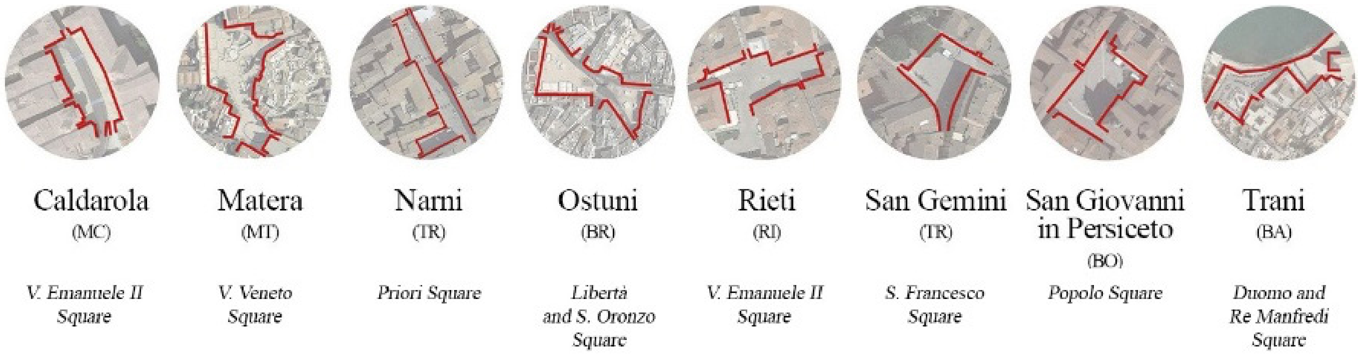

Fig. 2. *Areal Spaces of eight case studies for the application of the survey form.*

It was possible to identify three more relevant case studies by accomplishing a parametric analysis of the data collected. The values were evaluated as the sum of single parameters. The quartiles were analyzed, and the case studies were selected based on values lower than 25% percentile (Q1) and greater than 75% percentile (Q3), as these represented a greater or lesser complexity within the sample.

3. RESULTS AND DISCUSSION

3.1. THE SURVEY FORM

According to the explained methodology, the content of each section in the survey form is detailed described:

Section 1 – Morpho-typological characteristics: the objective of this section was the identification of the morpho-typological characteristics of the ASs and the LSs, affecting the vulnerability of the OSs to the SUODs and SLODs. The survey form adopted the classification proposed in M. Russo et al. [5], based on consolidated approaches including morpho-typological studies, historical-geographical studies, and urban vulnerability [18]. This classification consisted of six categories for the ASs [19] and four categories for the LSs [20], developed in relation to the evacuation difficulties for the SUODs [21] (e.g., number and location of escape routes, functional aspects related to accessibility level) and the environmental factors for the SLODs (e.g., orientation and solar exposure, natural ventilation, and pollutant concentration) [17].

Section 2 – Characteristics of geometry and space: this section aimed to record the geometrical characteristics of the OSs by describing the buildings along their perimeter (i.e., frontier) and the elements within them (i.e., content) [19]. The frontier was defined by the presence of Structural Aggregates (SA), Interferent Structural Unit (SUi), Continuous Built Font (CBS) in line with CLE (Limit Condition of Emergency) [6], and special buildings (in terms of architectonical peculiarity compared to the regular urban fabric). Other parameters were introduced to characterize different types of built and not-built fronts, such as town walls, porticoes, water, green area, access, and the presence of quote differences (e.g., stairs, ramps). The content considered those elements that can impede the users during the emergency phase [16]. For example, temporary elements (e.g., dehors, canopy), cultural or artistical elements (e.g., fountains, monuments, statues, archaeological sites), and green areas. The presence of natural or human-made underground cavities was also included, considering their role in amplifying the local seismic frequency spectrum [22].

Section 3 – Constructive characteristics: this section considered the potential conditions that affected the extrinsic and intrinsic vulnerability of the OS to the SLODs and SUODs, specifically the construction techniques and building materials along the frontiers and the pavement of the OS. For the SUODs, the OS extrinsic vulnerability was influenced by the buildings' structural performance along the frontiers (i.e., the debris caused by the facades overturning during a seismic event [16] or an explosion in case of a terroristic attack [21]). For the SLODs, the intrinsic vulnerability was affected by the energy performance of the building's façades (e.g., the perceived temperatures near the frontier itself, as a function of the albedo coefficients of the finishing materials). The intrinsic vulnerability depended on the type and condition of the pavements and the presence of particular elements (e.g., protective devices in proximity of the accesses) [23] that influenced the evacuation safety during a SUOD [16] evacuation paths can suffer significant damages and modifications due to both extrinsic (i.e.: building facing the path or micro-climate condition for a SLOD.

Section 4 – Characteristics of uses: this section focused on the uses and users of the public OSs, and of the buildings along the frontiers, determining the exposition level of the BE [8]. The type (e.g., age, physics condition, local knowledge of the place) and density of users (e.g., inhabitant, tourists, daily workers) influenced the effectiveness of the evacuation flow and the behavior of the people during a SUOD [5, 16]. In particular, considering a terroristic attack and in line with the principle of the maximization of damage [21], the presence of sensitive targets affects the mediatic relevance of the attack.

Section 5 – Characteristics of the context: this section collected those parameters that connected the specific OS with the features of its surrounding area, which can affect its overall hazard level [9]. Considering the SLODs, the hazard level is affected by the climatic zone classification (e.g., maximum temperatures, solar exposure, and wind velocity) [24]. Conversely, the presence of lifeline utilities was considered for the SUODs that, although they provide essential infrastructure services to the community, are susceptible to damages and can compromise the evacuation paths [22]. Moreover, this section also reported the multi-hazard potential of the area (according to the national classification for each type of risk), considering that the interaction between disasters can cause collateral risk conditions (e.g., landslides, explosions, floods) [13].

3.2. DATA OF APPLICATION TO AREAL SPACE CASE STUDIES

The form's application to the 8 selected case studies highlighted both a good capability of the process and the form itself to summarize the main characteristics of OSs. The compiled results were compared in the various aspects which characterized the analyzed ASs (Fig. 3).

SECTION 1: MAIN TYPE

AREAL SPACE:

1. Tending to quadrangle	2. Elongated with parallel sides	3. Tending to triangular and funnel-shaped	4. Trapezoidal and polygonal	5. Tending to circular, ovoid and ellipsoid	6. Composite

LINEAR SPACE:

1. Passage	2. Traditional street	3. Main street	4. Gateway/Mobility street

DIMENSIONS:		
Area (m²)	Orientation	N
H max built front (m)	Sea level (m)	
H min built front (m)		*draw a scheme of the OS with the main dimension and accesses location

SECTION 2: CHARACTERISTICS OF GEOMETRY AND SPACE

FRONTIER		*CONTENT*	
SA (Structural Aggregates)		Special building	
Aggregated (SU≥1)	Isolated (SA=SU)		
SUi (Interferent Structural Unit)		Church	City Hall
CBF (Continuous Built Front)		Theatre	School
Access		Museum	Other: ....
Vehicular	Pedestrian	Canopy	
Controlled /with obstacles		Fontaine	
Special building		Monuments (i.e. obelisk, statues)	
Church	City Hall	Dehors	
Theatre	School	Height difference	
Museum	Other:	Upward (i.e. stairs, ramps, containment walls)	
Porches		Downward (i.e. stairs, ramps, balconies)	
Water / Green area		Archaeological sites	
Height difference		Water / Green area	
Upward (i.e. stairs, ramps, containment walls)		Underground park	
Downward (i.e. stairs, ramps, balconies)		Underground cavities	

SECTION 3: CONSTRUCTIVE CHARACTERISTICS

FRONTIER		*CONTENT*	
Homogeneity of built environment age		Pavement materials (i.e. marble, travertine…)	
Yes	No	Pavement lying (i.e. compact, disjointed, big slabs, small tiles, cobblestones…)	
Homogeneity of constructive techniques			
Yes	No	Pavement finishing (i.e. smooth, coarse, irregular…)	
Façade finishing (e.g. albedo coefficient…)			
Urban furniture/obstacles		Urban furniture/obstacles	
Benches	Flowerpot	Benches	Flowerpot
Bumps	Railings	Bumps	Railings
Poles	Traffic barriers	Poles	Traffic barriers
Bike Rack	Other:	Bike Rack	Other: ....

SECTION 4: CHARACTERISTICS OF USE

Daily crowding		Strategic buildings	
Morning	Afternoon	City Hall and administrative buildings	Operational headquarters for emergency management
Evening	Night	Law enforcement offices	Healthcare facilities
Special uses of open space		Sights	
Concerts	Theater	Overall Areal o Linear Space	Church
Parking	Festivals	City Hall	Theatre
Other:		Museum	Other: ....
Accessible to		Sensitive targets	
Vehicle	Pedestrian	High profile people	Symbolic buildings
Bike /Scooter	Other:	Tourists or crowd of them	

SECTION 5: CONTEXT CHARACTERISTICS

Climate classification [DPR 412/1993]		Hazard assessment	
A	B	Earthquake	Landslide
C	D	Tsunami	Wildfire
E	F	Mass Movement (dry)	Chemical
Infrastructural network		Volcanic activity	Explosion/fire
		Storm/tornado	Transport accident
Primary urbanization	Uncovered pipes	Extreme temperature	Terrorist attack
High tension wire	Other:	Flood	Miscellaneous accident

Fig. 3. *Rapid survey form to collect and manage risk factors.*

Figures 4 and 5 show the results of the scores; for each case study, the values are indicated for the "frontier" and "content".

When considering Section 1, two squares belonged to the first morphological category (tending to the quadrangle; i.e., San Gemini and San Giovanni in Persiceto - SGP), one to the second category (elongated with parallel sides; i.e., Caldarola), one to the third category (tending to the triangle; i.e., Ostuni, composed of two spaces tending to the triangle) and four to the sixth category (composites; i.e., Rieti, Narni, Matera, and Trani). An average planimetric extension of 3.731 m^2 was observed, with a minimum for San Gemini (1.240 m^2) and a maximum for Trani (12.000 m^2).

Section 2 showed a median value for the structural aggregates present in the squares analyzed equal to 6, with a maximum for Ostuni (9) and a minimum for San Gemini (3). The accesses were analyzed considering the different transport modes permitted (pedestrian, vehicular, and controlled access), and their global count resulted in a median of 7 accesses per square, with a minimum for San Gemini (4) and a maximum for Matera (12). Regarding special buildings, a median of 3 is observed, with a minimum for Rieti, San Gemini, and Ostuni (2) and a maximum for Matera (7).

Referring to Section 3, the selected cases showed a non-homogeneity of constructive techniques and building age, except for Caldarola. There were an equivalent number of cases with compact and non-compact lying regarding the pavement, with an irregular finish prevalence (6 cases out of 8). The obstacle presence in space reported a median of 3, with a minimum for San Giovanni in Persiceto and Caldarola (1) and a maximum for Rieti and Matera (4).

The characteristics of the uses, reported in Section 4, showed a homogeneous frequentation of the spaces in the day and afternoon bands for all cases, except for Trani and Ostuni, also characterized by prevalent evening use. The temporary functions inside the OSs included festivals and concerts in the most frequent cases; parking functions are found for 5 cases (Caldarola, Trani, Narni, San Gemini, and Rieti); and theatrical performances for only one case (Narni). Strategic buildings reported a median of 1, with a minimum for Ostuni (0) and a maximum for San Giovanni in Persiceto (3). The tourist attractions identified had a median value of 2, with a minimum for

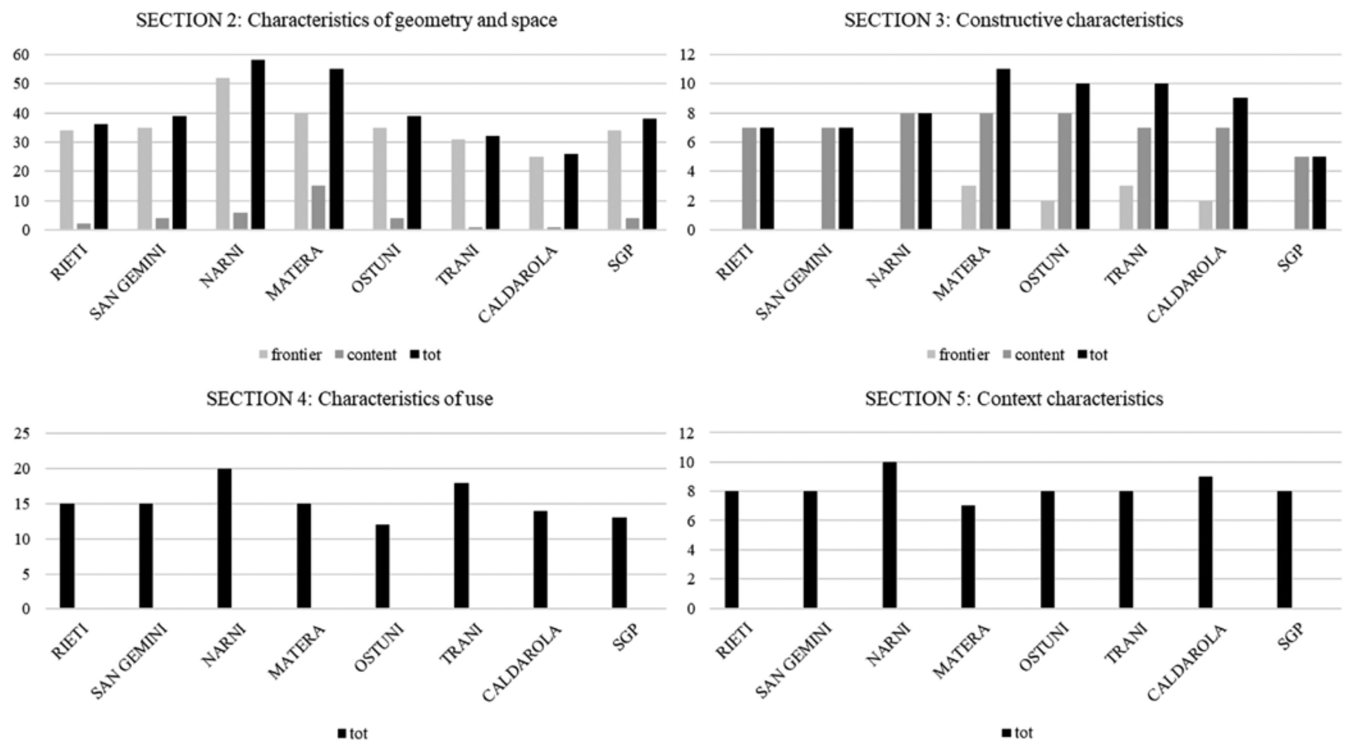

Fig. 4. *Graphs of the values are divided into sections of the survey form for the selected AS - elaboration by the Authors.*

San Giovanni (0) in Persiceto and a maximum for Narni and Matera (5).

Finally, section 5 highlighted the types and levels of danger associated with each space; the median in the number of identifiable dangers was 6, with a minimum for Matera (5) and a maximum for Caldarola (7). According to data reported in the national earthquake regulations, 4 cases fell into class 2 (Rieti, San Gemini, Narni, and Caldarola), 2 cases in class 3 (Matera and San Giovanni in Persiceto), and 2 cases in class 4 (Ostuni and Trani).

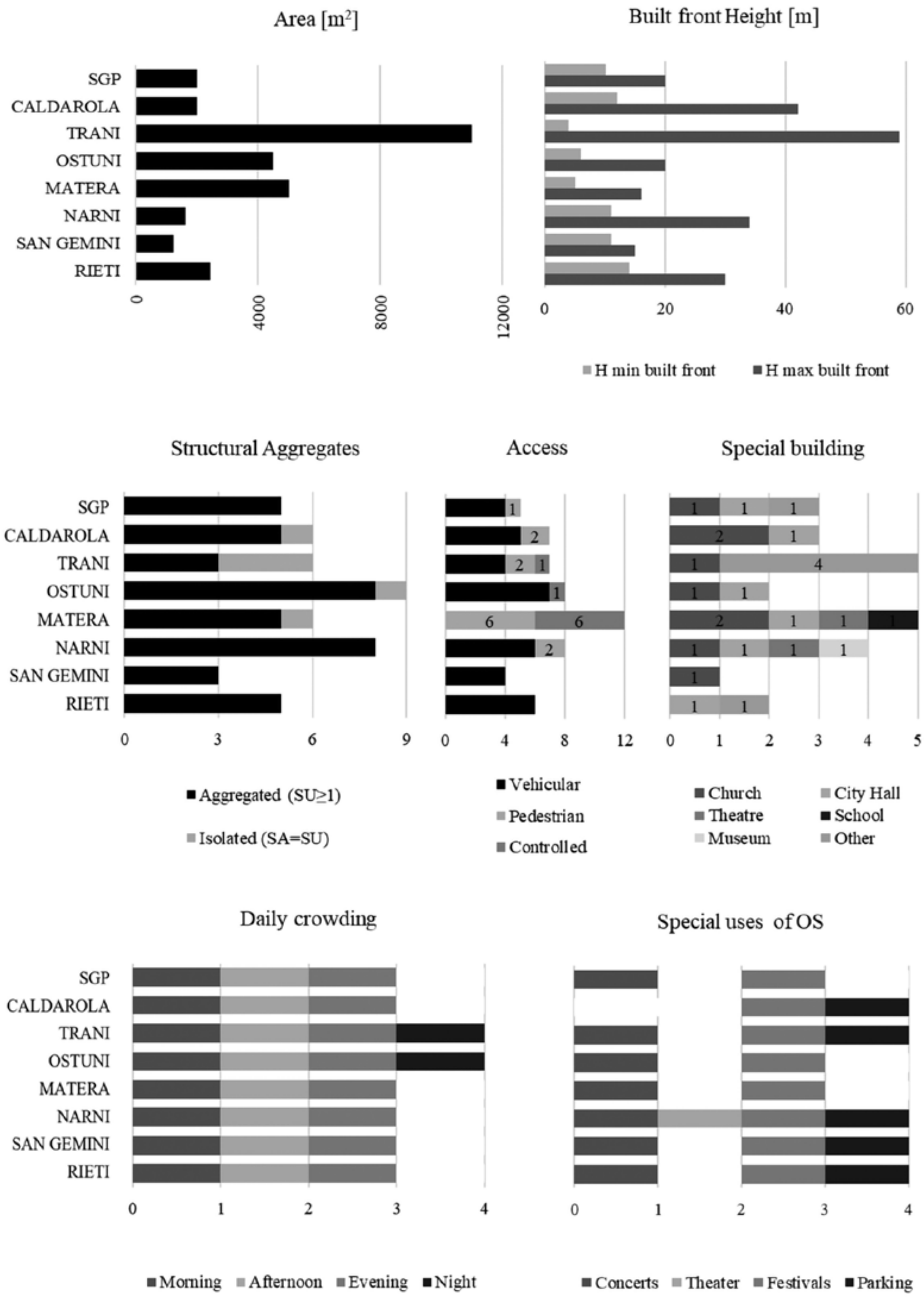

Fig. 5. *Charts of the data of the 8 case studies. Top Row: the extension of the squares and the maximum and minimum height of the buildings. Middle Row: relation between the number of Structural Aggregates SA and interferent Structural Units (SU) on the AS frontiers, the number and type of accesses to AS, and the types of special buildings on the AS fronts. Bottom Row: crowding data concerning time stages and the special and temporary uses of the AS - elaboration by the Authors.*

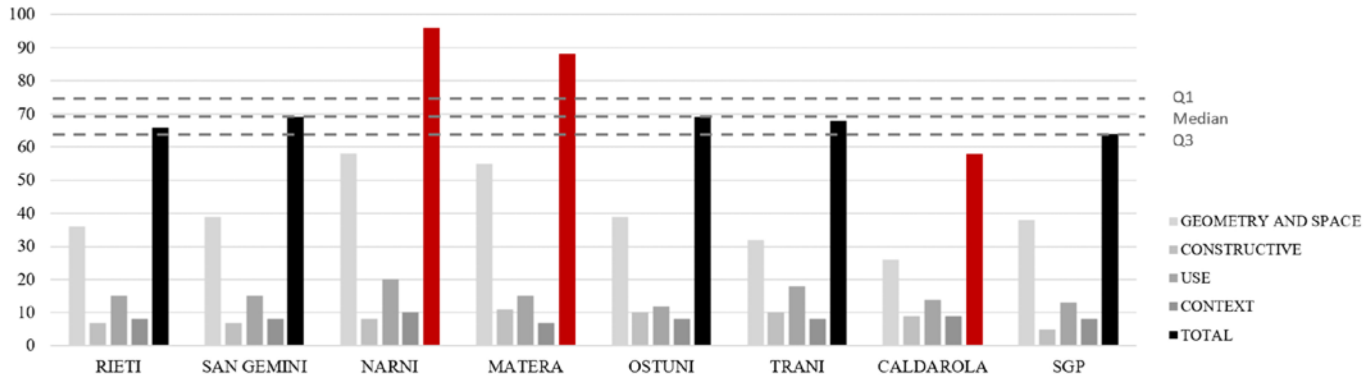

Fig. 6. *Results of the analysis on the data collected: Narni and Matera were the cases with greater complexity, exceeding the Q1 threshold; Caldarola was the case that reported the lowest complexity, lower than the Q3 threshold - elaboration by the Authors.*

By analyzing the recurrences of the results on the parameters present in Sections 2, 3, 4, and 5, it was possible to select the three most relevant cases among those considered (Fig. 6). For Section 2, the median of the scores is 38.5, with a minimum for Caldarola (26) and a maximum for Narni (58). Section 3 showed a median of 8.5, with a minimum for San Giovanni in Persiceto (5) and a maximum for Matera (11). In Section 4 the median value was 15, with a minimum for Ostuni (12) and a maximum for Narni (20). Finally, section 5 showed a median of 8, with a minimum for Matera (7) and a maximum for Narni (10).

3.3. FUTURE DEVELOPMENTS

The application of the form allowed describing BE scenarios and their reliability in a multi-risk perspective. Firstly, the form innovatively collected OSs risk factors and distinguished between its content (the outdoor space) and its frontier (surrounding buildings), thus allowing practitioners to evidence which set of factors OSs risk-affecting complexities relied more on. Moreover, the expeditious nature of the survey form is given by its checklist structure, with mainly Boolean evaluations or estimations of the number of elements. Input data can be retrieved through existing databases (e.g., constructive characteristics, use, function, context factors), already available at the local and municipal level (e.g., through geo-referenced data), and/or easily consulted remotely (e.g., through Geographic Information Systems-GIS). Therefore, the form allows for rapid application by local administrations and non-expert technicians to develop multi-risk analyses and promote mitigation strategies. Indeed, the presented approach could support the elaboration of specific actions for each case study based on simulation-oriented tools, starting from the selected characteristics, proposing, and evaluating tailored risk-mitigation strategies. In this sense, specific work actions should address additional efforts on the users' vulnerability and exposure characterization. In particular, analysis of temporalities affecting the BE use should be added by defining variations to the exposure conditions under different reference times (e.g., yearly/monthly/weekly/daily/hourly) [8]. The form of this study could be used to support such quick analyses, creating separate conditions for the Section 4 factors.

Despite the limited number of selected case studies, they can be considered sufficient to consolidate the survey form structure for future application. Future developments in the BE S^{2}ECURe project will use this preliminary study to expand the OSs sample to retrieve recurring complexity levels in historical OSs. According to the project goals, trends in the OSs features can be managed to define typological conditions of the BE and its users, thus representing them through digital tools (GIS/BIM) and supporting practitioners in classifying the BE risks into homogeneous categories.

The application of the proposed survey form to further case studies supports the identification of specific types of the built environment (BETs, Built Environmental Typologies) resulting from a more extensive statistical survey base (e.g., using open-access GIS datasets) and advanced statistical techniques (e.g., cluster analysis). The identification of BETs allows for connecting recurring and significant risk conditions in the national context to the BEs characteristics. This specific step was already achieved within the BE S^{2}ECURE project and published in D'Amico et al. [12]. Moreover, the data collection methods could be implemented with further specialist analyses to better represent the BE and their specific risks, as well as to support the risk communication to users of the BE (technical and not technical) through disruptive technologies [25]. Finally, using the BETs within simulation processes will be possible to evaluate their response to the possible multi-hazard conditions, determining the influence of specific aspects of the OSs (i.e., morphology, geometrical aspects, construction features, uses) on the resilience of the BE.

4. CONCLUSIONS

The complexity of the interactions between the historical built environment (HBE) and its users, and the multiple risks to which cities are constantly exposed, require an organized identification of the risk factors influencing the BE performance to assess the disaster resilience and elaborate risk scenarios. This paper proposed a methodology to detect the main risk factors of open spaces (OSs) in the HBE as mesoscale elements that play a crucial role before and during the emergency phases and influence vulnerability, exposure, and hazard of BE with a multi-risk and user-centered approach. The rapid survey form for Areal Spaces (ASs) and Linear Spaces (LSs) was developed to build a database for the risk factors of Sudden Onset (SUODs) and Slow Onset Disasters (SLODs), in terms of morphological, geometric, constructive, use, and contextual characteristics of the OSs. The results validate the reliability of the survey form in expressing the risk factors for the 8 studied ASs, which were selected to evaluate a variety of real BE conditions within the Italian territory. The survey form can be extended, with appropriate modifications, to the risk assessment of urban complexes at a larger scale or applied on non-historical OSs.

Essential contents

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Conceptualization of the research, E.Cu., A.D., M.R., and E.Q.; conceptualization of the paper, A.D. and M.R.; methodology, E.Cu., A.D., and M.R.; validation, G.B., E.Cu., A.D., E.Q. and M.R. and; statical analysis, A.D.; investigation, M.R.; data curation, A.D. and M.R.; writing - original draft preparation, A.D., M.R., E.Cu.; writing - review and editing, E.Cu., A.D., M.R., L.B., M.A., E.Ca., G.S., F.F., G.M., and G.B.; form visualization, M.A. and L.B.; data visualization A.D. and M.R.; supervision, E.Cu.; project administration, E.Cu., and E.Q.; funding acquisition, E.Cu., G.S., F.F., G.M., and E.Q. All authors have read and agreed to the published version of the manuscript.

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