



Proprietà Fondazione Carit, Collezione Patumi Simone, Narni, piazza dei Priori e Scolopi

H-BET Historic Built Environment Typologies. Open spaces and SUOD events in the compact historic town

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Abstract: The relationships between the Built Environment (BE) and Sudden-Onset Disasters (SUOD) are increasingly the focus of hazard mitigation investigation. Specifically, in the Historic Built Environment (HBE), defined as the network of buildings, infrastructure, and open spaces of the compact historic city, recent and past events have shown the need for an elevation of the resilience of the resident community. Previous studies by the author's research team have objectified the characterisation of HBEs prone to SUODs. What emerged was the primary importance of open spaces in the Built Environment as elements to be characterised with respect to possible emergency phases and BE user behaviour. Specifically, the Historic Built Environment Typologies (H-BETs) can help to evaluate user behaviour during and after the event. Focusing on the role of the classification of the open spaces, the paper presents the H-BETs and their potential role in the multi-risk assessment of the compact historic town. The specific risk conditions of the urban areas (e.g., crowding, the complexity of the overall form of BEs, characteristics of built elements, uses of BEs), and the physical characteristics of historic urban BE (e.g., the height of the built fronts, number, and type of accesses, the slope of the ground) are considered together in order to propose a classification of different type of open spaces, starting from morphological classes towards the definition of a complete typological categorisation, representative of the urban system's variables that interact with the identified SUOD hazards.

Keywords: built environment, multi-risk, cluster analysis, historic town, urban fabric.

1. Introduction and aims

In the context of Sudden-Onset Disasters (SUOD), the morphological characteristics of the Built Environment (BE) have a significant influence on people's safety. In particular, it is a priority to be concerned with the features of Open Space (OS) and building-infrastructure-open space interfaces, as they can be affected by significant conditions of increased risk. In addition, one can act on the boundaries in a way that affects the BE and its users. Specifically, in the Historic Built Environment (HBE), defined as the network of buildings, infrastructure, and open spaces of the compact historic city, recent and past events have shown the need for an elevation of the resilience of the resident community (Fatiguso *et al.*, 2017). In particular, we were concerned with defining the morphological characteristics of the built environment of the compact historic city and investigating the distribution in Italian cities of such configurations. To do this, a reconnaissance of the criteria currently adopted for morphological classification and the determination of risk factors was used. They were put in reciprocal relation to highlight the relevance between open space characters and risk. Therefore, on the one hand, the aim is to understand which morphological characteristics of BE are most likely to influence the possibility of reducing the number of people seriously affected by a disaster event and, on the other hand, to investigate their recurrence in compact urban fabrics. Recurrence in compact urban fabrics was done with an open methodology based on data collection in open-GIS (Geographic information system) and subsequent investigation with cluster analysis. At present, 1111 open spaces have been investigated, but after time it will be possible to acquire updated data for the constant expansion of the territories covered by the open-GIS and detect any settlements.

Such typologies of the built environment, informed by the many factors involved, are termed BET. In the compact historic city, they prompt the introduction of the definition of H-BET Historic Built Environment Typologies. The survey has resulted in the identification of BETs, which for the compact city can thus be considered H-BETs.

This work aims to define typical scenarios, referring to areal spaces (i.e., squares) as significant open spaces in the BE (Russo *et al.*, 2020) and considering the Italian context as a reference. The characterisation of these scenarios represents a significant step from BEs to historic built environment typologies (H-BETs), where H-BETs represent the idealisation of common features of Italian open spaces in historic BEs.

1.1 State of the art: from the typological studies to the classification of the built environment

Various classifications of open space in urban context are available in scientific literature.

Significant research on the squares typological analysis was developed by Enrico Mandolesi and Alessandra Ferrero (Mandolesi and Ferrero, 2001). It analysed and classified typologically the squares of Piceno, an Italian area in the region of Marche. Mandolesi's results show a grouping of the analysed square in twelve main types: unique, tending to quadrangle, elongated, funnel-shaped, pentagonal, tending to triangle, tending to trapezoidal, zigzag-shaped, open with overlook, with two levels, regular and with garden.

Considering the analysis of urban connection, Moughtin (Moughtin 1991) analyses the roads in the European context, from Vitruvio to contemporary urbanism, describing some parameters to use in the classification. Forbes compared different types of international classification, mainly based on the functional aspects (Forbes 1999). It is necessary to acquire that, for both climate and safety challenges, there needs to be a scale-up of the performance approach from the individual building to the fabric and built environment (Fatiguso *et al.*, 2015; Cecere and Currà, 2017; Cantatore and Fatiguso, 2021).

Several methods have been investigated in the scientific literature to face the problem of multi-risk scenarios.

The reduction of the built environment toward a manageable model is the basis of several studies that have engaged in the extension of the performance approach to a larger scale (Cecere *et al.*, 2017). It is a scientific approach that well represents our time, more markedly holistic. It mainly concerns studies geared toward managing safety in the face of seismic risk, and those dealing with energy balancing at the urban scale. The methodology is inductive, as in the present contribution: structural and energy typologies as well as building fabric characteristics are extracted from a more or less extensive field survey. On the one hand, seismic risk scholars systematize vulnerability factors at the land scale (Zuccaro *et al.*, 2016; Dolce *et al.*, 2021) by proposing a theorization of building and structural typologies and extending structural analysis considerations on types to a larger scale; On the other hand, scholars of heat island and other urban environmental phenomena have coined an approach that introduces the concept of urban metabolism. One can first consider the research of H. Coch Roura and R. Serra Florensae and later insights (Morganti *et al.*, 2017; Currà *et al.*, 2019; Morganti, 2021). Building types were identified from their frequency in urban fabrics taken as case studies in some European

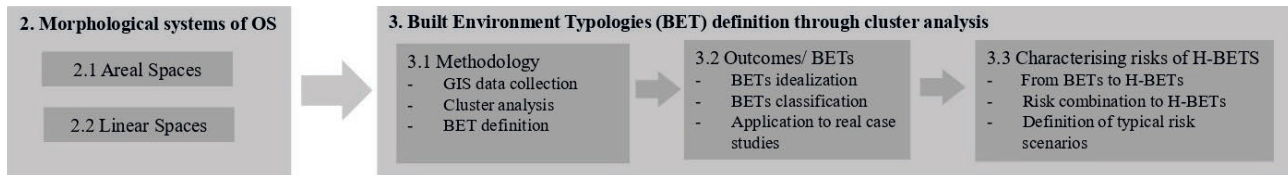


Figure 1 | Representation of the methodology workflow.

cities. The outcome of these studies is a metric that aims to interpret the performance behavior of urban forms made up of buildings, public and private open spaces.

1.2 Structure of the paper

The paper addresses the consideration of the identification of H-BETs, from studies of the morphological systems of open spaces in the historic city, as shown in Fig. 1. This is followed by an initial classification into areal and linear spaces, made within the BEs of the compact city, thus including all dense fabrics of the historic city (Section 2).

Thus, the paper shows idealised scenarios of open spaces aimed at multi-risk analysis. The manner in which the characterisation of the BEs was conducted within the project is traced in the text (Section 3). This was done by turning to data available in open-GIS environments. The complex sequence of steps that led to the selection of basic data is described. Then, a subsequent phase of the statistical cluster analysis was carried out in order to identify a reduced number of BET.

After that analysis, characteristic recurrences emerged that allowed for a defined number of built environment types (Section 4). It is noted that they are all identified by typical configurations of the compact city, hence the possibility with the present reflection, to highlight their functionality in the historic city. Based on the analysis, each BET is highlighted as a combination of characterising hazards related to morphological, geometric, and functional aspects (Section 5). The built environments analysed could be affected by all SUODs and SLODs considered; however, the specific characteristics of each BET determined their greater or lesser susceptibility to typical hazard scenarios.

2. Morphological Systems of Open Spaces in the Historic Built Environment compact fabric

In current literature, it is possible to find many approaches to defining types of open space in the historical urban context that could play a role in disaster resilience. Among

those, the analysis of urban morphology and systems of the open spaces within them is decisive for risk assessment in the historical BE.

The preliminary morphological classification of the open space in historical BE proposed by the authors was mainly influenced by the relationship between users and urban open spaces, especially in relation to SUOD events.

According to the classification elaborated by Koren and Rus (Koren and Rus, 2019), two main morphological systems could be identified in the historical urban town: the areal spaces (AS) and the linear spaces (LS).

2.1 Areal Spaces

The Areal Spaces (AS) can be defined as open space enclosed partially or completely by constructions, with various urban functions, at the intersection of streets or along the route of a main road (Ronzani and Boschi, 2001). Squares, parks, and parking areas are examples of AS.

In order to connect the morpho-typological analysis of AS with the risk assessment in historical urban towns, the spatial classification proposed by Mandolesi (Mandolesi and Ferrero, 2001) and the historical-procedural one proposed by Caniggia and Maffei (Caniggia and Maffei, 2001) has been evaluated compared to the escape issue, the criteria for expeditious evaluation of urban vulnerability (Olivieri (a cura di), 2004), and the emergency limit condition (CLE) (AA.VV. and Italian technical commission for seismic micro-zoning, 2014).

In light of the above, six main categories for classifying AS occurred from the early stages of the Bes2ecure research (Russo *et al.*, 2020). A first set covers those with a central plan: quadrangular, circular, ovoid, and ellipsoidal in shape. Then there are the less centric ones, from elongated with parallel sides, to those tending to be triangular and funnel-shaped, to trapezoidal and polygonal. All of these shapes together eventually combine to constitute a category of composite AS (Fig. 2).

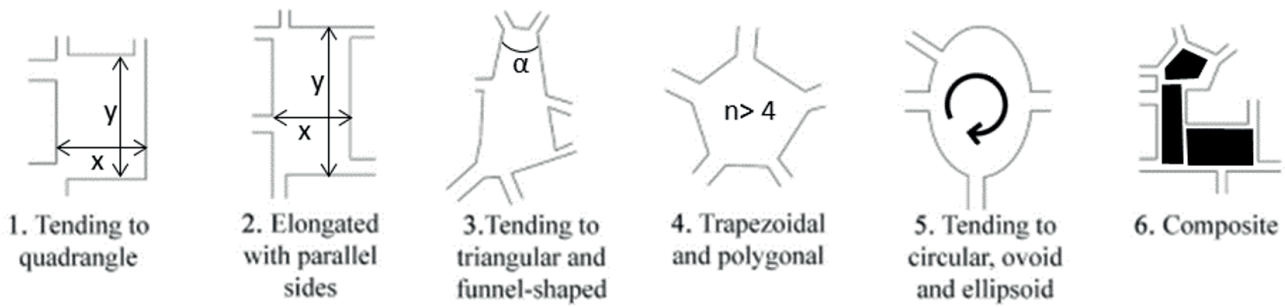


Figure 2 | The six main types of Areal Spaces identified by the authors for the preliminary morphological classification.

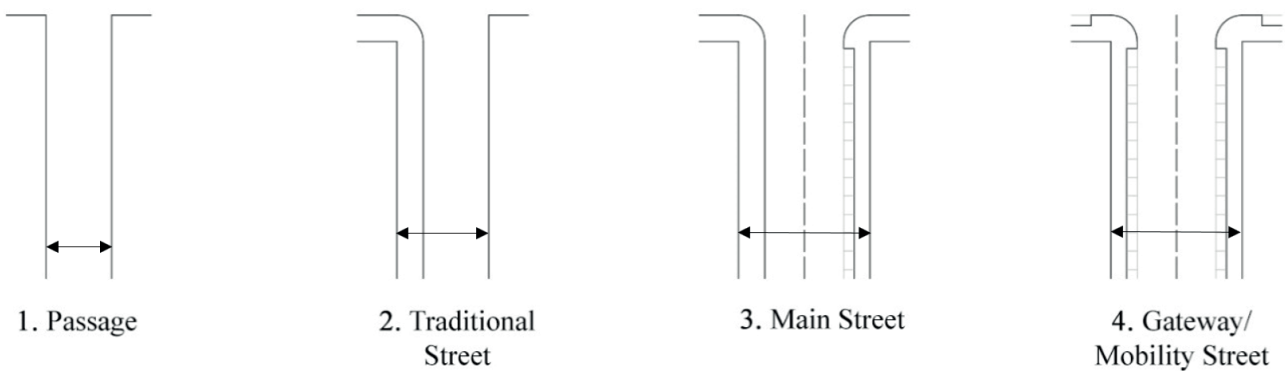


Figure 3 | The four main types of Linear Spaces identified by the authors for the preliminary morphological classification.

2.2 Linear Spaces

The Linear Spaces (LS) can be defined as space of public use, partially delimited by construction and mostly equipped with roadbed and paving, intended for the passage and transit of people and vehicles (Ronzi and Boschi, 2001). Streets, roads, and paths are examples of LS that link AS.

The main types of linear BE are elaborated starting from the Region of Hamilton-Wentworth Classification System analysed by Forbes (Forbes, 1999), also considering the studies developed by Olivieri and his group that focus on the case study of Nocera Umbra, a historical town in Italian Region of Umbria, to deepening the studies on Minimum Urban Structure (SUM), a holistic approach to the seismic vulnerability of urban organism (Olivieri (a cura di), 2004). Therefore, this research proposed four main categories for the classification of LS: passage, traditional street, main street, and gateway/mobility street (3).

3. Methodology

Following the BE S2ECURE research project outcomes (Rosso et al. 2022), BETs identification results from the

parameters described in Table 1, relevant to assess specific SLODs and SUODs risk, considered in the context of the BE S2ECURE project (Cadena et al. 2021; Fatiguso et al. 2021; Quagliarini et al. 2021a, b; Salvalai et al. 2021)..

The subsequent phase was the definition of the archetypal BETs. It was developed on a sample of OSs identified in a GIS environment, applying an advanced statistical methodology, i.e., cluster analysis, which allows statistically significant clusters to be identified and homogeneous elements to be grouped in a data set (D'Amico et al., 2021).

The nine parameters identified in the previous steps for the risk assessment were classified into two groups: the parameters for a quick assessment, which describe morphological, geometrical, and functional aspects (P1, P2, P4, P5, P8, and P9), and the parameters for a detailed assessment, which include constructive aspects (P3, P6, and P7). Although the group of construction parameters is not secondary, in order to carry out the next phase to define the types of the built environment, it was decided to proceed using only the six parameters for a detailed assessment, which are available on georeferenced databases and thus allow a quantitative exploration on a larger sample of data.

Table 1 | Parameters to define BETs, according to the BE S2ECURe research project. Definitions of selected parameters have been elaborated, according to the GIS database. (D'Amico et al. 2021).

Parameter	Definition
P1 Morphology*	The prevalent shape of the OS, in terms of compactness and regularity of the shape
P2 Height*	Comparison between maximum height (Hmax) of the built fronts that define the OS perimeter and OS minimum width (d2)
P3 Structural type	Related to the presence of a built frontier along the OS perimeter
P4 Accesses*	In terms of number compared to the perimeter of the OS
P5 Special building*	Numbers of buildings with a special function, according to four categories: places of worship, public buildings, education, and cultural and tourism attractions
P6 Construction technique	In terms of homogeneity of the construction technique, considering masonry as the prevalent type
P7 Porches	Presence of porches along the perimeter of the OS (%)
P8 Slope*	Presence of sloped ground, in terms of maximum difference in height
P9 Green*	Presence of green space, in terms of the percentage of green areas on the overall OS area

* Selected parameters for fast analysis.

Parameters not included in this phase will be included in a subsequent step.

Two databases containing information on selected parameters were chosen: OpenStreetMap (OSM) and the Ministry of the Environment's Building of Provincial Capitals, to extend the sample of analysed squares and to apply cluster analysis to a more extensive selection.

The data collected in the GIS databases on the selected speditive parameters were explored by employing cluster analysis to identify classes of squares with homogeneous characteristics (D'Amico et al., 2021). It was applied an unsupervised multivariate analysis technique capable of investigating within a dataset the presence of groups of statistical units that share a high degree of similarity (MacQueen, 1967; Halkidi, 2001). Specifically, hierarchical methods (Ward's method, single link, and full link) were employed to identify multivariate outliers. While the non-hierarchical k-means method was applied for the clustering analysis on the five variables chosen as active (the parameters P1, P2, P4, P8, and P9), using P5 as an additional variable to characterise the results in a second stage.

The analysis was conducted using SPSS Version 26.0 software. Two control indicators were used to determine the optimal number of clusters to divide the statistical units: the R-square (R2) and the pseudo-F (pF). The combined observation of the two values allows identifying the optimal number of classes to maximise the similarity between the characteristics of the units within the clusters (distance within) and to minimise the similarity between the characteristics of two clusters (distance between) (MacQueen, 1967; Halkidi, 2001).

The archetypal BETs were identified from the clustering analysis results by performing a critical comparative reading between the representative values of the individual classes found and those of the entire dataset. Critical classes were formulated for each parameter involved as an active variable in the clustering analysis in order to relate the numerical value to a morpho-geometric meaning (D'Amico et al., 2021).

4. Outcomes/BETs

The three hierarchical methods (Ward's method, single linkage, and complete linkage) and the non-hierarchical k-medium method were applied to the sample of 1111 OS. Partitions formed by a number of clusters ranging from three to twelve groups were selected from the results of each method. For each technique, the pF and R2 values have indicated as the optimal solution a partitioning into five clusters in terms of OS similarity. Furthermore, the k-medium method showed the highest R2 values as the most capable of characterising the distinctiveness of the clusters.

In Table 2 Clusters are described referred to the characterizing value of active variables (P1, P2, P4, P8 and P9). According to the cluster analysis developed, the first cluster of OSs present sloping terrain or elevation changes that characterize the public space (P8); the second and the third cluster are respectively characterised by low and high level of compactness and regularity of OSs shape (P1); the fourth cluster is defined by two distinctive characteristics, the P2 and P4, problems of overturning fronts but without a critical ratio between accesses numbers and perimeter; the

last cluster is defined by the presence of green areas within the OSs (P9).

After this first step, the analysis involved the additional variable concerning the presence of special buildings (P5) and a deeper investigation of the relation between the median height of the fronts and the width of the OS, evolving the data of P2 that only consider the maximum height. Through this further analysis clusters 1, 2 and 4 were divided in sub-clusters highlighting the presence or not of special buildings, reaching out 9 final BETs definition.

The correspondence between the idealisation of BETs and real case studies was investigated for OSs in the final database. Some examples are reported in Figure 4, together with the corresponding images, parameter values and the diagram of the final BETs configurations from the identified clusters.

5. Characterising risks of H-BETs

The combination of morphological, geometrical and functional aspects can define the combination of characterising hazards each BET is prone to. The built environments analysed could be affected by all SUODs and SLODs considered; however, the specific characteristics of each BET determined their greater or lesser susceptibility to typical risk scenarios (D'Amico *et al.*, 2021). The BETs represent ideal scenarios and can form the basis for more in-depth risk analyses. The BETs resulting from the analysis are detectable and identifiable within the dense and compact fabrics typical of the historic city; therefore, the results shown here and defined as BETs can be extended to what is defined as H-BETs.

Each BET is prone to specific risk combination due the analysed characteristics. The combination of risk represent greater or lesser susceptibility to specific risks,

and not related to the simultaneity of disastrous events. Considering the SLODs, the Pollution events could have stronger impacts when affect the BETs 1A, 1B, 2A, 2B, 3, 4A, 4B and 4C; while Heatwaves on BETs 1A, 1B, 2A, 2B and 3. Considering the SUODs, Terrorist attacks on BETs 1A, 2A, 4A and 4B, while Seismic events on BETs 2A, 2B, 4A, 4B and 4C. According to these descriptions, BET 2A represents the most critical ideal scenario, as it is prone to the complete combination of risks considered, while BET 5 is the least inclined to the multi-risk scenarios analysed.

6. Conclusions

The research group was interested in identifying of H-BE scenarios suitable for multi-hazard assessment for two main reasons: to enable the characterisation of the incidence of risk factors in the compact historic city and to prepare simulation models aimed at estimating the risk levels of OSs in BEs for the safety of their occupants. The specific characteristics of BEs in Italian cities are all recognisable in the historic city, with specific factors affecting SUOD (e.g., earthquake and terrorist attack) and SLOD (e.g., heat waves and air pollution) risks. Of particular interest among these are morphological, geometric, functional, and construction aspects. The identification of potential scenarios characterised by features common to Italian H-BEs provides an opportunity to plan further analysis and simulations for the description of risk levels.

The analysis of H-BE types (H-BETs) were previously characterised according to nine parameters describing multi-hazard scenarios and then identified through Cluster analysis using configurations and open space information derived from GIS databases. As described in detail, of the initial nine parameters, only six (P1, morphology; P2, height of frontages; P4, number of entrances; P5, presence of special buildings; P8, slope of terrain; and P9, presence of green area) that characterise P.O.'s (e.g., squares) in Italian city-specific H-BEs were

Table 2 | Clusters definition referred to active variables.

Risk	P1 level of compactness and morphological regularity	P2 problems of over- turning fronts	P4 critical ratio between the number of accesses and perimeter	P8 sloping terrain or with changes in elevation	P9 green areas
Cluster 1	Medium	No	Yes	Yes*	No
Cluster 2	Low*	No	Yes	No	No
Cluster 3	High*	No	Yes	No	No
Cluster 4	Medium	Yes*	No*	No	No
Cluster 5	Medium	No	Yes	No	Yes*

* characterizing aspects of each cluster.

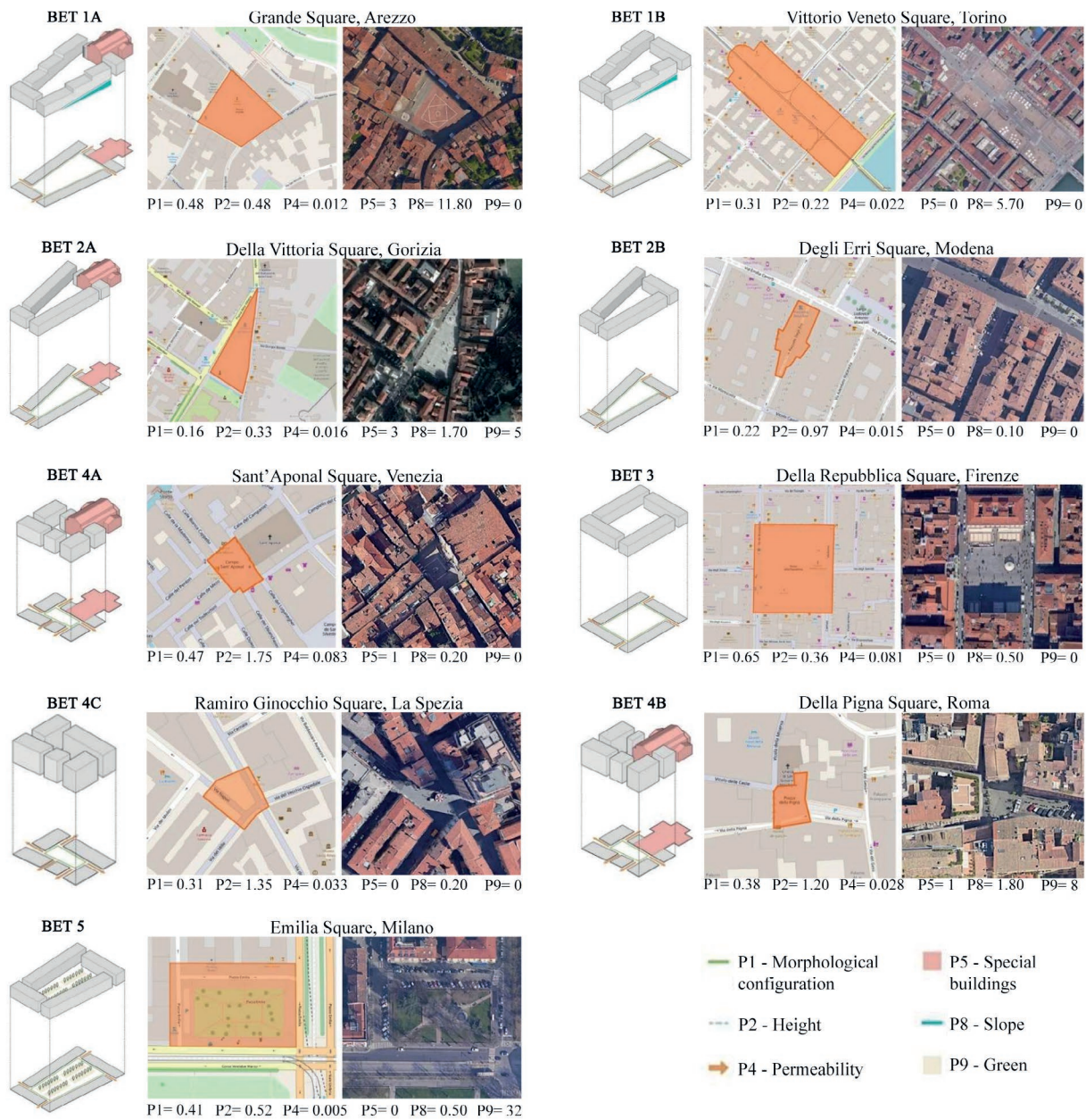


Figure 4 | Diagram of the resulting BETs and real case studies presented in the database and BET classification. Parameter values are reported for each case.

selected to perform a quick data extraction from the GIS datasets, using appropriate queries and algorithms.

The multi-hazard scenarios identified thus lay the foundation for future BE risk assessments of compact urban fabrics in Italian cities.

Acknowledgments

This research was funded by the MIUR (the Italian Ministry of Education, University, and Research) Project BE

S2ECURE—(make) Built Environment Safer in Slow and Emergency Conditions through behavioral assessed/ designed Resilient solutions (grant number: 2017LR75XK). Conceptualisation, E.C.; methodology, E.C., A.D., M.R. and C.C.; data curation, A.D., M.R. and M. A.; supervision and concept of the statistical analysis Donatella Vicari; writing—original draft preparation, E.C. [Section 1 and Section 6], M.R. [Section 2, Section 3], A.D. [Section 4, Section 5], C.C. [§ 1.2, Section 5]; writing—review and editing, C.C.; data visualisation C.C.; project administration, E.C. and E.Q.

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