WP 3 – Representative models of Built Environment Typologies (BETs) prone to SUOD/SLOD. Case studies selection and data collection

T 3.1 - Definition of representative BETs models prone to both SUOD and SLOD. BE characterisation as function of the building-open space-infrastructures interfaces (e.g. Façades on Square, Street, Pedestrian route) in terms of morphology and construction technologies. Development of tools/methods for BETs representation in extensive models (BIM based) and fast models (VR/AR oriented)

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Abstract

With the aim of analyzing the impacts of disasters on the BE, the characterization of the urban environment needs to be simplified into parameters that should be handled and modified depending on different contexts. According to this purpose, the current deliverable focuses on the definition of BETs as essential components of the BE composed of the smallest amount of morphological, geometric, and constructive characteristics that summarize the whole relevant physical aspects influencing the response to both SUODs and SLODs. In detail, the process of selection of the parameters composing BETs is based on the results which emerged from WP1 (SUODs) and WP2 (SLODs). Finally, the definition of BETs has been performed by a combinatorial process of the relevant parameters and graphical 2D and 3D representation of six examples of BETs have been provided to visualize the characterization of all the parameters. Furthermore, the final part presents a validation of this procedure through the application to real case studies, which were studied in WP1 and WP2.
Therefore, this work plays a key role in connecting the broad state of art developed in the earlier stages of BE S^{2}ECURE research and further developments in modeling and simulation processes.

Keywords

BETs, building typology, morphological parameters, combinatorial process

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Approvals

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Revision	Date	Short summary of modifications	Name	Partner
0.1	30.07.2020	Revisions to the case studies and improvements in outputs organization	Quagliarini Enrico Lucesoli Michele Giovanni Mochi Letizia Bernabei	UNIVPM UNIPG
0.2	15.09.2020	Minor comments to Section 3 for BET organization towards D3.2.1	Quagliarini Enrico	UNIVPM
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Summary

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1. Introduction

Considering the scope of BE S²ECURE project, the purpose of the current report is to set out a systematisation of the whole parameters, which influence the disaster response, and, to provide criteria for the evaluation of the performance of the Built Environment (BE) in emergency conditions, that is described in other terms as the resilience of an urban system. As reported by D1.1.1 (section 1) and D1.2.4 (section 4), to be considered resilient, a BE should exhibit a large number of features compared to the critical risk conditions it could face; in fact, it commonly refers to general types of features of urban systems, such as flexibility, diversity, redundancy, modularity, resourcefulness, responsiveness, rapidity, etc. Especially in historical contexts, the complexity of the BE located in disaster-prone areas and the specificity of the types of risk which can occur demand that a wealth of parameters is considered for identifying critical conditions concerning the disaster response with the aim of determining effective mitigation strategies.

On the basis of these assumptions, a way to encompass all such issues is to provide a classification of Built Environment Typologies (BETs) which are composed of all the characteristics that may produce positive or negative effects on disaster response.

All the report's findings are based on the broad dissertation developed in the previous deliverable of WP1 and WP2 about the four different types of disaster: earthquake and the terrorist attack in the SUODs, while, the increasing temperature and air pollution concentration in the SLODs. The current deliverable tries to link together these aspects strengthening the conviction that a multi-risk approach is fundamental in addressing risk because natural events can affect the management of other disasters and, therefore, worsen the situation of the affected communities.

The understanding of the components of each risk and its assessment process has demonstrated that different types of input are involved. In this regard, section 2 is a useful aid to systematise the knowledge regarding the difference between SUOD/SLOD, and, outlines the interrelationship between different physical features of the BE. Sections 2.1 and 2.2, instead, adopt the characterisation of the BE provided by D1.1.1. and D1.1.2, and, connect the components of the risk assessment with the physical features of the built environment. Therefore, these two phases of validation demonstrate the relevance of the aspects involved in SUOD/SLOD which are also parameters that may describe the BE in terms of morphology, geometrical dimensions and construction technologies. The results of this step are the basis for the selection of parameters that define the BETs. It is worth clarifying that this procedure does not represent a methodology to assess disaster risks or urban resilience, but, encompasses parameters that characterise the different elements of BE in relationship to both SUODs and SLODs, and thus, allows rapid evaluation of all the aspects that could have more influence on the disaster response. According to this methodology, the BET is conceived as an essential component of the BE which is composed of the smallest amount of characteristics that summarize all the relevant physical aspects which could influence disaster conditions and occurrences.

The definition of BETs is the preliminary step required for the development of tools and methods for the comprehensive representation of the BE in extensive models BIM-based (D3.1.2) and in fast models, such as VR/AR oriented (D3.1.3).

2. Methodology: expert judgment and statistical analysis for defining BETs

The current work allows the unification of all aspects concerning SUOD/SLOD that might help to develop the further steps of the BE S²ECURE project. To understand specific issues characterising the BE typologies it is

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necessary to provide a detailed definition of parameters describing physical characteristics which can play a key role in determining risks. In this regard, summarising the results of WP1 and WP2, which have been carried out distinguishing separately SUOD and SLOD, seems to be a useful aid for defining which factors are more relevant to this discussion. This step relies on the judgment based on the experts' knowledge that is used in developing a set of assumptions that determine the correlation between risks and physical aspects of the BE by the definition of synthetic parameters. As shown in Figure 1, the overall procedure of selection of these parameters is developed essentially in two steps: (i) reviewing and merging consideration about SUOD of WP1 (D1.2.1, D1.2.3, D1.3.1) and SLOD of WP2 (D2.1.1, D2.1.2, D2.2.5) by reporting Table 2 carried out for the D2.2.5 Annex; (ii) reviewing criteria developed in D1.1.1, D1.1.2, which are referred to the characterisation of BE. In this way, we consider the physical aspects of the BE which are involved in the risks: in section 2.1 the assessment of risks (D2.2.5) is considered; and then, in section 2.2, the BE characterisation (D1.1.2) is evaluated. This discussion allows us to select physical parameters that characterise the morpho-typological configuration of OS, and, at the same time, plays a key role in assessing the response of OS to SUOD/SLOD. The choice of parameters (Table 5) is based on the judgment of the experts, who are eight building engineers members of the current BE S2ECURE project (2 by POLIBA, 2 by UNIPG, 2 by UNIROMA, 2 by POLIMI), based on the insight provided by WP1 and WP2. In fact, for SUODs, the judgment relies on the engineering knowledge of researchers who study the behavior of buildings under seismic action. As already highlighted in the previous deliverables (D1.2.1 and D1.2.2) there is specific scientific literature that shows how the damage to buildings, which may be caused by structural features and constructive weakness and historical modifications (see section 5.2 of D1.2.1), strongly influence the response to earthquakes (see section 7 of D1.2.1, section 3 of D1.2.2). Moreover, the impacts on the urban environment are strictly related to specific characteristics of the whole BE influencing outdoor seismic risk (see sections 3 and 4 of D1.2.3). Also, f or the risk of terrorism, a large bibliography has been analyzed focusing on the risk assessment in open areas and public and symbolic/strategic buildings, which are the elements most exposed in the BE (see sections 4 and 5 of D1.3.1). Similarly, for SLODs it emerges how many researchers studied the relationship between the characteristics of the BE and the environmental conditions that underlie these risks and favor their occurrence or severity (see sections 4 and 5 of D2.1.1, section 3.3 of D2.1.2). Therefore, it can be assumed that the acquired knowledge by the WP1 and the WP2 is the basis of the judgment approach that has been adopted for identifying with certainty the influence existing between the risks considered for this research and the physical parameters describing the BE. The use of judgment of experts, on the other hand, is nowadays widely accepted and sanctioned by specific technical procedures, such as the assessment of damage due to earthquakes and that of seismic vulnerabilities (i.e. AEDES datasheet of the Italian Civil Protection) or in the case of Fire Prevention (i.e. the DM 09 May 2007 of the Italian Government).

After selecting parameters for BETs (section 2.3), a statistical analysis of the main Italian AS-based survey (section 3) has been carried out for gathering information to assign numerical values to the selected parameters. This step ensures the reliability of BET models obtained given that they contain characteristics that are both relevant to SUOD/SLOD risks and prevalent among the main cities of the entire Italian territory.

In conclusion, section 4 presents a validation of the reliability of the current proposal of BETs' definition by applying the procedure of detection of parameters and representation of BET model to real case studies. This final step allows highlighting which BET models may be more typical than others among the great amount of 768; moreover, it is useful for the next D3.2.1 focused on providing typological models of BETs, defined as "basic BETs".

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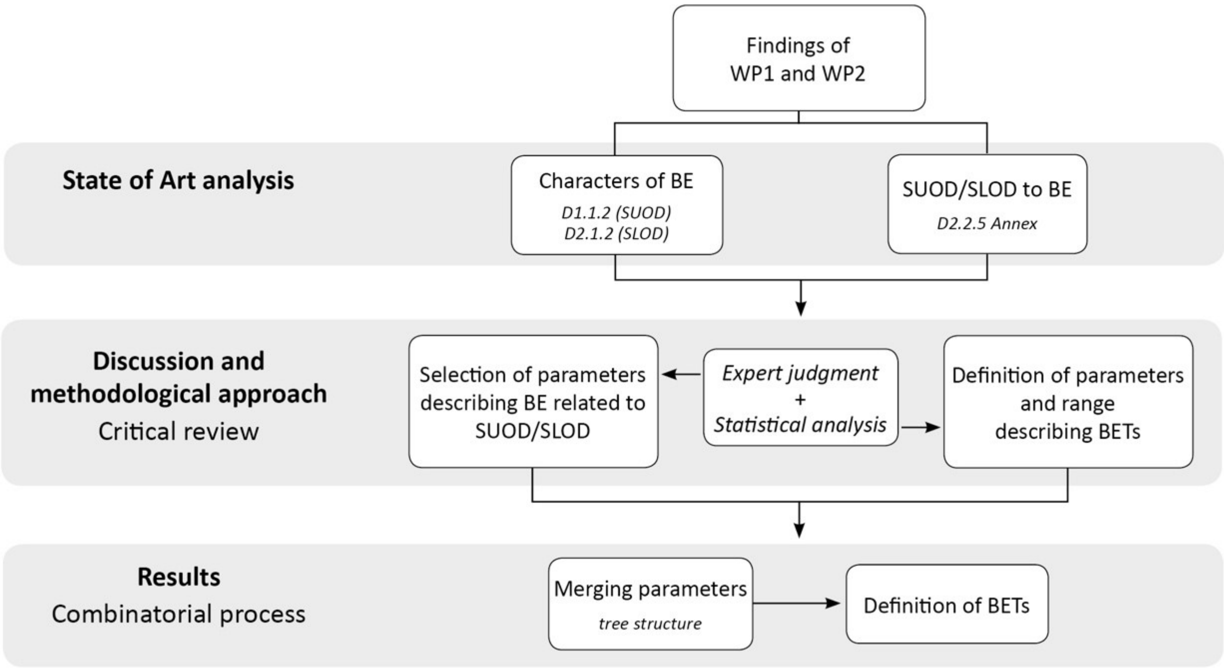

Figure 1: Synthesis of structure and methodology of the report

2.1 Detection of relevant disaster type-related issues describing BE

The annex of D2.2.5 takes into account the components of SLOD and SUOD risks to avoid misunderstanding and providing an overall picture of multi-hazard approaches. Results that the four types of risks (earthquake, terrorism acts, increasing temperature, and air pollution) adopt different classes of input data for simulation and risk assessment in the BE. Nevertheless, it is possible to identify some significative factors for describing physical models of BE, considering morpho-typological, geometric and constructive parameters common to all the built-up areas. Notwithstanding findings highlight the difference between the types of risk (related to diverse timeframe, thus, frequency, intensity and duration), Table 2 of the Annex allows finding common characteristics of the BE that are relevant for determining or influencing all the risks.

Table 1 reports section 2 (Table 2 of Annex D2.2.5) referred to the "BE vulnerability" in order to outline which physical parameters of the OS could influence the performance under risks. We opted for the vulnerability among the components of the risk (hazard, exposure) because it usually refers to the objective features of BE, and hence, it allows the quick detection of physical factors influencing risks, even from a rapid survey and without detailed knowledge of the whole open spaces' characteristics. The first column of the table "input class" concerns the physical and structural features of the Built Environment for the four types of risks (earthquakes, terrorist acts, temperature increase, air pollution). This comparison allows understanding whether the same physical character could play a key role in both SUOD and SLOD. Given the difference between the four types of risks, an assessment process, based on experts' opinion, has been adopted for detecting the relevance of parameters simultaneously for SLOD and SUOD. Each parameter is labeled by using three signs: "•", for parameters that aid to strongly determine the risk; "+", for parameters increasing risk conditions but that are not determining; "-"; for parameters decreasing risk conditions but that are not determining. This labeling is a judgment given to each input element based on the knowledge about specific risks explained in WP1 (e.g. D1.2.1, D1.2.3) and WP2 (e.g. D.2.1.1, D.2.1.2), that supports the experts in providing values.

Table 1: SLODs and SUODs input classes developed in D2.2.5 Annex (Table 2) for assessing the level of relevance of each parameter through "•" determining risk, "+" increasing risk conditions, "–" decreasing risk conditions.

BE vulnerability					
	Input class	**Earthquake**	**Terrorist acts**	**Increasing temperature**	**Air Pollution**
2.1	**OS elements**				
2.1.1	*Layout configuration*	Streets seismic vulnerability and redundant paths •	BE configuration and layout and accessibility •	BE typologies and layout •	BE typologies and layout •
2.1.2	*Green areas*	Extension distance from buildings enclosure, fences and access points -	Extension presence of elements where to refuge, enclosure, fences, and access points -	Extension, shading and cooling capabilities, presence of inner and alternative pathways •	Extension, adsorption capabilities, presence of inner and alternative pathways •
2.1.3	*Low obstacles/street furniture*	Obstacle presence impeding the evacuation +	Obstacle presence impeding the evacuation, +	Urban furniture as awning and canopy providing shading •	
2.1.4	*Other low obstacles including trees*	Urban furniture handholds or trees where hold on to keep balance -	Low wall or vegetation where to refuges -	Trees providing shading •	Trees and green structures providing pollutant adsorption and/or protection from the pollution source. Their size could also affect the wind flow for pollutant dilution. •
2.2	**Building related issues**				
		Seismic vulnerability concerning their typologies and structural features •	Building shape, facades protection measures and sheltering •	Geometries, heights and facades materials (green facades) •	Shapes, heights and facades materials (green facades) •
2.2.2	*Materials*	Constructive typologies are	Reinforced materials against bombing	Facades material property to	Facades materials able to adsorb pollutants, surface roughness

		relapsed into seismic vulnerability		reflect/absorb solar radiation (albedo)	
		•	•	•	•
2.2.3	*Geometry*	building heights (H) vs facing OS width (w) to estimate path blockages in the evacuation layout	building heights (H) vs facing OS width (w) to estimate path blockages (i.e. bombing attack) and the overall evacuation layout	building heights (H) vs facing OS width (w) to estimate canyon effects. Orientation.	building heights (H) vs facing OS width (w) to estimate canyon effects. Orientation.
		•	•	•	•
2.3	**OS surfaces**	Conservation state and maintenance	Conservation state and maintenance	Reflection properties of materials	Adsorption properties of materials
		+	+	+	+

After assigning values (•, +, -) to parameters, the cells that score "•" for each of the four risks are green. Therefore, the great relevance in determining risk conditions of both SUODs and SLODs of parameters related to configurational and layout aspects of OS (2.1.1) and geometric and constructive features (2.2.2, 2.2.3) of buildings facing OS emerges. On the other hand, also parameter 2.2 has great relevance but is referred to specific features that are not detectable from a survey from outside but require detailed information and assessment methods about buildings facing the OS.

2.2 Detection of relevant BE physical characteristics related to SUOD/SLOD

The most relevant issues about the OS characterisation are widely debated in the previous deliverable of the WP1 (SUOD) and WP2 (SLOD). The D2.1.1 has classified the main typologies of AS (piazza and Piazzale) and LS (canyon) prone to SLODs assessing the severity of different configuration considering: (i) the Height/width ratio, (ii) tree presence, (iii) albedo. For SUOD, the D1.1.1 and the D1.1.2 have described the morphological systems of BE, Areal Space (AS) and Linear Space (LS), according to 5 macro-areas of features: (i) morpho-typological characteristics, (ii) characteristics of geometry and space, (iii) constructive characteristics, (iv) characteristics of use, (v) environmental characteristics. For each category some qualitative parameters have been selected to provide a comprehensive description of frontier and content placed in the OS considering both morphological approach and social-cultural aspects. This preliminary classification has led to the definition of a survey form for assessing OS in BE of historical context (section 2.4 of D1.1.2). Therefore, it represents a useful tool for the expeditious identification of significant aspects of the OS.

So that, the same process of review, adopted in Table 1, has been carried out considering the parameters belonging to the survey form of the D1.1.2, to detect which parameters have great relevance not only for describing BETs in physical terms but also for linking the four types of disasters. For this purpose, the table of Appendix 7.1 has been compiled considering the connection with the parameters of the survey form of D.1.1.2 for each component of risks (hazard, vulnerability and exposure). The parameters of sections 1, 2 and 3 of the survey form have been considered because are referred to geometrical, morphological and constructive characteristics of OS. Instead, sections 4 and 5 of the survey form have not been considered because they concern issues depending on specific conditions of the environment. This synthetic evaluation

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has been performed by the experts based on the knowledge of the risks acquired in previous deliverables (D1.2.1, D1.2.2, D1.2.3, D1.3.1, D2.1.1).

These results have been subsequently collected in Table 2: the parameters reported in Appendix 7.1 are marked with "•", and thus, have a key role in determining critical conditions during risks. The last column "sum of relevance" highlights which parameters are relevant simultaneously for the four types of risks, and hence, the green-colored cells identify which parameters score up to "3•" or "4•".

Table 2: Review of parameters belonging to the survey form of D1.1.2 describing OS in the BE through "•" (determining risk)

Code SECTION	Description PARAMETERS	relevance for TERRORIST ACTS (counting codes)	relevance for EARTHQUAKE (counting codes)	relevance for INCREASING TEMPERATURE (counting codes)	relevance for AIR POLLUTION (counting codes)	**sum of relevances**
SECTION 1: MAIN TYPE						
S1_0	Prevalent shape	●	●	●	●	**4**
S1_1	Dimension	●	●	●	●	**4**
S1_2	H_{max} built front		●	●	●	**3**
S1_3	H_{min} built front			●	●	**2**
SECTION 2: CHARACTERISTICS OF GEOMETRY AND SPACE						
Frontier						
S2_F_1	Structural Type (SA/SU)	●	●	●		**3**
S2_F_2	Accesses	●	●	●	●	**4**
S2_F_3	Special buildings	●	●	●		**3**
S2_F_4	Town walls	●	●			**2**
S2_F_5	Porches	●	●	●		**3**
S2_F_6	Water			●		**1**
S2_F_7	Quote differences	●	●	●	●	**4**
S2_F_8	Green area			●	●	**2**
Content						
S2_C_1	Special Buildings	●	●	●	●	**4**
S2_C_2	Canopy	●		●		**2**
S2_C_3	Fountain	●		●		**2**
S2_C_4	Monuments	●	●			**2**
S2_C_5	Dehors	●				**1**
S2_C_6	Quote difference	●	●	●	●	**4**
S2_C_7	Archaeological sites	●				**1**
S2_C_8	Green area	●		●	●	**3**
S2_C_9	Underground park		●			**1**
S2_C_10	Underground cavities		●			**1**
SECTION 3: CONSTRUCTIVE CHARACTERISTICS						
Frontier						
S3_F_1	Homogeneity of built environment age		●			**1**
S3_F_2	Homogeneity of constructive techniques		●	●	●	**3**

S3_F_3	Urban furniture/obstacles	●	●	●	●	4
Content						
S3_C_1	Pavement materials					
S3_C_2	Pavement lying					
S3_C_3	Pavement finishing			●	●	2
S3_C_4	Urban furniture/obstacles	●		●	●	3

This analysis has led us to conclude that the marked parameters may be adopted to characterise the BETs because represent the physical features of the OS, and, influence the response to risks. In fact, the S1_0 (Prevalent shape), S1_1 (Dimension), S1_2 (H_{max} built front) provide a morphological and geometrical description of the urban space and the S2_F_2 (Accesses) of the accessibility; the S2_F_1 (Structural Type - SA/SU) influences the response to risks; the S2_F_3 and S2_C_1 (Special buildings), S2_F_5 (Porches) indicate the presence of peculiar construction typologies that influence the response to risks; S2_F_7, S2_C_6 (Quote differences) provide a characterisation of the natural relief of the OS; S2_C_8 (Green area) indicates the presence of trees, bushes or grass; the S3_F_2 (Homogeneity of constructive techniques) provides a characterisation of the type of construction (e.g. masonry, concrete, steel). Although the S3_F_3 and S3_C_4 (Urban furniture/obstacles) have emerged as relevant parameters, we cannot consider them for characterising BETs in this step of the research because they are as temporary elements of the OS and do not provide a permanent characterisation of the OS hence.

In conclusion, these results have been considered together with those of Table 1 as the basis of the definition of the parameters that characterise and compose the BETs.

2.3 Selection of parameters characterising BETs and definition of the sample for statistical analysis

The previous steps allow outlining which features characterising the BE have a strong link with SUOD/SLOD risks, and hence allow determining parameters describing BETs in physical terms. The findings of Table 1 and Table 2 validate the usefulness of morphological, geometric and constructive features as characteristics identifying BETs. As stated in section 1, the BET is conceived as an essential component of BE described in physical terms and containing the most common morphological, geometric and constructive features detectable in urban systems. Moreover, such characteristics have a key role in the assessment of the types of risk, according to the findings of section 2.1. Therefore, on the one side the sele,cted parameters encompass common characteristics of OS widespread in Italian territory, on the other side, the same characteristics present correlation to risks.

To synthetically define the BETs, a systematisation of morpho-typological and constructive features is carried out considering the results of Table 1 and Table 2 to select parameters that will compose the BETs. The choice of these parameters has been carried out mainly on the expert judgment basis, according to the variety of insight and assumptions developed in previous WP 1 and WP 2. In fact, nine parameters (Table 3), which emerged as the most significant simultaneously for the four types of risk, have been chosen.

Table 3: Choice of relevant parameters for defining BETs by merging results of sections 2.1 and 2.2

PARAMETER	reference to Table 1 (D2.2.5)	reference to Table 2 (D1.1.2)

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P1	Morphological configuration	2.1.1, 2.1.3, 2.1.4	S1_0, S2_F_2
P2	Dimensions	2.2.3	S1_1, S1_2, S1_3
P3	Structural type		S2_F_1
P4	Access		S2_F_2
P5	Special buildings	2.2.1	S2_F_3
P6	Homogeneity of constructive technique	2.2.2	S3_F_2
P7	Porches		S2_F_5
P8	Slope		S2_F_7, S2_C_6
P9	Green	2.1.2, 2.1.4	S2_F_7, S2_C_8

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This selection criterion could be not completely exhaustive to the definition of BETs. It seemed appropriate to introduce a critical review based on empirical observations and statistical analysis of a large number of real cases. Therefore, a set of 133 Italian squares (see Appendix 0) among the main cities of the entire territory: 112 provincial capitals of Italian regions, and, 21 cities of medium size (over 20,000 inhabitants). The 21 towns have been included even if they are not provincial capitals because they were considered useful to enrich the sample with situations that are commonly widespread also in medium and small urban contexts. The spreadsheet has been arranged in ten columns (Table 4) of which four of these are related to the parameters P1, P2, P3 for the calculation of the percentage of values variation. The whole table with results is reported in Appendix 0. While, the column of P4 only indicates which samples among the 133 have been chosen for a detailed investigation of permeability's measurements, which is explained in Appendix 7.3.

Table 4: Spreadsheet for the statistical analysis of the 133 Italian squares

							P1			P2			P3	P4
	Region	Province	Town	Square	CONCAVE	CONVEX	L	w	R	H_{max}	w	range	n. SA	selected sample
1	VALLE D'AOSTA	AO	Aosta	Piazza Emile Chanoux		X	150	37	0,25	17	37	e	4	

...	...							
133	...							

The first step of the statistical analysis relies on the need to determine an unambiguous geometrical description for OS in analytical terms. Given the great amount of different shapes of AS, it is worth adopting a geometrical simplification for reducing the number of variants of parameters and hence ensure the reliability of the selected parameters. We assume that all polygonal shapes that may be considered as concave, in geometrical terms, are excluded from the current analysis that hence considers only the convex ones. A polygon is defined as convex if and only if for any pair of points A and B in *P* (polygon) the line segment between A and B lies entirely in *P*. Hence, all polygons that are not convex are concave.

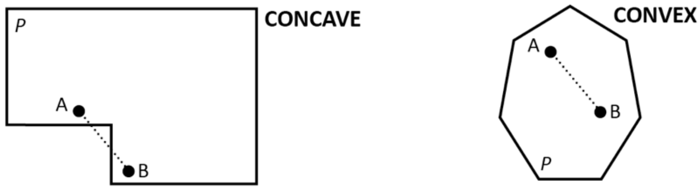

Figure 2: Definition of convex and concave polygon

In this way, the composite forms of AS are excluded. This choice is based on the statistical results of the 133 sample of Italian squares: the 32% (43 squares) of the AS is concave, the 68% (90 squares) convex instead (Figure 3). So that, the 43 squares were not considered for the calculation of range for parameters, thus, the final sample is composed of 90 squares.

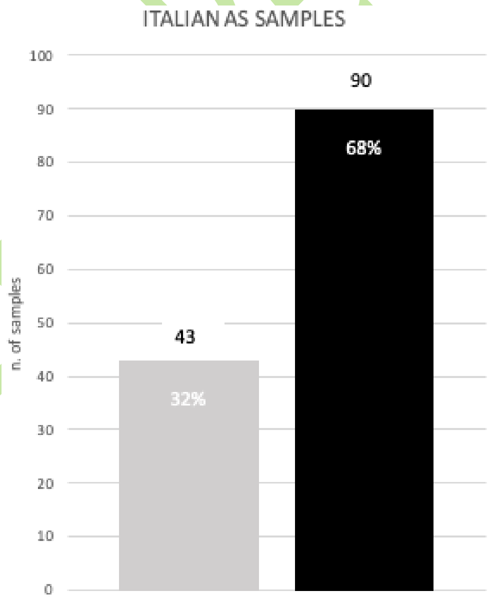

Figure 3: chart representing the number of concave or convex squares

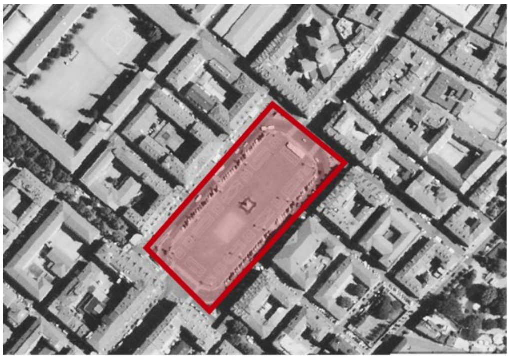


Figure 4: Example of convex and concave squares among the 133 samples: 1) Cuneo (CN), Piazza Tancredi Galimberti; 2) Altamura (BA-1), Piazza Duomo

This criterion has been adopted only for this preliminary step of the current research and could be revised for further developments of WP3. However, treating the concave squares as the combination of convex squares could be a hypothesis to be adopted for the validation of the procedure in the following steps of the research.

Once defined the final sample, the definition of threshold values for each parameter has been carried out to distinguish different range (options) of each parameter. In this regard, the statistical analysis of the Italian squares allows the verification of the presence of the selected parameters for describing the main features of these samples; moreover, it provides a useful aid to define the variation range of some of the nine parameters (P1, P3, P4). These results have been reported in the following section 3 and detailed in Appendix 0 and 7.3.

The nine selected parameters univocally describe both AS (Areal Space) and LS (Linear Space) because they generally present similar characteristics of the frontiers. However, the only difference between AS and LS is the morphological configuration: for this reason, the parameter P1 encompasses three options of which two are referred to AS (a., b.) and one is to LS (c.). In this way, we obtain a unique description of BETs in terms of both AS and LS, and hence, it is not necessary to carry out the same procedure only for the definition of BETs for LS. Even if the P1 encompasses results that are valid both for AS and LS, nonetheless that is not possible for P4 because the accessibility requires a different investigation between the AS and LS. So that, the calculation of the range has been carried out separately for ASs and LSs and has been dealt with in more detail in Appendix 7.3. Different types of indices have been employed for this detailed analysis to detect the measurement that provides the best description of permeability. Due to the considerable effort to calculate indices, the 90 samples of squares have been reduced to 40 and the streets of the same towns have been considered as the samples of LSs.

Moreover, the parameters are mainly referred to the features of the frontiers given that they strongly determine critical conditions against SUOD/SLOD. While elements content in the OS (such as urban furniture/obstacles) will be deemed in the following steps of Task 3 for modeling purpose.

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3. Definition of parameters characterising BETs

Table 5 summarizes parameters and their options/ranges that define BETs by using a combinatorial process. For each parameter is also provided a brief description of its meaning and the choice of options/range based on both empirical observation and statistical results about main Italian AS. The ranges defined in statistical terms (P1, P3, P4) are indicated in the last column of Table 5.

Table 5: Definition of parameters (P1-P9) and options (a-u) describing the BETs

PARAMETER CODE	PARAMETER descriptor	OPTIONS CODE	OPTIONS range	*u. of m.*	*Statistical results*
P1	Morphological configuration	**a**	Compact $(1 \geq R \geq 0.70)$	[-]	X
		b	Elongated $(0.70 > R > 0.30)$	[-]	X
		c	Very elongated $(R \leq 0.30)$	[-]	X
P2	Dimensions	**d**	$H_{max} > w$	[m]	
		e	$H_{max} \leq w$	[m]	
P3	Structural type	**f**	SA (all fronts)	[True]	X
		g	SA (not all fronts)	[False]	X
P4	Permeability (accesses)	**h**	$\Sigma \alpha_i > 36°$ (a., b.) / $\lambda > 0.06$ (c.)	[°],[-]	X
		i	$\Sigma \alpha_i \leq 36°$ (a., b.) / $\lambda \leq 0.06$ (c.)	[°],[-]	X
P5	Special buildings	**l**	yes	[True]	
		m	no	[False]	
P6	Homogeneity of constructive technique	**n**	yes	[True]	
		o	no	[False]	
P7	Porches	**p**	yes (>25% of Frontier)	[True]	
		q	no (0 – 25% of Frontier)	[False]	
P8	Slope	**r**	no	[False]	
		s	yes	[True]	
P9	Green	**t**	yes	[True]	
		u	no	[False]	

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P1 - Morphological configuration: contains parameters S1_0 “Prevalent shape” (Table 2) that encompasses the main typologies of the BE prone to both SUODs and SLODs. Six different types of AS (tending to quadrangle, elongated with parallel sides, tending to triangular and funnel-shaped, trapezoidal and polygonal, tending to circular, ovoid and ellipsoid, composite), as defined by the D1.1.2. for SUODs, and the “piazza”, “piazzale” and “urban canyon”, as defined by the D2.1.1 for SLODs. With the aim of reducing the variability, the morphological category is distinguished into three main types: a. (very elongated), b. (elongated), c. (compact), which represent not only the shape but also the dimension ratio and proportion between the short side and the long side (R= width/Length). The composite type, instead, is not considered due to concave layout. While the “urban canyon” type is represented by the option c. (very elongated), that represents, hence, mainly LS, but also very elongated AS. Finally, the a. and b. options are referred to ASs, and the c. to LSs.

Different thresholds of Ratio=width/Length [-] (Figure 5) are based on the results of the Italian sample-based survey among quadrangular and rectangular shape. It is worth clarifying that the Length (L) dimension refers to the long side of the OS configuration, while, the width (w) is the short side.

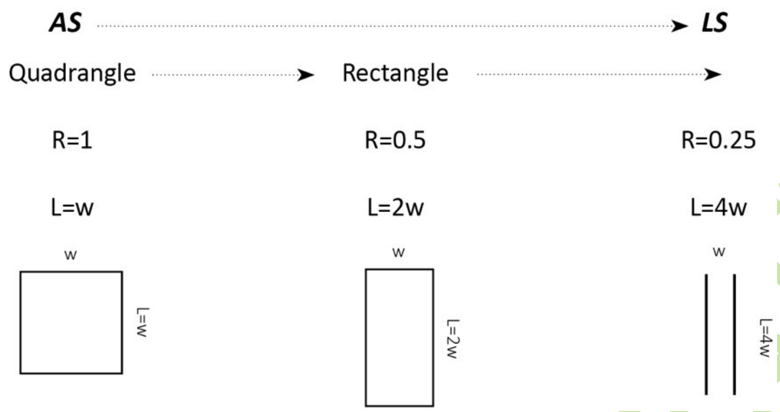

Figure 5: Classes of dimensional range and shapes of OSs

Figure 5 shows the common dimensional ratio of OS considering the prevalent shape quadrangular and rectangular. The R=1 and R=0.5 are referred to ideal shapes, because rarely real cases present this perfect proportion. So that, the need to introduce a threshold between quadrangle and rectangle types emerges. With this purpose, has been carried out an analysis of the dimensional ratio (R=w/L) of the 90 samples of convex ASs. The output has been represented by a frequency histogram (Figure 6) that has the numbers of samples on the y-axis, while the x-axis is scaled between 0 and 1, whose scores refer to the result of the R=w/L for each of the 90 samples. The histogram is composed of 9 classes of frequency whose homogeneous width of the intervals is 0.10, so that, they represent how many samples have the corresponding value. The classes of the histogram have been compared with three main ratios which are based on the geometrical shape of squares: 0.30, 0.50, 0.70 (which are marked in red). In fact, introducing the value R=0.70 as threshold seems to be convenient to distinguish better shapes tending to quadrangular and rectangular shapes. Moreover, a small percentage of samples (less than 15%) score R<0.30 because this ratio is common for LS, which are not included among the 90 samples of this statistical analysis, and also, this type of shape is not so common among AS. According to these statistical results, the R=0.70 is the correct threshold between the two options b. (elongated) and a. (compact), while, c. defines a very elongated configuration of AS and thus the whole LS category.

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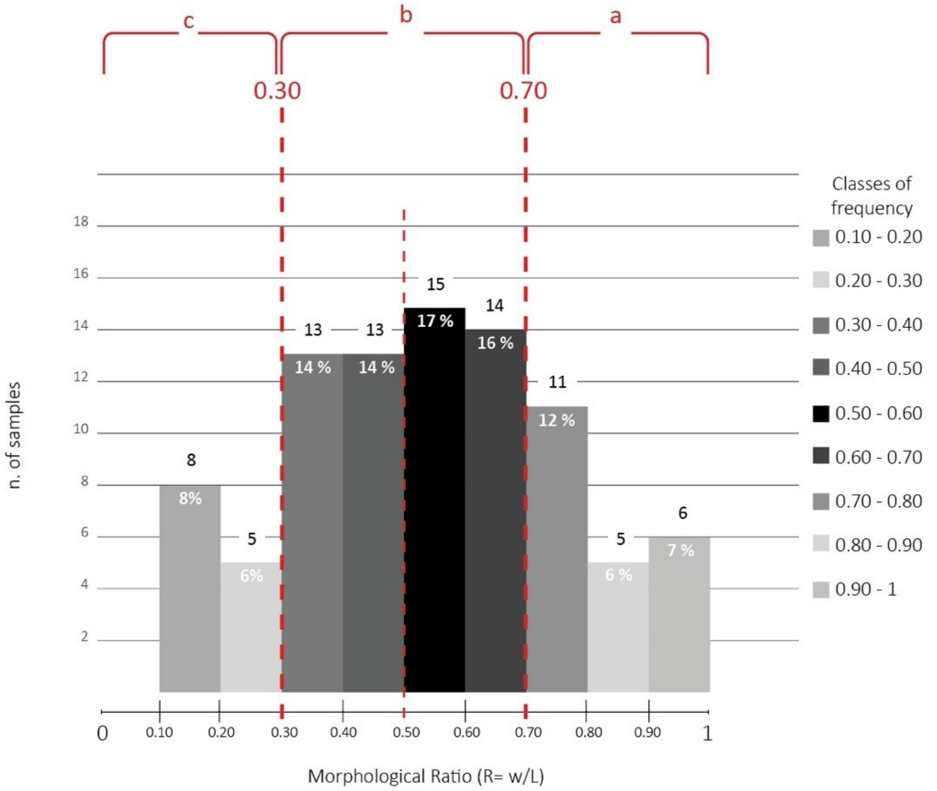

Figure 6: chart representing the frequency classes of the dimensional ratio of the 67% of the sample of Italian squares

a. Compact: contains tending to quadrangle, polygonal, tending to circular; has a constant ratio between length and width, and hence concentric and radial path. The space spreading out from a central point that is equidistant from all the other extreme points. The dimension range of the width/length ratio varies between 0.70 and 1.

Relation with SUOD: similar proximity of evacuees to fronts. Moreover, the central point has a key role during the emergency phase as the safest place of the AS.

Relation with SLOD: similar proximity of users to the cool-shaded/ventilated area, but the central point can be more exposed to heat concentration.

b. Elongated: contains elongated with parallel sides, tending to triangular and funnel-shaped, trapezoidal, ovoid and ellipsoid; has one dimension prevailing that determines the prevalent longitudinal development. The dimension range of the width/length ratio varies between 0.70 and 0.30.

Relation with SUOD: no similar proximity of evacuees to each frontier.

Relation with SLOD: the probability of wind funnel effect, heat alleviation and pollutant dilution.

c. Very elongated: contains the very elongated configuration of AS and LS, which can't be considered into the previous range a. and b instead. In this way BETs composed of the c. option of the P1 are configured as LS.

Relation with SUOD: this morphological type may determine critical condition for the evacuation paths due to its narrowness because the street could be partially or completely may be occluded from debris or could be overcrowded.

Relation with SLOD: this configuration encompasses the urban canyon type that has been adequately studied in WP2. In fact, the risk severity depends on the height of frontiers and the way they are oriented with respect to the sun position: for example, buildings of considerable height in which both sides of a wide urban canyon would provide sufficient shade. Moreover, the wind velocity cooling capacity would mostly be favored in rather wide urban canyons, and hence, it has a better performance on pollutant absorption or dilution.

P2 - Dimensions (height, width): expressed in terms of maximum height (H_{max}) of the frontiers and width (w) of the OS, which is the short side as it has been defined for the P1. It means that there is at least one building/front that has the maximum height among others, and that is > or < of the width of the AS.

d. $H_{max} > w$

e. $H_{max} \leq w$

Relation with SUOD: allow to estimate the path blockages and the overall evacuation layout. In fact, high frontiers increase the risk due to the possibility of failure causing debris that occlude the OS and avoid the evacuation, not only in case of earthquake but also in case of terrorism due to explosion.

Relation with SLOD: allow to estimate canyon effects. High frontiers decrease the risk of solar radiant exposure of the OS, but wind flow might be reduced.

P3 - Structural type: according to the definition provided for the parameter S2_F_1 in D1.1.2 (section 2.1), SA (structural Aggregates) is a set of buildings (structural units), placed in substantial contiguity buildings placed in substantial contiguity that are connected to form a unitary structural organism. We distinguish between OSs which have all the fronts built and composed of SA (e.), and, OSs which have not all frontiers composed of SA, and hence they may have open sides as frontiers. This qualitative threshold has emerged as a result of the statistical analysis of the 90 squares because 80% of the sample has SA to all fronts, so that it seems to be the adequate threshold of the two different options.

f. SA (all fronts)

g. SA (not all fronts)

Relation with SUOD: e., rather than f., could increase the probability of damage scenarios because all the frontiers are built. At the same time, the free sides of the AS (option f.) represent physical boundaries that are not passable (such as terrace open to the landscape) and hence, this reduces the number of possible evacuation roads.

Relation with SLOD: the open side could increase or decrease the heat concentration depending on the orientation of frontiers and the sun position, moreover, it reduces the perceived temperatures and pollution concentration, if it is favorable to the prevalent wind direction.

P4 - Permeability: it is referred to the "quality" of the accesses in relationship with the frontiers (both if built or if not built but also not accessible) of the OS. The access may be described by different parameters that

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influence the whole evacuation process: the total number of accesses, the width of access, the position in the OS, the distance between accesses. For the purpose of the initial identification of the BETs, we focus on these features that encompass the morphological characterisation of the accesses system, such as the layout in relationship with the perimeter of the OS; while, the width of accesses will be considered as a variable parameter for the modeling and simulation phases of Tasks 3 and 4.

In this regard, some authors (Huan-Huan et al. 2015) have investigated the influence of the exits' configuration on the evacuation process in a room without obstacle and the evacuation time for different widths and positions of the exits. In the case of a single exit, the evacuation time depends on the exit width. For the case of two exits, different configurations have been considered varying the separation between exits, the width, the distance to exits which are the main factors affecting the evacuation time. If two exits on the adjacent walls are set symmetrically, the average distance of evacuees to two exits is the shortest and the evacuation time is the shortest. Moreover, when the separation between two exits is large the pedestrians do not hesitate to choose the exit, and hence, the total evacuation time is shorter. For instance, it is found that a certain distance between the two exits and between the exits with the corners is helpful to decrease the evacuation time (Huan-Huan et al. 2015). Each parameter may be varied during the simulation process in order to identify the best access configuration that ensures the shortest evacuation time.

Moving from all the previous assumptions, a novel characterisation of accesses has been carried out in terms of permeability, referring simultaneously to the width of access and the subtended angle of that access. In fact, considering the barycenter of the OS, the subtended angle (Figure 7) has been calculated for each access and thus, the permeability is represented by the sum of the subtended angle. It is worth clarifying that the measure of the angle varies between different position of access: HP1) accesses with same width will have different angle if set in the middle of the side or in the corner; HP2) accesses with same measure of angle will have different width depending on their placement. This rationale allows providing an objective definition of permeability and "quality" of accesses in geometrical terms, without defining judgment related to risks.

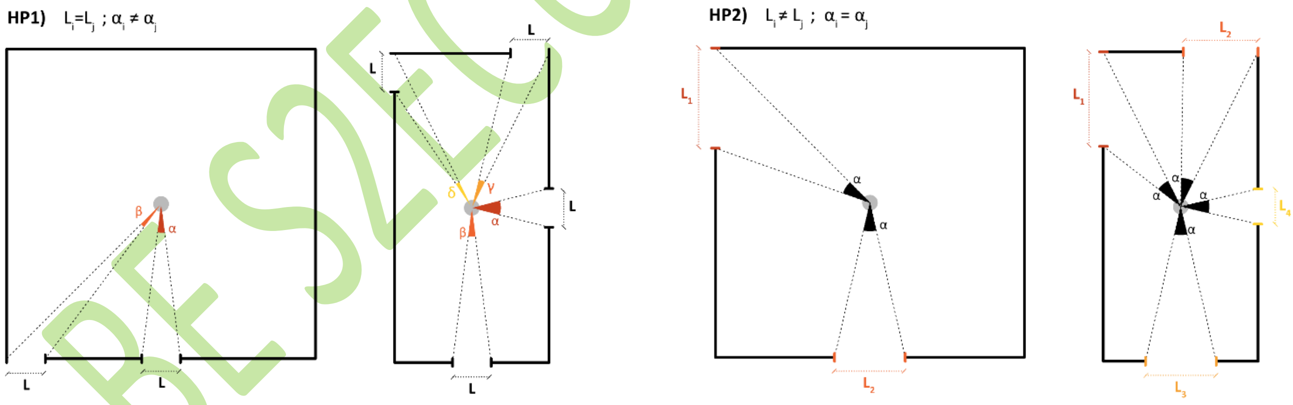

Figure 7: Representation of permeability in terms of distance from the barycenter of quadrangle (a) and rectangle (b) shape to accesses, considering the subtended angle.

The geometric value of the sum of angles takes into account the width of accesses depending on the overall dimension and morphology of the OS. This value is thus related to the maximum value of angle's degree (360°) that encompasses the totality of frontiers which are not accessible.

For the definition of two different classes of this parameter, it is necessary to define a threshold of the possible sum of the measures of subtended angle. The definition of this threshold value derives from the

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statistical analysis conducted on a set of 40 Italian squares, randomly selected among the largest sample of 90 convex squares (section 2.3), spread throughout the Italian territory (considering at least two for each region). On the basis of the analyzes carried out, it emerges that the chosen value has a statistic average meaning. The validation of this threshold value was obtained also considering the contribution of other factors such as the width of the entrances (L_i in Figure 7) and the total area of the square. The calculation of the definitive threshold for LS has been carried out comparing the results of the two indices: $\sum\alpha_i$, λ, considered for the statistical analysis (see Appendix 7.3).

- $\sum\alpha_i$ [rad,°]: α is the subtended angle of each *i* accesses of the AS.
- $\lambda_{AS} = \Sigma L_i/2P$ [-]: ratio between the width of the accesses ($\sum L_i$) [m] and the perimeter the overall AS (2P) [m] and LS (2L). For the LS is considered the double of the total length (2Le).

From the comparison (see Appendix 7.3) it emerges that the $\sum\alpha_i$ is the most adequate to represent the permeability parameter for AS (a. and b. configurations of P1); therefore, the value used as the threshold of the two options h. and i. has been calculated as the mean value of the sample of 40 squares and it is around 0.66 rad, thus approximated to $\pi/5$ (36 °).

For LS (c. configuration of P1), the $\sum\alpha_i$ is not an adequate measure to evaluate the permeability. That is because in extremely elongated elements, the measurement of the angles that subtend each access would be extremely difficult and therefore a source of errors. So that, we use the coefficient λ_{LS}, given by the ratio between the width of the accesses ($\sum L_i$) and the twice the length of the same street (2Le), considering only for parts of the street with continuous fronts.

$$\lambda_{LS} = \Sigma L_i/2Le \quad [-]$$

This criterion has been applied to 40 streets that originate in each of the same 40 squares considered for the sample (Appendix 7.3). The λ_{LS_m} mean value obtained is 0.059, thus approximated to 0.06, and the standard deviation is 0.034, approximated to 0.03. The standard deviation value shows how the chosen sample is really various and therefore the mean value is able to discriminate streets with high permeability from those with lower permeability. Streets with $\lambda_{LS} > 0.06$ will be considered more permeable (h.), while streets with $\lambda_{LS} < 0.06$ will be considered less permeable (i)

Comparing the result of λ_{LS} with the result of λ_{AS} (Appendix 7.3) emerges that the λ_{AS_m} (0.13) is slightly higher than twice λ_{LS_m} (0.06). The standard deviation of the λ_{AS_m} is also about the twice (0.062) of the corresponding value for the λ_{LS_m} (0.034). The greater permeability of the square compared to the streets depends on their different morphological configurations in terms of dimensions, given that a square may be the natural terminal element of multiple LSs (node function of squares).

h. $\Sigma\,\alpha_i > 36°$ (a., b. of P1) \ $\lambda_{LS} > 0.06$ (c. of P1)

i. $\Sigma\,\alpha_i \leq 36°$ (a., b. of P1) \ $\lambda_{LS} \leq 0.06$ (c. of P1)

<u>Relation with SUOD:</u> h. configuration enhances the evacuation process scattering the number of users to avoid overcrowding; instead, the permeability of OS decreases for i. option.

<u>Relation with SLOD:</u> h. option increases the number of ventilated paths, and hence, facilitates the choice of users for alleviating route, avoiding overcrowding. Contrary, less permeability (i.) reduces the ventilation but ensures cool-shaded paths.

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P5 - Special buildings: according to the definition provided for the parameter S2_F_3 in D1.1.2 (section 2.1), are all those buildings that stand out from the built context and constitute the emerging elements of the urban qualification. It is relevant not only for the specific function but also for the structural quality and performance of specific construction technique adopted. The observation of the AS sample has revealed that the majority of the more relevant square of cities within the Italian territory has a church, usually placed in the middle of the long side.

l. yes

m. no

Relation with SUOD: the presence of special buildings increases both the vulnerability and the exposure component of risks, due to the higher concentration of people, such as tourists and determine a huge economic loss due to the value, both in case of earthquake and terroristic attack. Moreover, if these are specialised buildings (e.g. church, tower bell) or cultural heritage, in case of earthquake, they have typical damage mechanisms; in case of terrorist acts, they generate tourism and thus are vulnerable for the higher concentration of people.

Relation with SLOD: the presence of special buildings increases the vulnerability component of risk, due to the higher concentration of people, and the occupation type (health fragility, related to social vulnerability).

P6 - Homogeneity of constructive techniques: is referred to buildings that were built with the same construction techniques, considering masonry as the prevalent structural type since most of the buildings placed in OSs among the observed samples of the Italian historical centres is masonry structures. The homogeneity is considered for ASs that have all frontiers (100%) masonry built (o.). Alternatively, in case of the presence of concrete frame or steel frame buildings there is not homogeneity (p.) we chose the i. option assuming that the common technique is the masonry ones. However, the current parameter could be changed according to the prevalent structure type of the context under investigation.

n. yes

o. no

Relation with SUOD: this parameter strongly influences the structural performance in case of seismic risk. In fact, in case of lack of homogeneity (o.), other types of buildings, such as concrete or steel structure, have a different response to seismic actions provoking damage due to the hammering effect.

Relation with SLOD: irrelevant.

P7 - Porches: the presence of porches causes the interruption of construction homogeneity because they are considered as the addition of pre-existing structures from a structural perspective. On the other side

p. yes (>25% of Frontier)

q. no (0-25% of Frontier)

Relation with SUOD: they may represent a structural weakness of the global behaviour of buildings of the frontier. They are considered as a semi-public space and hence they could increase the temporary presence of people.

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Relation with SLOD: it may be a place with a lower level of heat concentration (shaded space) and wind velocity (obstructed wind flow).

P8 – Slope: refers to the presence of slope ground, overhangs, cliffs, ramp/stairs and difference in altitude with a break of continuity between OS and a generic lower altitude. The presence of a single stair/ramp is sufficient condition to select the s. option. Regarding the constant terrain slope instead, the Italian regulation about the accessibility for people with disabilities (DM 239/1989 andL9/1989) establishes the limit of 8% (≅ 5°) as the maximum slope for wheelchair accessible ramps. Moreover, some authors (León and March 2014) evaluate the variation of evacuation time according to the terrain slope (i.e. steeper gradients lead to slower movement), demonstrating that the conservation of the evacuation speed decreases by 20% already between 5°-15° degrees of slope (Post et al. 2009). According to these suggestions, we consider also the constant terrain slope over 8% into the s. option.

r. no (flat ground)

s. yes (quote difference/stairs/ slope over 8%)

Relation with SUOD: this parameter affects the evacuation process, because accesses placed inside of OS with high quote difference, or with stairs, do not may be considered as safety exit during an emergency because the slope (degree) alters the evacuee's movement and speed. Moreover, the presence of walls against the ground for containing parts of cities at a higher altitude than the OS could cause indirect physical damage during an earthquake.

Relation with SLOD: the no presence of, or constant, slope (s.) ensures good ventilation conditions leading to pollutants transport and/or dilution.

P9 – Green: refers to the presence of green considering trees, bushes and hedges or grass without distinction. For the further steps when modeling this parameter, it needs to be detailed into three categories according to the following consideration:

	Green type	Parameter	SLOD – T°	SLOD – Pollution
1	*Tall green (trees)*	Presence (Y/N) Height (from ground) [m] Crown size, diameter/width [m] Location (center or street side)	T° control Shade size Shade provision	Pollution control Wind obstruction Pollution blocking
2	*Green to land (bushes and hedges)*	Presence (Y/N) Height (from ground) [m] Location (center or street side)	T° control Shade size Shade provision	Pollution control Pollution control Pollution blocking
3	*Green to land (grass)*	Presence (Y/N) Location (center or street side)	T° control T° control	Pollution control Pollution control

*T° = temperature grade in Celsius

t. yes

u. no

Relation with SUOD: the current parameter doesn't influence the definition of earthquakes and terrorism risks, however, it assumes relevance for the evacuation process. In fact, green areas may be used to a refuge or as a temporary shelter, if there is no great distance from buildings and if they have adequate dimensions. But, at the same time, they could represent obstacles to the evacuation depending on their position in the OS and their dimension.

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Relation with SLOD: the presence of green (t.) has a mitigation role in the increase of temperature risk because green areas change the outdoor temperature condition and the way in which people can feel discomfort by providing a cooling walkable paths and sits shaded from radiation. Similarly, the green infrastructure increases the adsorption capabilities of air pollutants. Therefore, the absence of green infrastructures reduces evapotranspiration and shading, especially in dense urban areas. Care must be taken with the size and location, large green elements may result in wind obstruction.

3.1 Definition and representation of BETs

The final step of the definition of BETs consists of obtaining all the possible combinations from the latter parameters. The methodology adopted is a simplest combinatorial pattern, arranging *n* options *k* times following the formula $D_{n,k} = n^k$. The process of defining the BETs is shown in Figure 8.

3.1.1 Merging process for the definition of BETs

As explained, the first step of the current process considers the nine parameters pointed out in section 2.3 that describe the characteristics of the AS in physical terms (according to morpho-typological, geometric, constructive issues).

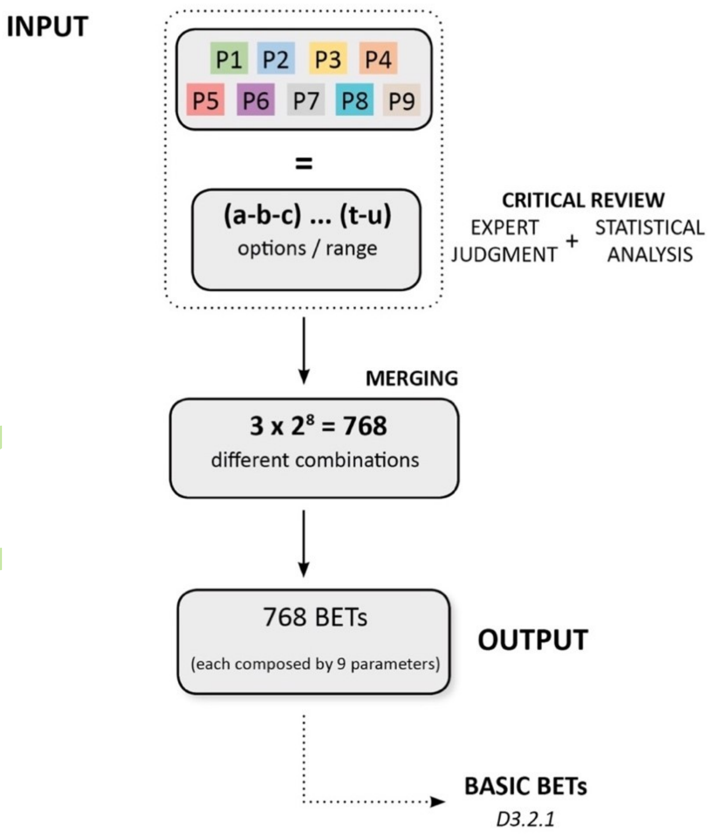

Figure 8: Schematic overview flowchart of the BETs (AS) definition process

Hence, the input is composed of the nine parameters (P1, P2, P3, P4, P5, P6, P7, P8, P9) containing each other two or three options (Table 5). Each option represents the variation range of the parameter, and they have been alternatively chosen and combined. The final results (Figure 9) consist of 768 different combinations (calculated as $3 \times 2^8 = 3 \times 256 = 768$). This great amount of combinations does not allow to highlight significative models of the BE and surely would require a huge computational effort. Therefore, some representative "basic" BETs configurations will be selected for further modeling and simulation phases in the following D3.2.1, which is focused on the identification of typical combinations among the 768 BETs developing the statistic analysis's results. In fact, the current deliverable represents, on the one side, a point of connection between the SoA carried out in tasks 1 and 2, on the other side, the first step of the simulation process, which will be debated in task 3.

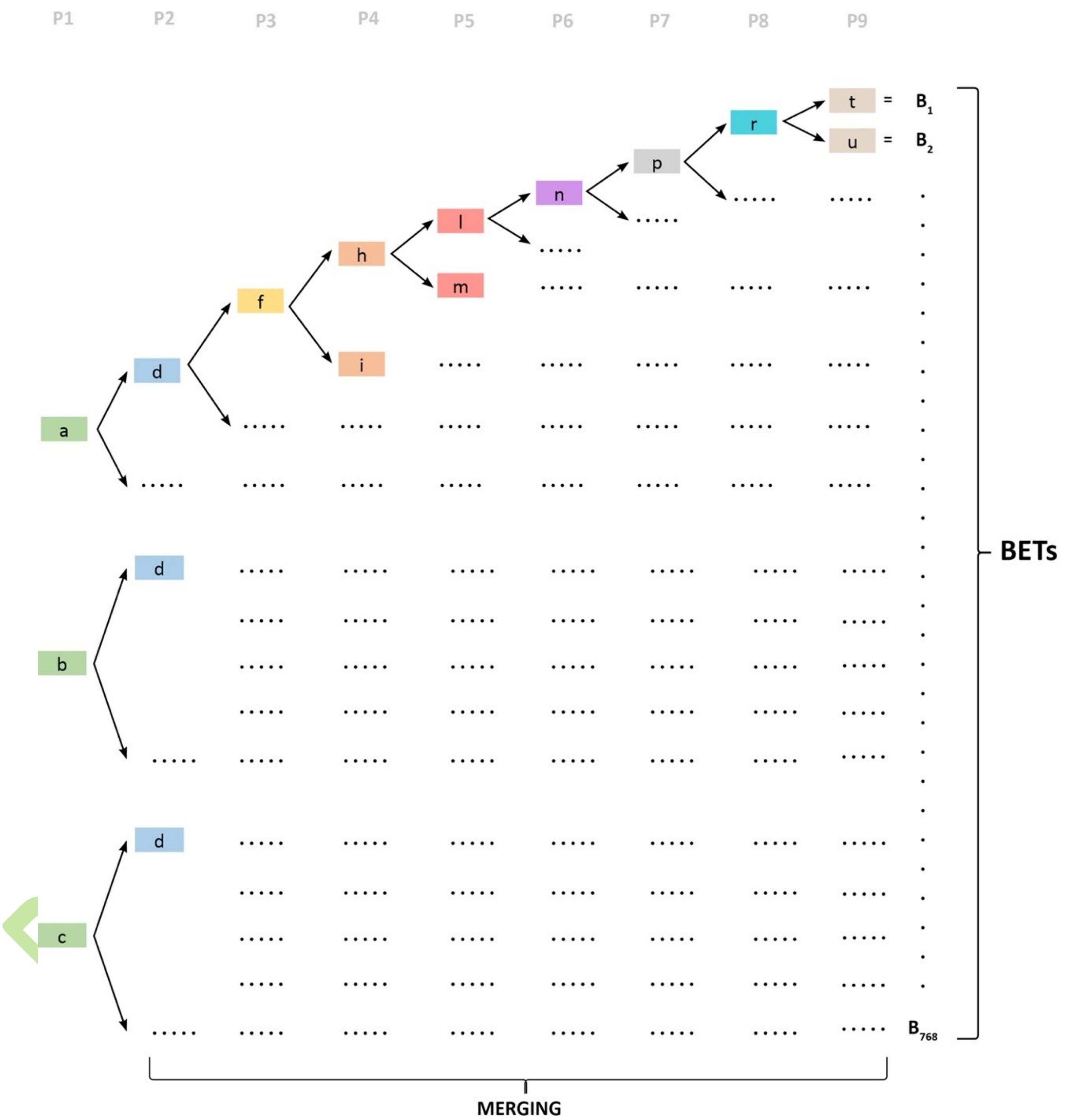

Figure 9: Combinatorial process used for the definition of BETs

3.1.2 Representation of BETs

A different order of parameters has been adopted to obtain a synthetic and exhaustive graphical representation of BETs. In fact, the order of the nine parameters is according to the order of the parameters of Table 2, and thus, they firstly focus on the morphological and geometrical features, and then, on the constructive ones. However, each parameter represents characteristics that can be drawn in different ways. In this regard, Figure 10 shows the type of representation required for each parameter. It emerges that an exhaustive representation may be performed by drawing firstly the plan, at the urban scale, and then the section of frontiers, which needs more detailed information at the building scale.

CODE	PARAMETERS	OPTIONS	REPRESENTATION TYPE
P1	Morphological configuration	a	PLAN
		b	
		c	
P2	Dimensions	d	SECTION
		e	
P3	Structural type	f	PLAN
		g	
P4	Permeability (accesses)	h	PLAN
		i	
P5	Special buildings	l	PLAN, SECTION
		m	
P6	Homogeneity of constructive technique	n	PLAN, SECTION
		o	
P7	Porches	p	PLAN, SECTION
		q	
P8	Slope	r	PLAN, SECTION
		s	
P9	Green	t	PLAN, SECTION
		u	

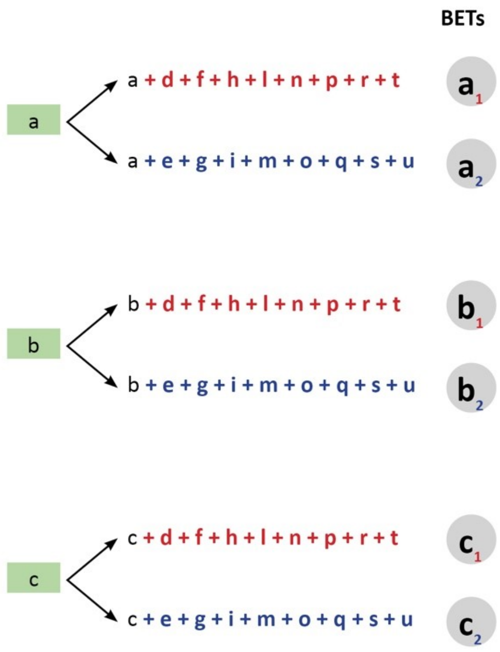

Figure 10: Choice criterion for the graphical representation of the six examples of BETs

Moreover, six different combinations of BETs have been performed with the aim of providing examples of the graphical representations for each parameter and all of the options. So that, the BETs models, selected for the representation, are the results of the combination shown in Figure 10: the morphological types *a, b, c* (i.e. options of P1) are matched once with the first options of each parameter (marked in red), and then with the second options (marked in blue). This procedure allows showing the characterization of each option because the combination marked in blue represents the opposite of the combination in red. In this way we obtain 6 different examples of BETs (a_1, a_2, b_1, b_2, c_1 and c_2) that have been represented in plan and section (2D) and in axonometric 3D view (Figure 11, Figure 12, Figure 13, Figure 14, Figure 15 and Figure 16). The dimensions of the width, the length and the height are only used as an example, so as the types of buildings and green. The special buildings are marked with the corresponding color of P5. The P7 (Homogeneity of constructive technique) is differently represented by two different types of hatches only for option o., that is for not masonry buildings. For P8, the direction of the slope is explained by the arrow.

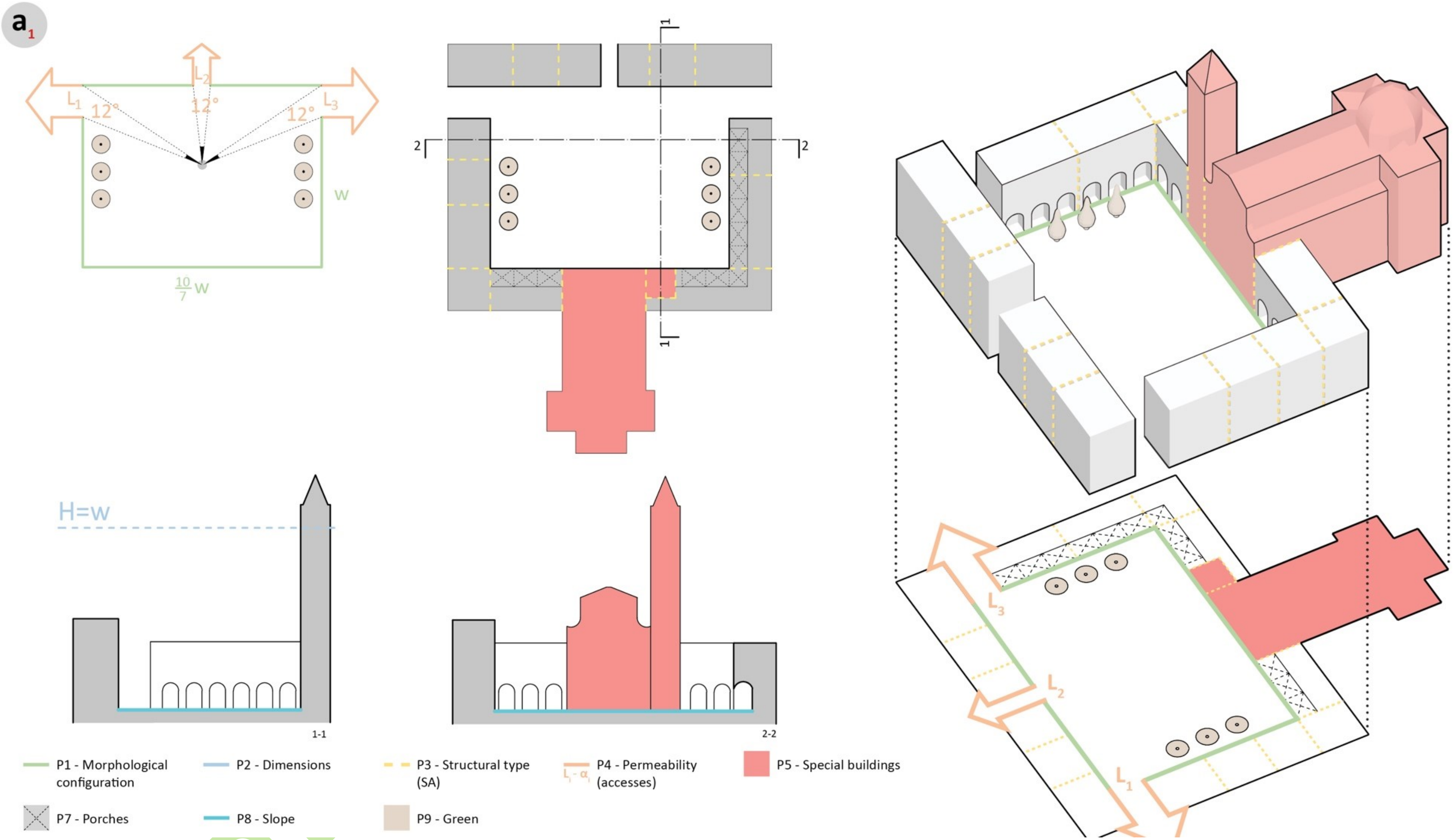

Figure 11: Graphical representation in plan, section and axonometric view of BET models a_1

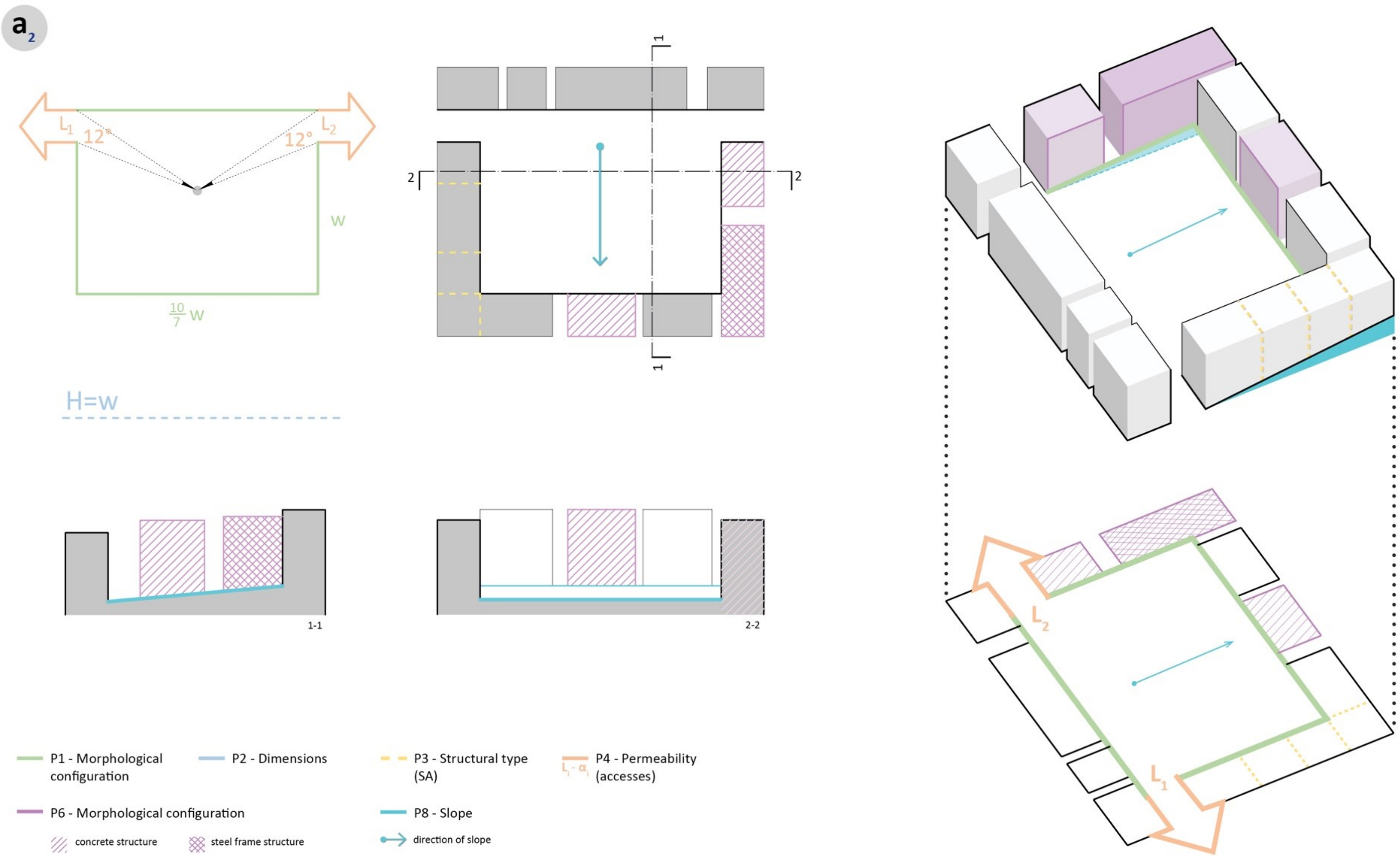

Figure 12: Graphical representation in plan, section and axonometric view of BET models a_2

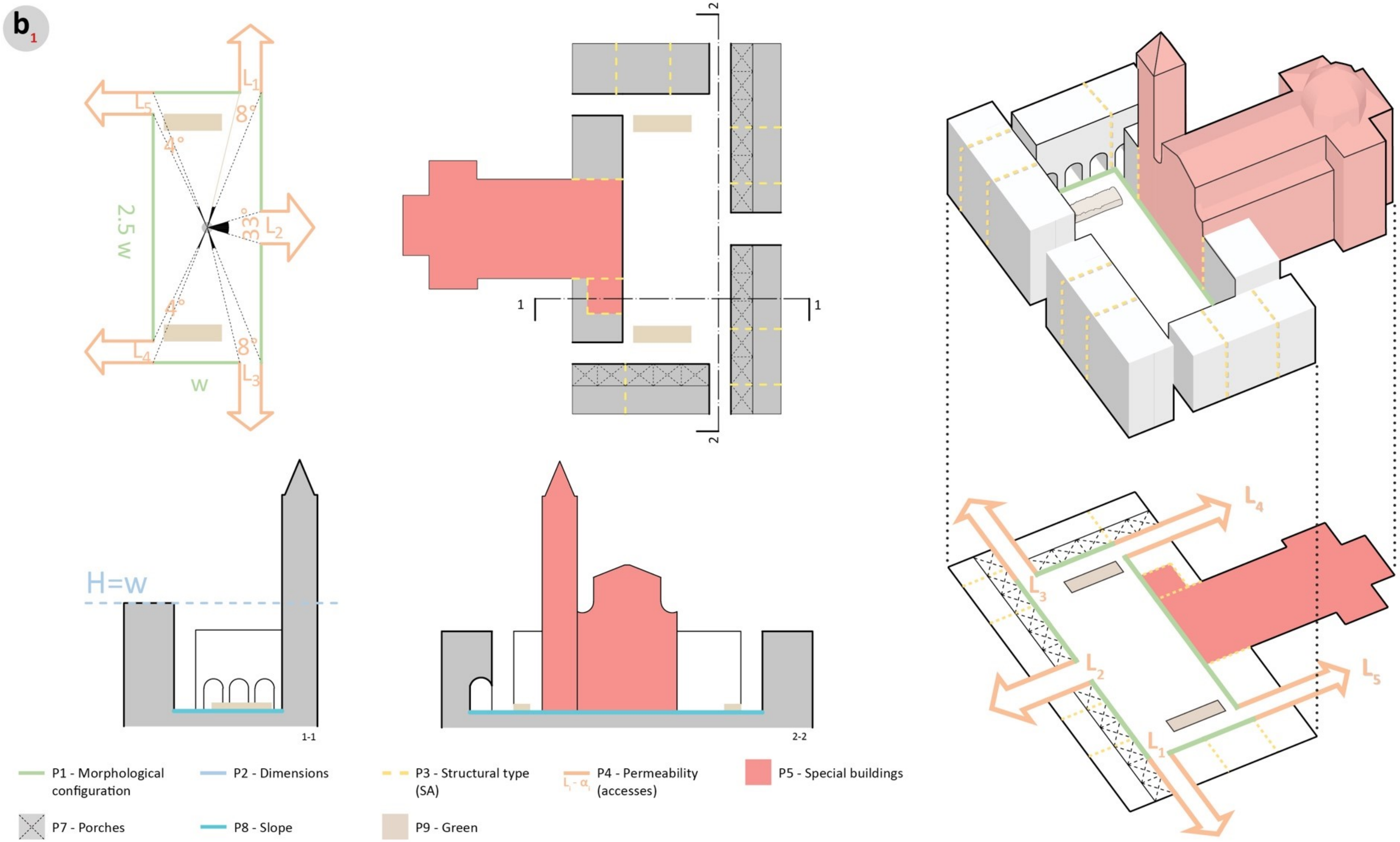

Figure 13: Graphical representation in plan, section and axonometric view of BET models b_1

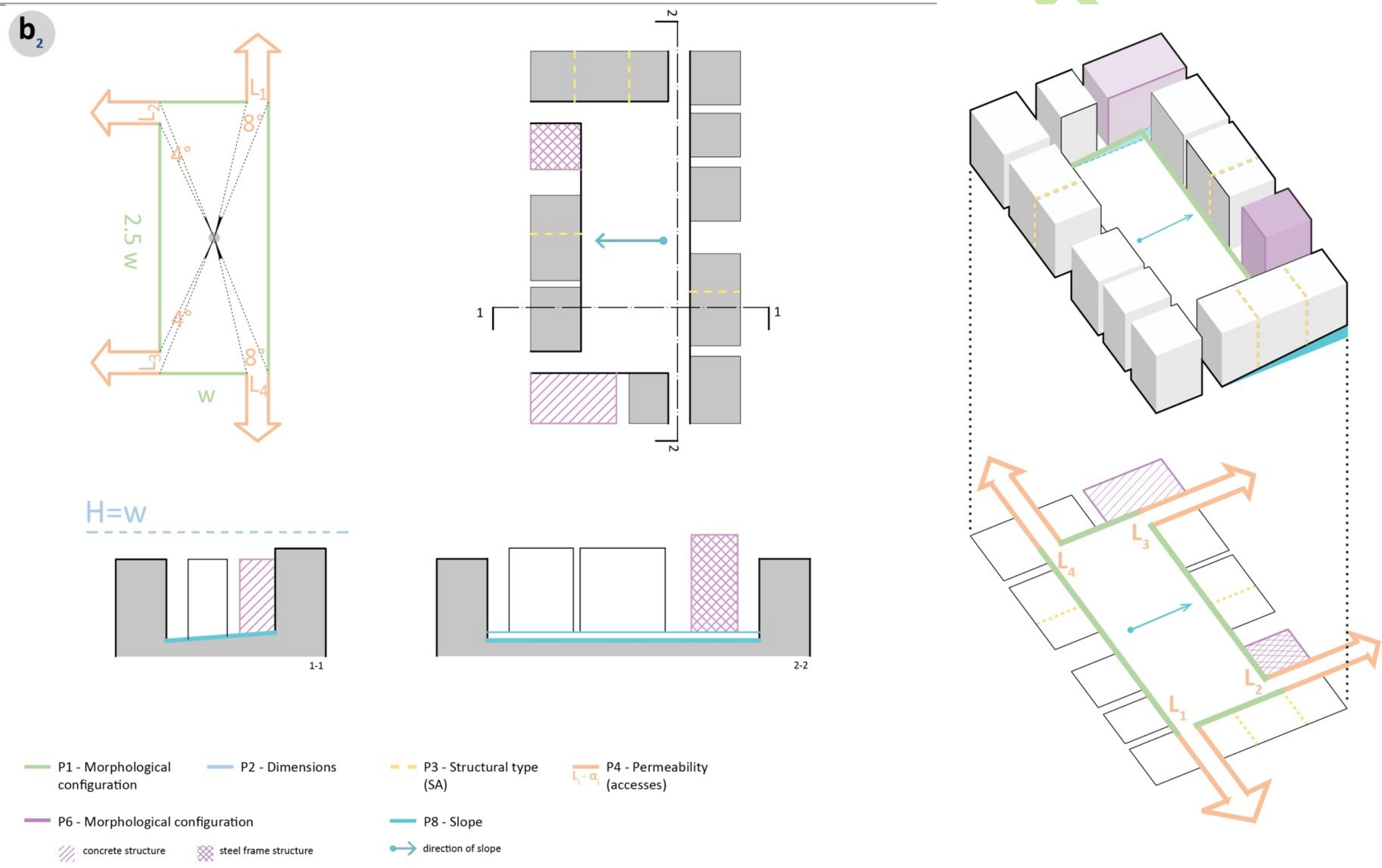

Figure 14: Graphical representation in plan, section and axonometric view of BET models b_2

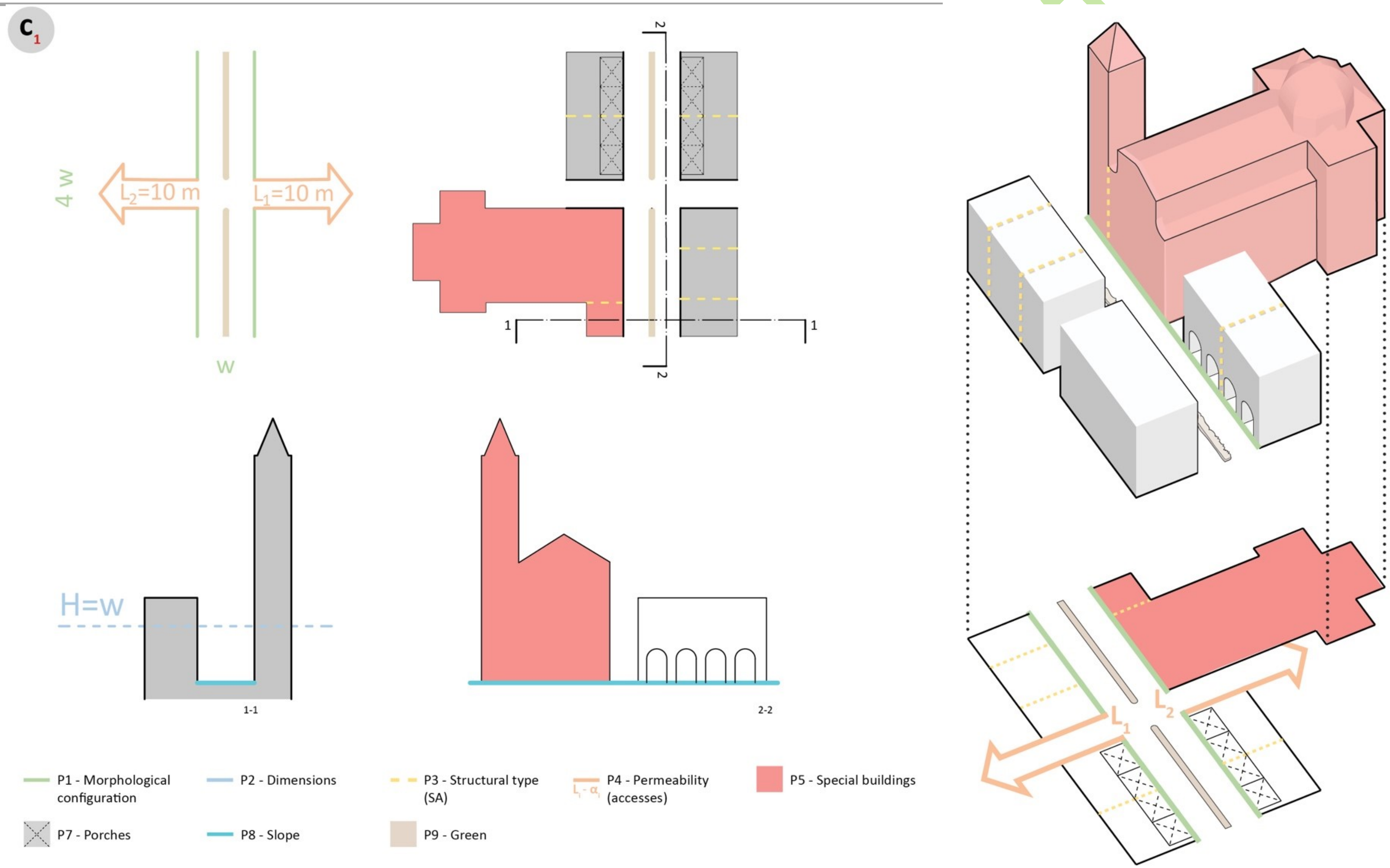

Figure 15: Graphical representation in plan, section and axonometric view of BET models c_1

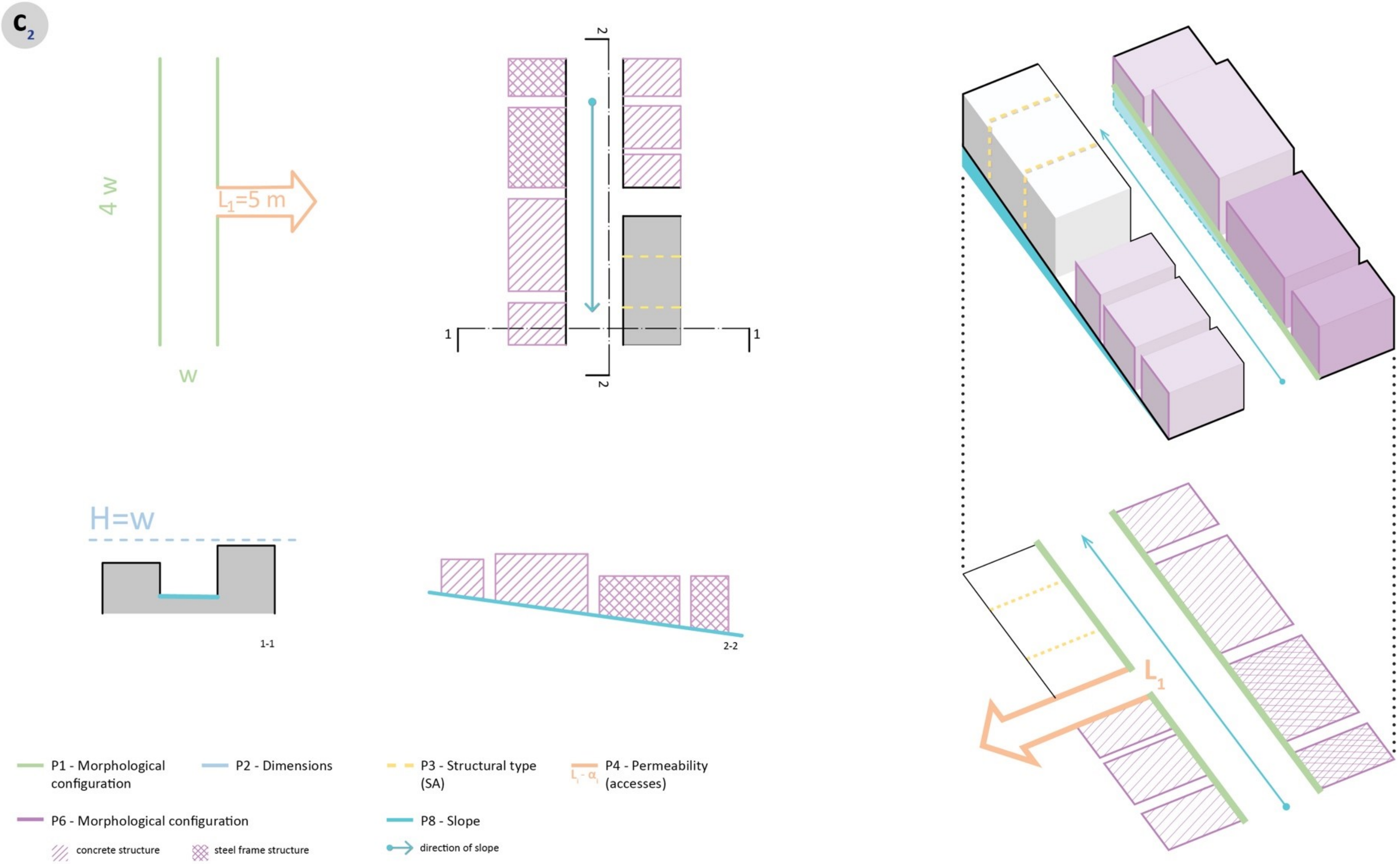

Figure 16: Graphical representation in plan, section and axonometric view of BET models c_2

4. Identification of BETs corresponding to real case studies

With the aim of verifying the reliability of the selected parameters and the completeness of the process of definition of BETs, it seems necessary to apply this procedure to real case studies. So that, three convex ASs (Piazza Vittorio Emanuele II - Caldarola, Piazza San Francesco - San Gemini, Piazza del Popolo - San Giovanni in Persiceto) among the eight ASs studied for the WP1 and the four LSs for WP2 (Milano) have been chosen for the validation. Table 6 shows which options belong to each case study and the graphical representations of the corresponding BETs are reported in Appendix 7.4.

Table 6: Check of parameters characterising the BETs corresponding to the nine case studies of WP1 and WP2

PARAMETER			Caldarola	San Gemini	S. G. in Persiceto	Milano			
						Via Zanoia	Via F.lli Fossati	Via G. Ponzio	Via G. Pacini
P1	Morphological configuration	a		X					
		b	X		X				
		c				X	X	X	X
P2	Dimensions	d	X		X	X	X	X	X
		e		X					
P3	Structural type	f			X				
		g	X	X		X	X	X	X
P4	Permeability (accesses)	h	X	X	X			X	X
		i				X	X		
P5	Special buildings	l	X	X	X	X	X	X	
		m							X
P6	Homogeneity of constructive technique	n	X	X					
		o			X	X	X	X	X
P7	Porches	p	X		X				
		q		X		X	X	X	X
P8	Slope	r	X		X	X	X	X	X
		s		X					
P9	Green	t				X		X	X
		u	X	X	X		X		

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DISCUSSION

The AS of **Caldarola** is a rectangular square and thus belongs to the elongated class (b - P1); there is a construction whose height is more than the width of the square (d - P2); two of four sides of the square are composed of structural aggregates (g - P3); the permeability is high (h - P4); there are four special buildings (l - P5); all the constructions are masonry buildings (n - P6); the 29% of frontiers are characterised by porches (p - P7); the ground is flat (r - P8); the green is absent (u - P9). The resulting BET summarizes all the relevant morphological, geometrical and constructive aspects of the Vittorio Emanuele II square. Therefore, this case study confirms the correctness of the procedure.

The AS of **San Gemini** is a compact square (a - P1), the maximum height of the frontiers is not over the width of the AS (e - P2), there is only one frontier that is composed of a structural aggregate (g - P3); given the four accesses and their position and dimensions, the permeability is high (h - P4); there are two special buildings (l - P5); all the constructions are masonry buildings (n - P6); there are no porches in the frontiers (q - P7); there are stairs in the L_3 access (s - P8); the green is absent into the squares (u - P9). The resulting BET summarizes all the relevant morphological, geometrical and constructive aspects of the Piazza San Francesco, so that the correctness of the procedure is confirmed.

The AS of **San Giovanni in Persiceto** belongs to the elongated class (b - P1); there are constructions whose height is more than the width of the square (d - P2); all the four sides of the square are composed of structural aggregates (g - P3); the permeability is high (h - P4); there are four special buildings (l - P5); there is one concrete building (o - P6); the 67% of frontiers are characterised by porches (p - P7); the ground is flat (r - P8); the green is absent (u - P9). The resulting BET summarizes all the relevant morphological, geometrical and constructive aspects of the Piazza del Popolo. Therefore, this case study confirms the correctness of the procedure.

The four LSs of **Milano** (Via Zanoia, Via F.lli Fossati, Via G. Ponzio, Via G. Pacini) belong to the very elongated class (c - P1) and are characterised by the same features (P2, P3, P6, P7 and P8). They differ in P4 that depends on the type of street because the main street is generally wider and hence the maximum height of its frontiers is not over the width. The resulting BETs comprehensively summarizes all the relevant physical aspects of the case studies.

5. Conclusion

The current deliverable has systematized the wealth of information acquired by the WP1 and WP2 about SUODs and SLODs to outline which morphological and constructive aspects affect the BE performance during emergency conditions.

In this regard, a first fundamental step was the selection based on the expert judgment of the whole parameters emerged by the D1.1.2 and D2.2.5 that, on the one side, describe the BE in physical terms, and, one the other side, are considered the most relevant for the risk assessment. Moreover, additional information has been acquired thanks to a statistical analysis developed on a sample of 133 square of the main Italian towns. Both two steps of this selection process allow the definition of the nine parameters characterising the BE that summarise the relevant issue related to the risks.

In this way, it is possible to determine physical models that have a strong connection to the response to disasters, and hence, to develop the main purpose of the current research project focused on the human behaviour simulation within the urban environment. These significative models of the BE have been defined as BETs that are conceived in analytical terms as results of a combinatorial process of the nine selected parameters. Given the numbers of input variables, the final number of BETs is about 768. This large quantity requires a huge computational effort for detecting BETs models in the urban environment, and hence, for evaluating the performance of the whole BE under disasters.

Notwithstanding this limitation, the current work represents the initial step of the WP3 aiming at identifying a methodology to represent the BETs according to the multi-risk approach, considering all the required

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phases of the modeling work-flow (survey campaign, data acquisition, parameters implementation in Revit BIM software, information exchange for interoperability) and of the simulation process.

6. References

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7. Appendix

7.1 Correlation between assessment of risks and survey form of D.1.1.2

This table demonstrates the correlation of the components (hazard, vulnerability and exposure) of risks with the parameters of the survey form of the D1.1.2 and provides the basis of Table 2 of section 2.2.

TYPE OF RISK	INDEXES FOR RISK ASSESSMENT	PARAMETER CODE (SURVEY FORM OF D1.1.2)	
TERRORISM	**HAZARD**		
	Target type	S2_F_3 S2_C_4 S2_C_1	Special buildings Monuments Special Buildings
	Uses		
	Protection	S2_F_2 S3_F_3	Accesses Urban furniture/obstacles
	VULNERABILITY		
	Shape	S1_1 S1_0	dimension Prevalent shape
	Accessibility	S1_1 S2_F_1 S2_F_2 S2_F_7 S2_F_4 S2_F_5	dimension type of Aggregates Accesses Quote differences Town walls Porches
	Obstacles	S2_C_3 S2_C_4 S2_C_5 S2_C_6 S2_C_8 S2_C_7 S3_C_4 S2_C_2	Fontaine Monuments Dehors Quote difference Green area Archaeological sites Urban furniture/obstacles Canopy
	EXPOSURE		
	Type of attack		
	Crowding		
	Reaction	S2_C_3 S2_C_4	Fontaine Monuments

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		S2_C_5 Dehors S2_C_6 Quote difference S2_C_8 Green area S2_C_7 Archaeological sites S3_C_4 Urban furniture/obstacles
EARTHQUAKE	**HAZARD**	
	Ground motion severity (magnitude, intensity, PGA, spectral response)	
	Seismic microzonation	
	VULNERABILITY	
	Physical - Constructive and structural characteristics of buildings	S1_2 dimension S2_F_1 type of Aggregates S2_F_3 Special buildings S2_F_4 Town walls S2_F_5 Porches S2_F_7 Quote differences S2_C_1 Special Buildings S2_C_4 Monuments S3_F_1 Homogeneity of built environment age S3_F_2 Homogeneity of constructive techniques S3_F_3 Urban furniture/obstacles
	Physical – Characteristics of OS	S1_0 Prevalent shape S1_1 dimension S2_C_6 Quote difference S2_C_9 Underground park S2_C_10 Underground cavities S2_F_2 Accesses
	Social – type of users	
	EXPOSURE	
	Occupancy of buildings	
	Crowding	
HEAT-WAVES	**HAZARD**	
	Reached temperature, humidity levels, wind velocity and prevalent direction	
	VULNERABILITY	
	Physical – BE typologies and layout	S1_0 Prevalent shape S1_1 dimension S1_2 Hmax built front S1_3 hmin built front S2_F_1 type of Aggregates S2_F_2 Accesses S2_F_3 Special buildings S2_F_5 Porches S2_F_6 Water S2_F_7 Quote differences S2_C_6 Quote difference

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		S2_F_8 Green area S2_C_2 Canopy S2_C_3 Fontaine S2_C_8 Green area S3_F_2 Homogeneity of constructive techniques S3_F_3 Urban furniture/obstacles S3_C_3 Pavement finishing S3_C_4 Urban furniture/obstacles
	Social - type of users	S2_C_1 Special Buildings
	EXPOSURE	
	Crowding	
	Uses	
	Time of permanence	
AIR POLLUTION	**HAZARD**	
	Exceeded thresholds, particulate matters concentrations	
	VULNERABILITY	
	Physical – BE typologies and layout	S1_0 Prevalent shape S1_1 dimension S1_2 H_{max} built front S1_3 h_{min} built front S2_F_2 Accesses S2_F_7 Quote differences S2_C_6 Quote difference S2_F_8 Green area S2_C_8 Green area S3_F_2 Homogeneity of constructive techniques S3_F_3 Urban furniture/obstacles S3_C_3 Pavement finishing S3_C_4 Urban furniture/obstacles
	Social – type of users	S2_C_1 Special Buildings
	EXPOSURE	
	Crowding	
	Uses	
	Time of permanence	

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7.2 Samples of main cities of the Italian Regions

The following table summarizes the whole data used for the statistical analysis of the initial sample of 133 Italian squares, then reduced to 90 convex types, for each of which has been calculated the threshold of parameters P1, P2, P3 and P4.

							P1			P2			P3	P4
	Region	Province	Town	Square	CONCAVE	CONVEX	L	w	R	H_{max}	w	range	n SA	sample
1	VALLE D'AOSTA	AO	Aosta	Piazza Emile Chanoux		X	150	37	0,25	17	37	e	4	
2	PIEMONTE	AL	Alessandria	Piazza Papa Giovanni XXIII		X	73	25	0,34	70	25	d	3	X
3	PIEMONTE	AT	Asti	Piazza San Secondo		X	50	45	0,90	20	45	e	3	X
4	PIEMONTE	BI	Biella	Piazza Duomo		X	100	50	0,50	20	50	e	1	
5	PIEMONTE	CN	Cuneo	Piazza Tancredi Galimberti		X	200	100	0,50	20	100	e	0	X
6	PIEMONTE	NO	Novara	Piazza della Repubblica		X	70	20	0,29	40	20	d	4	X
7	PIEMONTE	TO	Torino	Piazza San Carlo		X	160	70	0,44	20	70	e	4	
8	PIEMONTE	TO-1	Moncalieri	Piazza Umberto I	X									
9	PIEMONTE	VB	Verbania	Piazza Ranzoni	X									
10	PIEMONTE	VC	Vercelli	Piazza Cavour		X	75	50	0,67	17	50	e	4	
11	LOMBARDIA	BG	Bergamo	Piazza Vecchia		X	60	30	0,50	14	30	e	4	X
12	LOMBARDIA	BS	Brescia	Piazza della Loggia	X									
13	LOMBARDIA	CO	Como	Piazza del Duomo	X									
14	LOMBARDIA	CR	Cremona	Piazza del Comune		X	65	35	0,54	80	35	d	4	
15	LOMBARDIA	LC	Lecco	Piazza XX Settembre	X									
16	LOMBARDIA	LO	Lodi	Piazza della Vittoria		X	70	65	0,93	40	65	e	4	X
17	LOMBARDIA	MI	Milano	Piazza del Duomo		X	168	120	0,71	38	120	e	3	
18	LOMBARDIA	MN	Mantova	Piazza Sordello		X	135	50	0,37	25	50	e	4	
19	LOMBARDIA	MB	Monza	Piazza Trento e Trieste		X	120	70	0,58	15	70	e	2	
20	LOMBARDIA	PV	Pavia	Piazza Duomo		X	80	25	0,31	35	25	d	3	
21	LOMBARDIA	PV-1	Vigevano	Piazza Ducale		X	120	38	0,32	15	38	e	4	X
22	LOMBARDIA	SO	Sondrio	Piazza Garibaldi		X	80	50	0,63	14	50	e	2	
23	LOMBARDIA	VA	Varese	Piazza San Vittore		X	35	25	0,71	16	25	e	4	
24	TRENTINO ALTO ADIGE	BZ	Bolzano	Piazza del Grano	X									
25	TRENTINO ALTO ADIGE	TN	Trento	Piazza Duomo		X	80	65	0,81	45	65	e	4	X
26	VENETO	BL	Belluno	Piazza Duomo		X	60	35	0,58	22	35	e	4	
27	VENETO	PD	Padova	Piazza delle Erbe		X	115	35	0,30	25	35	e	3	
28	VENETO	RO	Rovigo	Piazza Vittorio Emanuele		X	95	35	0,37	18	35	e	4	X
29	VENETO	TV	Treviso	Piazza Duomo	X									
30	VENETO	VE	Venezia	Piazza San Marco		X	172	65	0,38	99	65	d	3	
31	VENETO	VR	Verona	Piazza dei Signori		X	65	30	0,46	25	30	e	4	
32	VENETO	VI-1	Bassano del Grappa	Piazza del Castello	X									
33	VENETO	VI	Vicenza	Piazza dei Signori	X									

34	FRIULI VENEZIA GIULIA	GO	Gorizia	Piazza della Vittoria		X	150	50	0,33	30	50	e	4	
35	FRIULI VENEZIA GIULIA	PN	Pordenone	Piazza San Marco	X									
36	FRIULI VENEZIA GIULIA	TS	Trieste	Piazza Unità d'Italia		X	150	75	0,50	25	75	e	0	X
37	FRIULI VENEZIA GIULIA	UD	Udine	Piazza Matteotti		X	75	50	0,67	18	50	e	4	
38	LIGURIA	GE	Genova	Piazza delle Vigne		X	30	10	0,33	20	10	d	3	X
39	LIGURIA	SP	La Spezia	Piazza Cavour		X	130	70	0,54	18	70	e	4	X
40	LIGURIA	IM	Imperia	Piazza S.Giovanni		X	45	30	0,67	20	30	e	3	
41	LIGURIA	IM-1	Sanremo	Piazza Santa Brigida	X									
42	LIGURIA	SV	Savona	Piazza Sisto IV		X	75	40	0,53	20	40	e	4	
43	TOSCANA	AR	Arezzo	Piazza Grande		X	70	50	0,71	25	50	e	4	X
44	TOSCANA	FI	Firenze	Piazza del Duomo	X									
45	TOSCANA	FI-1	Empoli	Piazza Farinata degli Uberti		X	50	40	0,80	20	40	e	4	
46	TOSCANA	GR	Grosseto	Piazza Dante	X									
47	TOSCANA	LI	Livorno	Piazza Grande	X									
48	TOSCANA	LU	Lucca	Piazza dell'Anfiteatro		X	75	50	0,67	25	50	e	4	X
49	TOSCANA	MS	Massa	Piazza Mercurio		X	48	47	0,98	15	47	e	4	X
50	TOSCANA	MS-1	Carrara	Piazza Alberica		X	100	25	0,25	20	25	e	4	
51	TOSCANA	PI	Pisa	Piazza dei Cavalieri		X	90	50	0,56	24	50	e	3	
52	TOSCANA	PT	Pistoia	Piazza del Duomo	X									
53	TOSCANA	PO	Prato	Piazza del Comune		X	43	20	0,47		20	e	4	
54	TOSCANA	SI	Siena	Piazza del Campo		X	115	90	0,78	88	90	e	4	X
55	EMILIA ROMAGNA	BO	Bologna	Piazza Maggiore	X									
56	EMILIA ROMAGNA	FE	Ferrara	Piazza Trento e Trieste		X	180	25	0,14	45	25	d	4	
57	EMILIA ROMAGNA	FC	Forli	Piazza Aurelio Saffi		X	140	80	0,57	67	80	e	3	X
58	EMILIA ROMAGNA	FC-1	Cesena	Piazza del Popolo		X	115	35	0,30	25	35	e	3	
59	EMILIA ROMAGNA	MO	Modena	Piazza Grande		X	75	45	0,60	25	45	e	3	
60	EMILIA ROMAGNA	MO-1	Carpi	Piazza Martiri		X	270	40	0,15	30	40	e	4	X
61	EMILIA ROMAGNA	PR	Parma	Piazza Duomo		X	50	45	0,90	64	45	d	4	X
62	EMILIA ROMAGNA	PC	Piacenza	Piazza dei Cavalli	X									
63	EMILIA ROMAGNA	RA	Ravenna	Piazza del Popolo		X	100	30	0,30	15	30	e	4	
64	EMILIA ROMAGNA	RN	Rimini	Piazza Cavour		X	120	75	0,63	18	75	e	4	
65	EMILIA ROMAGNA	RA-1	Faenza	Piazza del Popolo		X	115	35	0,30	48	35	d	4	X
66	EMILIA ROMAGNA	RE	Reggio Emilia	Piazza Camillo Prampolini		X	85	40	0,47	35	40	e	4	X
67	UMBRIA	PG	Perugia	Piazza IV Novembre	X									
68	UMBRIA	PG-1	Spoleto	Piazza del Mercato	X									
69	UMBRIA	TR	Terni	Piazza della Repubblica		1	75	35	0,47	30	35	e	4	X
70	MARCHE	AN	Ancona	Piazza del Plebiscito		X	140	25	0,18	35	25	d	4	X
71	MARCHE	AP	Ascoli Piceno	Piazza del Popolo		X	85	30	0,35	40	30	d	4	X
72	MARCHE	FM	Fermo	Piazza del Popolo		X	130	20	0,15	20	20	e	4	X
73	MARCHE	MC	Macerata	Piazza della Libertà		X	65	35	0,54	64	35	d	4	X
74	MARCHE	PU	Pesaro	Piazza del Popolo		X	80	55	0,69	16	55	e	4	X
75	MARCHE	PU-1	Urbino	Piazza Rinascimento	X									
76	ABRUZZO	CH	Chieti	Piazza San Giustino		X	75	35	0,47	66	35	d	4	

77	ABRUZZO	AQ	L'Aquila	Piazza del Duomo		X	130	60	0,46	23	60	e	4	X
78	ABRUZZO	AQ-1	Sulmona	Piazza XX Settembre	X									
79	ABRUZZO	PE	Pescara	Piazza della Rinascita		X	100	70	0,70	28	70	e	2	
80	ABRUZZO	TE	Teramo	Piazza Sant'Anna		X	60	25	0,42	15	25	e	4	
81	LAZIO	FR	Frosinone	Piazza Cairoli		X	17	13	0,76	62	13	d	4	
82	LAZIO	LT	Latina	Piazza del Popolo		X	120	80	0,67	32	80	e	4	
83	LAZIO	RI	Rieti	Piazza Cesare Battisti	X									
84	LAZIO	RM	Roma	Piazza Navona		X	250	45	0,18	48	45	d	4	
85	LAZIO	RM-1	Velletri	Piazza Giuseppe Mazzini	X									
86	LAZIO	RM-2	Tivoli	Piazza del Seminario	X									
87	LAZIO	VT	Viterbo	Piazza del Plebiscito		X	60	35	0,58	16	35	e	4	X
88	MOLISE	CB	Campobasso	Largo San Leonardo		X	20	16	0,80	20	16	d	4	
89	MOLISE	CB-1	Termoli	Piazza Duomo	X									
90	MOLISE	IS	Isernia	Piazza Andrea d'Isernia	X									
91	CAMPANIA	NA	Napoli	Piazza Plebiscito		X	160	160	1,00	20	160	e	4	X
92	CAMPANIA	NA-1	Pompei	Piazza Bartolo Longo	X									
93	CAMPANIA	SA	Salerno	Piazza Alfano	X									
94	CAMPANIA	AV	Avellino	Piazza Libertà		X	140	50	0,36	25	50	e	4	X
95	CAMPANIA	BN	Benevento	Piazza Orsini	X									
96	CAMPANIA	CE	Caserta	Piazza Duomo		X	65	15	0,23	30	15	d	4	
97	PUGLIA	BA	Bari	Piazza dell'Odegitria	X									
98	PUGLIA	BA-1	Altamura	Piazza del Duomo	X									
99	PUGLIA	BA-2	Bitonto	Piazza Cavour	X									
100	PUGLIA	BA-3	Gravina in Puglia	Piazza Benedetto XIII	X									
101	PUGLIA	BAT	Andria	Piazza Duomo		X	37	35	0,95	50	35	d	4	X
102	PUGLIA	BAT-1	Barletta	Piazzetta del Duomo	X									
103	PUGLIA	BAT-2	Bisceglie	Piazza Duomo		X	50	10	0,20	15	10	d	4	
104	PUGLIA	BAT-3	Trani	Piazza Duomo	X									
105	PUGLIA	BR	Brindisi	Piazza Duomo		X	35	30	0,86	20	30	e	4	X
106	PUGLIA	FG	Foggia	Piazza Francesco De Santis	X									
107	PUGLIA	FG-1	Manfredonia	Piazza del Popolo		X	50	40	0,80	33	40	e	4	
108	PUGLIA	FG-5	San Severo	Piazza della Repubblica		X	60	10	0,17	22	10	d	4	
109	PUGLIA	LE	Lecce	Piazza Duomo	X									
110	PUGLIA	TA	Taranto	Piazza Duomo		X	25	15	0,60	12	15	e	4	
111	BASILICATA	MT	Matera	Piazza Vittorio Emanuele	X									
112	BASILICATA	PT	Potenza	Largo Duomo		X	30	20	0,67	12	20	e	4	X
113	CALABRIA	CT	Catanzaro	Piazza Duomo		X	40	30	0,75	17	30	e	4	X
114	CALABRIA	CS	Cosenza	Piazza Duomo		X	50	30	0,60	20	30	e	4	
115	CALABRIA	KR	Crotone	Piazza Duomo		X	40	20	0,50	12	20	e	4	X
116	CALABRIA	RC	Reggio Calabria	Piazza Duomo		X	75	50	0,67	18	50	e	4	
117	CALABRIA	VV	Vibo Valentia	Piazza Armando Diaz		X	45	30	0,67	20	30	e	4	
118	SICILIA	AG	Agrigento	Piazza Don Giovanni Minzoni		X	40	25	0,63	14	25	e	4	
119	SICILIA	CL	Caltanisetta	Piazza Garibaldi		X	40	30	0,75	20	30	e	4	X
120	SICILIA	CT	Catania	Piazza Università		X	65	60	0,92	18	60	e	4	

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121	SICILIA	EN	Enna	Piazza Duomo		X	25	15	0,60	35	15	d	4	
122	SICILIA	EN-1	Piazza Armerina	Piazza Cattedrale	X									
123	SICILIA	ME	Messina	Piazza Duomo		X	130	70	0,54	60	70	e	3	
124	SICILIA	PA	Palermo	Piazza Pretoria		X	60	50	0,83	17	50	e	4	X
125	SICILIA	RG	Ragusa	Piazza Duomo	X									
126	SICILIA	SR	Siracusa	Piazza Minerva		X	120	20	0,17	15	20	e	4	
127	SICILIA	TR	Trapani	Piazza Lucatelli		X	50	30	0,60	16	30	e	4	
128	SARDEGNA	CA	Cagliari	Piazza Palazzo	X									
129	SARDEGNA	NU	Nuoro	Piazza Sebastiano Satta	X									
130	SARDEGNA	OR	Oristano	Piazza Eleonara d'Arboria	X									
131	SARDEGNA	SS	Sassari	Piazza d'Italia		X	95	95	1,00	17	95	e	4	X
132	SARDEGNA	SS-1	Alghero	Piazza del Teatro		X	20	15	0,75	12	15	e	4	
133	SARDEGNA	SU	Iglesias	Piazza Municipio		X	30	20	0,67	17	20	e	4	X
	RESULTS				43	90						d	e	4	4 0
	* cities of over 20,000 inhabitants				32%	68%					21	69	71	
											23%	77%	79%	

3	2	1	0
13	3	1	2
14%	3%	1,1%	2%

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7.3 Definition of the threshold value for the P4 parameter

For each square, four different quantities have been considered useful for identifying the concept of permeability: (i) the sum of subtended angles defined for P4 ($\sum\alpha_i$) [rad]; (ii) the overall width of the accesses ($\sum L_i$) [m]; (iii) the perimeter (2P) [m]; and (iv) the area of the square (A) [m^2]. In addition to these, 3 other indices have been identified: the ratio between the width of the accesses and the perimeter (λ) [-]; the ratio between the area and the product between the width of the accesses and the perimeter (ρ) [-]; and finally, the ratio between ρ and the sum of the corners subtended by the accesses (ψ) [1/rad].

$$\lambda = \Sigma L_i / 2P \quad [-]$$

$$\rho = A/(\Sigma \mathrm{L_i} * 2P) \quad [\text{-}]$$

$$\psi = \rho/\Sigma\alpha_i \quad [1/\text{rad}]$$

This last parameter is considered useful for relating the area of the square, the perimeter, the number and width of the accesses with their arrangement. Table 7 presents the values calculated for all the parameters according to the alphabetical order of the 40 towns.

Table 7: Values of measures and parameters adopted for the permeability

	Town	name of the square	$\Sigma\alpha_i$ [rad]	ΣL_i [m]	A [m²]	2P [m]	λ [-]	ρ [-]	ψ [1/rad]
1	ALESSANDRIA	Giovanni XXIII	0,416	24,00	2120,23	211,03	0,11	0,42	1,01
2	ANCONA	del Plebiscito	0,100	25,18	4395,01	398,23	0,06	0,44	4,40
3	ANDRIA	Duomo	0,566	19,04	1632,71	176,15	0,11	0,49	0,86
4	AQUILA	Duomo	0,472	48,57	10781,00	448,31	0,11	0,50	1,05
5	AREZZO	Grande	0,272	14,72	4131,90	261,37	0,06	1,07	3,94
6	ASCOLI PICENO	del Popolo	0,372	26,47	2920,10	253,28	0,10	0,44	1,17
7	ASTI	San Secondo	1,059	43,05	3098,48	231,26	0,19	0,31	0,29
8	AVELLINO	della Libertà	0,851	91,07	11663,80	475,58	0,19	0,27	0,32
9	BERGAMO	Vecchia	0,294	16,96	2447,49	221,60	0,08	0,65	2,21
10	BRINDISI	Duomo	0,571	15,99	1490,78	176,77	0,09	0,53	0,92
11	CALTANISSETTA	Garibaldi	1,870	76,99	2921,66	221,15	0,35	0,17	0,09
12	CARPI	dei Martiri	0,267	85,29	15630,60	641,40	0,13	0,29	1,07
13	CATANZARO	Duomo	0,442	19,44	1581,71	187,23	0,10	0,43	0,98
14	CROTONE	Duomo	0,589	27,56	1271,30	159,78	0,17	0,29	0,49
15	CUNEO	Tancredi Galimberti	1,203	143,67	22335,20	630,79	0,23	0,25	0,20
16	FAENZA	del Popolo	0,965	75,04	7284,29	543,35	0,14	0,18	0,19
17	FERMO	del Popolo	0,191	26,74	2785,36	327,45	0,08	0,32	1,66
18	FORLI	Saffi	0,867	84,84	13145,20	491,50	0,17	0,32	0,36
19	GENOVA	delle Vigne	0,550	15,04	463,56	94,94	0,16	0,32	0,59
20	IGLESIAS	Duomo	0,675	19,07	1038,30	170,32	0,11	0,32	0,47
21	LA SPEZIA	Cavour	1,421	117,40	11386,50	454,84	0,26	0,21	0,15
22	LODI	della Vittoria	0,307	22,54	4795,44	289,36	0,08	0,74	2,39
23	LUCCA	dell'Anfiteatro	0,442	13,98	3069,75	205,84	0,07	1,07	2,41
24	MACERATA	della Liberta	0,611	26,20	2609,93	220,74	0,12	0,45	0,74
25	MASSA	Mercurio	0,625	21,71	2596,68	204,80	0,11	0,58	0,93
26	NAPOLI	Plebiscito	0,459	66,19	25884,90	647,88	0,10	0,60	1,32
27	NOVARA	della Repubblica	0,243	9,38	1371,56	182,04	0,05	0,80	3,31
28	PALERMO	Pretoria	0,672	32,57	3706,21	244,97	0,13	0,46	0,69
29	PARMA	Duomo	0,921	46,08	2622,53	231,42	0,20	0,25	0,27
30	PESARO	del Popolo	0,689	39,46	4543,75	273,26	0,14	0,42	0,61
31	POTENZA	Duomo	0,378	10,10	818,01	134,62	0,08	0,60	1,59
32	REGGIO EMILIA	Duomo	0,591	28,99	4212,81	274,91	0,11	0,53	0,89
33	ROVIGO	Vittorio Emanuele	0,246	27,37	4322,50	291,25	0,09	0,54	2,21
34	SASSARI	d'Italia	1,024	60,77	9986,32	400,07	0,15	0,41	0,40
35	SIENA	del Campo	0,192	17,16	11479,20	420,14	0,04	1,59	8,28
36	TERNI	della Repubblica	1,139	48,71	2921,09	240,14	0,20	0,25	0,22
37	TRENTO	Duomo	0,702	37,56	5244,35	312,13	0,12	0,45	0,64
38	TRIESTE	dell'Unità d'Italia	1,857	102,02	15086,10	522,97	0,20	0,28	0,15
39	VIGEVANO	Ducale	0,530	25,86	4894,29	327,87	0,08	0,58	1,09
40	VITERBO	del Plebiscito	0,713	28,23	2740,86	218,94	0,13	0,44	0,62

Once the measurements were made and the values of the various parameters obtained, the rankings of the parameter $\sum\alpha_i$ and the parameter ψ have been constructed. From the comparison of the two rankings it emerges that they present coherent positions, and hence, the parameter sum of subtended angles ($\sum\alpha_i$) may be considered sufficiently adequate to characterise the quality of the accesses, considering that the parameter ψ is more costly in terms of calculation instead.

Furthermore, the mean value of the sum of the subtended angles ($\sum\alpha_i$) corresponding to the 40 squares is close to 0.65 rad that is approximated to $\pi/5$, i.e. 36 °, to simplify the definition of the threshold value. According to this result, it is possible to distinguish the quality of the accesses (in terms of position, width, and about the extension of the square) into two categories: one of better permeability $\sum\alpha_i>36°$, and one of lower permeability $\sum\alpha_i<36°$.

Table 8: Ranking of the 40 squares of the sample based on $\sum\alpha_i$ values

	Town	name of the square	$\Sigma\alpha_i$ [rad]	ΣL_i [m]	A [m²]	2P [m]	λ_{AS} [-]
1	ANCONA	del Plebiscito	0,100	25,18	4395,01	398,23	0,06
2	FERMO	del Popolo	0,191	26,74	2785,36	327,45	0,08
3	SIENA	del Campo	0,192	17,16	11479,20	420,14	0,04
4	NOVARA	della Repubblica	0,243	9,38	1371,56	182,04	0,05
5	ROVIGO	Vittorio Emanuele	0,246	27,37	4322,50	291,25	0,09
6	CARPI	dei Martiri	0,267	85,29	15630,60	641,40	0,13
7	AREZZO	Grande	0,272	14,72	4131,90	261,37	0,06
8	BERGAMO	Vecchia	0,294	16,96	2447,49	221,60	0,08
9	LODI	della Vittoria	0,307	22,54	4795,44	289,36	0,08
10	ASCOLI PICENO	del Popolo	0,372	26,47	2920,10	253,28	0,10
11	POTENZA	Duomo	0,378	10,10	818,01	134,62	0,08
12	ALESSANDRIA	Giovanni XXIII	0,416	24,00	2120,23	211,03	0,11
13	LUCCA	dell'Anfiteatro	0,442	13,98	3069,75	205,84	0,07
14	CATANZARO	Duomo	0,442	19,44	1581,71	187,23	0,10
15	NAPOLI	Plebiscito	0,459	66,19	25884,90	647,88	0,10
16	AQUILA	Duomo	0,472	48,57	10781,00	448,31	0,11
17	VIGEVANO	Ducale	0,530	25,86	4894,29	327,87	0,08
18	GENOVA	delle Vigne	0,550	15,04	463,56	94,94	0,16
19	ANDRIA	Duomo	0,566	19,04	1632,71	176,15	0,11
20	BRINDISI	Duomo	0,571	15,99	1490,78	176,77	0,09
21	CROTONE	Duomo	0,589	27,56	1271,30	159,78	0,17
22	REGGIO EMILIA	Duomo	0,591	28,99	4212,81	274,91	0,11
23	MACERATA	della Liberta	0,611	26,20	2609,93	220,74	0,12
24	MASSA	Mercurio	0,625	21,71	2596,68	204,80	0,11
25	PALERMO	Pretoria	0,672	32,57	3706,21	244,97	0,13
26	IGLESIAS	Duomo	0,675	19,07	1038,30	170,32	0,11
27	PESARO	del Popolo	0,689	39,46	4543,75	273,26	0,14
28	TRENTO	Duomo	0,702	37,56	5244,35	312,13	0,12
29	VITERBO	del Plebiscito	0,713	28,23	2740,86	218,94	0,13
30	AVELLINO	della Libertà	0,851	91,07	11663,80	475,58	0,19
31	FORLI	Saffi	0,867	84,84	13145,20	491,50	0,17
32	PARMA	Duomo	0,921	46,08	2622,53	231,42	0,20
33	FAENZA	del Popolo	0,965	75,04	7284,29	543,35	0,14
34	SASSARI	d'Italia	1,024	60,77	9986,32	400,07	0,15
35	ASTI	San Secondo	1,059	43,05	3098,48	231,26	0,19
36	TERNI	della Repubblica	1,139	48,71	2921,09	240,14	0,20
37	CUNEO	Tancredi Galimberti	1,203	143,67	22335,20	630,79	0,23
38	LA SPEZIA	Cavour	1,421	117,40	11386,50	454,84	0,26
39	TRIESTE	dell'Unità d'Italia	1,857	102,02	15086,10	522,97	0,20
40	CALTANISSETTA	Garibaldi	1,870	76,99	2921,66	221,15	0,35
	Mean value of $\Sigma\alpha_i$ = 0,659 rad = 38° ~ $\pi/5$ (36°)						

The ranking obtained for the parameter λ_{AS} is also reported. It emerges that, even the extreme positions of the ranking do not vary significantly, nevertheless there is less consistency with the results of the rankings of the other two parameters ($\sum\alpha_I$, ψ). The parameter λ_{AS} is not adequate to represent the quality of access and therefore the permeability of the AS.

Table 9: Ranking the 40 squares of the sample based on λ_{AS} values

	Town	name of the square	$\Sigma\alpha_i$ [rad]	ΣL_i [m]	A [m²]	2P [m]	λ_{AS} [-]
1	SIENA	del Campo	0,192	17,16	11479,20	420,14	0,04
2	NOVARA	della Repubblica	0,243	9,38	1371,56	182,04	0,05
3	AREZZO	Grande	0,272	14,72	4131,90	261,37	0,06
4	ANCONA	del Plebiscito	0,100	25,18	4395,01	398,23	0,06
5	LUCCA	dell'Anfiteatro	0,442	13,98	3069,75	205,84	0,07
6	POTENZA	Duomo	0,378	10,10	818,01	134,62	0,08
7	BERGAMO	Vecchia	0,294	16,96	2447,49	221,60	0,08
8	LODI	della Vittoria	0,307	22,54	4795,44	289,36	0,08
9	VIGEVANO	Ducale	0,530	25,86	4894,29	327,87	0,08
10	FERMO	del Popolo	0,191	26,74	2785,36	327,45	0,08
11	BRINDISI	Duomo	0,571	15,99	1490,78	176,77	0,09
12	ROVIGO	Vittorio Emanuele	0,246	27,37	4322,50	291,25	0,09
13	NAPOLI	Plebiscito	0,459	66,19	25884,90	647,88	0,10
14	CATANZARO	Duomo	0,442	19,44	1581,71	187,23	0,10
15	ASCOLI PICENO	del Popolo	0,372	26,47	2920,10	253,28	0,10
16	REGGIO EMILIA	Duomo	0,591	28,99	4212,81	274,91	0,11
17	MASSA	Mercurio	0,625	21,71	2596,68	204,80	0,11
18	ANDRIA	Duomo	0,566	19,04	1632,71	176,15	0,11
19	AQUILA	Duomo	0,472	48,57	10781,00	448,31	0,11
20	IGLESIAS	Duomo	0,675	19,07	1038,30	170,32	0,11
21	ALESSANDRIA	Giovanni XXIII	0,416	24,00	2120,23	211,03	0,11
22	MACERATA	della Liberta	0,611	26,20	2609,93	220,74	0,12
23	TRENTO	Duomo	0,702	37,56	5244,35	312,13	0,12
24	VITERBO	del Plebiscito	0,713	28,23	2740,86	218,94	0,13
25	PALERMO	Pretoria	0,672	32,57	3706,21	244,97	0,13
26	CARPI	dei Martiri	0,267	85,29	15630,60	641,40	0,13
27	FAENZA	del Popolo	0,965	75,04	7284,29	543,35	0,14
28	PESARO	del Popolo	0,689	39,46	4543,75	273,26	0,14
29	SASSARI	d'Italia	1,024	60,77	9986,32	400,07	0,15
30	GENOVA	delle Vigne	0,550	15,04	463,56	94,94	0,16
31	CROTONE	Duomo	0,589	27,56	1271,30	159,78	0,17
32	FORLI	Saffi	0,867	84,84	13145,20	491,50	0,17
33	ASTI	San Secondo	1,059	43,05	3098,48	231,26	0,19
34	AVELLINO	della Libertà	0,851	91,07	11663,80	475,58	0,19
35	TRIESTE	dell'Unità d'Italia	1,857	102,02	15086,10	522,97	0,20
36	PARMA	Duomo	0,921	46,08	2622,53	231,42	0,20
37	TERNI	della Repubblica	1,139	48,71	2921,09	240,14	0,20
38	CUNEO	Tancredi Galimberti	1,203	143,67	22335,20	630,79	0,23
39	LA SPEZIA	Cavour	1,421	117,40	11386,50	454,84	0,26
40	CALTANISSETTA	Garibaldi	1,870	76,99	2921,66	221,15	0,35
Mean value of λ_{AS_m} = 0,13 Standard deviation= 0.062							

For the LSs, the parameter $\sum\alpha_i$ is not adequate to feature the permeability. In fact, in the street it is difficult to materialize the concept of a central point from which to analyze the entrances as in a square. Furthermore, the parameter λ_{AS} is not suitable for estimating the permeability of LS because it is based on the calculation of AS samples. So that, it is introduced a new sample of 40 streets that belong to the same towns of the previous samples of AS. They have been measured from a starting point to the final point that correspond to the access of the square considered for the previous sample of the 40 squares.

Table 10: Ranking the 40 LS of the sample based on λ_{LS} values

	Town	name of the street	start point	endpoint	Total Length=Le [m]	ΣL_i [m]	λ_{LS} [-]
1	ALESSANDRIA	Via Parma	Giovanni XXIII	Corso Lamarmora	293	26,9	0,05
2	ANCONA	Via Ciriaco Pizzecolli	del Plebiscito	p. San Francesco	156,6	8,6	0,03
3	ANDRIA	Via Arcamone	Duomo	P. Pincerna	33,96	3,3	0,05
4	AQUILA	Via Vittorio Emanuele	Duomo	C.so Principe Umberto	208,1	28,12	0,07
5	AREZZO	Pescaia	Grande	Via Mazzini	110,2	3,7	0,02

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6	ASCOLI PICENO	C.so Giuseppe Mazzini	del Popolo	Via della Tribù Fabia	122,4	35,9	0,15
7	ASTI	Via G. Garibaldi	San Secondo	P. Vittorio Alfieri	129,5	15,55	0,06
8	AVELLINO	Via G. Nappi	della Libertà	P.za Amendola	141,9	10,11	0,04
9	BERGAMO	Via Gombito	Vecchia	P. Mercato delle scarpe	171,7	12,9	0,04
10	BRINDISI	Via G. Tarantini	Duomo	P. Dante	148	18	0,06
11	CALTANISSETTA	C.so Vittorio Emanuele II	Garibaldi	Via F. Crispi	210,6	18,7	0,04
12	CARPI	C.so Alberto Pio	dei Martiri	Via Aldrovandi	252,6	17	0,03
13	CATANZARO	Via Arcivescovado	Duomo	P. B. Grimaldi	134,3	13,7	0,05
14	CROTONE	Via Pitagora	Duomo	P. Albani	81,2	4,5	0,03
15	CUNEO	Via F.A. Bonelli	Tancredi Galimberti	C.so Giovanni XXIII	142	29,06	0,10
16	FAENZA	Via Garibaldi	del Popolo	P.za S. Francesco	229	21,7	0,05
17	FERMO	C.so Cefalonia	del Popolo	V. Bergamasca	206	14,5	0,04
18	FORLI	Via delle Torri	Saffi	P.za Cavour	156,3	19,04	0,06
19	GENOVA	Vico del Santo Sepolcro	delle Vigne	Via S. Luca	90,8	14	0,08
20	IGLESIAS	V- G. Mazzini	Duomo	Via Don Minzoni	76	4,3	0,03
21	LA SPEZIA	V. Dei Mille	Cavour	V.le G. Amendola	139	43,8	0,16
22	LODI	C.so Roma	della Vittoria	Via XX Settembre	208,5	17,35	0,04
23	LUCCA	P.za degli Scalpellini	dell'Anfiteatro	Via Fillungo	266,5	15,2	0,03
24	MACERATA	V. Don Minzoni	della Liberta	P. V.M. Strambi	180	18,8	0,05
25	MASSA	via Beatrice	Mercurio	P.za Martana	164,8	15,3	0,05
26	NAPOLI	Via Toledo	Plebiscito	Via Santa Brigida	165	34,6	0,10
27	NOVARA	V. Fratelli Rosselli	della Repubblica	P.za G. Matteorri	165	18,4	0,06
28	PALERMO	Via Maqueda	Pretoria	Via Calderai	114,5	21,3	0,09
29	PARMA	Via Borgo XX Marzo	Duomo	Strada della Repubblica	228,1	24,4	0,05
30	PESARO	Via Gioacchino Rossini	del Popolo	L.go Aldo Moro	244,3	28,35	0,06
31	POTENZA	Via V. Scafarelli	Duomo	Via Vescovado	101,5	9,9	0,05
32	REGGIO EMILIA	V. Luigi Carlo Farini	Camillo Prampolini	P. Luigi Roveresi	185,9	13,75	0,04
33	ROVIGO	Via C.B. conte di Cavour	Vittorio Emanuele	P. Umberto Merlin	125,5	6,62	0,03
34	SASSARI	Via Carlo Alberto	d'Italia	Emiciclo G. Garibaldi	205,5	44	0,11
35	SIENA	Casato di sotto	del Campo	Costa larga	208,1	15,7	0,04
36	TERNI	Via Cornelio Tacito	della Repubblica	C.so B. Faustini	273	63,1	0,12
37	TRENTO	Via Rodolfo Belenzani	Duomo	Via Roma	215,3	4,6	0,01
38	TRIESTE	Via Armando Diaz	dell'Unità d'Italia	Via Armando Diaz	216	38,9	0,09
39	VIGEVANO	C.so Vittorio Emauele	Ducale	Via G. Merula	171	30,1	0,09
40	VITERBO	Via San Lorenzo	del Plebiscito	P.za del Gesù	139,4	14,7	0,05
Mean value of λ_{LS_m} = 0.059 Standard deviation= 0.034							

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7.4 Definition of BET models for real case studies

Caldarola (Piazza Vittorio Emanuele II)

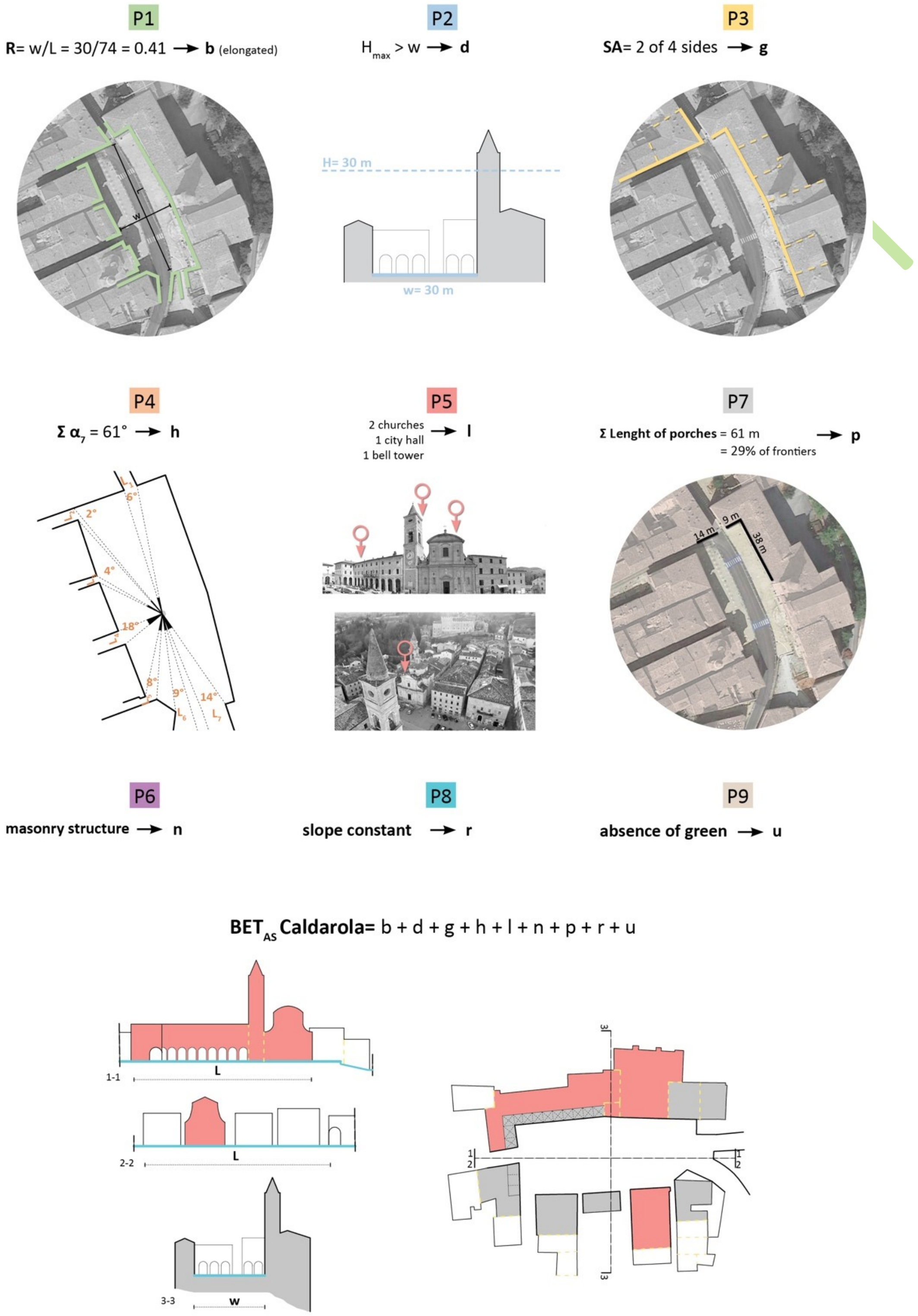

Figure 17: Representation of the BET corresponding to the AS of Caldarola

San Gemini (Piazza San Francesco)

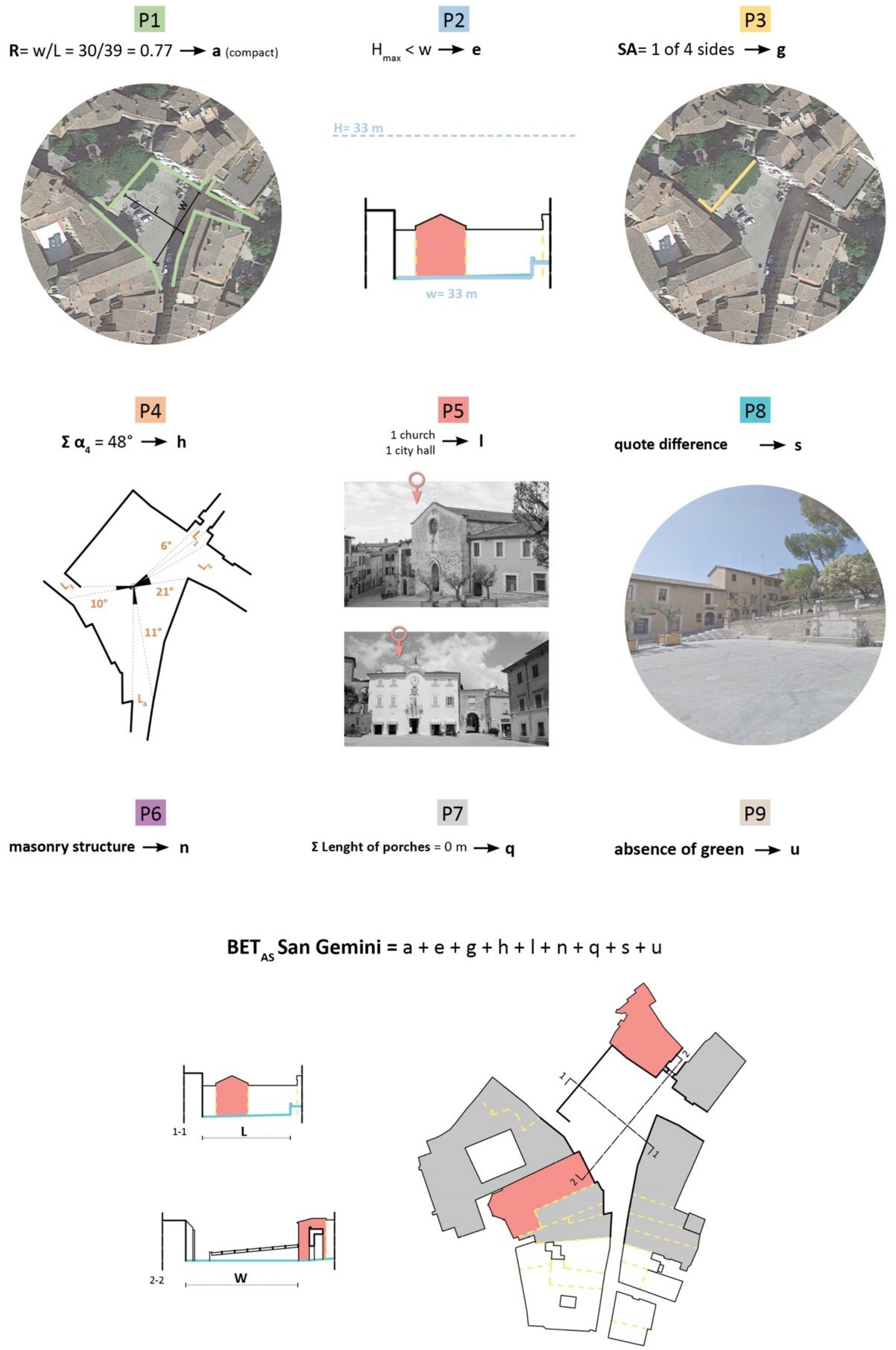

Figure 18: Representation of the BET corresponding to the AS of San Gemini

San Giovanni in Persiceto (Piazza del Popolo)

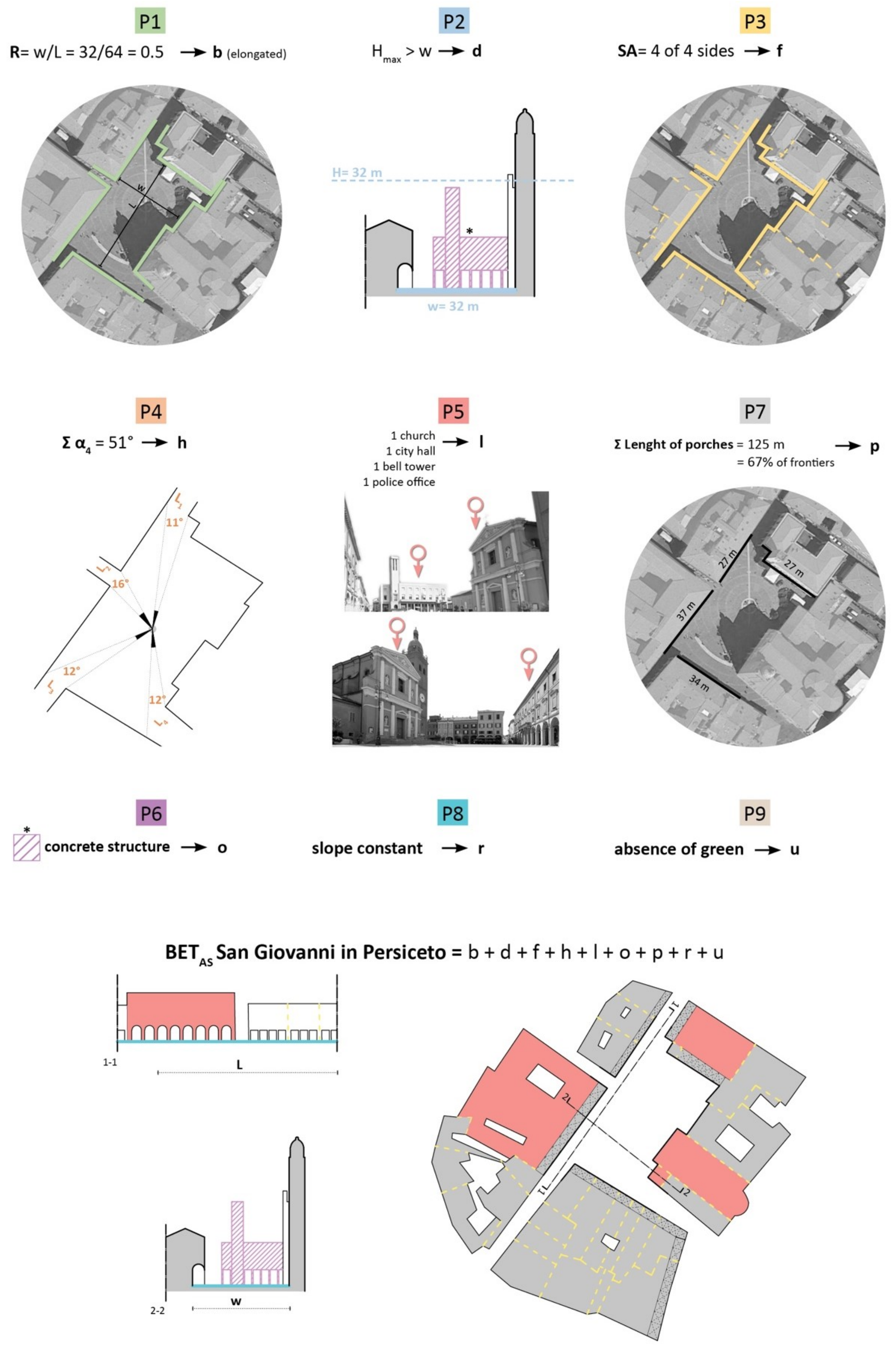

Figure 19: Representation of the BET corresponding to the AS of San Giovanni in Persiceto

Milano – Città Studi – Via Zanoia

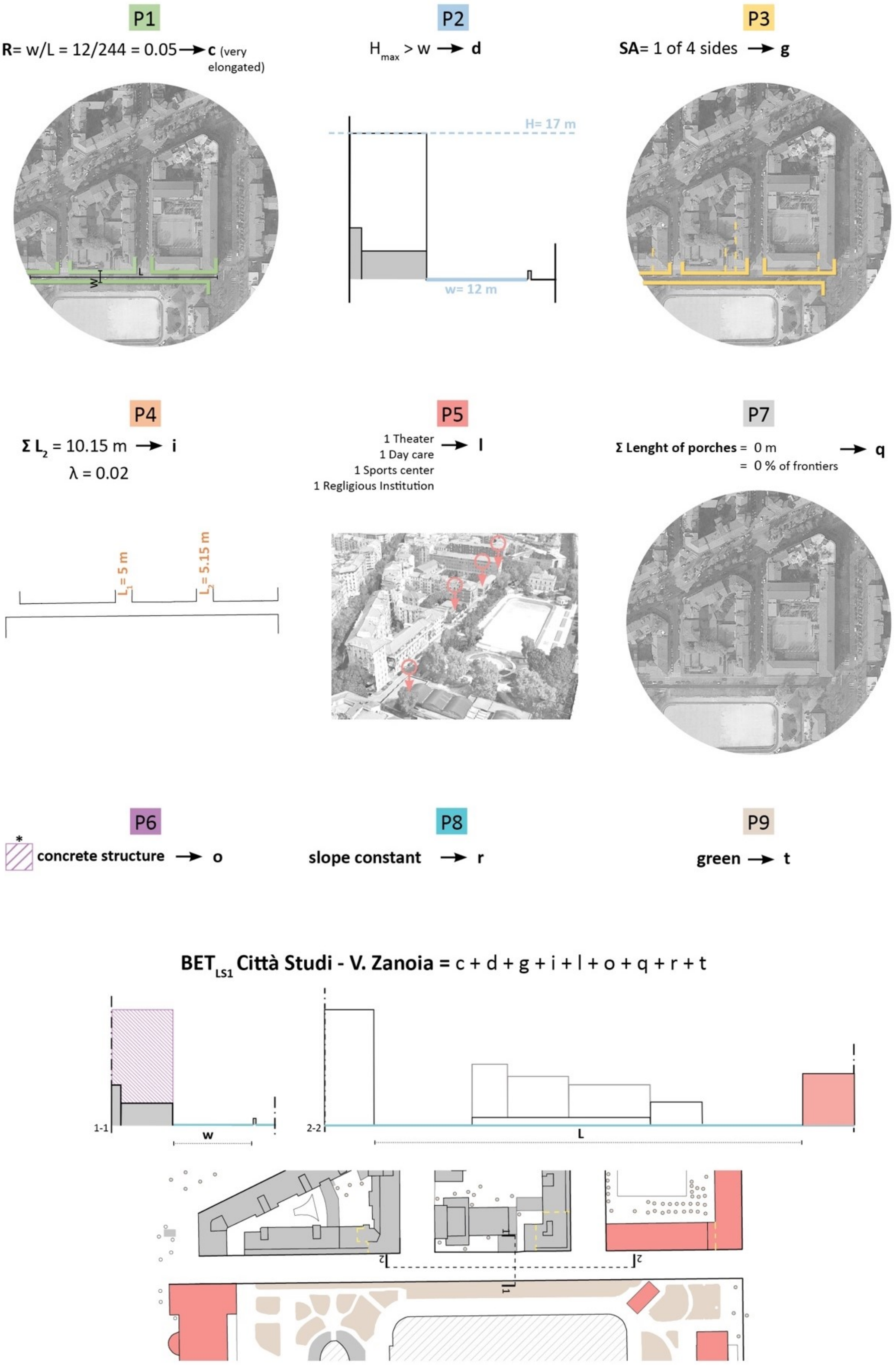

Figure 20: Representation of the BET corresponding to the LS_1 of Milano – Via Zanoia

Milano – Città Studi – Via Fratelli Fossati

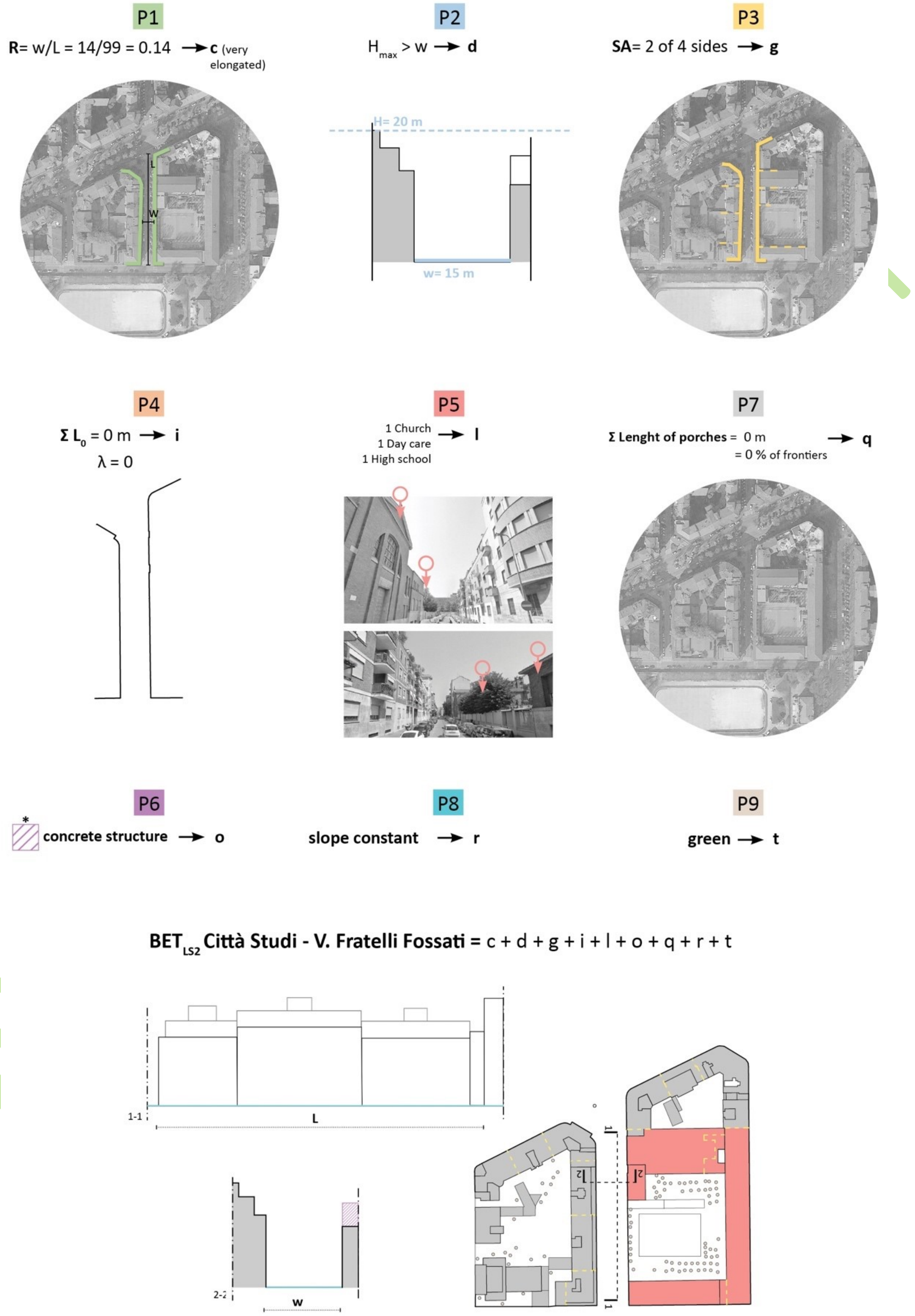

Figure 21: Representation of the BET corresponding to the LS_2 of Milano – Via F.lli Fossati

Milano – Città Studi – Via Giuseppe Ponzio

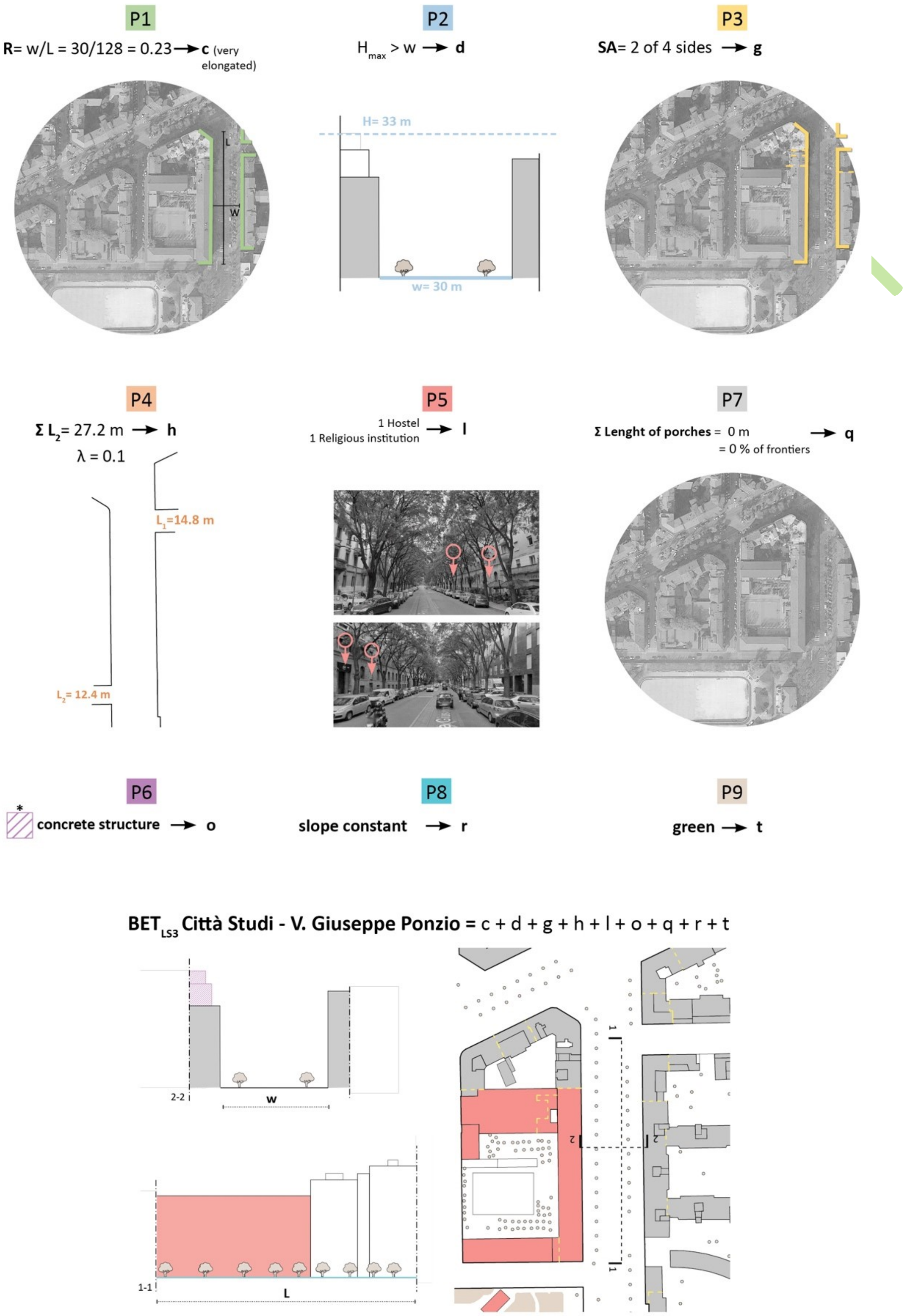

Figure 22: Representation of the BET corresponding to the LS_3 of Milano – Via G. Ponzio

Milano – Città Studi – Via Giovanni Pacini

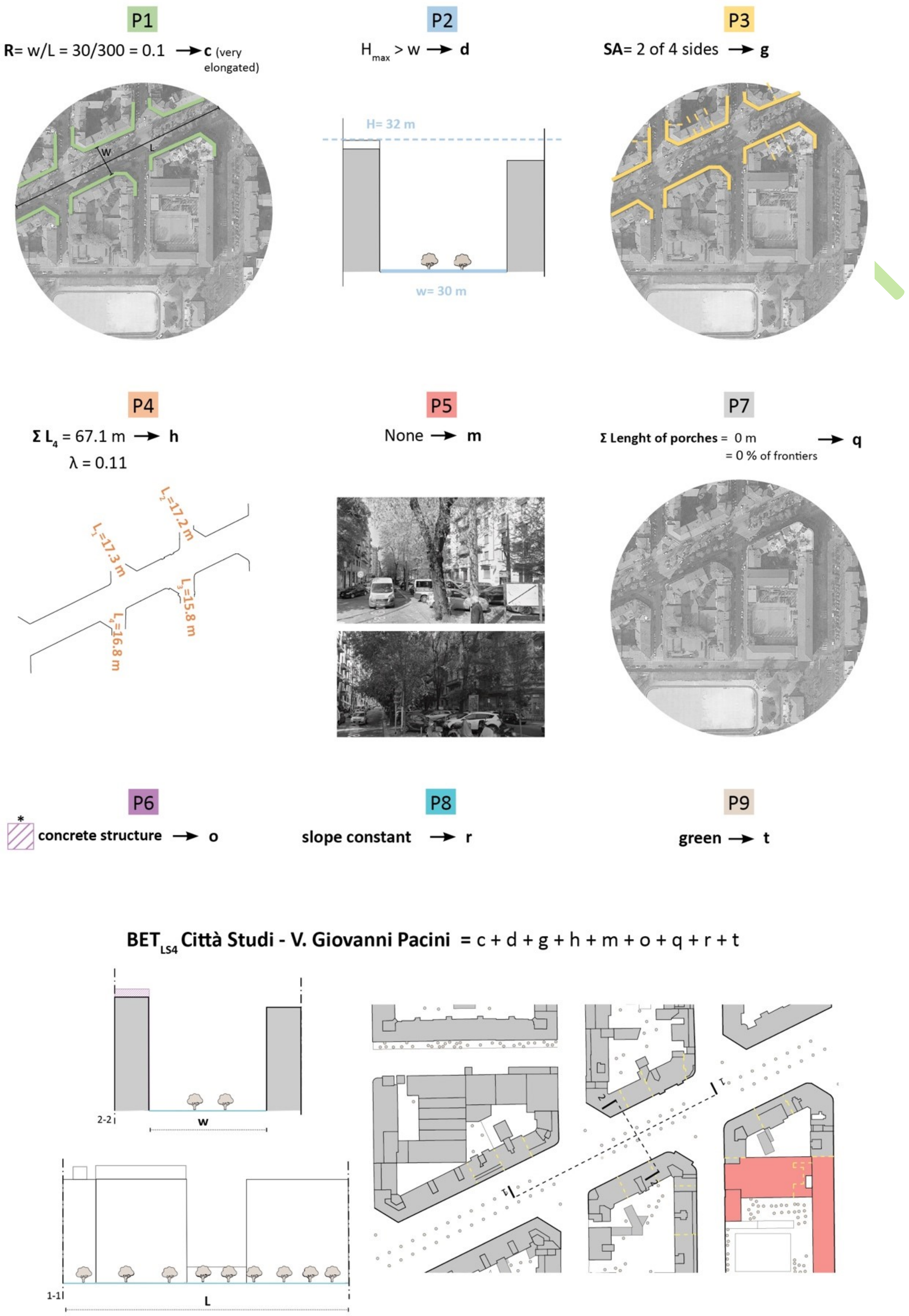

Figure 23: Representation of the BET corresponding to the LS_4 of Milano – Via G. Pacini