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

T3.3 - Selection and survey of significant real-World case studies. Scan to BIM and implementation of risk parameters to set scenarios for VR. Case studies VR/AR representation. Users' exposure data collection.

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Abstract

After the identification of the nine BETs (D3.2.1), the case studies samples have been selected, categorized, and characterized according to BE type, BE taxonomy and possible multi-hazard scenarios (D3.2.1 and D3.2.2). The results of D3.1.2 and D3.1.3 supported the setting up of BIM models, integrated surveys, and preparatory activities to create multi-hazard scenarios to be adopted in Virtual Reality. In particular, the approach has been tested on the case study of Narni, in Italy, affected by earthquake and air pollution. Firstly, the Open Space of Piazza dei Priori has been surveyed with laser scanning and photogrammetry providing an accurate point cloud, used to generate a BIM model of the content and the frontiers. Successively, BE parameters identified in D3.2.2 have been inserted in this information three-dimensional model to be available for risk assessment procedures and risk mapping. In parallel, the study proposes to structure the parameters' list according to GIS and BIM data models requirements. The digital reconstruction of the BE in GIS and BIM and the risk assessment outcomes, including evacuation simulation, are investigated, and selected as training material to be inserted in the Virtual Environment (VE) based on Virtual Tour of the case study. The VR-centric workflow could enhance pervasive training with the aim of enhancing preparedness and awareness of BE vulnerability and safe behaviour thanks to web-based applications.

Keywords

Multi-risk scenario, BIM models, VR/AR models, real-word case studies.

Approvals

Role	Name	Partner	Date
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Summary

1. Introduction and research aim

Following the structure of the Be2Secure research project, the Work Package 3 aims to provide representative models of Built Environment Typologies (BETs) prone to SUOD/ SLOD (Russo et al. 2020; Angelosanti et al. 2022). In particular, Task 3 selects and studies significant real-World case studies using digital BE models obtained from Scan-to-BIM process. Based on that, Task 3 implement risk parameters to set scenarios for VR case studies with users' exposure data collection. In view of above, this deliverable set up a workflow to use the BIM-based models for a specific BET case study representation to collect the information for BETs classification and analysis. Moreover, the herein work has been developed to evaluate BIM potential as repository of information on the BE useful for the specific needs of the next phases of this research project. All by taking into account primarily the information exchange needs among BIM models and simulation software, towards the aims of WP4 - BETs' simulations with human behaviour representation. This deliverable puts together the topics dealt with in the previous Project Deliverables and specifically in Task 3, for which we include a direct reference, as follows:

- Risk and BE with multi-hazard scenarios (D3.2.2);
- Digitisation of BIM and GIS scenarios (D3.1.2);
- Scenario visualisation and training with VR (D3.1.3);

In this deliverable, the authors develop a workflow for the generation of BET's (Built Environment Typologies) case studies in BIM environment, starting from the results obtained in D312 in which the bases for BET digital models' construction are set, and literature, codes and standards about BIM geometry and metadata description are introduced. Therefore, the process of BETs' case study representation in BIM deals with geometric modelling and informative deepening of BET-dependant reduced risk parameters matrix from D322, notably BET 2A and S-P multi-hazard condition for the presented case study: piazza dei Priori, Narni. Interoperability issues are the core of the study as the BET case study model is meant to be the multi-risk scenario for BE risk assessment through VR/AR and behavioural design simulations. For this reason, a common ground between BIM and GIS logic (2D and 3D) is identified to define and verify an innovative approach that aims at the geometric and informative digitisation of BE, which is consistent with the meso-scale defined by the OS.

2. Materials and methods

2.1 Significant case studies and final selection for BIM and VR/AR model: Piazza dei Priori, Narni

In order to select and present meaningful case studies associated with the BET classification proposed in D321, two main approaches have been proposed:

A. OSs selected from the database used for the D321 (Capital of Province), already classified in BET, that includes both OSs whose multi-hazard potential (D322) and exposure (D323) has been already evaluated (see D322 and D323) and a selection of OSs whose characteristics totally match the definition of the BET associated (Table 1);

B. other Italian OSs of interest (Capital of Province and not), whose multi-hazard potential, exposure and BET classification should be evaluated (the latter through the calculation of the parameters proposed in D321, §2.2) (Table 2);

As illustrated in D321 (§3.4), in some cases the count of the number of accesses and special buildings are subject to errors due to gaps in the GIS database. In order to report the correct data for the selected OSs in the following Table 1, the values of the number of accesses (# access and P4) and the special buildings (P5) have been checked and if necessary corrected. The values of the parameters for the OSs of group B (Table 2) were calculated as illustrated in D321 (§2.2). To associate each OS with the corresponding BET, priority was given to the matching of the most characterizing parameters.

Since the peculiar procedures of the cluster analysis proposed in D321, OSs grouped in the same cluster could not share the same characteristics. Not all the parameters match the values of the associated BET, as described in §3.3.4 of D321. The differences among BET definition and the characteristic of the associated BET are reported in the column "variation". The parameter P4 shows the most frequent variations. Differences in the number of special buildings (P5) are no reported, since in most cases the number of special buildings present was greater than one. Both OSs with and without problems of the overturning of the fronts (P2) were considered in the selection of Table 1 since this feature represents a significant aspect of the seismic risk. Moreover, both OSs with and without critical ratio between the number of accesses/perimeter (P4) were included since this parameter needs a deeper evaluation of the width of the accesses. Table 3 shows the final selection of case studies among those reported in Table 1 and Table 2**Errore. L'origine riferimento non è stata trovata.**. Three case studies are considered for each type of BET to represent the three most probable multi-hazard potential. The OSs in the final selection were chosen following two criteria: (i) similarity with the BET definition and (ii) MH potential associated.

Table 1: OSs of Capital of Province (A1); the values of the parameters and the resulting BET classification are based on GIS extraction and cluster analysis proposed in D321.

Name	Town	P1	P2	P4	# acc.	P5	P8	P9	BET	Variations						M-Hazard	Exposure
Cluster 1										P1	P2	P4	P5	P8	P9		
Piazza del Popolo	Ascoli Piceno	0,314	1,19	0,030	8	2	7,50	0,00	1A		x	x				S-H	x
Piazza Grande	Arezzo	0,478	0,48	0,012	4	3	11,80	0,00	1A							S-P	x
Piazza Garibaldi	Caltanissetta	0,268	0,87	0,020	7	3	6,10	0,00	1A							H	x
Piazza del Duomo	L'Aquila	0,370	0,35	0,021	13	2	7,20	0,00	1A			x				S	x
Piazza della Libertà	Macerata	0,385	1,29	0,009	5	3	9,20	0,00	1A		x					S-T-H	
Piazza Vittorio Veneto	Matera	0,218	0,37	0,015	8	3	11,00	0,00	1A	x						S-H	
Piazza Duomo	Messina	0,349	0,72	0,014	8	2	6,30	0,00	1A							S-H	x
Piazza Cesare Battisti	Rieti	0,144	1,48	0,010	5	2	10,20	0,00	1A	x	x					S	
Piazza Alfano I	Salerno	0,082	1,40	0,019	5	1	14,10	0,00	1A	x	x					S-P	
Piazza dei Signori	Verona	0,284	1,00	0,039	7	4	10,20	0,00	1A		x	x				S-T-H-P	x
Piazza del Plebiscito	Viterbo	0,413	0,99	0,023	5	2	6,20	0,00	1A			x				S-T	x
Piazza del Palazzo	L'Aquila	0,370	0,95	0,031	7	0	5,40	5,00	1B			x				S	
Piazza Biordo Michelotti	Perugia	0,380	0,98	0,027	4	0	9,60	0,00	1B			x				S-T	
Piazza Della Repubblica	Perugia	0,370	0,74	0,034	6	0	8,30	0,00	1B			x				S-T	
Piazza dei Campani	Roma	0,390	0,90	0,040	5	0	7,80	0,00	1B			x				S-T-H-P	
Piazza di Ovile	Siena	0,420	0,41	0,030	4	0	8,30	20,00	1B			x				S-P	
Piazza Vittorio Veneto	Torino	0,310	0,22	0,012	10	0	5,70	0,00	1B							S-T-H-P	
Cluster 2										P1	P2	P4	P5	P8	P9		
Piazza del plebiscito	Ancona	0,118	1,30	0,021	8	4	19,50	0,00	2A		x	x		x		S-H	x
Piazza Duomo	Brindisi	0,379	0,83	0,011	5	4	3,10	14,00	2A	x				x		P	x
Piazza San Giustino	Chieti	0,276	1,27	0,012	5	2	4,10	0,00	2A	x	x			x		S	x
Piazza del Duomo	Firenze	0,091	1,83	0,009	10	6	1,20	0,00	2A		x					S-T-H-P	
Piazza della vittoria	Gorizia	0,157	0,33	0,016	6	3	1,70	0,00	2A							S-H	x
Piazza Duomo	Lecce	0,418	1,43	0,004	1	2	0,80	0,00	2A	x	x					H	
Piazza del Duomo	Milano	0,322	0,60	0,012	14	5	2,20	0,00	2A	x						S-T-H-P	x
Piazza Eleonora d'Arborea	Oristano	0,081	0,64	0,006	7	2	1,90	0,00	2A							-	
Piazza IV Novembre	Perugia	0,312	1,01	0,014	5	3	5,10	0,00	2A	x	x			x		S-T	
Piazza dei Cavalieri	Pisa	0,333	0,33	0,020	6	6	0,80	0,00	2A	x		x				S-P	x

Piazza Cavour	Rimini	0,246	0,66	0,020	9	3	1,80	0,00	2A			x				S-P	x
Piazza Navona	Roma	0,192	0,59	0,013	7	4	4,50	0,00	2A					x		S-T-H-P	x
Piazza Minerva	Siracusa	0,128	1,15	0,004	4	2	2,10	0,00	2A		x					S-H	x
Piazza Santa Maria	Lucca	0,100	0,35	0,008	5	0	1,00	11,00	2B							S-P	
Piazzale Monferrato	Mantova	0,070	0,59	0,009	5	0	0,50	0,00	2B							S-P	
Piazza Fratelli Bandiera	Milano	0,250	0,84	0,023	4	0	0,10	25,00	2B	x		x				S-T-H-P	
Piazzale Degli Erri	Modena	0,220	0,97	0,023	3	0	0,10	0,00	2B			x				S-T-P	
Piazza San G. Decollato	Palermo	0,220	0,83	0,024	4	0	2,90	0,00	2B			x				S-T-H-P	
Piazza della Rinascita	Pescara	0,350	0,53	0,002	5	0	0,90	0,00	2B	x						S-P	x
Piazza Emanuele Pancali	Siracusa	0,170	0,37	0,017	7	0	2,20	20,00	2B							S-H	
Cluster 3										**P1**	**P2**	**P4**	**P5**	**P8**	**P9**		
Piazza Maggiore	Bologna	0,501	0,61	0,024	9	3	2,00	0,00	3			x				S-H	x
Piazza della Repubblica	Firenze	0,650	0,36	0,018	6	0	0,50	0,00	3							S-T-H-P	
Piazza Cavour	La Spezia	0,433	0,43	0,005	9	1	1,10	0,00	3	x						S	x
Piazza Giuseppe Mazzini	Lecce	0,650	0,30	0,017	9	0	1,60	20,00	3							H	
Piazza Anfiteatro	Lucca	0,522	0,30	0,020	4	0	0,50	0,00	3			x				S-P	x
Piazza Risorgimento	Milano	0,580	0,33	0,015	7	0	1,20	25,00	3							S-T-H-P	
Piazza Pretoria	Palermo	0,506	0,76	0,008	5	3	2,30	0,00	3							S-T-H	x
Piazza Camillo Prampolini	Reggio Emilia	0,396	0,72	0,030	8	4	1,10	0,00	3	x		x				S-P	x
Piazza Sisto IV	Savona	0,538	0,70	0,006	6	2	0,80	16,00	3							S	x
Piazza Sant'Anna	Teramo	0,386	0,56	0,006	5	0	1,50	0,00	3	x						S	x
Piazza San Vittore	Varese	0,599	0,68	0,042	5	1	0,80	1,14	3				x			T-H-P	x
Piazza Cavour	Vercelli	0,490	0,46	0,027	8	0	0,80	0,00	3	x		x				P	x
Cluster 4										**P1**	**P2**	**P4**	**P5**	**P8**	**P9**		
Piazza Giordano Bruno	Perugia	0,370	1,01	0,037	5	2	4,70	0,00	4A					x		S-T	
Piazza del Comune	Prato	0,308	1,14	0,022	4	4	0,90	0,00	4A							S-P	x
Campo Sant'Aponal	Venezia	0,470	1,75	0,083	8	1	0,20	0,00	4A							S-T-H-P	
Piazza Mensini	Grosseto	0,450	1,34	0,099	6	1	1,00	0,00	4B							P	
Piazza XX Settembre	Pisa	0,470	1,84	0,048	5	2	1,20	0,00	4B							S-P	
Piazza della Pigna	Roma	0,380	1,20	0,037	4	1	1,80	0,00	4B							S-T-H-P	
Piazza Ramiro Ginocchio	La Spezia	0,310	1,35	0,066	6	0	2,20	0,00	4C							S	
Piazza Lancellotti	Roma	0,370	1,17	0,034	4	0	1,60	0,00	4C							S-T-H-P	

Name	Town	P1	P2	P4	# acc.	P5	P8	P9	BET	Variation P1	Variation P2	Variation P4	Variation P5	Variation P8	Variation P9	M-Hazard	Exposure
Piazza Lucatelli	Trapani	0,516	0,75	0,054	6	0	0,50	0,00	4C	x		x				S-H	x
Cluster 5										**P1**	**P2**	**P4**	**P5**	**P8**	**P9**		
Piazza Vecchia	Bergamo	0,391	1,39	0,025	6	4	6,60	30,00	5		x	x	x	x		S-P	x
Piazza Duomo	Caserta	0,138	1,62	0,028	5	2	1,30	34,00	5	x	x	x	x			S-T-P	x
Piazza dell'Università	Catania	0,638	0,35	0,022	6	2	1,40	38,00	5	x		x	x			S-H	x
Piazza Cavour	Como	0,340	0,41	0,014	6	0	1,80	35,00	5							P	
Piazza Emilia	Milano	0,410	0,52	0,011	4	0	0,50	32,00	5							S-T-H-P	
Piazza della Radio	Roma	0,480	0,32	0,008	4	0	2,00	50,00	5							S-T-H-P	

Table 2: other OSs of interest, Capital of Province and not (B); the values of the parameters and the BET classification are based on parameters calculation illustrated in D321.

Name	Town	P1	P2	P4	# acc.	P5	P8	P9	BET	Variation						M-Hazard	Exposure
Cluster 1										**P1**	**P2**	**P4**	**P5**	**P8**	**P9**		
Piazza San Francesco	San Gemini (TR)	0,308	0,48	0,024	4	2	5,00	0,01	1A			x				S	
Piazza del Popolo	S.G. Persiceto (BO)	0,409	0,72	0,021	4	3	0,00	0,00	1A			x		x		S-T	x
Piazza Conciliazione	Mirandola (MO)	0,467	0,63	0,028	5	5	0,00	0,00	1A			x		x		S-T	
Piazza V. Emanuele II	Caldarola (MC)	0,335	0,74	0,034	7	2	0,00	0,00	1A			x		x		S-T-H	x
Cluster 2																	
Piazza V. Emanuele II	Rieti (RI)	0,202	1,04	0,018	5	2	3,10	0,00	2A		x			x		S	
Piazza dei Priori	Narni (TR)	0,068	2,01	0,018	5	3	1,50	0,00	2A		x					S-P	x
Piazza delle erbe	Padova	0,162	0,52	0,017	7	3	1,50	0,00	2A							T-H-P	
Piazza San Marco	Venezia	0,181	1,26	0,014	10	3	0,40	0,00	2A		x					T-H-P	
Cluster 4																	
Piazza dell'Odegitria	Bari	0,222		0,036	7	2	2,00	0.00	4B	x						T-H-P	
Cluster 5																	
Piazza Umberto I	Bari	0,630	0,18	0,018	11	1	0,00	30,00	5	x			x			S-H-P	

Table 3: Final selection of case studies and their correlation with BET classification and most probable multi-Hazard potential.

	S-P	S-H	T-H-P
1A	Piazza Grande, Arezzo	Piazza Duomo, Messina	Piazza dei signori, Verona
1B	Piazza di Ovile, Siena	Piazza Vittorio Veneto, Torino	Piazza Vittorio Veneto, Torino
2A	Piazza dei Priori, Narni (TR)	Piazza della vittoria, Gorizia	Piazza delle erbe, Padova
2B	Piazza della rinascita, Pescara	Piazza Fratelli Bandiera, Milano	Piazza Fratelli Bandiera, Milano
3	Piazza Anfiteatro, Lucca	Piazza Maggiore, Bologna	Piazza San Vittore, Varese
4A	Piazza del comune, Prato	Campo Sant'Aponal, Venezia	Campo Sant'Aponal, Venezia
4B	Piazza XX settembre, Pisa	Piazza della pigna, Roma	Piazza dell'Odegitria
4C	Piazza Lancellotti, Roma	Piazza Lucatelli, Trapani	Piazza Lancellotti, Roma
5	Piazza Umberto I, Bari	Piazza Umberto I, Bari	Piazza Emilia, Milano

The criteria that led to the selection of the case study are related to the type of experimentation proposed in this deliverable. Since the goal is to set up and evaluate a methodology for modeling a case study in a BIM environment, the selection should encompass a case that presents complexities to be tested in the BIM environment and have a proper correspondence to the characteristics of the associated BET. In this sense, factors of interest include:

- low level of compactness and regularity of the morphology. Choosing a case belonging to Cluster 2 allows testing more complex modeling in terms of the geometry of the space.
- presence of special buildings. Choosing a case belonging to the subcategories 1A, 1B, 4A, and 4B allows testing a further degree of complexity of the model in terms of the implementation of information about exposure and crowding potential.
- the coexistence of at least two hazards belonging to different categories (SLOD and SWOD), in particular with the combinations S-P, S-H, or T-P-H.

For these reasons, the selected case study has been Piazza dei Priori in Narni (TR), which presents a low level of compactness and regularity of the morphology, three special buildings, and the multi-hazard potential (seismic and pollution). Furthermore, this case study also allows evaluating the implementation of the parameters relating to the overturning of the fronts, having Hmax greater than the width (i.e., the tower).

2.2 BIM modelling strategies based on scan-to-BIM process

2.2.1 Case study rapid point cloud-based survey

The expeditious survey of the BE defined the modelling strategy steps (D312 §2). Notably, the architectural survey is a necessarily critical operation, therefore the most appropriate instrumentation has been chosen according to the geometric-morphological needs of the selected case study. A photogrammetric and a Terrestrial Laser Scanner (TLS) survey were carried out, in order to make the methodology replicable with both instruments and obtain a point cloud for the Scan-to-BIM process (Currà et al. 2021) (D312 §2).

The photogrammetric survey was performed with mirrorless full frame Sony A7. Moreover, the use of a UAV DJI Spark has allowed to reach the upper floors and to document the roofs. The shooting methodology has considered consolidated principles [5] and the following specifications have been used:

1. Sony FE 28-70mm f / 3.5-5.6 lens, used fixed at 28mm, with a horizontal angle of view of 75.4° and a vertical one of 34.4°;
2. RAW shooting format with export to TIFF, arranging the exposure, the shadows and the lights;
3. ISO 50 to reduce sensor noise, keeping the dynamic range as high as possible;
4. Diaphragm opening f / 8.0 in order to guarantee the best resolution, in lines / mm;
5. Manual focus at hyperfocal distance, so that the depth of field is fixed;
6. Automatic shooting time to assure uniform exposure for all photographs avoiding blurred pictures;

7. Manual white balance at 4800k in order to guarantee uniform colour to all photographs, both for Mirrorless and UAV;

A horizontal overlap of 80% and a vertical one of 60% has been guaranteed during the acquisition of vertical and oblique photos of e.g., all the built fronts, the paving, the urban furniture. 561 photos have been acquired by an operator in a single day and the whole acquisition time has been 1 h and 20 minutes.

As mentioned above, the survey of the case study was also carried out with the use of the TLS. As for photogrammetry, priority was given to both accuracy and speed of survey operations. Nine scans were acquired at each access to the square, in the centre of the square and under the covered areas e.g., porches and canopies. The TLS was set to acquire only the reflectance of the surveyed objects, without recording their colours. This allowed for a faster process that took 5 minutes per scan (including moving the TLS to the next position) for a total of 45 minutes in a single day.

2.2.2 BIM modelling strategies

Geometric and informative modelling of the Scan-to-BIM process is herein based on dual compatibility with the BIM and GIS environments, as well as OS LOD definition in (D312 §4.1). Specifically, the BIM model developed in this deliverable is GIS compliant for two main reasons:

1. The BIM model is able to dialogue with geospatial data (i.e., OSM data) both in input and output. Indeed, the BIM reference system is corresponding with the reference cartographic system because both digital photogrammetry and TLS point clouds were geolocated in cartographic system RDN2008 / Zone 12 (N-E) (Identifier 6876) (Istituto Geografico Militare (IGM) Direzione Geodetica 2019).
2. Both the geometric entities and the list of parameters were arranged according to 2D-GIS logic and systematic modelling in BIM was then performed to allow a streamlined data transfer back to GIS as an output of the workflow.

Therefore, elements and parameters suitable for easy bi-directional conversion between 2D and 3D level (i.e. based on point, line and surface) have been chosen (D'Amico et al. 2021). As a first step, a division in High Level (HL) and Low Level (LL) elements has been made, identifying in the former the main synthetic elements that best represent the meso-scale of the OSs in the BE and that can allow an easy dialogue between GIS and BIM being a repository that hierarchically inherit and store the OS content and frontier information. Notably, the HL elements are the OS itself, the Interferent Structural Unit (SU_i) and the Interferent Structural Aggregate (SA_i), while the LL elements are all HL element components (e.g., wall, roofs, windows, paving, topography, road, parking, urban furniture).

A SU represents a detached building and can be distinguished from other adjacent SUs by different typological and morphological characteristics. Distinctive attributes and factors such as height, planimetric and volumetric layout, size and distribution of openings, age of construction, state of preservation can help to identify them (Italian technical commission for seismic micro-zoning 2014). A SU is considered interfering when its maximum height is greater than the distance between the base of the SU at the point at which H is measured and the perimeter of the OS.

A not necessarily homogeneous set of SUs, structurally interconnected in their evolutionary history so that they may interact under seismic or dynamic action, compose a SA (Structural Aggregate). The identification of the structural aggregate can be performed starting from the identification of the city block, i.e., the basic portion of a building fabric delimited by OSs. Once the block has been identified, it is necessary to verify that the USs into which a SA is subdivided are mutually interconnected from a structural point of view. A SA may be composed of SUs of different types and morphology, homogeneous or inhomogeneous from a construction, temporal, functional point of view (DPC-Reluis 2010; Italian technical commission for seismic micro-zoning 2014). A SA is considered to be interfering with the OS if it contains at least one SU_i.

Nevertheless, studying SAs as a whole is a rather complex and time-consuming operation (Valente et al. 2019). Moreover, the SU_is composing an AS interfering with the OS being studied are often a small percentage of the total SUs due to the complexity of the historical BE (REF), as demonstrated by the application to the case study selected in this deliverable. In addition, the results of structural analyses on BE performed starting from BIM modelling have highlighted that for complex structures composed of mutually interacting SUs, the seismic assessment should be performed at the scale of the building units, taking into account the effect of the adjacent masonry structures (Ponte et al. 2019). For the reasons listed above, translating the concept of LL and HL elements into LL and HL BIM families, specifically for HL families the geometric representation of SUs rather than SAs has been chosen. In this way, SAs are described by several adjacent SUs, taking into account the relationships among them.

Hence, the model elements associated with risk factors are selected based on a BE schematization for its BIM digitalization in the BIM authoring software Autodesk Revit, updating the D312 (§4.2) and D322 (§7) proposal.

Specifically, the HL families are:

- **Space**: OS delimited by walls and Linear Spaces (LSs) corresponding to access between two or more US_i;
- **Generic Models (GM)**: SU_i composing the frontier of the OS. GM family name is corresponding with US_i Xy, where X is the SA number ans y is a letter that specifies a specific SU in the SA.

And the LL families are:

- **Wall**: frontiers walls composed by different SUs_i, specifying e.g., the core material, finishes; windows and doors are hosted by walls;
- **Floor**: floor with different material (i.e., grass) of the AS/LS. Floor elements do not include the nearby OS (other LS or AS). Three different types of floors can be included in the model: uncovered (e.g., the square), covered and balcony;
- **Roof**: Four different types of SUs_i roofs can be included in the model: n/d, Flat (F), Non-Pushing (NP), Slightly Pushing (SP), Pushing (P)
- **Road:** Access family corresponding to access between two or more US_i;
- **Window and door:** openings in the OS frontiers without including decorative elements (e.g., cornices, mouldings);
- **Furniture**: Urban furniture modelled representing the footprint of e.g., fixed and temporary obstacles, monuments, fountains;
- **Parking**: parking lots in the OS.

Moreover, Table 4 shows the hierarchical relationship between LL and HL families for what concerns geometric and informative BE representation for interoperability between BIM and GIS environment.

Table 4: Hierarchical relationship between LL and HL families

Low Level (LL) family	**→**	**High Level (HL) family**	**BE represented for interoperability**
[specific component properties]	**→**	***[global + inherited LL family's properties]***	
Wall, floor, topography, road, parking, furniture	→	Space	OS
Wall, floor, roof, window, door	→	Generic Models (GM)	US_i

By addressing the meso-scale of OSs in BE, the analogy between Mandolesi's sub-building systems and components proposed by (Currà et al. 2019, 2021) to describe the relationship between a BIM family and its components is shifted to the relationship between Mandolesi's building system and sub- systems to describe the relationship between SUs/OSs and their composing elements (Figure 1).

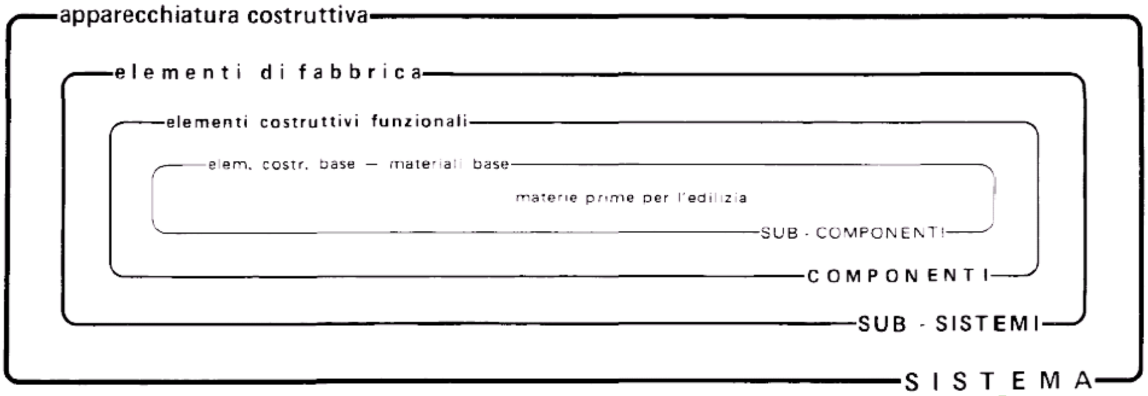


Figure 1: Building structure schematisation in (Mandolesi 1978)

To make the process replicable as much as possible, a step-by-step summary of the model implementation is herein presented:

1. **Setting** (Figure 2):
   1.1 Point cloud import;
   1.2 Definition of the OS frontiers through its identification in the point cloud;
   1.3 Setting of the buildings levels through its identification in the point cloud;
2. **Modelling**:
   2.1 OS facing SUs_i modelled through generic models from point cloud data integrating missing information with GIS/CAD sources;
   2.2 SUs_i walls by generic model face (“wall-by-face”), specifying e.g., core material (e.g., masonry, concrete, mix) and finishing (e.g., plaster);
   2.3 Toposurface of the OS, without considering the other nearby OS (e.g. LS);
   2.4 Subregion inside an existing toposurface with different paving material (if any; i.e., grass);
   2.5 Floor from toposurface modelled from the point-cloud data cleaned of e.g., walls, urban furnitures;
   2.6 Road family modelled as an extrusion along the main direction of the road for space delimitation;
   2.7 Porches floor modeled specifying the core material and finishing if possible;
   2.8 Roofs from generic models (previously modelled based on the point-cloud) face (“roof-by-face”);
   2.9 Windows modeled with metric window family;
   2.10 Doors modelled with metric door family, specifying if the element is open (without a frame) or not.
   2.11 OS automatic space generation by walls and LS delimitation. The height of the space should be equivalent to $H_{average}$;
   2.12 Parking family estrusion along a path;
   2.13 Urban furniture and obstacles modelled as vertical extrusion to represent the footprint of e.g., flowerpot, benches, lights, dehors, monuments, fountains.

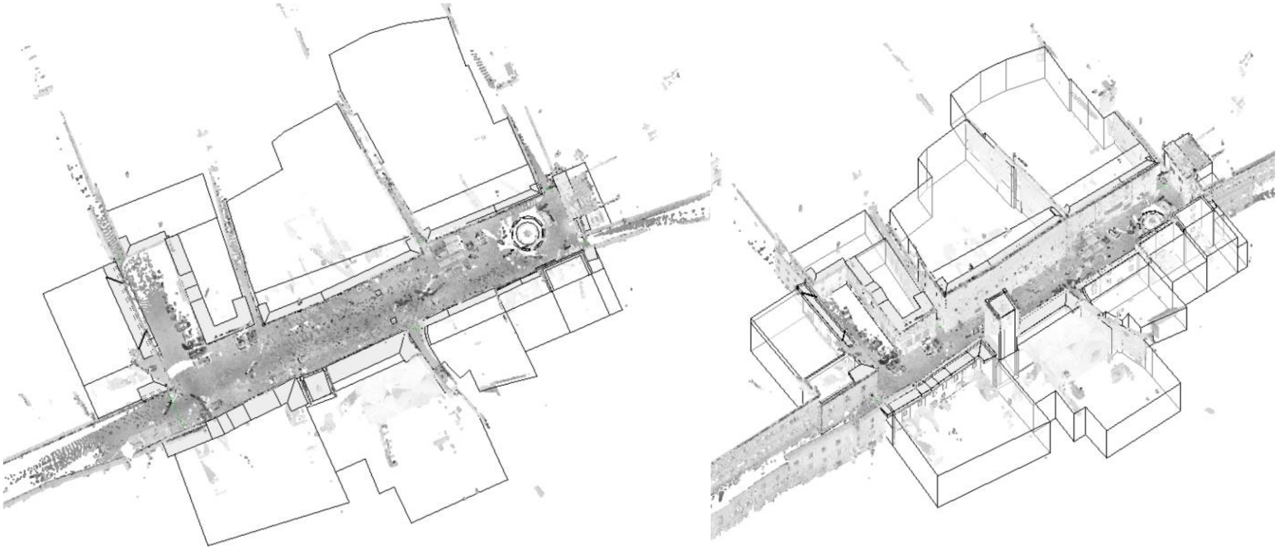


Figure 2: Setting of the OS frontiers and import of the point cloud.

2.3 Assessment of risk parameters in BIM process

2.3.1 Preliminary selection of risk parameters

The procedure of BIM modelling is followed by risk parameters implementation. Risk parameters were preliminary selected based on type of BET and multi-hazard combination associated with the case study in the reduced matrix type 2, elaborated in D322, §9, Table 33.

Moreover, each parameter in the reduced matrix was catalogued into two main categories, based on the method to implement them in BIM environment:

- **Fillable:** parameters that need to be filled by the users;
- **Computable**: parameters that can be computable through the software.

Furthermore, each parameter was associated to a family category, either HL or LL family, according to the three implementation categories in Table 5:

Table 5: Risk parameters implementation in BIM, divided in three main categories: (i) parameters to be filled directly in HL families; (ii) parameters to be filled in LL families and inherited by HL families with specific synthetic operations (direct transposition, average, sum, count minimum, maximum); (iii) parameters to be computed in HL families using geometric properties of LL families with specific synthetic operations (direct transposition, average, sum, count, minimum, maximum). The brackets mean that the family category is only used for its properties and the parameters is not associated to it.

	LL	→	HL	Computable	Fillable
i	/	→	×		×
ii	×	→	×		×
iii	(×)	→	×	×	

The first parameter implementation category includes global US/OS parameters that are fillable directly in HL families e.g., Proximity of sidewalk to traffic, last intervention period, state of conservation, crowding potential, Traffic intensity, Parking area location, presence of Sensitive target and all environmental characteristics parameters. The second parameter implementation category includes parameters to be filled in LL families and inherited by HL families with specific synthetic operations (direct transposition, average, sum, count, minimum, maximum). Examples of such parameters are presence parameters and all specific parameters, mainly coming from out of the BIM environment simulations and computations (e.g., state of conservation, wall disconnection in plan, wall disconnection in elevation, masonry quality, roof types, no-structural protruding and decorative elements, anti-seismic devices, Facade finishing current roughness, Facade pollutant deposition capacity, presence of special buildings or special uses, crowding potential), which require an association to individual elements in order to be read synthetically and inherited into the OS/US.

The last parameter implementation category includes parameters to be computed in HL families using geometric properties of LL families with specific synthetic operations (direct transposition, average, sum, count, minimum, maximum). The brackets mean that the family category is only used for its properties and the parameters is not associated to it.

All the aforementioned concepts about parametric implementation methods are summarised in Table 6:

Table 6: Reduced risk matrix from D322 for BET 2A and S-P multi-hazard condition. For each risk factor is specified the family category associated with, based on D312 (§4.2) and D322 (§7), according to the three main parameters implementation categories in Table 5;the method for the implementation (fill: parameters that need to be fill by the users; compute: parameters that can be compute by the software).

BET multi-hazard parameters				BIM implementation D331				
Code	**Description**	**Descriptor code**	**Descriptor**	**Family category (low level)**	**LL to HL**	**Family category (high level)**	**Comp.**	**Fill**
SECTION 1: MAIN TYPE								
S1_0	Morpho-typology	P1	Main class (compact/ elongated/very elongated)	(Floor)		Space	X	
		S1_0.2	Canyon aspect ratio	(Wall; floor)		Space	X	
		S1_0.3	Proximity of sidewalk to traffic			Space		X
S1_1	Dimension of OS	S1_1.3	Width	(Floor)		Space	X	
S1_2	Hmax built front	S1_2.1	H max	(Wall)	Max	Space	X	
		S1_2.2	Average building height	(Wall)	Average	Space	X	
SECTION 2: CHARACTERISTICS OF GEOMETRY AND SPACE								
Frontier								
S2_F_1	Type of Aggregates	S2_F_1.1	% of SA			Space		X
		S2_F_1.2	length of the built front	(Wall)	Sum	Space	X	
		S2_F_1.3	Number of SU			GM	X	
		S2_F_1.4	Length of SU	(Wall)	Sum	GM	X	
		S2_F_1.5	Height of SU front	(Wall)	Average	GM	X	
		S2_F_1.9	Number of storeys	Wall	Max	GM		X
S2_F_2	Accesses	S2_F_2.1	Number	(Road, space separation line)	Count	Space	X	
		S2_F_2.2	Width	(Road, space separation line)	Average	Space	X	
		S2_F_2.3	Position/orientation (azimuth)	Road	Average	Space		X
S2_F_3	Special buildings	P5	Presence	Wall	Direct	GM		X
		S2_F_3.4	Length of special buildings front	(Wall)	Sum	GM	X	
		S2_F_3.5	Height	(Wall)	Average	GM	X	
		S2_F_3.7	Height of gable	(Wall, Roof)	Max	GM	X	
S2_F_4a	Town walls	S2_F_4a.1	Presence	Wall	Direct	GM		X
		S2_F_4a.2	Linear extension			GM		X
		S2_F_4a.3	Position			GM		X
		S2_F_4a.4	Width or depth			GM		X
S2_F_4b	Porches	P7	Presence	Floor	Direct	GM		X
		S2_F_4b.2	Linear extension	(Floor)	Sum	GM	X	
		S2_F_4b.3	Position	Floor	Direct	GM		X
		S2_F_4b.4	Width or depth	(Floor)	Average	GM	X	
		S2_F_4b.5	Area	(Floor)	Average	GM	X	
S2_F_5a	Green area	P9f	Presence of green area	Floor	Direct	Space		X
		S2_F_5a.6	Green Area Position (related to LS or AS)	Floor	Direct	Space		X
		S2_F_5a.7	Green area density	Floor	Direct	Space		X
S2_F_5b	Water	S2_F_5b.1	Presence of Water	Floor	Direct	Space		X

S2_F_6	Quote differences/slope	P8f	Slope	Floor	Direct	Space		X
Content								
S2_C_1	Special buildings	S2_C_1.3	Height			GM		X
		S2_C_1.5	Lenght			GM		X
		S2_C_1.6	Width			GM		X
		S2_C_1.7	Height of gable			GM		X
S2_C_2	Quote difference/slope	P8	Slope	(Floor, topography)	Average	Space	X	
S2_C_5a	Green area	P9c	Presence of Green area	Floor	Direct	Space		X
		S2_C_5a.4	Extension (area)	Floor	Direct	Space		X
		S2_C_5a.6	Greenery adsorption capacity	Floor	Direct	Space		X
		S2_C_5a.10	Tree crown diameter	Floor	Direct	Space		X
	SECTION 3: CONSTRUCTIVE CHARACTERISTICS							
Frontier								
S3_F_1	Homogeneity of built environ. age	S3_F_1.2	Last intervention period			GM		X
		S3_F_1.3	State of conservation			GM		X
		S3_F_1.4	Wall disconnection in plan	Wall	Direct	GM		X
		S3_F_1.5	Wall disconnection in elevation	Wall	Direct	GM		X
S3_F_2	Homogeneity of constructive techniques	P6	Homogeneous/not homogeneous	Floor	Direct	Space		X
		S3_F_2.2	Masonry quality	Wall	Min	GM		X
		S3_F_2.3	Wall thickness	(Wall)	Average	GM	X	
		S3_F_2.5	Roof types	Roof	Min	GM		X
		S3_F_2.8	% openings	(Wall)	Average	GM	X	
		S3_F_2.13	No-structural protruding and decorative elements	Wall	Direct	GM		X
		S3_F_2.14	Anti-seismic devices	Wall	Min	GM		X
		S3_F_2.18	Facade finishing current roughness	Wall	Average	GM		X
		S3_F_2.22	Facade pollutant deposition capacity	Wall	Average	GM		X
Content								
S3_C_2	Pavement condition	S3_C_2.3	Pavement finishing current roughness	Floor	Direct	Space		X
SECTION 4: CHARACTERISTICS OF USE								
S4_1	Crowding	S4_1.1	People present			Space		X
		S4_1.2	Crowding potential			Space		X
		S4_1.4	Exposure duration			Space		X
S4_3	Strategic building / Special uses of building facing OS	S4_3.1	Presence of special buildings or special uses	Wall	Direct	GM		X
		S4_3.2	Crowding potential	Wall	Average	GM		X
		S4_3.4	Presence of Schools	Wall	Direct	GM		X
		S4_3.5	Presence of Hospitals	Wall	Direct	GM		X
		S4_3.7	Sensitive targets attraction to building use	Wall	Direct	GM		X
S4_4	Accessibility for vehicle	S4_4.2	Traffic intensity			Space		X
S4_6	Vehicles (parking)	S4_6.5	Parking area location	(Parking)	Sum	Space	X	
S4_8	Sensitive targets	S4_8.2	Presence of Sensitive target (elders/frail/youngsters)			Space		X

		S4_8.3	% presence of Sensitive target (elders/frail/ youngsters)	Space	X
SECTION 5: ENVIRONMENTAL CHARACTERISTICS					
S5_1	Seismic intensity	S5_1.1	Ground motion severity	Space	X
		S5_1.2	Seismic microzonation	Space	X
S5_3	Climate conditions	S5_3.1	Wind/breeze speed	Space	X
		S5_3.3	Air temperature	Space	X
		S5_3.4	Solar Irradiation	Space	X
		S5_3.6	Pollutant concentration	Space	X
S5_4	Multi-hazard potential	S5_4.2	Pollution sources presence Boolean	Space	X
S5_5	Ground type	S5_5.1	Classes of types	Space	X
		S5_5.2	Ground roughness	Space	X

2.3.2 BIM Parameters compliant to IFC Standard

The IFC standard is continually evolving and provides for the change and addition of new standard property sets for objects from one version to another; for this reason, the authors propose a new property set useful for containing all the information concerning the risk factors for multi-hazard potential assessment.

Methodologically, the research starts from the review of the parameters for the risk assessment found in the property sets already provided in the IFC 4.3 schema. It has not been possible to identify property sets already containing parameters that can be used for the present model.

For this reason, additional parameters to those already provided for the IFC 4.3 schema have to be identified and proposed for the multi-risk assessment.

The shared parameters implemented by the authors in the new property set "BeS2ecure multi-risk factors" has been organized following the five sections already set for the risk factors classification: Section 1 Main type (Table 7), Section 2 Characteristics of geometry and space (Table 8), Section 3 Constructive characteristics (Table 9), Section 4 Characteristics of use (Table 10), and Section 5 Environmental characteristics (Table 11).

The new parameters were set based on the already selected risk factors for BET 2A prone to S-P multi-hazard condition (see Table 6). To each parameter was associated a name as consistent as possible with that of the international standard IFC 4.3. It was set with the following structure of the name:

parameter code + associated BE component + parameter description

The "associated BE component" represent the main elements of BE associated with the parameter. It can refer to: Open Space and Structural Unit. Each parameter could be associated to one or more entities, among them: Space (IfcSpace), Generic Models (IfcBuildingElementProxy), Wall (IfcWall), Floor (IfcFloor), Roof (IfcRoof).

Table 7: Parameters for "Section 1 Main type", their name, and entities to be associated with.

SECTION 1		
Parameter Name	**Parameter Description**	**Entities**
S1_0_OpenSpaceMainClass	Main class	IfcSpace
S1_0.2_OpenSpaceCanyonAspectRatio	Canyon aspect ratio	IfcSpace
S1_0.3_OpenSpaceProximitySidewalkToTraffic	Proximity of sidewalk to traffic	IfcSpace
S1_1.3_OpenSpaceWidth	Width	IfcSpace
S1_2.1_OpenSpaceBuiltFrontMaxHeight	H max	IfcSpace
S1_2.2_OpenSpaceBuiltFrontAverageHeight	Average building height	IfcSpace

Table 8: Parameters for "Section 2 Characteristics of geometry and space", their name, and entities to be associated with.

SECTION 2		
Parameter Name	**Parameter Description**	**Entities**
S2_F_1.1_OpenSpaceStructuralAggregatePercentage	% of SA	IfcSpace
S2_F_1.2_StructuralUnitLenght	Length of the built front	IfcSpace
S2_F_1.3_StructuralUnitNumber	Number of SU	IfcBuildingElementProxy
S2_F_1.4_StructuralUnitLenght	Length of SU	IfcBuildingElementProxy
S2_F_1.5_StructuralUnitHeight	Height of SU front	IfcBuildingElementProxy
S2_F_1.9_StructuralUnitStoreysNumber	Number of storeys	IfcWall, IfcBuildingElementProxy
S2_F_2.1_OpenSpaceAccessesNumber	Number	IfcSpace
S2_F_2.2_OpenSpaceAccessWidth	Width	IfcSpace
S2_F_2.3_OpenSpaceAccessOrientation	Position/orientation	IfcRoad, IfcSpace
S2_F_3_StructuralUnitSpecialBuildingPresence	Presence	IfcWall, IfcBuildingElementProxy
S2_F_3.4_StructuralUnitSpecialBuildingBuiltFrontLenght	Length of special buildings front	IfcBuildingElementProxy
S2_F_3.5_StructuralUnitSpecialBuildingHeight	Height	IfcBuildingElementProxy
S2_F_3.7_StructuralUnitSpecialBuildingGableHeight	Height of gable	IfcBuildingElementProxy
S2_F_4a.1_StructuralUnitTownWallsPresence	Presence	IfcWall, IfcBuildingElementProxy
S2_F_4a.2_StructuralUnitTownWallsLinearExtension	Linear extension	IfcBuildingElementProxy
S2_F_4a.3_StructuralUnitTownWallsPosition	Position	IfcBuildingElementProxy
S2_F_4a.4_StructuralUnitTownWallsDepth	Width or depth	IfcBuildingElementProxy
S2_F_4b_StructuralUnitPorchesPresence	Presence	IfcFloor, IfcBuildingElementProxy
S2_F_4b.2_StructuralUnitPorchesLenght	Linear extension	IfcBuildingElementProxy
S2_F_4b.3_StructuralUnitPorchesOrientation	Position	IfcFloor, IfcBuildingElementProxy
S2_F_4b.4_StructuralUnitPorchesWidth	Width or depth	IfcBuildingElementProxy
S2_F_4b.5_StructuralUnitPorchesArea	Area	IfcBuildingElementProxy
S2_F_5a_OpenSpaceGreenAreaPresence	Presence of green area	IfcFloor, IfcSpace
S2_F_5a.6_OpenSpaceGreenAreaPosition	Green Area Position	IfcFloor, IfcSpace
S2_F_5a.7_OpenSpaceGreenAreaDensity	Green area density	IfcFloor, IfcSpace
S2_F_5b.1_OpenSpaceWaterPresence	Presence of Water	IfcFloor, IfcSpace
S2_F_6_OpenSpaceSlope	Slope	IfcFloor, IfcSpace
S2_C_1.3_StructuralUnitSpecialBuildingHeight	Special building height	IfcBuildingElementProxy
S2_C_1.5_StructuralUnitSpecialBuildingLenght	Special building length	IfcBuildingElementProxy
S2_C_1.6_StructuralUnitSpecialBuildingWidth	Special building width	IfcBuildingElementProxy
S2_C_1.7_StructuralUnitSpecialBuildingGableHeight	Special building height of gable	IfcBuildingElementProxy
S2_C_2_OpenSpaceSlope	Slope	IfcSpace
S2_C_5a_OpenSpaceGreenAreaPresence	Presence of Green area	IfcFloor, IfcSpace
S2_C_5a.4_OpenSpaceGreenAreaExtension	Extension (area)	IfcFloor, IfcSpace
S2_C_5a.6_OpenSpaceGreenAreaAdsoprtionCapacityOfGreenery	Greenery adsoprtion capacity	IfcFloor, IfcSpace
S2_C_5a.10_OpenSpaceGreenAreaDiameterOfTreeCrown	Tree crown diameter	IfcFloor, IfcSpace

Table 9: Parameters for "Section 3 Constructive characteristics", their name, and entities to be associated with.

SECTION 3		
Parameter Name	**Parameter Description**	**Entities**
S3_F_1.2_StructuralUnitPeriodOfLastIntervention	Last intervention period	IfcBuildingElementProxy
S3_F_1.3_StructuralUnitStateOfConservation	State of conservation	IfcBuildingElementProxy
S3_F_1.4_StructuralUnitWallDisconnectionPlan	Wall disconnection in plan	IfcWall, IfcBuildingElementProxy
S3_F_1.5_StructuralUnitWallDisconnectionElevation	Wall disconnection in elevation	IfcWall, IfcBuildingElementProxy
S3_F_2_OpenSpaceConstructionTechniquesHomogeneity	Homogeneous/not homogeneous	IfcFloor, IfcSpace
S3_F_2.2_StructuralUnitMasonryQuality	Masonry quality	IfcWall, IfcBuildingElementProxy
S3_F_2.3_StructuralUnitMasonryThickness	Wall thickness	IfcBuildingElementProxy
S3_F_2.5_StructuralUnitRoofType	Roofs types	IfcRoof, IfcBuildingElementProxy
S3_F_2.8_StructuralUnitOpeningsPercentage	% openings	IfcBuildingElementProxy
S3_F_2.13_StructuralUnitDecorativeElementsPresence	No-structural protruding and decorative elements	IfcWall, IfcBuildingElementProxy
S3_F_2.14_StructuralUnitAntiSeismicDevicesPresence	Anti-seismic devices	IfcWall, IfcBuildingElementProxy

S3_F_2.18_StructuralUnitFinishingRoughness	Facade finishing current roughness	IfcWall, IfcBuildingElementProxy
S3_F_2.22_StructuralUnitPollutantDepositionCapacity	Facade pollutant deposition capacity	IfcWall, IfcBuildingElementProxy
S3_C_2.3_OpenSpacePavementFinishingRoughness	Pavement finishing current roughness	IfcWall, IfcBuildingElementProxy

Table 10: Parameters for "Section 4 Characteristics of use", their name, and entities to be associated with.

SECTION 4		
Parameter Name	**Parameter Description**	**Entities**
S4_1.1_OpenSpacePeoplePresence	People presents	IfcSpace
S4_1.2_OpenSpaceCrowdingPotential	Crowding potential	IfcSpace
S4_1.4_OpenSpaceExposureDuration	Exposure duration	IfcSpace
S4_3.1_StructuralUnitSpecialBuildingPresence	Presence of special buildings or special uses	IfcWall, IfcBuildingElementProxy
S4_3.2_StructuralUnitStrategicBuildingCrowdingPotential	Crowding potential	IfcWall, IfcBuildingElementProxy
S4_3.4_StructuralUnitSchoolsPresence	Presence of Schools	IfcWall, IfcBuildingElementProxy
S4_3.5_StructuralUnitHospitalsPresence	Presence of Hospitals	IfcWall, IfcBuildingElementProxy
S4_3.7_StructuralUnitSensitiveTargetPresence	Sensitive targets attraction to building use	IfcWall, IfcBuildingElementProxy
S4_4.2_OpenSpaceTrafficIntensity	Traffic intensity	IfcSpace
S4_6.5_OpenSpaceParkingAreaLocation	Parking area location	IfcSpace
S4_8.2_OpenSpaceSensitiveTargetPresence	Presence of sensitive target (elders/frail/gender/youngsters)	IfcSpace
S4_8.3_OpenSpaceSensitiveTargetPresencePercentage	% presence of sensitive target (elders/frail/gender/youngsters)	IfcSpace

Table 11: Parameters for "Section 5 Environmental characteristics", their name, and entities to be associated with.

SECTION 5		
Parameter Name	**Parameter Description**	**Entities**
S5_1.1_OpenSpaceGroundMotionSeverity	Ground motion severity	IfcSpace
S5_1.2_OpenSpaceSeismicMicrozonation	Seismic microzonation	IfcSpace
S5_3.1_OpenSpaceWindSpeed	Wind/breeze speed	IfcSpace
S5_3.3_OpenSpaceAirTemperature	Air temperature	IfcSpace
S5_3.4_OpenSpaceSolarIrradiation	Solar Irradiation	IfcSpace
S5_3.6_OpenSpacePollutantConcentration	Pollutant concentration	IfcSpace
S5_4.2_OpenSpacePollutionSourcesPresence	Pollution sources presence Boolean	IfcSpace
S5_5.1_OpenSpaceGroundClassType	classes of types	IfcSpace
S5_5.2_OpenSpaceGroundRoughness	Ground roughness	IfcSpace

2.3.3 BeS2ecure Property set implementation as project parameters related to specific BIM family categories

The parameters are inserted into the BIM model, developed in the Autodesk Revit environment, using "Shared Parameters". To speed up and automate the process as much as possible, the free add-in "ParaManager" developed by DiRoots was used.

ParaManager is an add-in for Revit that allows the management of the parameters from the model for individual families. It allows to create, modify, connect, transfer, export, and standardise all Revit parameters for reuse on current and future projects. It is chosen to operate with this tool because it allows assigning several parameters to multiple categories of BIM elements simultaneously. On the contrary, using the Revit basic commands can be assigned only one shared parameter at a time making this a very long, repetitive, and error-prone work.

After creating the information structure of all the parameters necessary for the analysis of the multi-risk assessment within the BIM model, they must be filled in with the appropriate values. The filling process regarded only the parameters that need to be filled by the users (see column "fill" in Table 4; Figure 3).

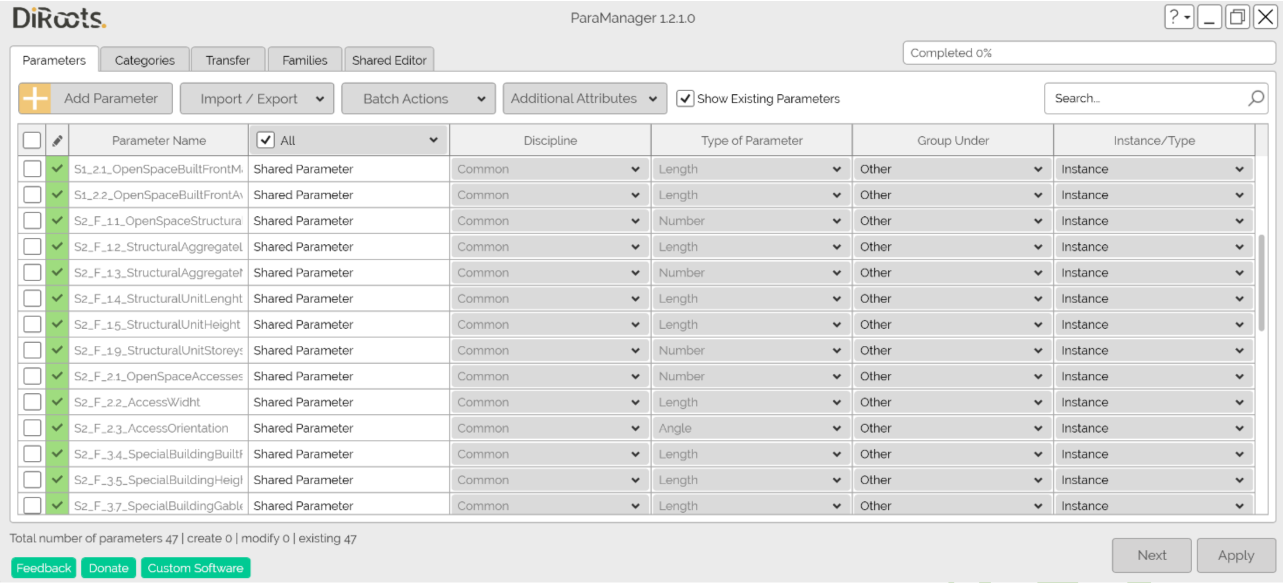


Figure 3: Process of conversion of the Shared Parameters in Project Parameters through ParaManager.

After the creation of the parameters and their compilation with the project values, there is the check of the correct insertion. Control takes place in two steps:

1. Checking the current presence of the shared parameters assigned to the correct category;
2. Check for the presence of a compiled value within the shared parameters created.

2.3.4 Process to associate values to fillable and computable Parameters

As reported in D3.1.2 §4.3, the integration of quantitative data derived from rapid point cloud-based survey or GIS/CAD data enrichment within the BIM model expands its capability. Hence, users and stakeholders can perform analysis of the entire system on a shared virtual platform. To achieve this level of integration, custom Visual Programming Language (VPL) packages are required. Dynamo tool (Autodesk 2020) within Revit is used in this study to import, display and elaborate recorded OS in BE data for reduced risk matrix parameters from D322 for BET 2A and S-P multi-hazard condition. The authors implemented several Dynamo nodes groups to extract data from Revit elements and systematize them, so to develop a repeatable workflow for other BET multi-risk case studies.

Table 12 shows the risk parameters in order of implementation: after the automatically filled HL (*i*) and LL (*ii*) parameters all others HL parameters (*ii, iii*) are filled with Inherited (I) and Computable to HL parameters (C_{HL}) operations.

Table 12: Risk parameters implementation in BIM, divided in three main categories as reported in Table 5, with Dynamo operations specifications divided in (i) No Dynamo operation as the parameters values are already implemented by the operator in HL family category; (ii) The information implemented through fillable LL parameters are Inherited (I) in HL parameters with direct transposition, average, sum, count, minimum, maximum; (iii) the HL parameters are computed (C_{HL}) using LL and HL geometric properties with specific synthetic operations (direct transposition, average, sum, count, minimum, maximum). The brackets mean that the family category is only used for its properties and the parameters is not associated to it.

	LL	→	HL	Computable	Fillable	Dynamo operations
i	/	→	×		×	NO DY
ii	×	→	×		×	I
iii	(×)	→	×	×		C_{HL}

Based on Table 12, the reduced risk matrix parameters from D322 for BET 2A and S-P multi-hazard condition can be divided in:

i. 18/77 parameters are filled directly in HL, following external processing or computation;

ii. 31/77 parameters are based on the concept of hierarchical lists in Dynamo to manage parameter inheritance (Figure 4);

iii. 28/77 whether the computation uses one or more LL or HL geometries (Figure 4; Figure 5; Figure 6; Figure 7).

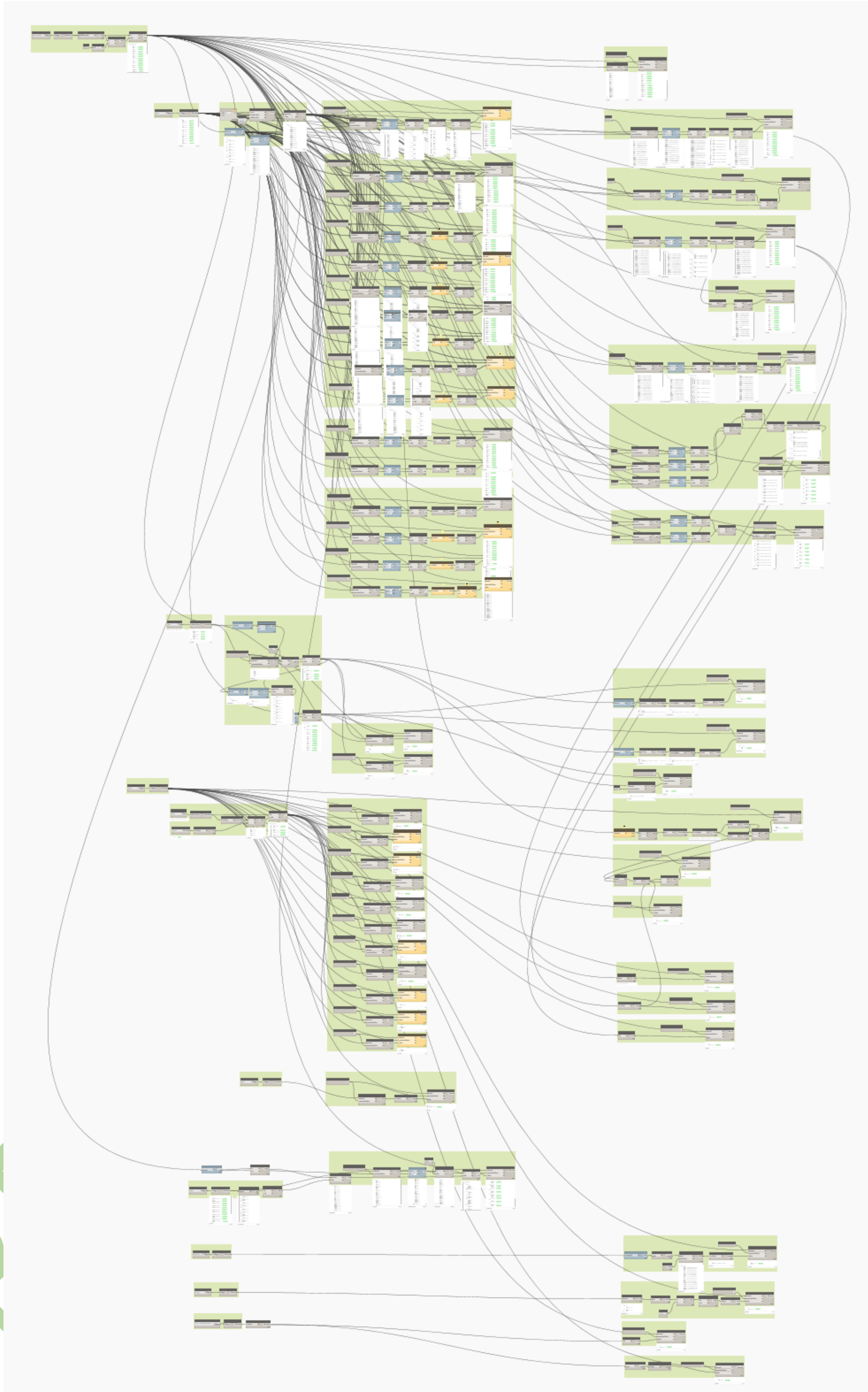


Figure 4: Dynamo keymap for focus on groups of nodes as the Dynamo package is one of the outputs of the Deliverable work to reproduce the analysis on other case studies.

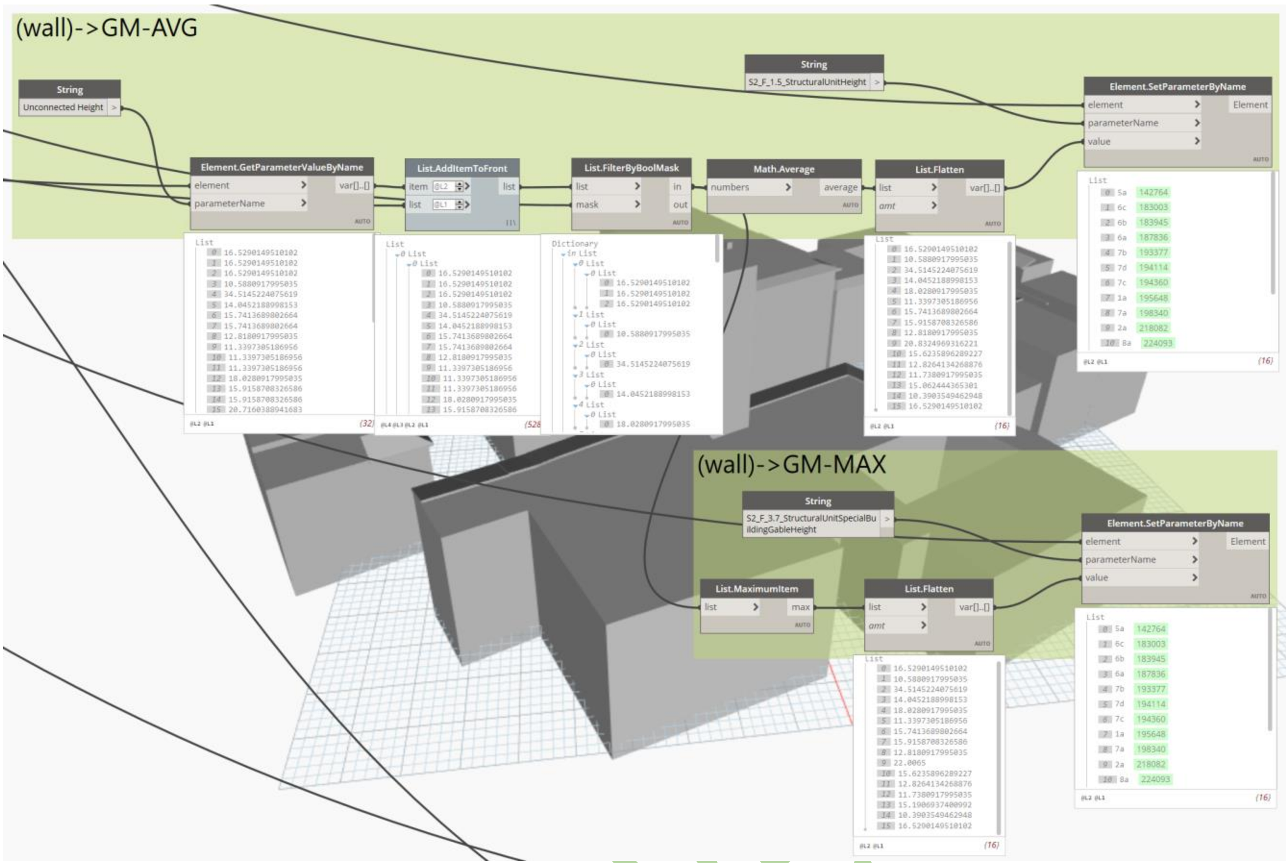


Figure 5: Wall maximum and average Special Building height computation through Boolean mask application to the USs list.

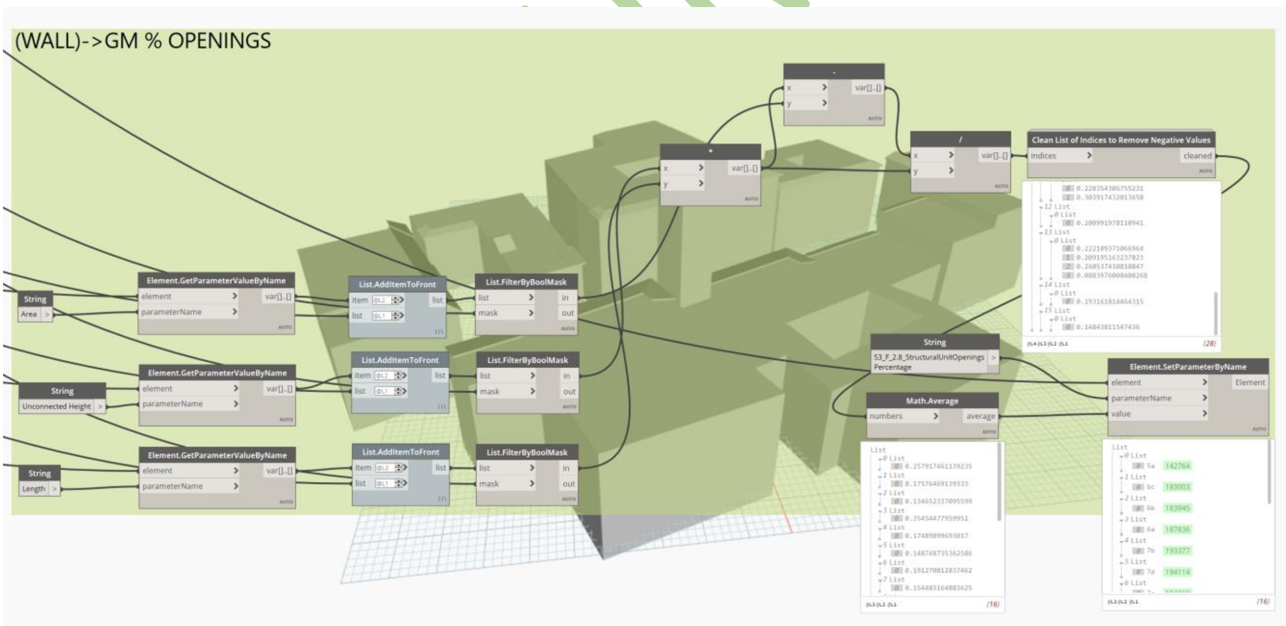


Figure 6: % opening which compares built-in Revit parameters, i.e. the gross wall area obtained by multiplying the floor projection of the individual walls (Lenghtwall) by their respective heights (Unconnected heightwall), with the net area in the dimensions properties of the individual instances (Areawall)

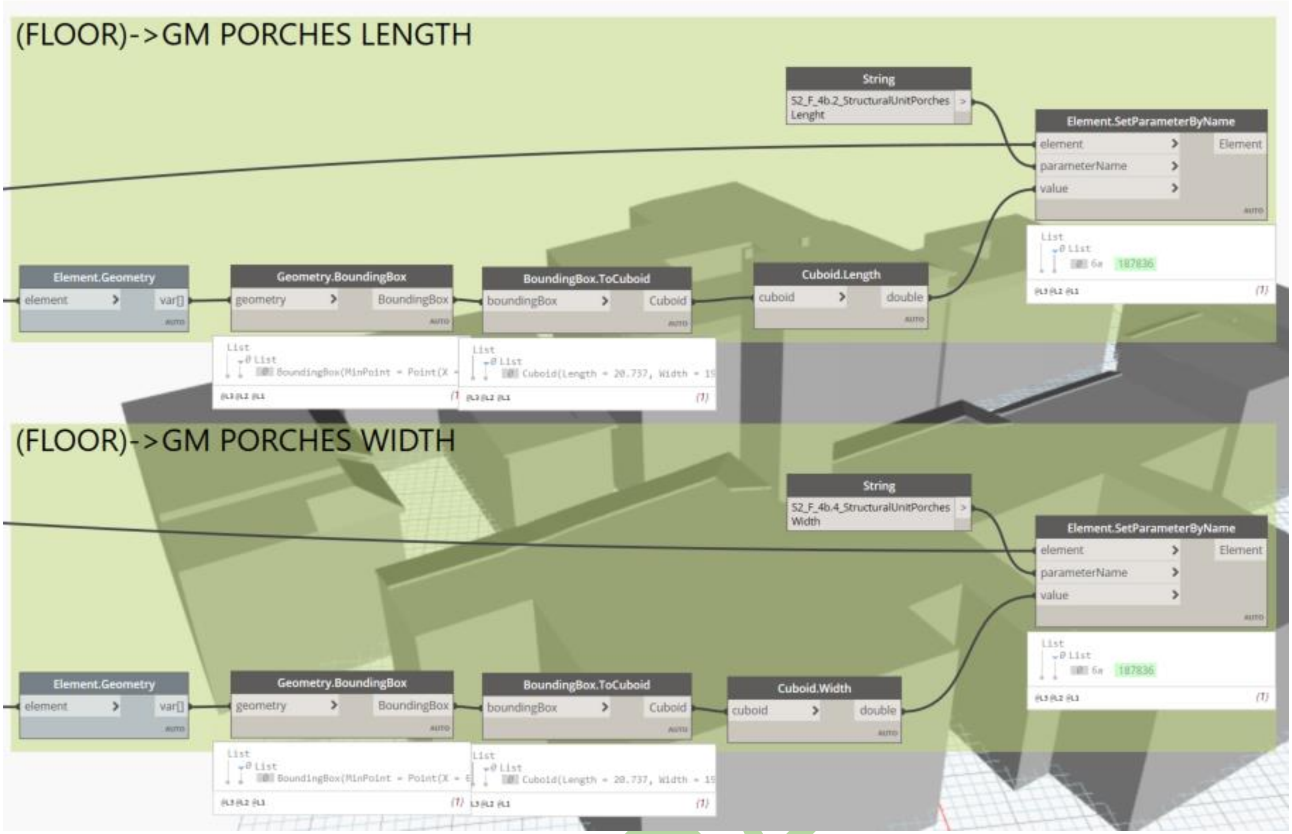


Figure 7: Porches Width and Length computation based on porches floor bounding box query.

2.4 Structuration of Virtual Environments: preparatory activities, specifications and digital content requirements related to BE, SUOD and SLOD

As investigated in D3.1.3, VR tools can represent BETs and real case studies with two different workflows: BIM-centric using a central 3D model (urban tissue/building) as a database of geometric features and risk-related properties, and VR-centric where a central Virtual Tour (VT), made up of reality-capture and BIM-based spherical photos augmented with hotspots, assumes the role of database navigated via web.

The selected workflow for **risk communication** is the VR-centric one for both expert and non-expert users, as the VT is easy to be implemented and updated (**section 7 in D3.1.3**), working as a collection and organization of data with any specific aims in supporting simulations, and also managing extensive BIM models and 3D models, such as point clouds and texturized meshes, when available among the working group. In particular, the structuration of Virtual Environments beginning from VTs consents to provide tools that are widely navigable thanks to the web applications. This allows to have pervasive training that reach everyone everywhere, against any criticalities caused by scarce interoperability among proprietary software products and applications' installation by non-expert users.

In particular, the VT tool for virtual training will be structured with parallel VTs about the BE as it is (i Sph_RGB) and BE mapped (i Sph_RM,r) according to the results of the risk assessment, consisting of reality-based panoramas mapped with hotspots and BIM-based panoramas with BE elements colour-mapped according to risk assessment algorithms coded within BIM environments (Figure 8).

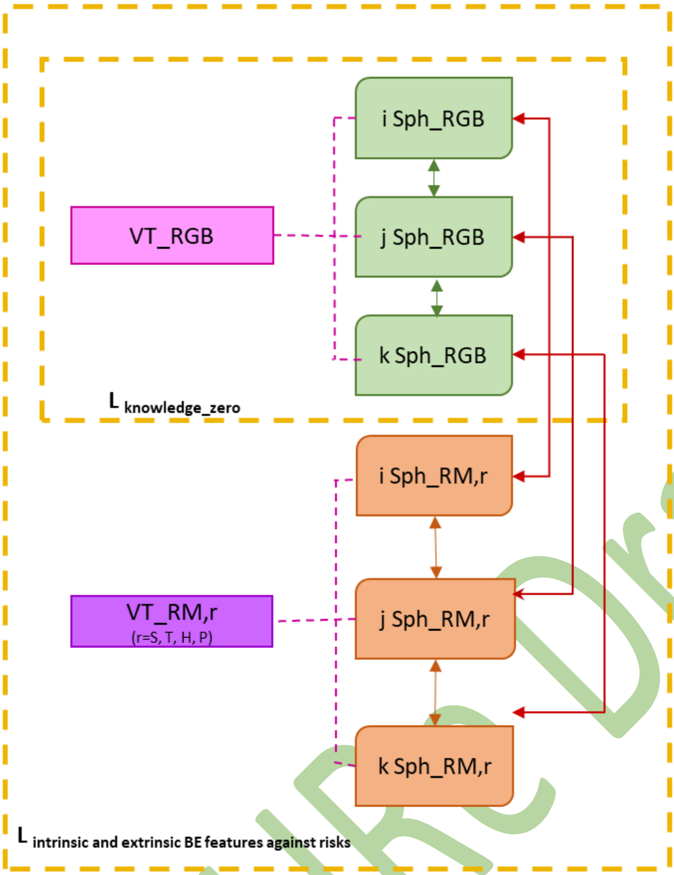


Figure 8 Virtual Training tool based on Virtual Tours

Among the preliminary activities to build a VE (VT_RGB), the acquisition of the reality-based 360° photos/video (i Sph_RGB, i=1…n) to be linked each other with switch hotspots to re-create the OS (LoR A). The acquisition modes of panoramic video could be in Live panorama (updated several times per hour) and HDR (High Dynamic Range) panorama for detailed pictures (Ferrari and Medici 2017). If laser scans are available, 360° photos can be extracted as preview files of the point cloud. Moreover, tools to extract available 360° photos from Google Street View exist (i.e. Street View Download 360°), as a first approach to the knowledge of the Built Environment. Nevertheless, the geometric characteristics of the Open Space influence the acquisition plan of 360° photos, both in plan and elevation, in order to guarantee an exhaustive representation of the space. For example, 360° photos capture should be done at different elevation level, using a telescopic rod or drone, when high buildings, such as towers, constitute the OS. Thus, the number of photo shots in plan should be coherent with the width and length of the Open Space, in order to not ignore some zones in the representation (**section 3.1 in D3.1.3**).

Another component of the VT is the floor plan to support orientation in the VT (orientation maps) thanks to synchronized radars to the user's panning (LoR B). These floor plans can derive by different media contents, such as a google map or a still image map, taken from GIS, CAD, BIM models or other image formats.

In this first stage, the selection of icons for switch hotspots is relevant in order to be understandable by users that interact with to open panoramas in a sequence of them. In addition, they may consent to cross the BE backward and forward. The combination of LoR A and LoR B allow for the basic representation of the Built Environment with its geometric, morphological and color appearance.

The use of reality-based panoramas (Sph_RGB) consent to represent and describe the BE elements visible in each scene, according to the specific **Representation Criteria** of parameters and descriptors in VT tools (R1 to R4 defined in section 7 D3.2.2). In particular, LOR B can effectively represent BE elements if the floor plan is created selecting a high level of detail (from scale 1:500 to 1:200), otherwise LoR B is not sufficient for the representation (Table 13).

Table 13 Level of Representation of BE elements and its dependance from the level of detail of the floor plan (from Table 22 in D3.2.2)

ELEMENT	CODE OF ELEMENT	VT - GRAPHICAL INFORMATION	REPRESENTATION IN FLOOR PLAN (LOR B) DEPENDENT FROM LEVEL OF DETAIL
OS	OS	LoR A + LoR B	
AS	AS	LoR A + LoR B	
BUILDING FRONTS/ SPECIAL BUILDINGS	BF	LoR A + LoR B	
SIDEWALK	SW	LoR A + LoR B	x
STREET	ST	LoR A + LoR B	
WATER	WT	LoR A + LoR B	x
MITIGATION/CONTROL SYSTEM	MC	LoR A + LoR B	x
ACCESSES	AC	LoR A + LoR B	x
TOWN WALLS	TW	LoR A + LoR B	x
PORCHES	PR	LoR A + LoR B	x
GREEN AREA	GR	LoR A + LoR B	x
TERRAIN/STAIRS	SL	LoR A + LoR B	
PROTECTION MISURES OF SLOPE/QUOTE DIFFERENCE	PM	LoR A + LoR B	x
MONUMENTS	MN	LoR A + LoR B	x
UNDERGROND CAVITIES	UC	LoR A + LoR B	x
FIXED OBSTACLES (including fontaine, manuments)	FO	LoR A + LoR B	x
TEMPORARY OBSTACLES	TO	LoR A + LoR B	x
VEHICLES (parking)	PK	LoR A + LoR B	x
CROWDING		LoR A + LoR B	x
SIGHTS	SG	LoR A + LoR B	x

Nevertheless, additional information and description of the BE must be included within the VE though graphical information in detailed hotspots (LOR C), thus with a Representation Criteria R4. In this case, parameters and descriptors are represented as digital content (image, pdf, etc).

The reference to parameters and descriptors that require a LoR C are illustrated in the Table 27 in D3.2.2. In this research, the typology of digital contents and their editing procedures are identified.

In particular, descriptive reports can be provided as *.pdf to illustrate those descriptors of SECTION 1: MAIN TYPE, SECTION 2: CHARACTERISTICS OF GEOMETRY AND SPACE – Frontier/Content that require LoR C. The descriptors "presence" and "number" can be directly identified from the panoramic scene (LoR A) and/or the floor plan (LoR B), as further described in LoR C. The VE interface is composed by two parts: the Menu with general information and the Main View that shows the spherical images and hotspots. The section parameters are organized within the VE as in Figure 9.

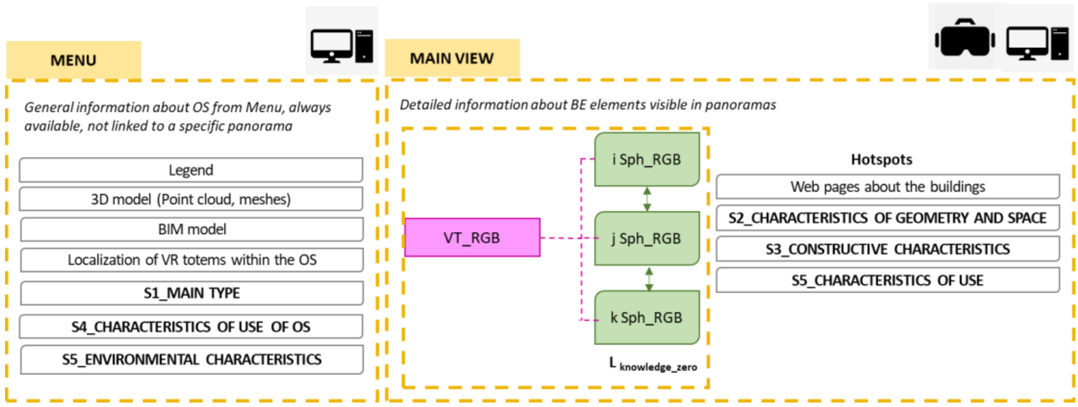


Figure 9 Interface structuration of the Virtual Environment

As the SECTION 1: MAIN TYPE descriptors regard the BE in its whole, the related detailed hotspot can be inserted in the Menu (Skin) of the VE, instead of the main view where panoramic scenes are. While, SECTION 2: CHARACTERISTICS OF GEOMETRY AND SPACE contains descriptors specific for BE elements, thus the detailed hotspot is inserted on the top of the panoramic scene, where the BE element is located and recognizable. This reports could be edited with common writing software products (such as Microsoft Word or Excel), photo-editing (such as Adobe Photoshop, Adobe Illustrator) or CAD/BIM/GIS software as exported sheets/schedules/drawings in *.pdf, according to software's availability within the working group. The pdf file (Portable Document Format) is selected as a suitable digital content, that report text, images, URL) as it is readable independently from software and hardware. SECTION 3: CONSTRUCTIVE CHARACTERISTICS Frontier/Content descriptors can be detailed illustrated in VE as *.pdf in a descriptive report that contains images and text, and this can be produced as described above. As a possible way to recall information about, the reports can be activated using QR code image popup on each BE element to be described (i.e. fixed and temporary obstacles). The graphical information of constructive characteristics of walls, roof and horizontal structures could be provided adding a hotspot with URL of the BIM model that represents the wall stratigraphy and the roof/horizontal structure technology, per each identified structural unit of the built frontier. As the SECTION 4: CHARACTERISTICS OF USE descriptors concern the OS or single BE elements (buildings, streets, parking area, sights, sensitive targets), they can be managed with different procedures starting from the editing of specific reports about (*.pdf or pictures). In particular, the properties related to the whole OS are collected in documents the user can interact with through hotspot in the Menu of the VE. While, the characteristics of use about BE elements can be assigned in hotspots within the panoramic scenes where they are present. Other global properties about the OS, that can be managed with hotspots in Menu, are the ones categorized SECTION 5: ENVIRONMENTAL CHARACTERISTICS as descriptive sheets in *.pdf file.

2.5 BIM models in VR application

Once the BIM model is created with the procedures discussed in previous paragraphs, it can be employed for risk assessment and produce risk maps via calculations of each indicator for probability, vulnerability and exposure per each SUOD and SLOD hazard. These calculations can be executed externally with software products not belonging to BIM platforms, or within the same BIM environment using customized Visual Programming Language scripts (in Dynamo or Grasshopper as examples). The objective is the production of risk maps of the Built Environment projected on the Open Space (squares/streets) and its elements (obstacles, monuments, fountains, green areas and so on) and or building fronts (about the vulnerabilities against seismic events). These risk maps can be exported from the BIM model as plans in .pdf, as colour-mapped 3D models and colour-mapped equirectangular pictures to be employed in Virtual Tour editors. The selected framework to build the virtual training for expert and non-expert users is a VR-centric one, for this reason the management of BIM-based equirectangular picture is a central requirement to handle the process and make recognizable each element of the BE frontier and content and its related involvement in risk assessment. Nevertheless, experts can necessitate values of parameters and descriptors for next consultations and analysis. For this reason, the entire BIM model should be navigable with its geometric and parametric information within the Virtual Tour. It is possible thanks to the functionality of hotspots in the Menu that consent to activate URLs, and BIM models can be published online to be shared though URL links. The publishing of BIM models is possible due to the development of webGL libraries embedded in web viewer, such as Autodesk Viewer. The webGL and semantic web permit the contemporary navigation of the model itself and the consultation of parameters when each object is selected.

3 Results and discussions

3.1 BIM modelling of the Piazza dei Priori case study

As for the BIM modelling, the Level of Development (LoD) 350 of the OS digitalization (D312 §4.1) was chosen to appropriately represent the case study of Piazza dei Priori in Narni. LOD 350 is informed by the results of the BET classification and includes a more detailed definition of both geometrical and informative data as it comes from a Scan-to-BIM survey (Figure 10).

(a) (b)

Figure 10: Results of the TLS (a) and photogrammetric (b) point cloud survey of Piazza dei Priori, Narni. The TLS pointcloud is in reflectance intensity scale, and the photogrammetric cloud is in RGB value scale.

With the aim of its digitization in BIM, the frontier defining Piazza dei Priori has been divided into SAs and SUs according to the terminology described in §2.2.1 (Figure 11). The 15 USs identified were then modelled as GM (

Figure 13; Figure 12). The presence of internal courts was detected by means of point cloud survey and GIS satellite data in Palazzo dei Priori (SU 2a), Loggia dei Priori (SU 6a) and Palazzo Calderini (SU 1a) and was modelled as extrusion voids. Starting from the faces of the GMs defining the square, 31 walls with different structural characteristics were modelled. The maximum number of walls associated with a single SU is 7 for the municipal theatre (SU 4a), while the minimum and the most recurrent case is 1 (SUs3b, 5b, 6b, 6c, 7a, 7c, 8a, 8b). The topography modelled from the point cloud shows a slight slope between SA 3 and 4. The presence of green areas is not recorded, but parking spaces and many elements of urban furniture, including a fountain, have been modelled. The accesses to the square are 8 of various sizes and there is only one portico open to the square in SU 6, whose floor has been modelled. Thanks to the use of the UAV in the survey phase and thanks to satellite data, the roofs of the different SUs were also modelled. The OS frontier was completed with the various openings, whether windows or doors, for which a wide variety of typologies was recorded. Once the boundaries of the square were defined, the space was automatically generated in the BIM model. Hence, the model deepens the characterization of building component of the OS frontier (e.g., the opening of the façade, the features of masonry in term of structure and finishing, types of roofs) and of OS content (e.g., paving materials and finishing, topography materials and condition).

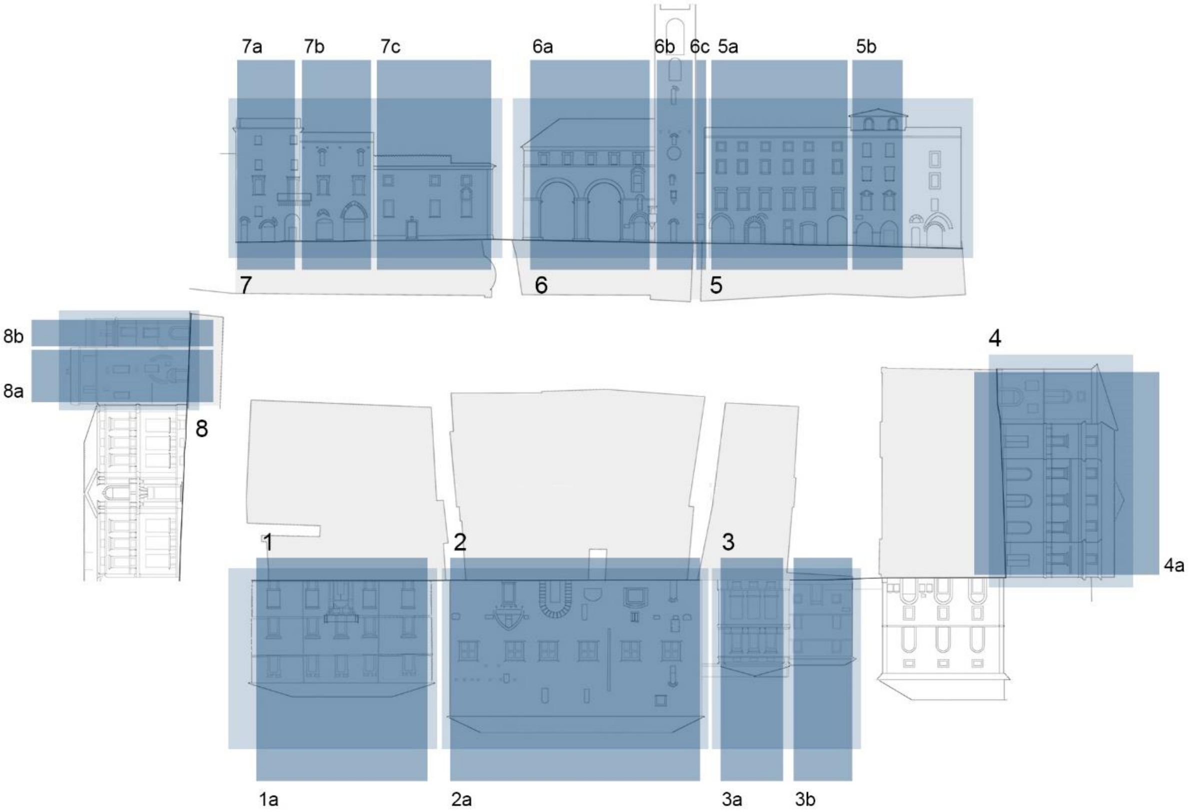


Figure 11: Piazza dei Priori frontier division in SAs (i.e., 1-8) e SUs (e.g., a, b, c)

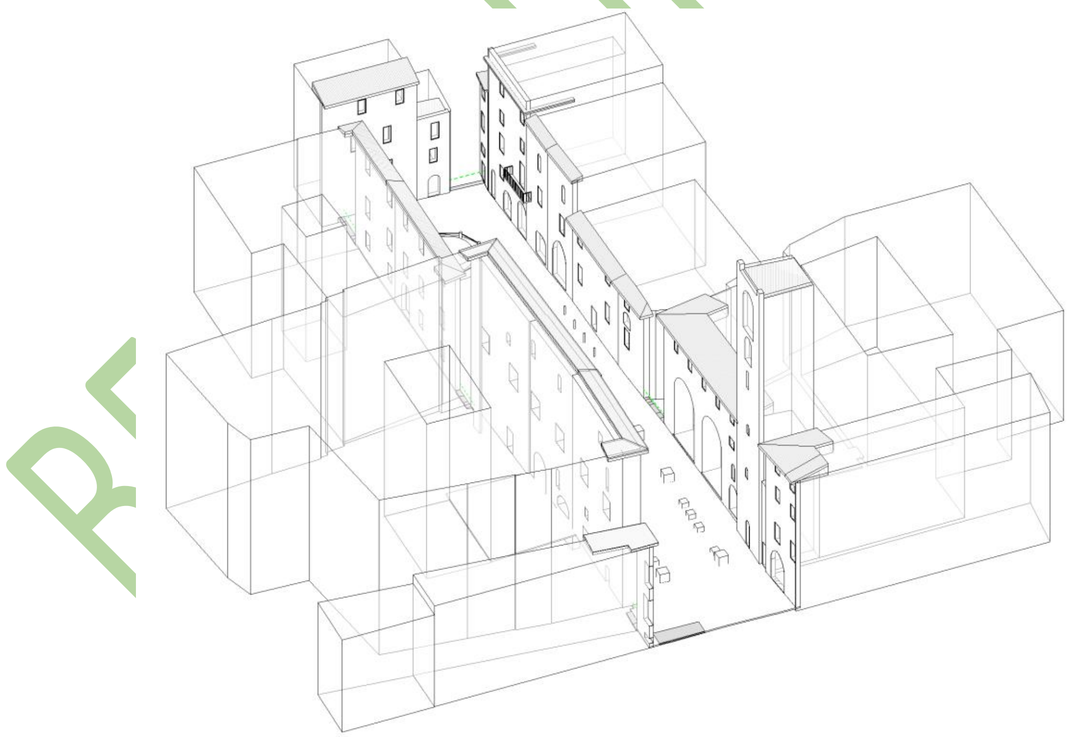


Figure 12: Section of the BIM model of Piazza dei Priori cutting SUs 3a-5a.

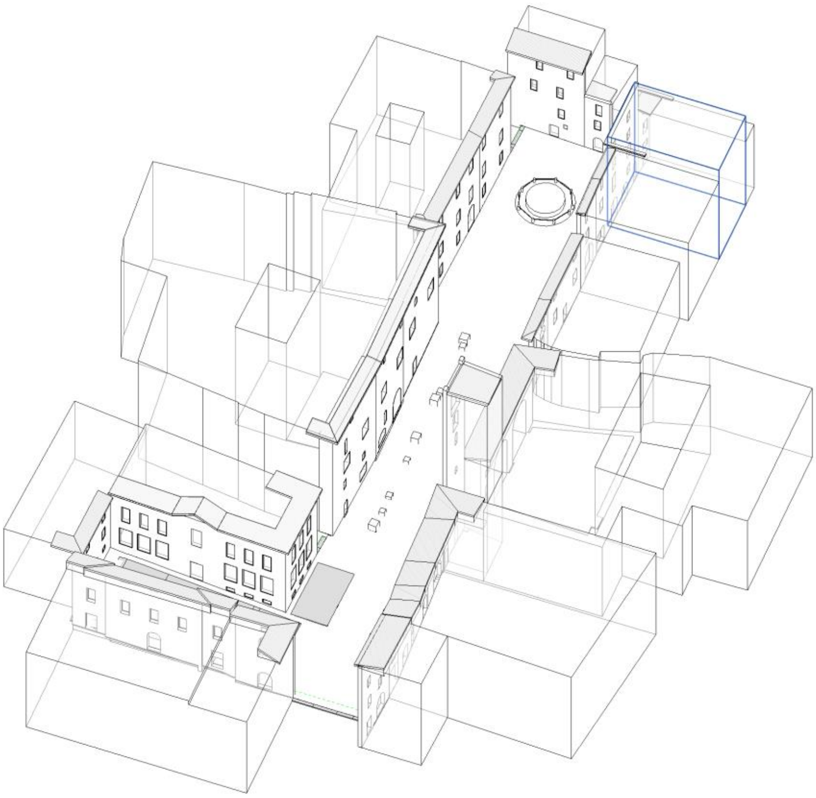


Figure 13: BIM model of Piazza dei Priori: SUs are modelled as GM; the OS frontiers are composed by walls and roofs with windows, doors, and porticoes; the OS is modelled as floor and includes urban furniture and parking.

3.2 Informative implementation of risk parameters to Piazza dei Priori BIM model

Once the reduced risk matrix parameters from D322 for BET 2A and S-P multi-hazard condition have been implemented as explained in 2.3 following the order of Table 5, the parameters were compiled and calculated in reverse hierarchical order.

The first parameters to be entered are those in point iii of Table 5 since the Dynamo algorithm has been set up to run automatically and the parameters of the HL families based on information from the geometry of the LL families can immediately be computed.

This step highlights the straightforward computation automation of parameters through Dynamo, allowing parameters to be nested between LL elements and HL elements.

Therefore, the process began with point ii of Table 5 with LL element families such as wall and roof (*Table 14*), floor (Table 15) and road (Table 16) by inserting the fields of the fillable parameters only, which are then inherited by HL families with specific synthetic operations in Dynamo (direct transposition, average, sum, count minimum, maximum).

Specifically, all parameters in *Table 14* are associated to the LL family wall or roof (to the latter only for S3_F_2.5 roof types) in order to include non-homogeneous values in the single instances of walls and roofs that make up the SU which, in turn, includes them with synthesis operations (direct transposition, average, minimum, maximum). In Figure 14 a wall of the SU 2a of Palazzo dei Priori is selected and the entered parameters are shown.

Table 14: Fillable parameters for Wall and roof (*) family category from the reduced risk matrix from D322 for BET 2A and S-P multi-hazard condition.

SA	1	2	3		4	5		6			7			8	
SU - Generic Model	1a	2a	3a	3b	4a	5a	5b	6a	6b	6c	7a	7b	7c	8a	8b
Section 2															

S2_F_1.9	number of storeys	3	3	2	3	1	4	4	2	-	-	4	3	1	4	3
S2_F_3	presence (special building)	no	yes	no	no	yes	no	no	yes	yes	no	no	no	no	no	no
S2_F_4a.1	presence (town walls)	no	no	no	no	no	no		no			no			no	
Section 3																
S3_F_1.4	wall disconnection in plan	yes	no	n/d	yes	yes	no	no	no	no	no	no	yes	yes	yes	no
S3_F_1.5	wall disconnection in elevation	no	no	n/d	n/d	no	no	yes	no	no	no	yes	no	no	no	no
S3_F_2.2	masonry quality	b	f	n/d	n/d	n/d	b	b	f	c	c	b	f	a	n/d	n/d
S3_F_2.5	roof types*	P	SP	n/d	SP	NP	SP	SP	NP	F	F	F	SP	NP	P	P
S3_F_2.13	no-structural protruding and decorative elements	yes	yes	yes	no	no	no	no	no	no	no	yes	no	no	no	no
S3_F_2.14	anti-seismic devices	0	0.65	0	0	0	0	0	0	0.85	0	0	0	0.55	0	0
S3_F_2.18	Facade finishing current roughness	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
S3_F_2.22	Facade pollutant deposition capacity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Section 4																
S4_3.1	presence of special buildings or special uses	yes	yes	no	no	yes	yes	yes	yes	no	no	no	no	no	no	no
S4_3.2	crowding potential	0.7	0.4	-	-	0.7	0.7	0.7	0.4	-	-	-	-	-	-	-
S4_3.4	Presence of Schools	no	no	no	no	no	no	no	yes	no	no	no	no	no	no	no
S4_3.5	Presence of Hospitals	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no
S4_3.7	sensitive targets attraction to building use	no	yes	no	no	yes	no	no	yes	no	no	no	no	no	no	no

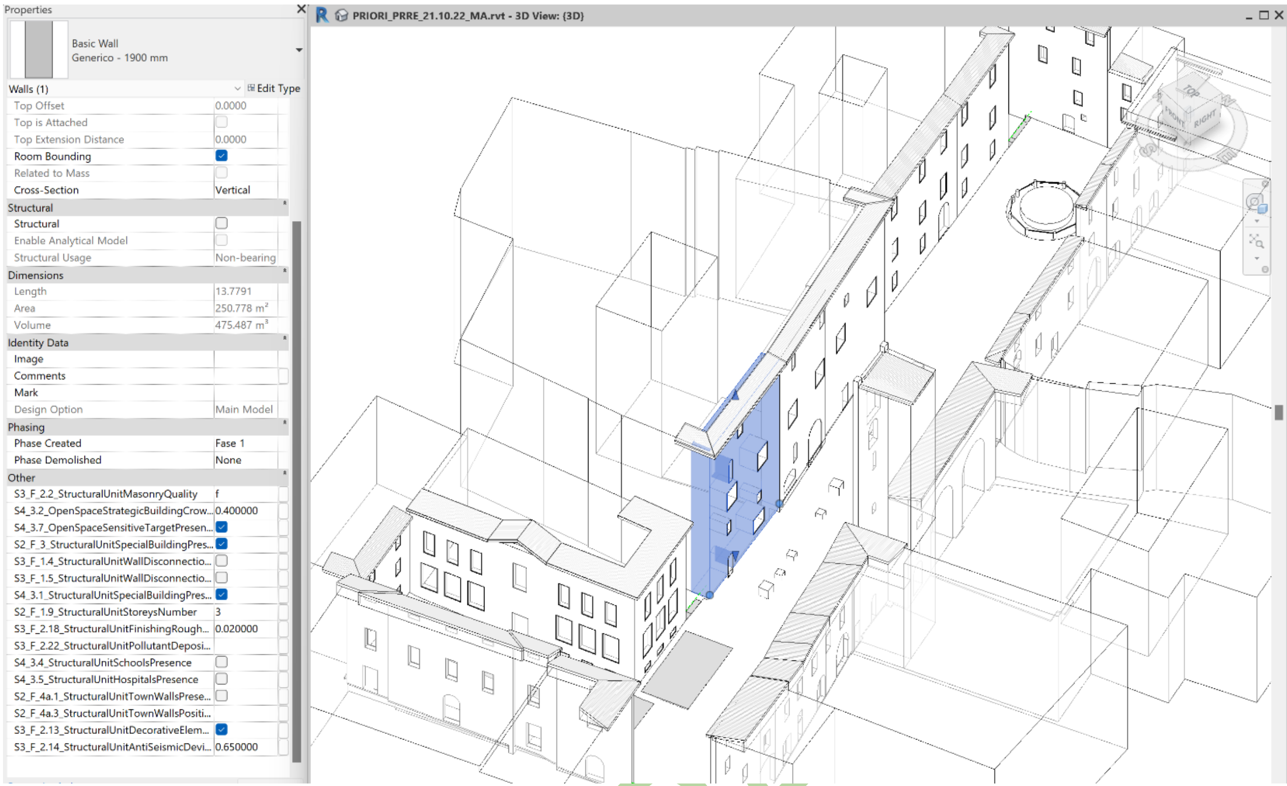


Figure 14: Parameters associated with LL Wall family.

The parameters in Table 15 are associated with the LL family floor, with two instances in the case of Narni being the floor describing the OS of the square in Piazza dei Priori and the floor describing the portico in SU 6a. Notably, in Figure 15 the floor of the square is selected and the relative parameters entered are shown.

Table 15: Fillable parameters for floor family category from the reduced risk matrix from D322 for BET 2A and S-P multi-hazard condition.

	Paving - Floor	square	porches in 6a
S2_F_4b	presence		yes
S2_F_4b.3	position		154° clockwise
S2_F_5a	presence of green area	no	
S2_F_5a.6	Green Area Position (related to LS or AS)	0	
S2_F_5a.7	green area density	0	
S2_F_5b.1	Presence of Water	no	
S2_F_6	slope	no	
S2_C_5a	Presence of Green area	no	
S2_C_5a.4	extension (area)	0	
S2_C_5a.6	Greenery adsoprtion capacity	0	
S2_C_5a.10	Tree crown diameter	0	
S3_F_2	homogeneous/not homogeneous	Homogeneous	
S3_C_2.3	Pavement finishing current roughness	0.02	

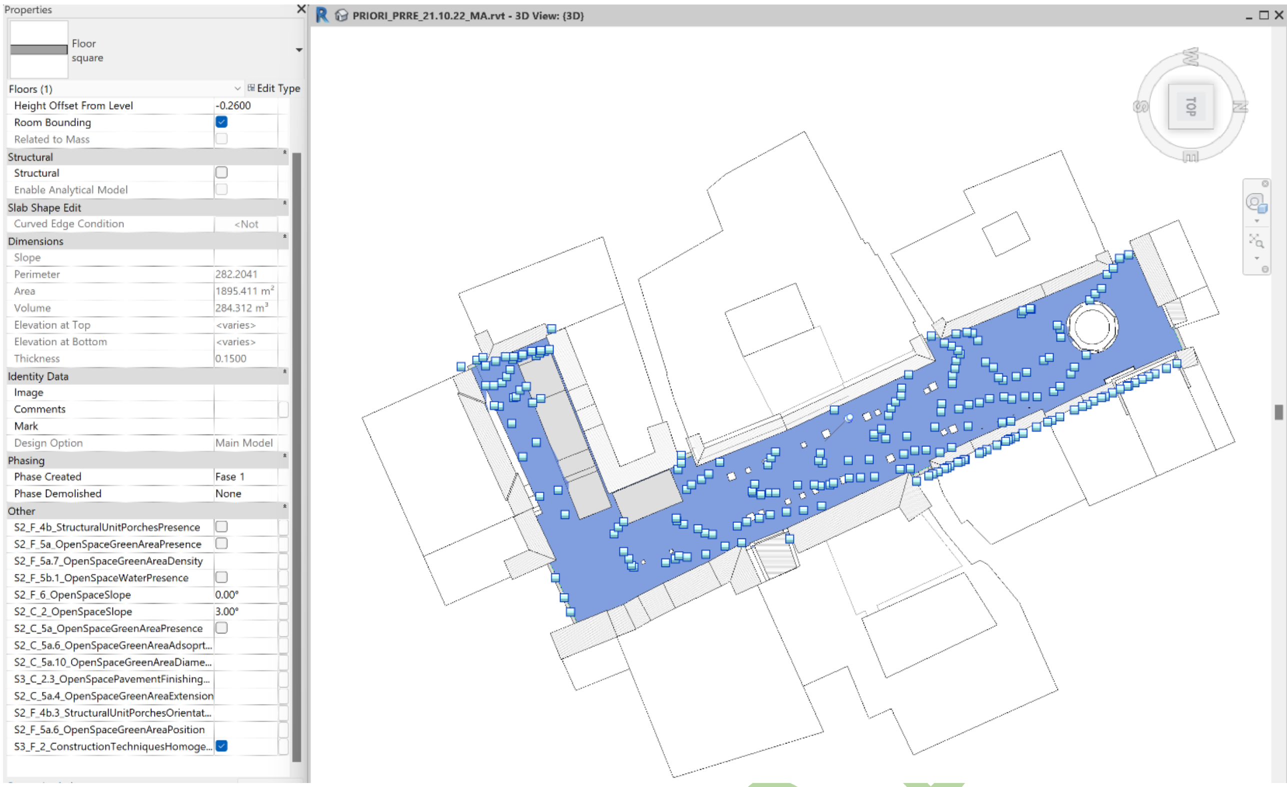


Figure 15: Parameters associated with LL Floor family.

As regards the road family, the only fillable parameter is the position/orientation of the access in relation to the N-S axis. Although the shape of Piazza dei Priori is complex and with a certain degree of irregularity in the frontier continuity, in Table 16 there are 4 values for the 8 accesses to the square, 90° apart.

Table 16: Fillable parameters for road family category from the reduced risk matrix from D322 for BET 2A and S-P multi-hazard condition.

	Access- road	8-1	1-2	2-3	3-4	4-5	6-7	7-8
S2_F_2.3	position/orientation (azimuth)	64°	154°	244°	334°	64°	64°	64°

The next step was to fill in the HL family parameters, point i of Table 5, which are the only ones left empty in GMs and space.

In the specific case of GMs, although in the case of Narni there is a homogeneity of association between the parameters in Table 14 and a specific SU (columns), only the parameters in Table 17 S3_F_1.2 last intervention period and S3_F_1.3 state of conservation are actually associated with the HL family GM, thus with the SU. Notably, in Figure 16 SU 6a is selected because it is the one with the greatest number of fields entered as it is a special building with porches, the period of last intervention is known and it has the presence of a school.

Table 17: Fillable parameters for GM family category from the reduced risk matrix from D322 for BET 2A and S-P multi-hazard condition.

	SA	1	2	3		4	5		6			7			8	
	SU - Generic Model	1a	2a	3a	3b	4a	5a	5b	6a	6b	6c	7a	7b	7c	8a	8b
S3_F_1.2	last intervention period	n/d	n/d	n/d	n/d	n/d	n/d	n/d	2010-2020	n/d	n/d	n/d	n/d	n/d	n/d	n/d
S3_F_1.3	state of conservation	H	H	H	M	H	H	M	H	H	H	H	H	H	H	H

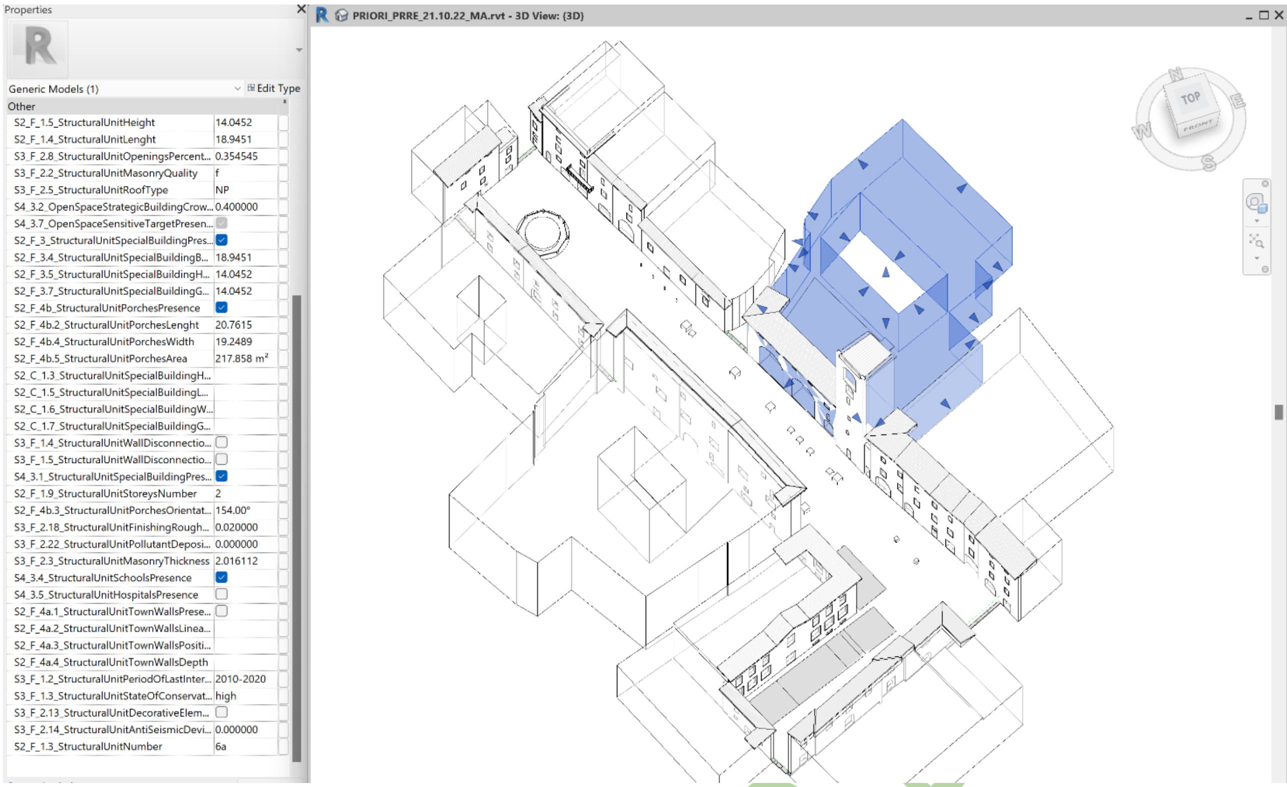


Figure 16: Parameters associated with HL GM family.

With regard to Space, in Table 18 the values to be filled in for the case of Piazza dei Priori in Narni are reported. As previously mentioned, many of these values are the product of external calculations and simulations. For this reason, they have been included as fillable. Figure 17 shows all the parameters entered at the end of the process in the specific space instance describing the square.

Table 18: Fillable parameters for space family category from the reduced risk matrix from D322 for BET 2A and S-P multi-hazard condition.

AS- space		square
S1_0.3	Proximity of sidewalk to traffic	0
S2_F_1.1	% of SA	100%
S4_1.1	people presents	1319
S4_1.2	crowding potential	0.73
S4_1.4	Exposure duration	***
S4_4.2	Traffic intensity	n/d
S4_8.2	presence of Sensitive target (elders/frail/gender/youngsters)	272
S4_8.3	% presence of Sensitive target (elders/frail/gender/youngsters)	21%
S5_1.1	Ground motion severity	PGA = 0,146-0,16
S5_1.2	Seismic microzonation	Zona 2
S5_3.1	Wind/breeze speed	1
S5_3.3	Air temperature	6
S5_3.4	Solar Irradiation	370
S5_3.6	Pollutant concentration	NO2=15; O3=9; PM10=13; PM2.5=30
S5_4.2	Pollution sources presence Boolean	no
S5_5.1	classes of types	T1
S5_5.2	Ground roughness	0.02

***	Day hour	1	2	3	4	5	6	8	9	10	11	12

Value	0.42	0.38	0.38	0.38	0.38	0.38	0.36	1.09	1.23	1.25	1.32
Day hour	13	14	15	16	17	18	20	21	22	23	24
Value	0.62	0.61	1.32	1.27	1.27	0.52	0.66	0.66	0.66	0.66	0.54

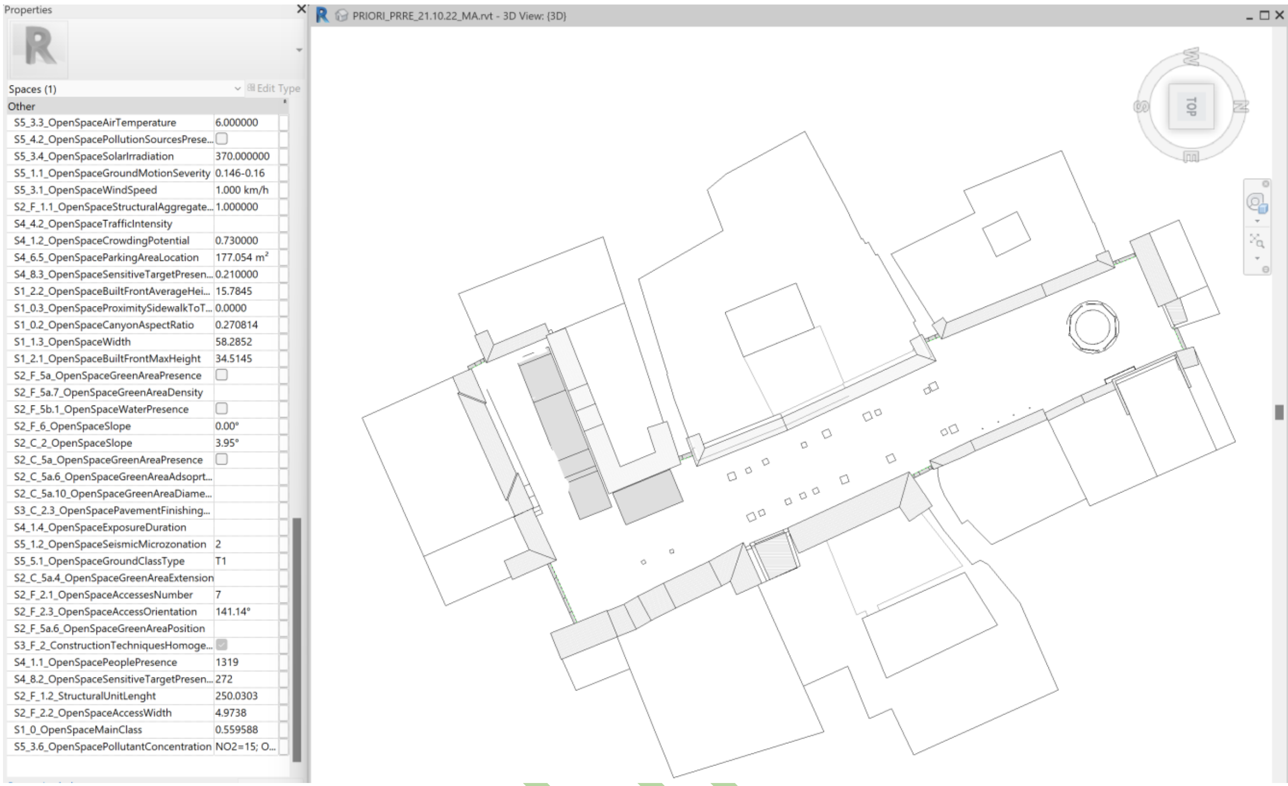


Figure 17: Parameters associated with HL Space family.

3.3 Specification and digital content requirements in selected case studies and hazard scenarios

According to the procedures illustrated in Section 2.4, the Virtual Environment for Narni has been edited using 3DVista® software. The VE is divided in two parts, the Menu that show general information about the OS, including the orientation map (LoR B) with the interactive radars, specific parallel thematic Virtual Tours to show information about the hazard scenario and intrinsic vulnerabilities. In addition, in the left/bottom, several hotspots are inserted to recall general information, including links to the BIM model and the point cloud (Figure 18).

Figure 18 Interface of the Virtual Environment for Piazza dei Priori, Narni

The Main View shows the reality-captured (a) or BIM-based (b) equirectangular pictures in spherical projection (LoR A) Figure 19.

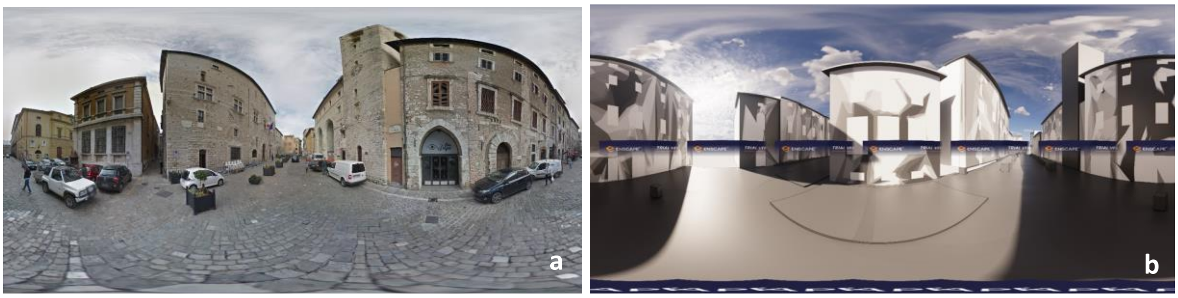


Figure 19 Reality-captured equirectangular photo (a) and BIM-based equirectangular photo (b) of Narni for 360° view in LoR A

Figure 20 highlights with over-imposed annotations the modality with which the OS is represented in the VE in LoR A (yellow polygon) and LoR B (blue polygon), giving a clue about the morphological configuration an appearance characteristics of Piazza dei Priori.

Each single BE element can be shown in the VE as well, to provide information about its presence or absence and support experts in compiling some of the parameters and indicators required for risk modelling and assessment that can be recognized directly with visual inspections. In particular, the procedures of representation (LoR A, LoR B, LoR C) of each indicator are defined in D3.2.2, per each BET and risk scenarios.

Figure 20 Level of Representation A and B of Open Space (OS) in a Virtual Tour (VT)

Figure 21 Level of Representation A and B of Building Front/Special Building (BF) in a Virtual Tour (VT)

Differently from BIM modelling, the central VE collects and displays indicators with a different granularity that is not parametric but digital content-based, as infographics grouping data and images to friendly explain the knowledge.

As the Piazza dei Priori falls under the BET **2A** and hazard combination of **S-P**, the information to be organized within the VE are the indicators related to that scenario in D3.2.2 and reported in Table 19.

Table 19 Reduced risk matrix from D322 for BET 2A and S-P multi-hazard condition. For each risk factor is specified the Level of Representation (LoR), based on D313 (§6) and D322 (§7); the digital content and related format file; localization in the VE.

BET multi-hazard parameters				VE implementation D331		
Code	Description	Descriptor code	Descriptor	LoR	Digital content of LoR C	MENU/MAIN VIEW

SECTION 1: MAIN TYPE						
S1_0	Morpho-typology	P1	Main class (compact/ elongated/very elongated)	LoR B + LoR C	- JPEG (orientation map) - URL (BIM model, point cloud, documentation)	MENU
		S1_0.2	Canyon aspect ratio	LoR C		MENU
		S1_0.3	Proximity of sidewalk to traffic	LoR C		MENU
S1_1	Dimension of OS	S1_1.3	Width	LoR C		MENU
S1_2	Hmax built front	S1_2.1	H max	LoR C		MENU
		S1_2.2	Average building height	LoR C		MENU
SECTION 2: CHARACTERISTICS OF GEOMETRY AND SPACE						
Frontier						
S2_F_1	Type of Aggregates	S2_F_1.1	% of SA	LoR C	- PDF (technical sheet) - *Also available in linked BIM model in MENU*	MAIN VIEW
		S2_F_1.2	length of the built front	LoR C		MAIN VIEW
		S2_F_1.3	Number of SU	LoR A + LoR C		MAIN VIEW
		S2_F_1.4	Length of SU	LoR C		MAIN VIEW
		S2_F_1.5	Height of SU front	LoR C		MAIN VIEW
		S2_F_1.9	Number of storeys	LoR A + LoR C		MAIN VIEW
S2_F_2	Accesses	S2_F_2.1	Number	LoR A + LoR B	- PDF (technical sheet) *Also available in linked BIM model in MENU*	MAIN VIEW
		S2_F_2.2	Width	LoR C		MAIN VIEW
		S2_F_2.3	Position/orientation (azimuth)	LoR C		MAIN VIEW
S2_F_3	Special buildings	P5	Presence	LoR A+ LoR B+LoR C	- PDF (technical sheet) *Also available in linked BIM model in MENU*	MAIN VIEW
		S2_F_3.4	Length of special buildings front	LoR C		MAIN VIEW
		S2_F_3.5	Height	LoR C	- PDF (technical sheet) *Also available in linked BIM model in MENU*	MAIN VIEW
		S2_F_3.7	Height of gable	LoR C		MAIN VIEW
S2_F_4a	Town walls	S2_F_4a.1	Presence	LoR A + LoR B		MAIN VIEW
		S2_F_4a.2	Linear extension	LoR C		MAIN VIEW
		S2_F_4a.3	Position	LoR C		MAIN VIEW
		S2_F_4a.4	Width or depth	LoR C		MAIN VIEW
S2_F_4b	Porches	P7	Presence	LoR A + LoR B+ LoR C	- PDF (technical sheet) *Also available in linked BIM model in MENU*	MAIN VIEW
		S2_F_4b.2	Linear extension	LoR C		MAIN VIEW
		S2_F_4b.3	Position	LoR C		MAIN VIEW
		S2_F_4b.4	Width or depth	LoR C		MAIN VIEW
		S2_F_4b.5	Area	LoR C		MAIN VIEW
S2_F_5a	Green area	P9f	Presence of green area	LoR A + LoR B + LoR C	- PDF (technical sheet) *Also available in linked BIM model in MENU*	MAIN VIEW
		S2_F_5a.6	Green Area Position (related to LS or AS)	LoR C		MAIN VIEW
		S2_F_5a.7	Green area density	LoR C		MAIN VIEW
S2_F_5b	Water	S2_F_5b.1	Presence of Water	LoR A+LoR B		MAIN VIEW
S2_F_6	Quote differences/slope	P8f	Slope	LoR C	- PDF (technical sheet) *Also available in linked BIM model in MENU*	MAIN VIEW
Content						
S2_C_1	Special buildings	S2_C_1.3	Height	LoR A + LoR B + LoR C	- PDF (technical sheet) Also available in linked BIM model in MENU	MAIN VIEW
		S2_C_1.5	Lenght	LoR A + LoR B + LoR C		MAIN VIEW

		S2_C_1.6	Width	LoR A + LoR B + LoR C		MAIN VIEW
		S2_C_1.7	Height of gable	LoR C		MAIN VIEW
S2_C_2	Quote difference/slope	P8	Slope	LoR C	- PDF (technical sheet) - Also available in linked BIM model in MENU	MAIN VIEW
S2_C_5a	Green area	P9c	Presence of Green area	LoRA+ LoR B	- PDF (technical sheet) *Also available in linked BIM model in MENU*	MAIN VIEW
		S2_C_5a.4	Extension (area)	LoR C		MAIN VIEW
		S2_C_5a.6	Greenery adsorption capacity	LoR C		MAIN VIEW
		S2_C_5a.10	Tree crown diameter	LoR C		MAIN VIEW
	SECTION 3: CONSTRUCTIVE CHARACTERISTICS					
Frontier						
S3_F_1	Homogeneity of built environ. age	S3_F_1.2	Last intervention period	LoR A + LoR C	- PDF (technical sheet) *Also available in linked BIM model in MENU*	MAIN VIEW
		S3_F_1.3	State of conservation	LoR A + LoR C		MAIN VIEW
		S3_F_1.4	Wall disconnection in plan	LoR A + LoR C		MAIN VIEW
		S3_F_1.5	Wall disconnection in elevation	LoR A + LoR C		MAIN VIEW
S3_F_2	Homogeneity of constructive techniques	P6	Homogeneous/not homogeneous	LoR A + LoR C	- PDF (technical sheet) *Also available in linked BIM model in MENU*	MAIN VIEW
		S3_F_2.2	Masonry quality	LoR A + LoR C		MAIN VIEW
		S3_F_2.3	Wall thickness	LoR C		MAIN VIEW
		S3_F_2.5	Roof types	LoR C		MAIN VIEW
		S3_F_2.8	% openings	LoR C		MAIN VIEW
		S3_F_2.13	No-structural protruding and decorative elements	LoR A + LoR C		MAIN VIEW
		S3_F_2.14	Anti-seismic devices	LoR A + LoR C		MAIN VIEW
		S3_F_2.18	Facade finishing current roughness	LoR C		MAIN VIEW
		S3_F_2.22	Facade pollutant deposition capacity	LoR C		MAIN VIEW
Content						
S3_C_2	Pavement condition	S3_C_2.3	Pavement finishing current roughness	LoR C	- PDF (technical sheet) *Also available in linked BIM model in MENU*	MAIN VIEW
SECTION 4: CHARACTERISTICS OF USE						
S4_1	Crowding	S4_1.1	People present	LoR A+ LoR B	- PDF (technical sheet) *Also available in linked BIM model*	MENU
		S4_1.2	Crowding potential	LoR A+ LoRB+LoR C		MENU
		S4_1.4	Exposure duration	LoR C		MENU
S4_3	Strategic building / Special uses of building facing OS	S4_3.1	Presence of special buildings or special uses	LoR A + LoR B		MAIN VIEW
		S4_3.2	Crowding potential	LoR A + LoR B + LoR C	- PDF (technical sheet) *Also available in linked BIM model in MENU*	MAIN VIEW
		S4_3.4	Presence of Schools	LoR A + LoR B		MAIN VIEW

		S4_3.5	Presence of Hospitals	LoR A + LoR B		MAIN VIEW
		S4_3.7	Sensitive targets attraction to building use	LoR A + LoR B		MAIN VIEW
S4_4	Accessibility for vehicle	S4_4.2	Traffic intensity	LoR C	- PDF (technical sheet) *Also available in linked BIM model in MENU*	MENU
S4_6	Vehicles (parking)	S4_6.5	Parking area location	LoR A + LoR B + LoR C	- PDF (technical sheet) *Also available in linked BIM model in MENU*	MAIN VIEW
S4_8	Sensitive targets	S4_8.2	Presence of Sensitive target (elders/frail/youngsters)	LoR A + LoR B		MENU
		S4_8.3	% presence of Sensitive target (elders/frail/ youngsters)	LoR A + LoR B + LoR C		MENU
SECTION 5: ENVIRONMENTAL CHARACTERISTICS						
S5_1	Seismic intensity	S5_1.1	Ground motion severity	LoR C		MENU
		S5_1.2	Seismic microzonation	LoR C		MENU
S5_3	Climate conditions	S5_3.1	Wind/breeze speed	LoR C		MENU
		S5_3.3	Air temperature	LoR C	- PDF (technical sheet) *Also available in linked BIM model in MENU*	MENU
		S5_3.4	Solar Irradiation	LoR C		MENU
		S5_3.6	Pollutant concentration	LoR C		MENU
S5_4	Multi-hazard potential	S5_4.2	Pollution sources presence Boolean	LoR A + LoR B + LoR C		MENU
S5_5	Ground type	S5_5.1	Classes of types	LoR C		MENU
		S5_5.2	Ground roughness	LoR C		MENU

The SECTION 2: CHARACTERISTICS OF GEOMETRY AND SPACE – Frontier/Content requires a LoR C, thus the addition of hotspots - localized in correspondence of each identifiable BE element – to open documents (.pdf file) to resume all these data. Figure 22 exemplifies the polygonal hotspot added to the frontier of Loggia dei Priori and Torre Medioevale to open the linked technical documentation in .pdf/.jpeg that comprehends the entire set of related parameters with explicative photos and graphs.

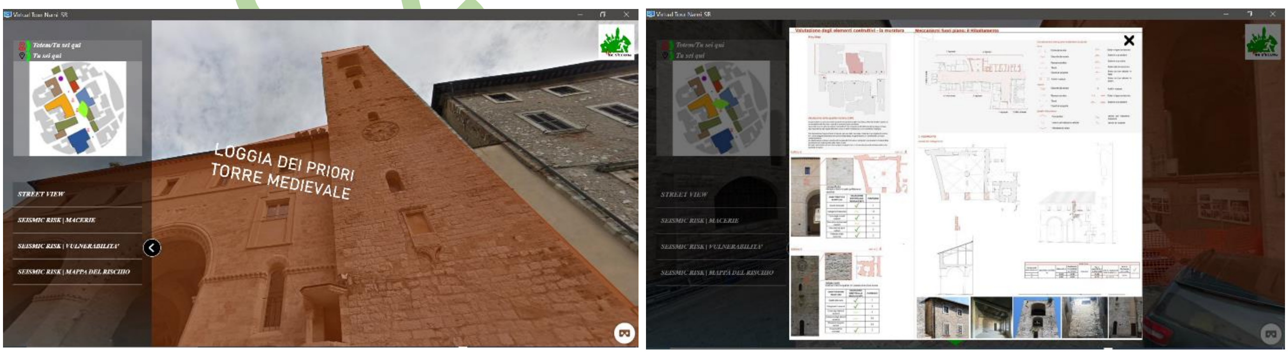
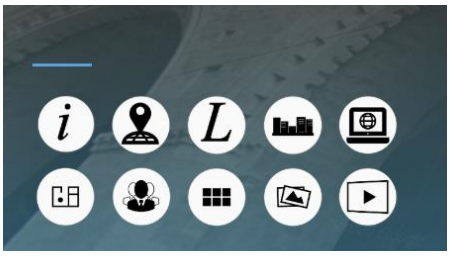
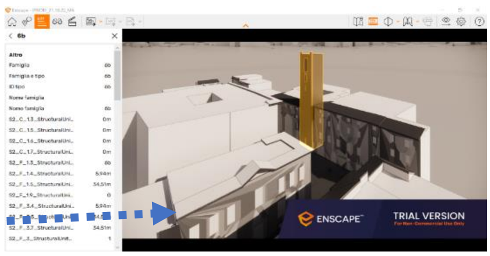


Figure 22. Polygonal hotspot on the Loggia dei Priori and Torre Medioevale to open SECTION 2 technical documentation

Some parameters and indicators are also available in the BIM model web linked in the MENU to the shared file on https://autode.sk/3mCoPn9, that is viewable only on-desk, and or with Enscape for immersive VR (Figure 23).





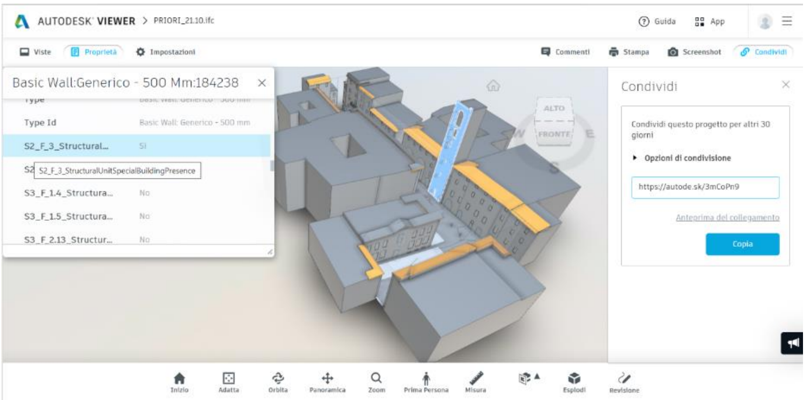


Figure 23. Fruition of BIM model in the VE for parameter/indicator consultation by experts.

4 Conclusions

The representation of BE in BIM-based model raises the issue of the implementation, both in term of geometric model and information details. Considering the meso-scale nature of the OS in the BE, this deliverable presents a workflow to use the BIM-based models for a specific BET case study representation to collect the information for BETs classification and analysis for the specific case study of Piazza dei Priori in Narni. The Deliverable is presented as an extension of the D3.1.2 results through the implementation of vulnerability, exposure and hazard parameters.

Starting from the transposition of BET-dependant reduced risk parameters matrix from D3.2.2, notably BET 2A and S-P multi-hazard condition, 77 parameters were implemented in BIM with a specific IFC compliant coding, associated to High Level (HL) and Low Level (LL) family category and divided between computable and fillable. Specific recurrences in the parameter processing allowed to highlight 3 main parameter categories, from which a set of node groups in Autodesk Dynamo was structured to allow maximum automation in parameter input and inheritance, less error prone as possible. Consequently, the Dynamo node package is one of the outputs of the Deliverable work to reproduce the analysis to other case studies, in particular for the goals of D3.3.2.

The workflow developed in this report will be further extended through the application to other case studies in D3.3.2 with other MH combinations. Moreover, to allow a more direct comparison between these case studies a common ground between BIM and GIS logic has been followed to describe the BE with interoperable geometric and informative elements, specifically the OS and the SU, which can be exported in 2D geometries to generate a GIS file with all the parameters inherited from the LL family.

Therefore, the present work presents implementation potentialities with the association of the novel BIM Property set BeS2ecure to the OSM parameters, with a reverse procedure with respect to the one of D3.2.1 (parameter extraction) to upload the GIS file and make it OPEN. Consequently, a comparison between GIS export of the different case studies from D3.3.2 and OSM geometries based on satellite data and uploaded by other users extracted for D3.2.1 will allow a complex reading of these OSs.

The same BIM model can be used within the VR-centric workflow based on Thematic Virtual Tours providing several digital contents according to specific objectives and knowledge to be shared. In fact, the BIM model can provide virtual spherical images of the Open Space, but also it can be consulted after its web publication, maintaining the relationship between each BIM element and its properties. Nevertheless, the working group could not have available BIM models and point cloud because of reduced economic and human resources, but the central Virtual Environment continue to be a possible and auto sufficient tool in risk management and communication, as it can manage digital contents as well, even if with different level of granularity that is not the parametric one, but based on documentations and infographics.

5 Abbreviations

AS - Areal Space

BE – Built Environment

BET – Built Environmental Typology

BIM – Building Information Model

GIS – Geographic Information System

GM – Generic Models

HL – High Level

LL – Low Level

LS - Linear Space

OS – Open Space

SA – Structural Aggregate

SLOD – SLow-Onset Disaster

SU – Structural Unit

SUOD - SUdden-Onset Disasters

6 References

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7 Appendix

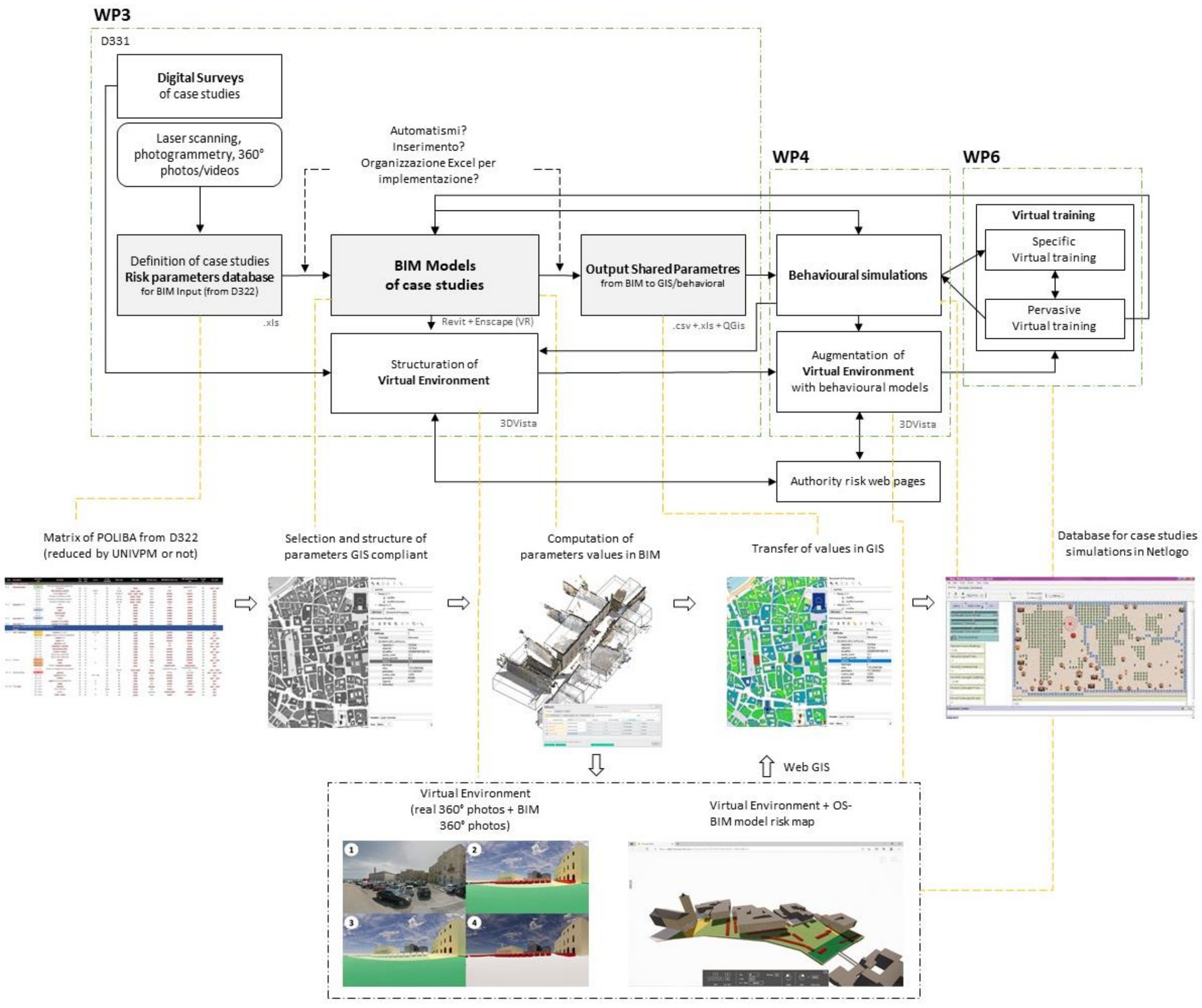

Figure 1: Proposed workflow for D331 in relation to the following research phases.