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

T3.1 - Definition of representative BETs models prone to both SUOD and SLOD. BE characterization 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

The problem of architectural heritage representation in BIM-based model is a debated topic in literature. The complex and variety of geometry and features of existing buildings raise the issue of their representation, both in term of geometric model and information details. Moreover, in the recent literature much attention is given to the organization of work-flow from the survey and data acquisition phase to the implementation phase, but mostly of them are focusing on single buildings or small aggregate. In line with the global objectives of BES2ECURe research project, the aim of this report is to study and develops a method for BETs representation in BIM-based models, that include buildings, infrastructures and open spaces. Considering the Level Of Detail (LOD) progression - introduced as standard in national and international regulations - and the interoperability for the information exchange, the authors develop a specific LOD progression for BETs representation, discuss the parameters implementation in Revit BIM software, and introduce the opportunity to develop a Property Set for the IFC interoperability standard.

Keywords

SUOD, SLOD, BETs, BIM, HBIM, parameters implementation, LOD.

Approvals

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

Revision versions

Revision	Date	Short summary of modifications	Name	Partner
0.1	15.06.2020	Comments to structure and improvements request in view of D3.1.1 activities	Enrico Quagliarini	UNIVPM
0.2	2.10.2020	Coordination with D3.1.1 and D3.1.3 improved	Edoardo Currà Alessandro D'Amico	UNIRM
1.0	6.11.2020	proofreading, integration with D3.1.3, editing, revision in view of WP4 next starting	Fabio Fatiguso Enrico Quagliarini Edoardo Currà	POLIBA UNIVPM UNIRM

Summary

1. Introduction to WP3 progress: BIM for BETs description

According with the structures of the Be2Secure research plan, the Work Package 3 aims to provide representative models of Built Environment Typologies (BETs) prone to SUOD/SLOD. In particular the Task 1, give the definition of BETs and their representation, taking into account both morphology and construction technologies of the BE, and develop tools and methods for BETs representation in extensive models BIM-based and in fast models (VR/AR oriented).

In view of above, this deliverable explores the opportunity to use the BIM-based models both to represent the BET with a 2D/3D model and to collect the information for BETs classification and analysis (according to D311), developing the concept of LOD for medium-scale models, i.e. the Open Space in BE. 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 behavior representation (Figure 15; Figure 16).

1.1 BIM for heritage: the concept of HBIM

As mentioned above, the need of collecting information is central. Moreover, investigating the building system of a historic architectural organism means investigating the material expression of the choices made by those who have contributed over time to the realization and modification in the span of the life cycle of a specific built organism. As Enrico Mandolesi stated: «A singular building apparatus corresponds to every building organism (both repeatable and unrepeatable). That is to say that system, and not others, that coherently integrates itself within the spatial conception that is the raison d'être of the organism itself» (Mandolesi 1978). This cognitive process of construction, fundamental for the evaluation, management and conservation of historical heritage, takes place in the opposite direction to the original action of the project; it is an integral part of the action of the new project, and is one of the most characteristic elements of the process. Survey tools, long supported by digital evolution (Murphy et al. 2009) are functional to the geometric and constructive definition of the building organism, and are available to the scholar and the professional to allow the definition of nature and composition of the construction elements within the defined geometry as much as possible.

In this sense, BIM related innovation according to (ISO 2018a; Castaing et al. 2019) is now focused on the interconnection among the Project Information Model (PIM), which relates to the design and construction stages of an asset, and the Asset Information Model (AIM) about the operation and maintenance of the built asset. The applications of BIM beyond the construction stage into the asset lifecycle (6D) are being revealed through significant research and professional works (O'Shea and Murphy 2020). Migrating from PIM to AIM in a new building project can be achieved by means of smart building sensors, Internet of Things, cloud-based integration, all subject to intense innovation.

To extend the adoption of AIM's to existing buildings, the present work provides insights into undertaking such a process. (Volk et al. 2014) outlined three challenging areas: the automation of capturing existing building, the updating and maintenance of BIM information beyond the constructions phase and the handling of uncertain data. This would include the creation of digital models and databases of existing buildings through point cloud and laser scanning technology. The application of this approach in conservation engineering capturing geometrics of culturally significant monuments is now known as Heritage Building Information Modelling or H-BIM (Murphy et al. 2009).

Despite the acknowledged advantages of BIM in the AEC (Architecture, Engineering & Construction) industry for new construction, the extension of this methodology to existing Built Environment (BE) requires specific considerations (Brusaporci et al. 2018). The uniqueness of such constructions is not only inherent in the relationship of sub-building systems and components at the level of the building organism but is also to be placed at the level of the functional building components themselves. For pre-industrial building the adoption of libraries of sub-system families is necessary, with specially structured parametric components (Mandolesi 1978; Apollonio et al. 2012; Sampietro et al. 2018), in order to ensure the inclusion in the model of construction characteristics upon which we base the working hypothesis: materials, construction technique, conservation status (Apollonio et al. 2012). From this perspective, HBIM is a process in which inter-scalar relationships are possible. It involves geometric modeling and referencing information on the properties of parameterized architectural elements based on the highest standards of a past constructive culture. To interpret it, treatises, manuals and historical technical literature, archive documents, and above all the experience of the operator and non-destructive investigations converge. The construction of the HBIM model is achieved when it is possible to obtain a coherent parametric and constructive definition of the constructive elements, within the geometry offered by the integrated digital survey. This representation of BE allows the assessment of the correspondence to the state of the art and the value of different levels of performance.

1.2 Research aims

In this deliverable, the authors develop a work-flow for the generation of BET's (Built Environment Typologies) models in BIM environment, starting from the state of the art of the consolidated literature, codes and standards about BIM geometry and metadata description (Figure 1). This process is possible by taking into account the actual need of geometry and data complexity in the BIM development, depending on the BIM used declared. In this sense, the deepening of geometry modelling and parameters implementation will be central to obtain a BET's BIM model without information waste.

Therefore, the process of BETs' representation through BIM model includes three phases: the geometric modelling, informative deepening and their synthesis in BET parameters implementation. In view of this process, the authors introduce an updated and specific definition of the Level Of Detail (LOD) – nowadays standard in national and international regulations – for the BET representation, according to the medium-scale nature of BETs and the specific requirement of each next interoperability phase planned (i.e. GIS analysis, behavioural design simulations, and VR/AR simulations). The representation of the BETs through BIM models is preparatory towards the next steps of the research project for risk assessment considering human behaviour and the consequent interoperability needs.

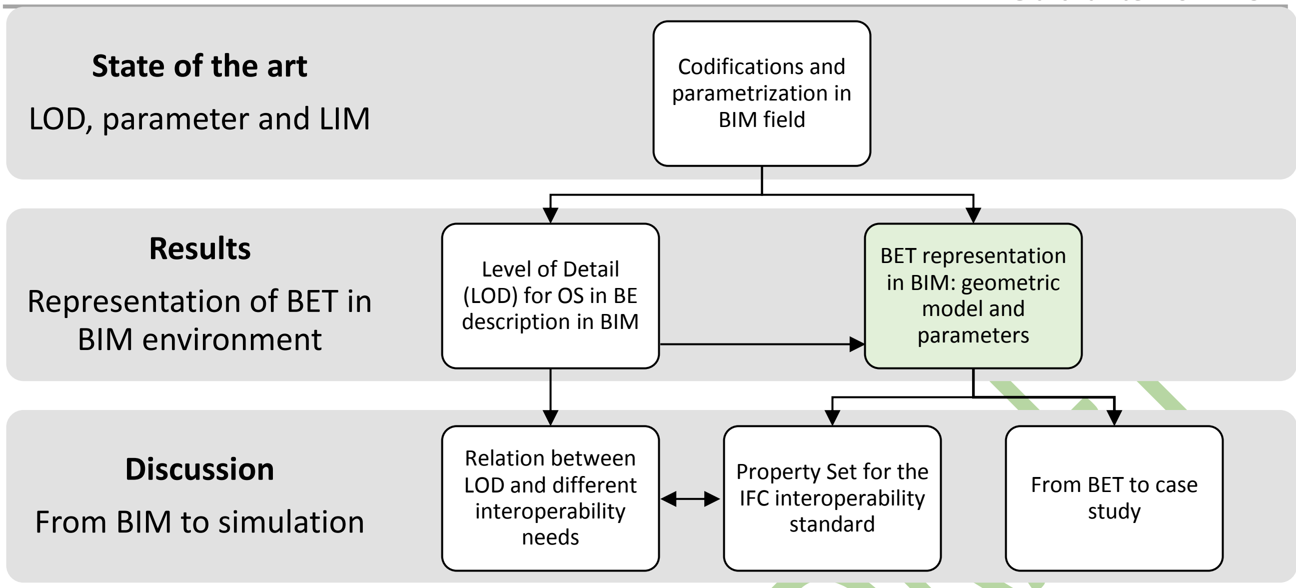


Figure 1: Synthesis of structure of the report and its contributions.

2. State of the art

2.1 Codifications and parametrization in BIM field

Referring to ISO 19650 (ISO 2018a) BIM definition is the use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions. In this sense, the words “built asset” that replace the word object of the previous version, is intended as item, thing or entity that has potential or actual value to an organization (ISO 55000:2014, 3.2.1, modified) and include, but are not limited to, buildings, bridges, roads, process plants (ISO 29481-1:2016, 3.2, modified).
Focusing on existing BE, in recent years the generation of HBIM models has been characterised by the production of simplified and complex models, underlining how the lack of established methods and guidelines led to free interpretation of modelling practices and project objectives (Brumana et al. 2019).
In this perspective, the problems of detail, geometry and accuracy require a new definition, as it becomes crucial that any HBIM model is labelled for its accuracy, purpose and significance.
The focus of this deliverable starts from the architectural scale, the specification conventionally adopted for the surveying, extend them to the HBIM domain, particularly in object modelling. An explicit value to measure the model accuracy could help to take informed decision and to use such models with a better knowledge of their contents by the different stakeholders. For this reason, together with the architectural scale with all its richness and complexity, it should be introduced the urban scale focus, where the HBIM turns toward the GIS domain (HBIM-GIS), starting from the city model accuracy, with a detail specific for that scale, enriched by many information together with specific geometric data integration (Matrone et al. 2019; Colucci et al. 2020). It often happens that the geometry complexity describe by the 3D volumetric representation of the single objects is sometimes derived from the skilled capacity more than from the geometric characteristic of the object itself. Moreover, geometry modelling is sometimes adopted with no reference to the required scale and to the specificity of the object.

The publication of ISO 19650-1:2018 (Concept and principles) (ISO 2018a) and ISO 19650-2:2018 (Delivery phase of assets) (ISO 2018b) in December 2018 defined a new standard for organising information about construction works. Through the mechanism of direct adoption of Vienna Agreement, the ISO 19650:2018 becomes European (EN) and national standard for each member state in 2019, as for Italian UNI EN ISO 10650-1 and UNI EN ISO 19650-2: 2019. The standards sets out the recommended concepts and principles for business processes across the built environment sector in support of the management and production of information during the life cycle of built assets (referred to as "information management") when using BIM, and explains that these processes can deliver beneficial business outcomes to asset owners/operators, project clients, their supply chains, and those involved in project funding including reduction of risk and reduction of cost through the creation and use of asset and project information models (ISO 2018a).
An EU BIM Task Group Handbook (EUBIM Task Group 2016) refers to ISO/TS 12911:2012 (ISO 2012) for a consistent description of BIM as a process or method of managing information related to facilities and projects to coordinate multiple inputs and outputs, using shared digital representations of physical and functional characteristics of any built object, including buildings, bridges, roads, process plant. The Task Group recognises a major benefit of using BIM as it allows, based on experience learned from real cases, to work according to strict and clear instructions regarding the detail, granularity, content and structure of the data to be generated. The process contributed to a more reliable and coherent design delivery process. The introductory chapter to the ISO 19650:2018 standard presents BIM not only as a 3D tool for managing digital information but also as a new approach to managing projects where digital information is being exchanged between contract parties at all stages of a project, including design, procurement, commissioning and construction. The outcome of BIM is a 'digital twin' of the asset to be constructed.

2.2 Level of Information Need for BIM model description

ISO 19650:2018 also introduces an important novelty in the model development description by defining the Level of Information Need as a framework that defines the extent and granularity of information to prevent waste of too much information. ISO committee has decided to refuse to use any acronym for this, to underline there is no tool for that.
In the past, with drawings, the 'granularity' of information was determined by scale or by a person's capacity to draw and to read a line on a drawing. With digital information, however, there is no physical limitation. The purpose drives the information to be embedded in the model. The level of information need is therefore developed to assure that the information is implemented in the model at the time it is needed to fulfil its purpose. It should take into account the specificities of data drops, domains and BIM uses which cannot be covered by single parameters, such as the outdated concept Level of Development (LOD coming from BIM Forum (BIMForum 2019a) or UNI 11337-4:2017 (UNI 2018)). The European Committee for Standardization (CEN) is publishing a guidance document to support the level of information need concept.
The level of information need drives the need to investigate different ways to deliver the relevant information, fit for purpose, and refers to three main approaches not defined in the ISO 19650-2018:

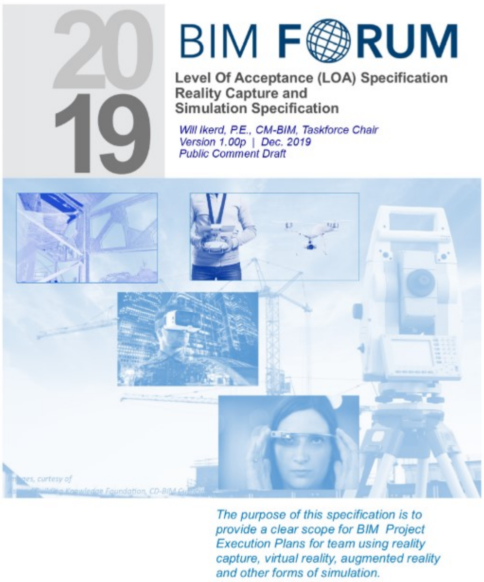
- Level of geometry:
  The geometric accuracy of the elements represented, by specifying also which parts of the element can be ignored or simplified in view of specific BIM uses such as clash detection.
- Level of information:
  The semantics to be attached to the object, including properties, material, etc.
- Level of documentation:
  The kind of documentation to be associated to the object.

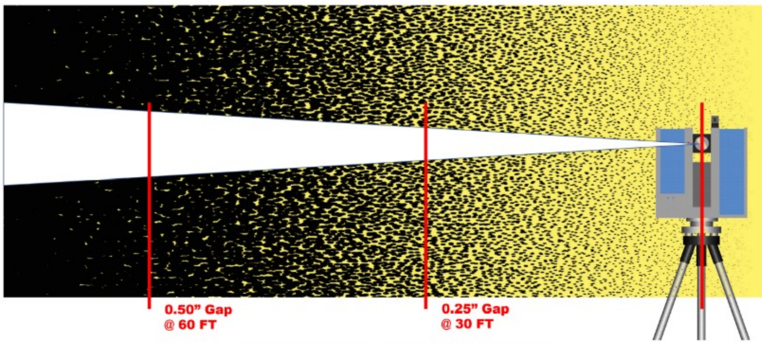
These three concepts are not exhaustive because, for instance, the accuracy of the “level” could be linked to the geometry or information. They have nothing to do with the status of the information in the delivery process (metadata) but the granularity of the information to be used for a dedicated purpose such as a BIM use or a data drop. The level of information need is a critical part of each BIM use, since the analyses and deliverables directly rely on information available in the BIM model. In this sense, the level of information need should be defined from very early on in the project stages, and must be agreed upon by all project participants, as it will influence the amount of information later on in the project, and facilitate other BIM uses which might not be required immediately. ISO is working to publish a more detailed documentation to help implement the level of information need concepts in a standard way. Nevertheless, Level of Information Need can be provided in a number of forms referring to the previous concepts of LOD that the AIA BIM Forum (BIMForum 2019a), the BS/PAS or the UNI 11337:(2015-2017-2018) (UNI 2018) defined as graphical or textual descriptions, and other projects use a more structural or descriptive approach. Some national guidance is emerging, with approaches based on similar concepts (Castaing et al. 2019).

2.3 Consolidated indices for BIM geometry and information description

Even if the Level of Information Need is a novelty in BIM, it is important to have a base for a clear understanding of the concept, through a comparison with the common LOD standard concept, taking into account the evolution requirement of ISO 19650:2018. In this way, instead of proposing a new separate modelling guideline, it is possible to integrate definition on model segmentation requirements. For the summary of the abbreviations see section 7.

The reliability of the information is the base for the validation and reliance of an HBIM model. Therefore, according to consolidated publications (Brusaporci et al. 2018; UNI 2018; BIMForum 2019a; Currà et al. 2019; Maiezza 2019) beyond the LOD (Level of Development), divided into the two components of the Level of Geometric attributes (LOG) which represents the graphic development of objects, and of the Level of Information (LOI) which indicates the information level of all available non-graphical information (Figure 4), LOR (Level of Reliability) has been developed and proposed (Bianchini and Nicastro 2018; Maiezza 2019). As well as LOD, LOR is also characterized by two parameters: Level of Accuracy (LOA) or Level of Acceptance (LOA in (BIMForum 2019b) Figure 2), concerning the geometric accuracy measured as deviation of the model from the data of the point cloud, and the Level of Quality of information (LOQ) associated with the quality of the single modelled element (Maiezza 2019).





Element	Captured						
	Tolerance (+/-)	Units	Density (Min)	Units	Gap		Validation
Masonry Wall Joints (3/8")	0.38	IN	1600	PT/SQ FT	0.300	In	2
Machine Aligment Dowels	0.005	IN	300	PT/SQ FT	0.693	In	1
Curtian Wall Extrusions	0.01	IN	400	PT/SQ FT	0.600	In	0
Civil Utlities	6	IN	2	PT/SQ FT	8.485	In	0
Surface Contours	6	IN	1	PT/SQ FT	12.000	In	1
Dry Wall	0.25	IN	80	PT/SQ FT	1.342	In	1

Figure 2: BIMForum Level of Acceptance (LoA) specification for different element accordig to Uniformat (BIMForum 2019b)

As regards the quantification of LOD and LOR, while the first follows a consolidated standardization, with numerical quantification in the international context (LOD from 100 to 400 in (BIMForum 2019a) for individual construction elements, according to the Uniformat classification) and quantification in alphabetic classes at national Italian level (from A to G, UNI 113374:2017), the second is proposed with a numerical qualitative scale that varies from 0 to 10 (Bianchini and Nicastro 2018).

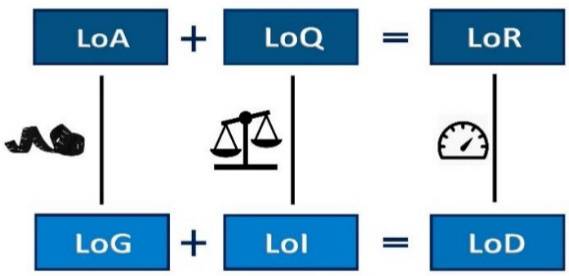


Figure 3: The model's reliability is the synergy of the geometric accuracy (LoA) and the quality of information sources (LoQ) (Maiezza 2019)

Therefore, the US LOD Specification (BIMForum 2019a) expands upon the LOD schema developed by the American Institute of Architects (AIA) for its E202-2009 BIM and Digital Data Exhibit and updated for the AIA's G202-2013 Project BIM Protocol Form (American Institute of Architects 2013) by providing definitions and illustrations of BIM elements of different building systems at different stages of their development and use in the design and construction process. In particular, as mentioned above, the LOD Specification addresses from LOD 100 to LOD 400 of the AIA's LOD Schema, along with a new level, the LOD 350, which was added between LOD 300 and LOD 400 to better address the information levels required for effective trade coordination (Figure 4). The LOD Specification does not address LOD 500 since that LOD relates to field verification and is not an indication of progression to a higher level of geometry or information.

(Brumana et al. 2019) point out that the choice of the scale deepening of the model depens from the aim of the survey and nowadays HBIM requests, the use of the product, the objects characteristics and state of decay to be detected. For these reason the research group of GIcarus Lab (Banfi et al. 2017; Banfi 2019; Brumana et al. 2019; Stanga et al. 2019) go beyond the traditional definition of "Level Of" (LOD - Level Of Development, LOI - Level Of Information, LOA - Level Of Accuracy, etc) defining "Grade Of" that represents macro sets or phases where different experts have to engage with different types of analysis, while the Level describe specific requirements for sub-BIM fields such as BIM Design, Construction Site BIM Monitoring, BIM for Conservation Plan, BEM (Energy Analysis), BIM for Facility Management, BIM for Infrastructure, etc.

B1010.10 21-02 10 10 10 Floor Structural Frame (Masonry Framing)

Includes: Structural elements required for support of floor construction within basements and above grade. Includes columns, girders, beams, trusses, joists. Includes cast-in-place concrete, precast concrete, unit masonry, metal framed, and wood framed systems. Includes framed and sleeved openings for services. Includes Floor Construction Supplementary Components as appropriate.

Associated Masterformat Sections: 04 20 00

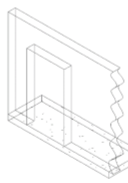
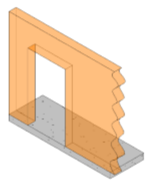
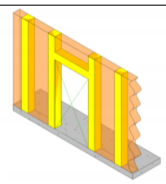
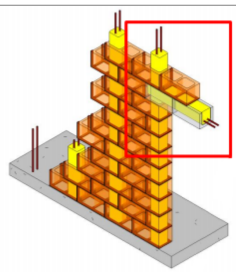
100	See B10	
200	See B10	 *38 B1010.10-LOD-200 Floor Structural Frame (Masonry Framing)*
300	Element modeling to include: • floor element with design-specified locations and geometries	 *39 B1010.10-LOD-300 Floor Structural Frame (Masonry Framing)*
350	Element modeling to include: • Members modeled at any interface with wall edges (top, bottom, sides) or opening through wall • Any regions that would impact coordination with other systems such as but not limited to: o Bond Beam & Lintel Regions o Reinforcing & Embed Regions o Jam Regions o Any other grouted regions	 *40 B1010.10-LOD-350 Floor Structural Frame (Masonry Framing)*
400	Element modeling to include: • Reinforcing • Connections • Grouting Material • Jams • Bond Beams • Lintels • Member fabrication part number • Any part required for complete installation	

Figure 4: Floor Structural Frame (Masonry Framing) LOD in Uniformat Omniclass (BIMForum 2019a)

2.4 Landscape Information Model (LIM) for medium-scale representation

As mentioned in the section 3.3, national and international regulations have introduced standards defining the levels of detail (LOD) related to new buildings, but have not determined a similar scale for the existing buildings or the Built Environment (BE). In this framework, it is necessary to go beyond the definition of modelled objects and information embedded within them for a single building, and translate the concept of LOD (Level of Detail; Figure 5) to the medium-scale towards the representation of BE and BETs in a BIM-based model.

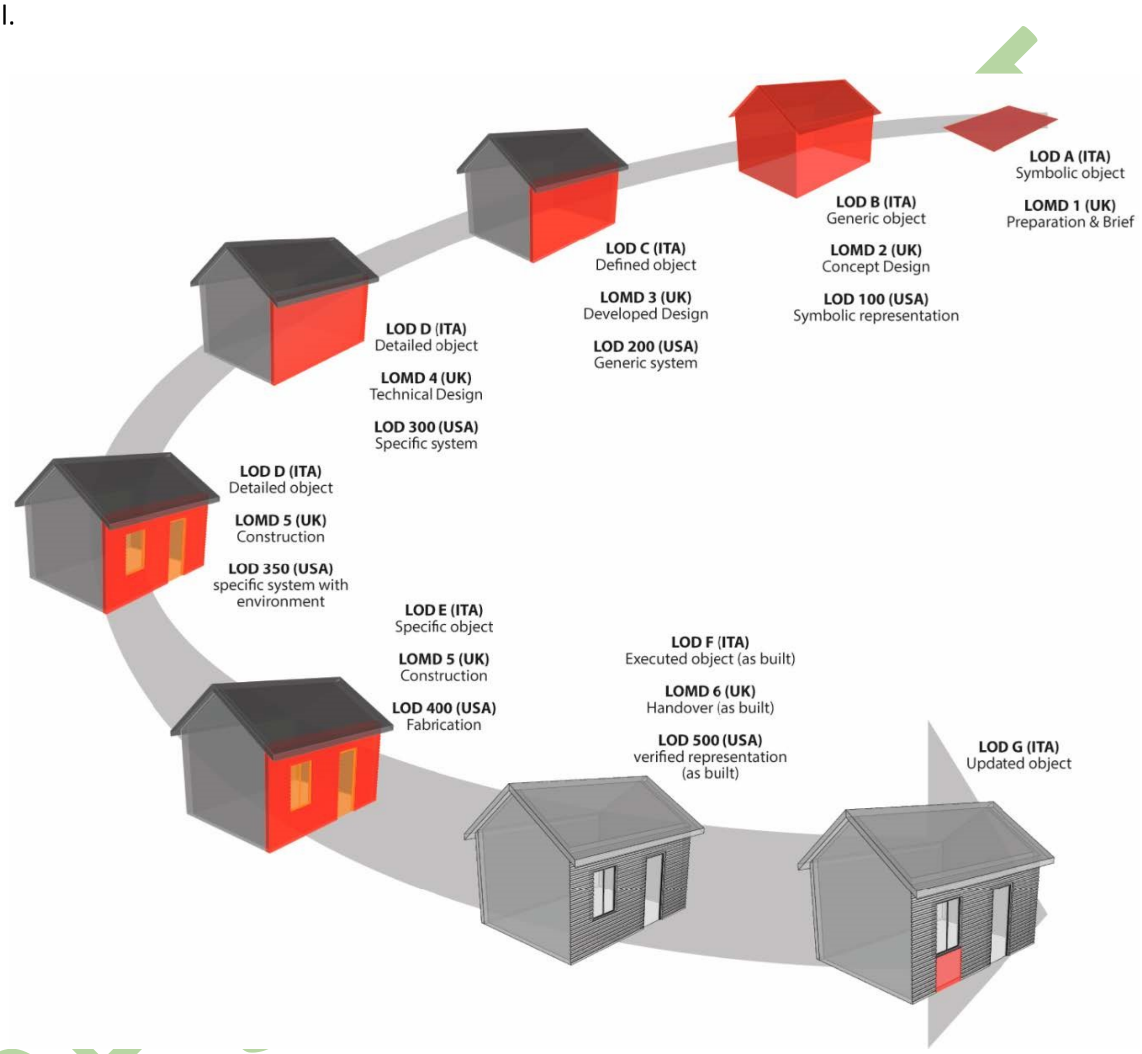


Figure 5: Comparison of Level Of Detail (LOD) in Italy, UK and USA (Carnevali et al. 2019).

Since the BE and the BETs include buildings/aggregates, open spaces and other elements, the literature review took into account both papers about BIM and LIM (Landscape Information Model). While the use of BIM in building and infrastructure planning is already established in both the public and private sectors, it is just beginning to be used in landscape architecture. Although, the IFC standards for landscape elements still need to be defined, the literature in this field could contribute to the purpose.

Discussing the lack of an international standards, (Peters and Thon 2019) present a state of the art of the strategies actually fostered to promote the BIM for landscape architecture.

(Cianci and Molinari 2019) analyzed the state of the art in the digital representation of the project of open spaces and formulated a methodology to represent in a model open spaces with urban green and atrophic elements, taking into account also the growth and decay process (Figure 6).

(Yang et al. 2019) formulated the concept of HLIM (Heritage Landscape Information Model), applying the BIM process to landscape heritage assessment and highlighting the current limits of the tools and the absence of key parameters, such as the difficult to implement information about users and tourists.

(Brückner et al. 2019) presented an example of geometrical model and data implementation for a paved area, addressing the issue of technical and constructional description and the exchange of information via IFC standard (Figure 7).

Figure 6: BIM model of the open space propose in Bruckner 2019: 3D model and plat map.

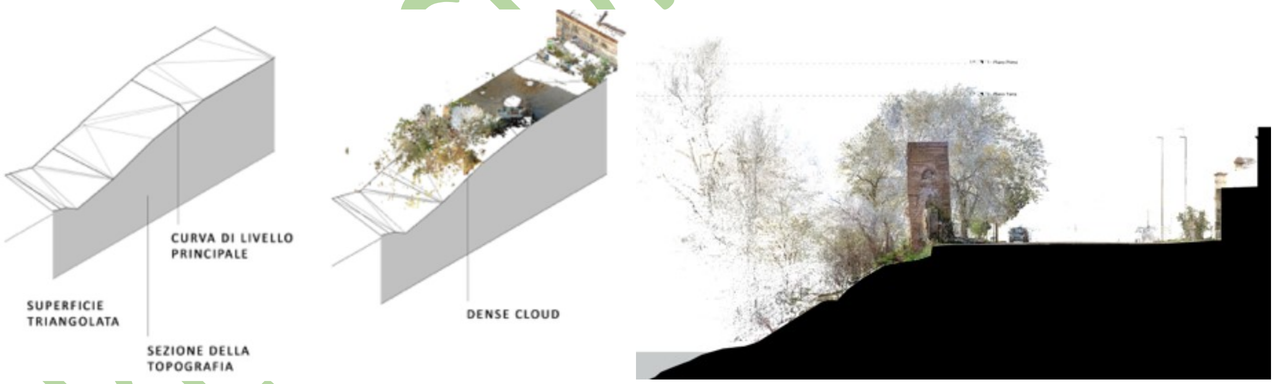


Figure 7: On the left: LIM model developed by Cianci et al. 2019; on the right: Longitudinal and transversal section, obtained by importing the dense cloud into Autodesk Revit software

3. Methodology

3.1 LOD to describe Built Environment in BIM

In order to elaborate an appropriate BETs' BIM model, the authors developed a description of the LOD progression suitable to represent the characteristic of the OS, considering the medium-scale nature of the BE. The LOD progression for OS in BE was set starting from the state of the art of codifications and parametrization in the fields of BIM (Building Information Modelling), HBIM (Heritage Building Information

Modelling) (§ 2.1), and LIM (Landscape Information Modelling) (§ 2.4). Moreover, national and international standards, i.e. UNI and ISO, were compared.
Considering the possibility offered by BIM of either physically modelling a specific geometry and implementing a parameter, the authors defined a five step LOD for OS in BE (100, 200, 300, 350, 400 as described in 4.1) with the aim of establish the level of details of each one, in term both of LOG – geometric modelling - and LOI – information implementation (§ 4.1). In light of the definition of BET gave in D3.1.1 ("*BETs definition and representation report*"), LOD 100 and 200 were identified as suitable to its BIM representation.

3.2 Representation of BETs in BIM: modelling and parameters implementation

The software selected to represent the BET has been Autodesk Revit v2021 (www.autodesk.it/products/revit). The authors firstly identified the most elementary and quick tools to model efficiently the BETs in a BIM environment, from a morphological point of view. Among those, the Conceptual Mass (In-place mass) is a tool used for conceptualize the geometry of a building in early design stage. In Revit Modeling Services, Conceptual 3D mass modeling process can help to understand overall building area, height, volume, location, weight and orientation and, herein, to describe the main basic geometric features of BETs (§ 4.2).
Once the building conceptual mass is modeled, it can be developed by adding more detailed information. Conceptual mass of a building can be implemented by different types of parameters, i.e. level, floor area, floor perimeter, and can be used to perform early energy analysis, useful for the SLOD analysis, for this reason it was considered suitable for the BET modelling.
In order to implement BETs' features in the BIM model (as define in D3.1.1, §3.1), the authors choose Shared Parameter and Project Parameter as most suitable to inform each element of the model with the corresponding characteristics. In the phase of BET representation, it was not necessary to include new PropertySet to describe the nine parameters identify in the D3.1.1, simplifying the implementation process for the LOD 200.
To speed up and automate the process of analysis of the result as much as possible, the authors implement a Dynamo procedure to read the values of the parameters and extract the data. Dynamo is an open-source tool, working with Revit, based on a visual program language. It is used to program graphically algorithms to analyze, transform, and combine data from Revit. The authors test the potential of Dynamo for the BET representation workflow and choose to implement a Dynamo routine both to quickly find and get access to the model data and to automate repetitive tasks.

4. Results

4.1 A LOD progression for OS in BE description

In view of the above, the authors elaborate a description of the LOD progression for the characterization of the medium-scale OS in BE following (BIMForum 2019a) (**Errore. L'origine riferimento non è stata trovata.**, Figure 9; Table 1), defining for each one the features of LOG and LOI, based on the following definition:

- LOG, Level of Geometry: express the geometric 3D development of the model, from schematic to detailed representation.
- LOI, Level of Information: express the non-geometric features of the model, including all technical information and characteristics.
- LOD, Level of Detail: defines how the model can achieve different levels of refinement, both in term of LOG and LOI.

In this framework, the BET has been represented by LOD 100, with a 2Dimentional graphic, and LOD 200, using 3Dimentional model (Figure 9, LOD 100 and 200). The lower level of details is particularly suitable to include the nine parameters defined to characterize the BETs (Morphological configuration, Dimensions, Structural type, Permeability / access, Special buildings, Homogeneity of constructive technique, Porches, Slope, Green) and could have an easy correlation both with GIS and BIM software (**Errore. L'origine riferimento non è stata trovata.**). LOD 100 and 200 are able to storage and analyze each BETs' peculiarity, in order to classify and compare different case studies.

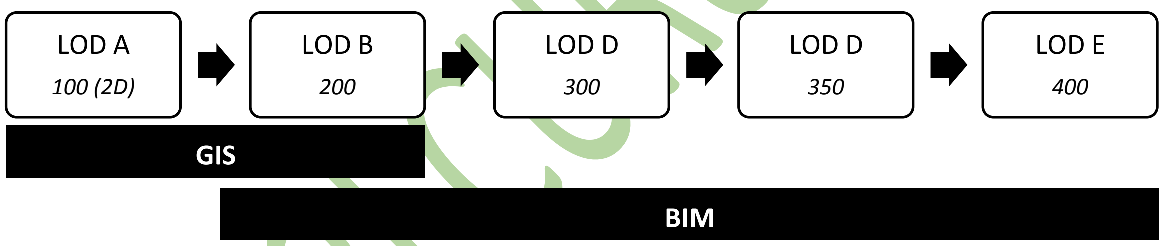


Figure 8: Correlation among Level of Detail, GIS and BIM systems.

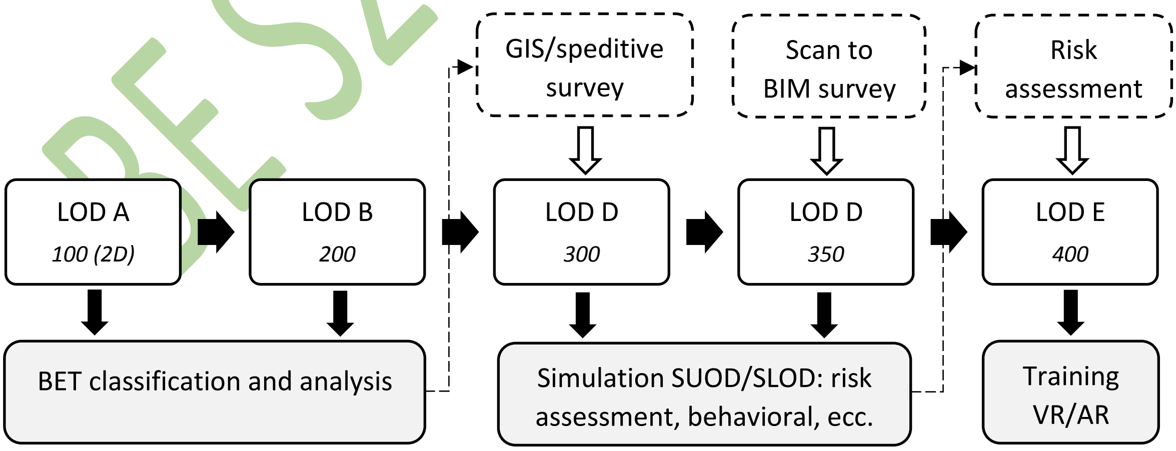


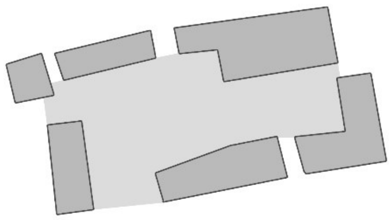
Figure 9: Relationship between Level of Detail of Open Space in Built Environment BIM model and output for BET classification, simulation, and training elaborated by the authors.

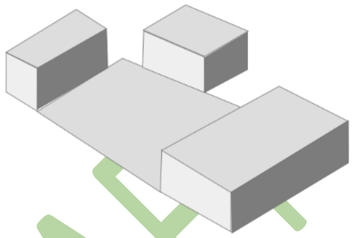
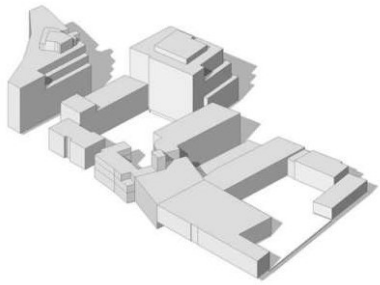
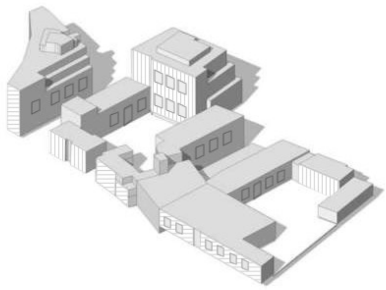
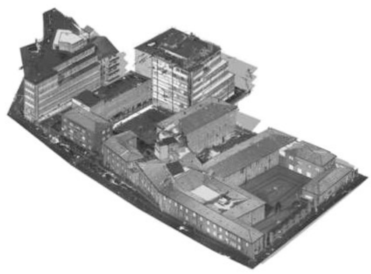
The more detailed LOD, i.e. 300, 350, 400, were defined to represent the case studies in the next phases of this research project (WP3, T3.2 and T3.3), characterized by different and more specific simulation needs.
Deepening both geometrical and informative data, LOD 300 includes a more detailed definition of the building component of the OS frontier, focusing in particular on the opening of the façade. It can also be informed by the results of the BET classification and analysis carried out in the previous phases (Figure 9, LOD 300). The metadata set implements also the human-related factors, consisting on the exposure and vulnerability parameters, such as crowding level, motion quantities information, and type of users (see D2.2.5 annex).

The geometric model of LOD 350 deepen the information about façade and opening comparing to the previous one, using the scan-to-BIM survey (Figure 9, LOD 350). The metadata implements also detail about wall, topography materials and conditions, structural aggregates of buildings in the frontier, fixed and temporary obstacle in the OS. The level of detail of this stage should be set considering the requirement of each simulation. LOD 300 and 350 are detailed enough to conduct simulation on SUOD/SLOD risk assessment and human behavior.

LOD 400 was conceive to represent the most exhaustive characterization of building components with a constructive in-depth level of definition. The metadata includes constructive details, technical information, and VR/AR 360° photos and virtual tour. This last LOD will be informed by the results of the simulations and could be used to perform training using VR/AR technology, enhancing the preparedness phase before a disaster event (Figure 9, LOD 400).

Table 1: Description of LOD 100 to LOD 400 characteristics for BE following (BIMForum 2019a) *template for building components, elaborated by authors.*

100	LOG → Element modeling to include: • Planimetric development with 2D graphics LOI → Metadata to include: • Morphological configuration • Dimensions • Structural type • Permeability (access) • Special buildings • Homogeneity of constructive technique • Porches • Slope • Green	

200	LOG → Element modeling to add: • 3D conceptual mass with single wall of Frontier of OS definition • space modeling • 3D topography surface LOI → Metadata to add: • Morphological configuration • Dimensions • Structural type • Permeability (access) • Special buildings • Homogeneity of constructive technique • Porches • Slope • Green	
300	LOG → Element modeling to add: Single building components definition, with different specifications, and openings. LOI→ Metadata to add: Detail about exposure and human-related factors (i.e. crowding level, motion quantities information, ecc.).	
350	LOG → Element modeling to add: Single building components deep definition, with different specifications, and openings with windows specifications. LOI→ Metadata to add: Detail about wall and topography materials and condition, structural aggregates of buildings in the frontier, fixed and temporary obstacle in the OS.	
400	LOG → Element modeling to add: Most exhaustive characterization of building components with a constructive deepening. LOI→ Metadata to add: Constructive details; technical information; VR/AR 360° photos; virtual tour.	

4.2 BET representation in BIM

In this section we describe the BET BIM implementation according to D3.1.1. Referring to LOD scale for OS in BE presented by authors in the previous section, we deepen the experimentation for BET description with LOD 200, as it embodies all 9 parameters characterizing BETs.

In Figure 10, BET B_1 from D3.1.1 is represented in Revit BIM authoring software. The BE is described as a schematic in-place mass and the OS Frontier is composed by by-face-wall with different material and dimension for constructive characterization description (Figure 10).

Furthermore, the OS pavement is modeled with a topography surface in which it is possible to add specific materials and condition parameters (Figure 11). An interesting option, for the research workflow, is to import topography surface from GIS open source directory or perform a scan-to-BIM for DEM pavement generation in absence of accurate GIS data.

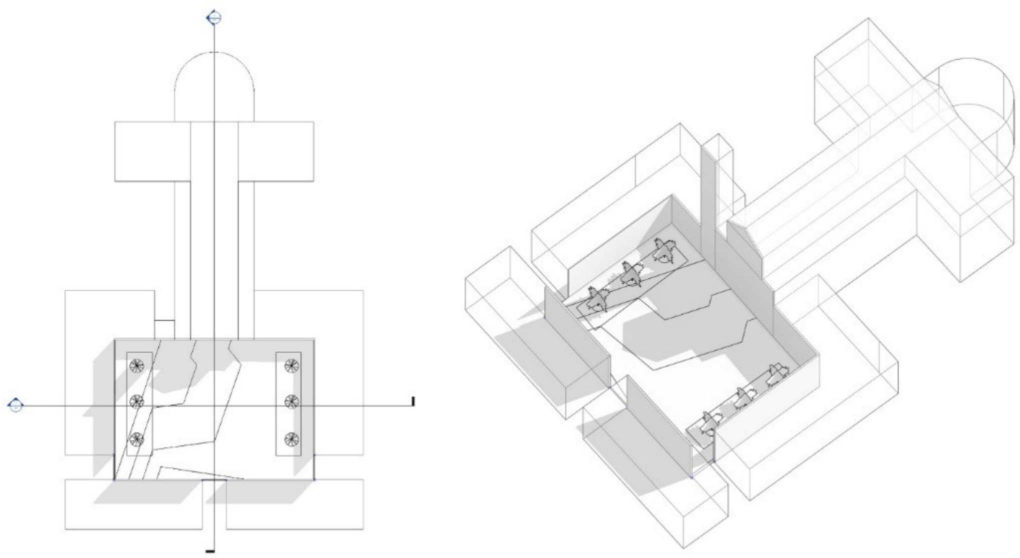


Figure 10: Bet 1.1 from D3.1.1 in BIM. The BE is described as an in-place mass and the OS Frontier is composed by by-face-wall with different material and dimension characterization. Implementation of P6 parameter from D3.1.1

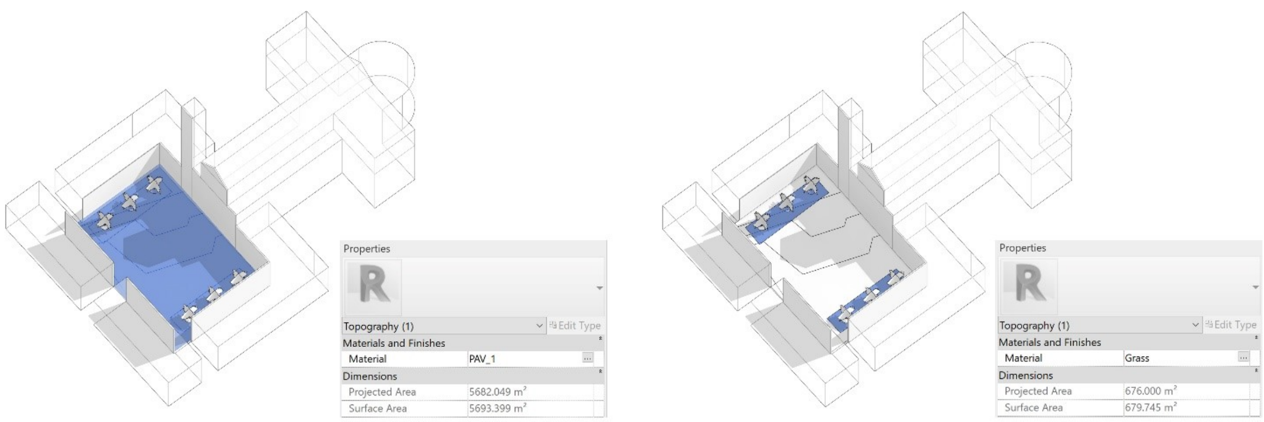


Figure 11: BET pavement modeling with a topography surface, with material and high difference specification, and topography surface sub-region for describing difference in material (i.e. green space) and high as well.

A solution proposed from authors for implementing the concept of OS in BE in the BET BIM model is “Space” modeling in Revit. The authors want to extend the potential of space BIM concept utilized to generate energy analytical model, for MEP application, to better describe OS in BE characteristics. The “space” can be referred to a specific height level and can compute the perimeter, the area and the total volume of the AS/LS. Furthermore, by utilizing “space separation line" in the access of OS, it is possible to make a complex system of all dimensional information for data extraction and elaboration.

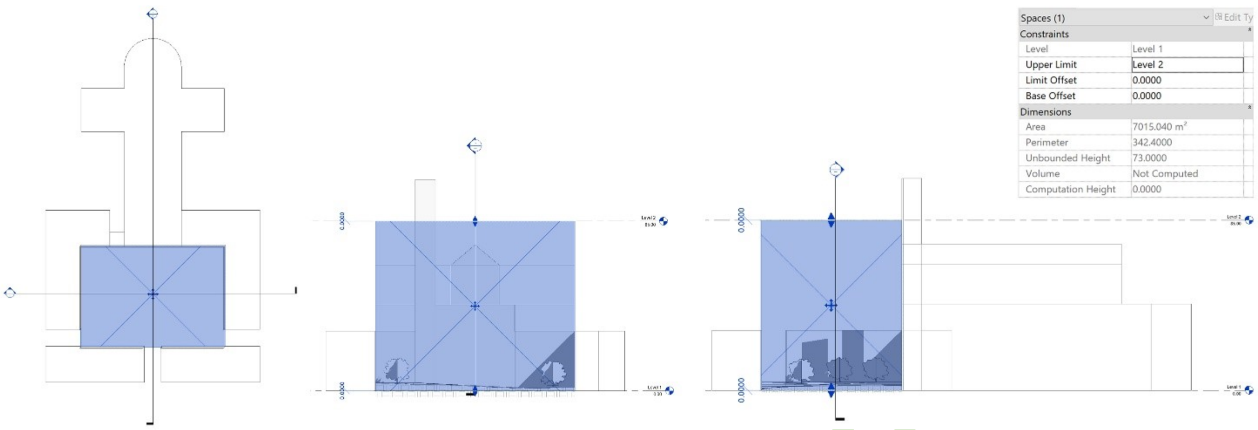


Figure 12: Space modeling in Revit. From MEP application, the authors want to extend the potential of space BIM concept utilized to generate energy analytical model to better describe OS in BE characteristics: The space can be referred to a specific height level and can compute the perimeter, the area and the total volume of the AS/LS. Furtheremore we utilized space separation line in the access of OS to put in a complex system all dimensional information for data extraction and elaboration in Dynamo/other VPL software.

In order to make the process replicable as much as possible, a recap with indication to model is presented:

- **Mass**: generic mass from CAD – GIS – SCAN data;
- **Wall-by-face**: AS/LS wall modelled by mass face, so to be updated if mass change for any reason, and specify only the core material (no plaster, finishes, etc);
- **Space separator line**: line for space delimitation, from 2 ends of wall, in correspondence of access;
- **Space**: automatic space delimited by wall and space separation line;
- **Topography**: Toposurface of the AS/LS, without considering the nearby OS (other LS or AS):
- **Subregion**: Area inside an existing toposurface, with different material (i.e. grass).

For other non-geometrical data, the authors add specific project parameters from a shared parameters file, specifically defined for BET definition and BIM implementation. In particular, project parameter “Special building on OS frontier” and “Not all built front” are added to “space” category in Revit and “porches” is added to “wall” category, under data parameter group. In this way it has been possible to describe the presence of special building, terrace, open side on OS frontier or porches on OS frontiers.

4.3 BIM Parameters Implementation for BET description

The integration of quantitative data derived from rapid survey or GIS data enrichment within the BIM model expands its capability. In this way, users can perform analysis of the entire system on a single virtual platform. To achieve this level of integration, custom visual programming language (VPL) packages are required.

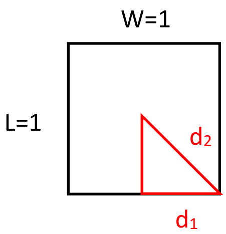
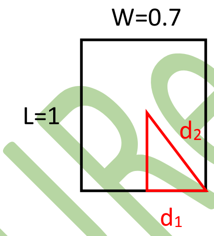
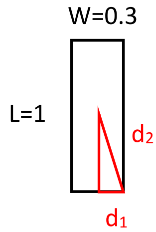
Dynamo tool (Autodesk 2020) within Revit is used in this study to import, display and elaborate recorded OS in BE data for the 9 parameters from D3.1.1 implementation.

The reasoning on P1 parameter starts with the assumption that the morphological characteristics, as developed for D311, are 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.

The authors implement a Dynamo node group to extract data from Revit BET model and systematize them, so to develop a repeatable workflow that include complex and irregular convex OS.

In particular, we integrate the ratio between OS length and width, with the more easy-to-implement ratio between min and max distance from OS barycenter and frontier. This integration starts from the assumption that the 2 different ratios are the same for the "compact" OS. Indeed, in the "compact" OS the space spreading out from a central point is equidistant from all the other extreme points. For the "elongated" and "very elongated" OS some geometric consideration needs to be done and they are synthesized in Table 2.

Table 2: Geometrical consideration to implement P1 parameter ranges from D3.1.1

Compact	Elongated	Very elongated
		
$R = \frac{w}{L} = 1$	$R = \frac{w}{L} = 0.7$	$R = \frac{w}{L} = 0.3$
$R_1 = \frac{d_1}{d_2} = \frac{\frac{w}{2}}{\frac{L}{2}\sqrt{2}} = 0.71$	$R_1 = \frac{d_1}{d_2} = \frac{\frac{w}{2}}{\sqrt{\frac{w^2 + L^2}{2}}} = 0.4$	$R_1 = \frac{d_1}{d_2} = \frac{\frac{w}{2}}{\sqrt{\frac{w^2 + L^2}{2}}} = 0.2$

In this way, the ranges defined for square/rectangular OS can be both implemented easily in Dynamo and extended to complex and irregular convex OS.

For P2 parameter, about dimensions ratio $\frac{H_{max}}{w}$, the authors developed a Dynamo node group to verify the intersection between each wall axis line and their overturning on OS projection (Figure 13), excluding the 10% start and end wall length to prevent the effects of small deviations from perpendicularity from altering the parameter. In this way, with a cross product intersection, we utilize a clash-detection Dynamo node to verify if at least a wall could overturn by invading all the AS/LS in front of it.

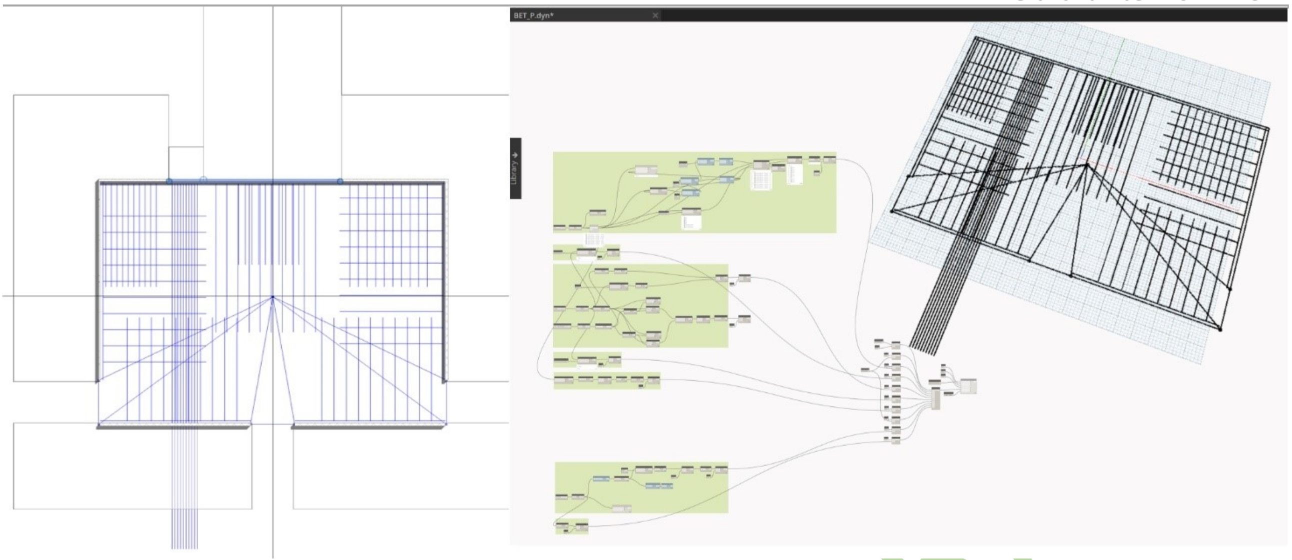


Figure 13: On the left: Dynamo node group to verify the intersection between each wall axis line and their overturning on OS projection. On the right: Revit interface with lines generated in Dynamo.

For P3, P5 and P7 the implementation is based on the extraction of Revit project parameters relating to spaces and wall, and the Boolean option relating to the presence of these parameters has been implemented in Dynamo.

The P4 parameter about OS permeability concept is based on "space" and "space separation line" parameter extraction (Figure 14). To obtain $\sum \alpha_i$, where α is the subtended angle of each *i* accesses of the AS, the space barycenter is connected with start and end point of space separation line and the angles generated are summed. For what concern $\lambda_{AS} = \frac{\Sigma L_i}{2P}$, the width of the accesses ($\sum L_i$) is obtained with the sum of "space separation line" length and the perimeter of the overall AS (2P) [m] and LS (2L) is the space perimeter.

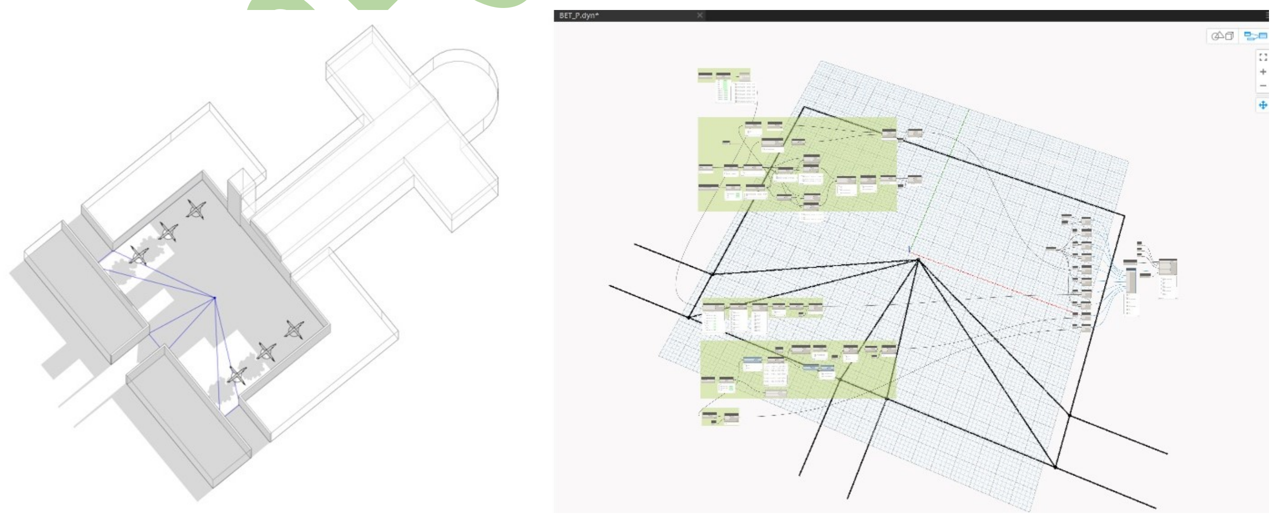


Figure 14: *On the left: Dynamo node group to obtain $\Sigma\alpha$ and $\lambda_{AS} = \frac{\Sigma L_i}{2P}$ for P4 parameter implementation. On the right: Revit interface with lines generated in Dynamo.*

In this way, P6 parameter “Homogeneity of constructive technique” from D3.1.1 can be assess with a rapid Wall core material cross-check to assess if there are more than one type of constructive technique.

BET pavement modeling with a BIM topography surface allows a rapid assessment of slope and quote difference, for P8 parameter “Slope”, just by calculating the angle between the mesh normal versor and z vector for all topography surface.

In the same way, the P9 parameter “Green” is implemented with topography surface sub-region for describing difference in material (i.e. green space) and quote as well.

The dynamo script presented in this section allows to collect the values of the 9 parameters in an Excel sheet (tab. 2) to identify and define the BET in a semi-automatic way. This script can be selected to run automatically on Revit start-up or manually deepening on the user preference. In

Table 4 there is a systematic recap of the element modeled and parameter defined for each of 9 BET parameter, with the indication of level of VPL implementation in Dynamo (low, medium and high).

Table 3: Example of BET parameter export from Dynamo.

BET PARAMETER	VALUE
P1	b
P2	d
P3	g
P4	h
P5	l
P6	n
P7	q
P8	s
P9	t

Table 4: Systematic recap of the element modeled and parameter defined for each of 9 BET parameters, with the indication of level of VPL implementation in Dynamo (low, medium and high).

	BETs’ PARAMETERS	BIM implementation		Element modeled	Parameter defined	Level of VPL implementation for P9 definition
		Model	Param.			
P1	Morphological configuration			Wall, space		high
P2	Dimensions	X		Wall, space		high
P3	Structural type		X		Not all built front	low
P4	Permeability (access)	X				high
P5	Special buildings		X		Special building on OS frontier	low
P6	Homogeneity of constructive technique	X	X	Wall	Wall material	medium

P7	Porches		Wall	low
P8	Slope	X	Topography surface	high
P9	Green	X	Topography surface	low

5. Discussion and conclusion: from BET to case study

The current study provides an example method of automating the transfer of data from BIM model to parameter implementation utilizing Dynamo visual programming language. Based on reasoning on LOIN concept from ISO 19650 standard, the authors set the P9 parameters from D3.1.1 as the "information needed" and define a LOD scale for OS in BE. The authors develop a LOD 200 BET model example with a dynamo script that could be replicated for other AS/LS so to be classified in a BET according to 9 parameters mentioned.

Once classified in a BET, a AS/LS can be deepened in geometry and information aspect to increase LOD value to perform more specific analysis. For example, BIM repository has the possibility of adding more parameters on walls, topography surface, spaces i.e. human presence (pp/mq), their qualification... The implementation of the system as developed in Revit/Dynamo to the IFC format to enable interoperability within other platforms will also be explored.

6. Conclusions

The representation of BE in BIM-based model raise the issue of the implementation, both in term of geometric model and information details. Considering the medium-scale nature of the BE and BETs (including buildings, infrastructures and open spaces), this report presents a LOD progression for the representation of BE in BIM, that sets the Level of Details required for each stage of the research (e.g. BETs' classification, simulations, risk assessment, training, etc.).

Starting from the literature in the field of HBIM and LIM, and national and international standard (i.e. ISO and UNI), the authors elaborate five class of LOD – 100, 200, 300, 350, 400 – defining for each one both the LOG and the LOI level.

In particular, LOD 100 and 200 were identified as the most suitable to represent the BETs, as defined in the D3.1.1, and their modeling were described in-depth in the report. The geometric model was realized starting from the Conceptual 3D Mass; the parameters implementation was based on Shared Parameter and Project Parameter; none new Property Set was introduced for this LOD. In order to analyze and extract data from the BETs model, the authors implement also a Dynamo routine in the workflow.
The workflow elaborate in this report will be further extend through the implementation of vulnerability and exposure risk parameters, towards the modeling of a complete case study and the next simulation phase.

7. Abbreviations

AIA – American Institute of Architects

AS - Areal Spaces

BE - Built Environment

BET – Built Environmental Typology

BIM – Building Information Model

CS – Case Studies

GIS – Geographic Information System

HBIM – Heritage Building Information Modeling

LIM – Landscape Information Model

LOA – Level of Accuracy / Acceptance

LOD – Level of Development / Detail

LOG – Level of Geometry

LOI – Level of Information

LOQ – Level of Quality of Information

LOR – Level of Reliability LS - Linear Spaces

OS – Open Spaces

SLOD – Slow-onset disaster

SUOD - Sudden-onset disasters

VR – Virtual reality

AR – Augmented reality

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9. Appendix

9.1 Evaluation matrix – BIM/VR for BETs parameters

The BIM-centric and VR-centric approach have different capability to represent the BETs and manage their data. In order to provide a preliminary evaluation of this capability, the research unit of POLIBA and UNIRM set up an evaluation matrix, taking into account four parameters:

- **Representation**: effectiveness of the representation and classification of BETs;
- **Management**: effectiveness of the data updating and management, both graphical data or not;
- **Modelling**: effectiveness of the modelling;
- **Time-resources**: time needed, human resources, and hardware/software.

Each parameter can have a score between 1 to 3. For BIM-centric approach: “1” means a limited capability to represent, model, or implement the parameters, “2” means good capability, and “3” means complete capability.

BETs PARAMETERS	Representation	Management	Modelling	Time-resources
		BIM-centric		
P1	3	2	-	2
P2	3	3	3	2
P3	1	3	1	2
P4	3	3	3	2
P5	1	3	1	2
P6	3	3	3	2
P7	-	-	-	-
P8	3	3	3	2
P9	3	3	3	2
TOTAL	20	23	17	16
				76/108
		VR-centric		
P1	2	3	1	2
P2	1	3	1	3
P3	3	3	0	3
P4	3	3	0	2
P5	3	3	0	3
P6	3	3	0	2
P7	3	3	0	2
P8	3	3	0	2
P9	3	3	0	2
TOTAL	24	27	2	21
				73/108

9.2 Workflow WP3: from literature to software implementation towards the simulations

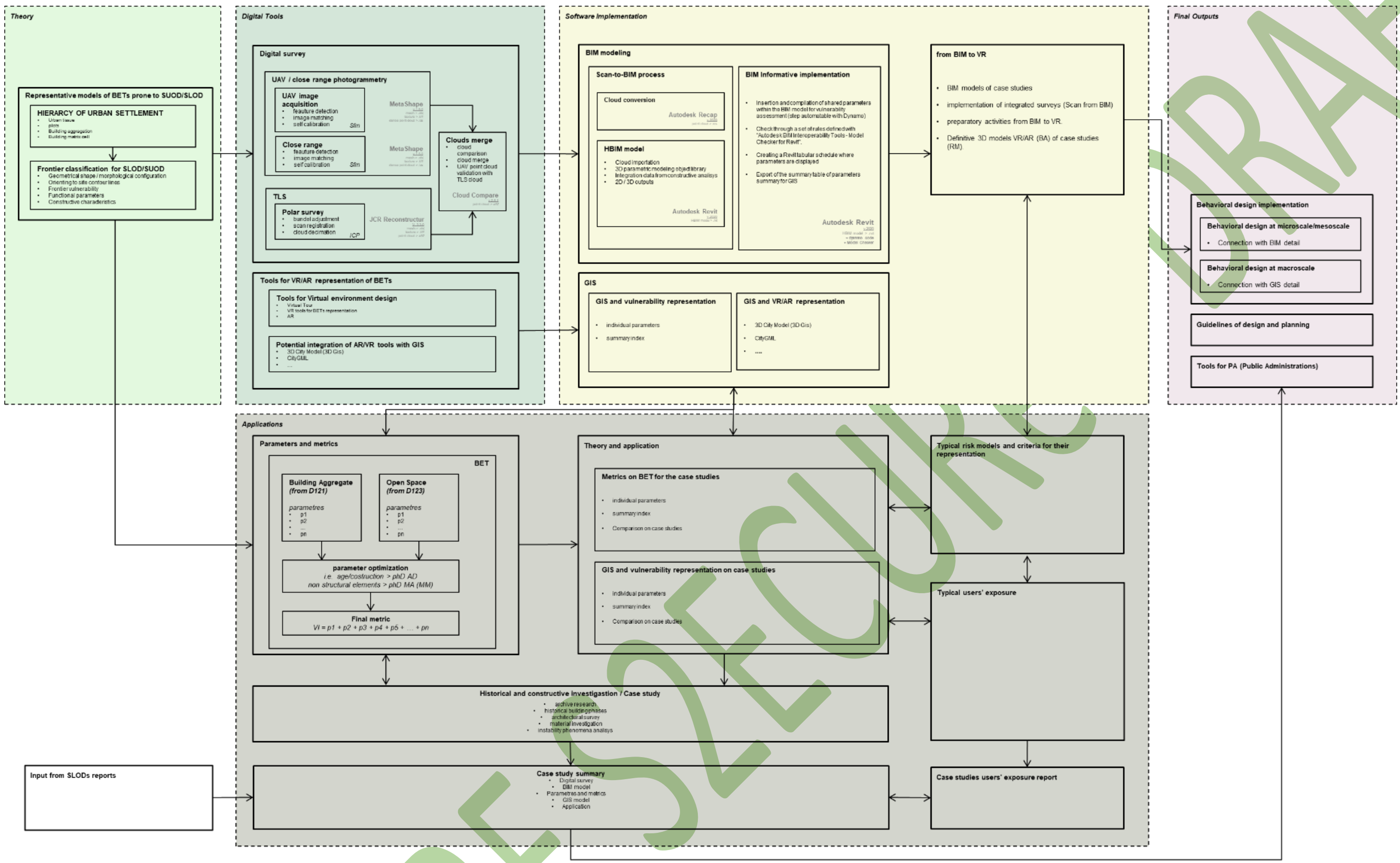

Figure 15: Workflow towards the simulations phase: BET definition and representation, digital tools selection and evaluation, software implementation, and applications.

Figure 16: Correlation among the deliverables of WP3: from BETs representation to case studies implementation in BIM models and VR/AR models.