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REPRESENTATION AND KNOWLEDGE OF HISTORIC CONSTRUCTION: HBIM FOR STRUCTURAL USE IN THE CASE OF VILLA PALMA-GUAZZARONI IN TERNI

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Highlights

The HBIM model provides a solid basis for heritage knowledge, design and management. The integrated survey is the most appropriate methodology to achieve a thorough knowledge of the construction. The verification and validation of the survey are an important stage in the construction of an HBIM model. The HBIM model allows evaluation of respect for the workmanlike manner of historical construction techniques, and of current performance. HBIM goes from construction of the model to the structural use. The HBIM model allows identification, understanding, and evaluation of the mechanisms of collapse that have been activated in the walls of the organism of the historical building.

Abstract

A validated method for the digital representation of historic construction through HBIM permits assessment of compliance with workmanlike practices and structural performance. The construction of an appropriate model is closely linked to survey methodology, to the integrated application of multiple techniques of direct and indirect survey and non-destructive tests. The paper specifically deals with the complementarity between photogrammetry based on UAV (Unmanned Aerial Vehicles) with TLS (Terrestrial Laser Scanner). Finally, through this methodology, the HBIM model set for structural use allows the analysis of local mechanisms in order to verify the performance of the building. The methodological approach to the relationship between constructive survey and construction of the HBIM model to understand and evaluate the building organism from a structural point of view is exposed using Villa Palma-Guazzaroni in Terni as a case study. The Villa is representative of architectural heritage resulting from an original unitary intervention and subsequently affected by several modifications that, without obscuring many of the original values, have nevertheless altered the building and its architectural characteristics.

Keywords

BIM, HBIM, Scan to BIM, Photogrammetry, Virtual reconstruction, Constructive survey, Heritage.

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1. INTRODUCTION

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 realisation and modification in the span of the life cycle of a specifically 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” [1]. 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 [2], and supplemented by non-destructive tests and historical-constructive studies, 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. This paper proposes a workflow to build a data storage and management system, including constructional systems, with high research and design potential [3]. This is based on the definition of a three-dimensional model made using photos from UAV (Unmanned Aerial Vehicle) [4] and Terrestrial Laser Scanner (TLS). It is in this context that the HBIM (Heritage Building Information Modelling) is developed and characterised [2, 4].

Despite the acknowledged advantages of BIM in the AEC (Architecture, Engineering & Construction) industry for new construction, the extension of this methodology to existing built heritage requires specific considerations [3]. 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 buildings, the adoption of libraries of sub-system families is necessary, with specially structured parametric components [1, 5, 6], in order to ensure the inclusion in the model of construction characteristics upon which we base the working hypothesis: materials, construction technique, conservation status [5]. From this perspective, HBIM is a process in which inter-scalar relationships are possible. It involves geometric modelling and referencing information on the properties of parameterised architectural elements based on the highest standards of a past constructive culture [8]. 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 the built object allows evaluation of the actual correspondence to the state of the art and the value of different levels of performance.

The methodological approach to the relationship between constructive survey and construction of the HBIM model to understand and evaluate the building organism from a structural point of view is exposed using Villa Palma-Guazzaroni in Terni as a case study (Fig. 1). The Villa is representative of architectural heritage resulting from an original unitary intervention and subsequently affected by several modifications that, without obscuring many of the original values, have nevertheless altered the building and its architectural characteristics.

2. OBJECTIVES AND METHODOLOGY

One of the major challenges in using the BIM methodology for the documentation of architectural heritage is overcoming the propensity of BIM Authoring software towards standardisation. Most of this software is optimised for new buildings, AD as-designed [7], with industrialised construction systems, where small geometric-dimensional deviations between similar elements are not considered relevant. The BIM for existing assets is more closely related to what is defined AB, as-built [7], in fact, they are built with unique components that, although similar, can never be considered identical [3]. The main factors that do not allow such standardisation are the craftsmanship of historical construction technologies, the processes of change and transformation over time, and the phenomena of degradation and deformation [3]. At the same time, with digital acquisition technologies becoming increasingly widespread and accessible, the ability to record these irregularities and deformations with precision, but uncritically, has increased significantly. It is thus necessary to find appropriate instruments to interpret and represent them. Our research activity followed an integrated recording process: multi-source, to cover the limits of different systems; and multi-resolution, where necessary to reach the greater density of data in significant places. In addition, through the HBIM, the process aimed at the construction of a multi-content model with the possibility of storing localised information of different kinds [8]. Therefore, the model is a 4D HBIM aimed at representing the different phases of the built object. This paper analyses the design and conservation purposes, but the same model is open to use for further research, as for new design phases, training, exploration, or virtual tourism.

The proposed process is based on the methodology of an integrated survey. It consists in the adoption of non-invasive optical recording both through active and passive systems. Both systems are referable to 3D imaging techniques, and to obtain a definitive constructive survey, they have to be integrated with direct survey and non-destructive tests.

On the one hand, the active optical survey system adopted in the process falls into LiDAR and specifically consists of terrestrial laser scanning [8]. While laser scanning is a polar process from a station point, frequently the configuration of the 3D volume determinates shadow areas, also called “grey areas” [4]. The 3D scanning results are influenced by intrinsic characteristics of the instrument (system calibration, measurement principles, etc.); properties of the objects in terms of reflection, light diffusion and absorption (amplitude response), and working environment characteristic; in addition to the properties of laser light. The presence of grey areas cannot always be resolved by carrying out multiple scans with the same scanner. On the other hand, the passive optical survey systems adopted are digital terrestrial photogrammetry and low-altitude UAV photogrammetry [9]. Digital photogrammetry is currently supported by an automatic analytical images’ processing that leads to the creation of an undifferentiated set of data that not only concerns the architectural object but also derives from the context and the medium, beyond the effect of disturbances [10]. The UAV takes advantage of the same principles and is made by “drones” equipped with a camera on a motorised node, which obviates the difficulty of reaching the parts of a building difficult to be surveyed, such as roofs visible only from above. However, the richness of the data thus acquired must be treated with caution: it varies in reliability and accuracy, and is greatly influenced by environmental conditions, instrumentation used, and operator experience [11]. The outputs of these techniques are structured or unstructured clouds of points, far from being informed models, a goal sought from the morphological and semantic point of view, to incorporate all meta-information [12]. Both methodological fields, therefore, require an important intervention of external editing, exemplified in the case of study, in which the operator must intervene both in the cleaning of the raw cloud data, to extract only the relevant architectural object, both in the reduction that allows passage from the generic points to the evidence of significant points for the three-dimensional metric description [13]. Although the two methodologies can theoretically provide similar results, the diversity of detection modes and the principles on which they are based is such that their integration can make up for their individual limitations. Therefore, the paper critically addresses the results of the experimentation, on a complex case study, of the construction of an HBIM model for structural use. It is divided into two parts. The first is the definition of an appropriate methodology to arrive at a geometrically controlled HBIM model in the individual building components. The main activities are those related to the survey, the study of architectural-constructional characteristics, and the return in an HBIM model, informed by the geometry and organised in the building components of the historical building system. This part ends with the validation of the model. The second part consists in the proposition and experimentation of specific structural use, with the specific aim of analysis in the case study of Villa Palma in Terni.

3. BUILDING AN HBIM FROM GEOMETRIC TO CONSTRUCTIVE SURVEY. A CASE STUDY

The selected case study, Villa Palma-Guazzaroni in Terni (Fig. 1), is subject to risk due to its extreme level of abandonment, and is characterised by a widespread

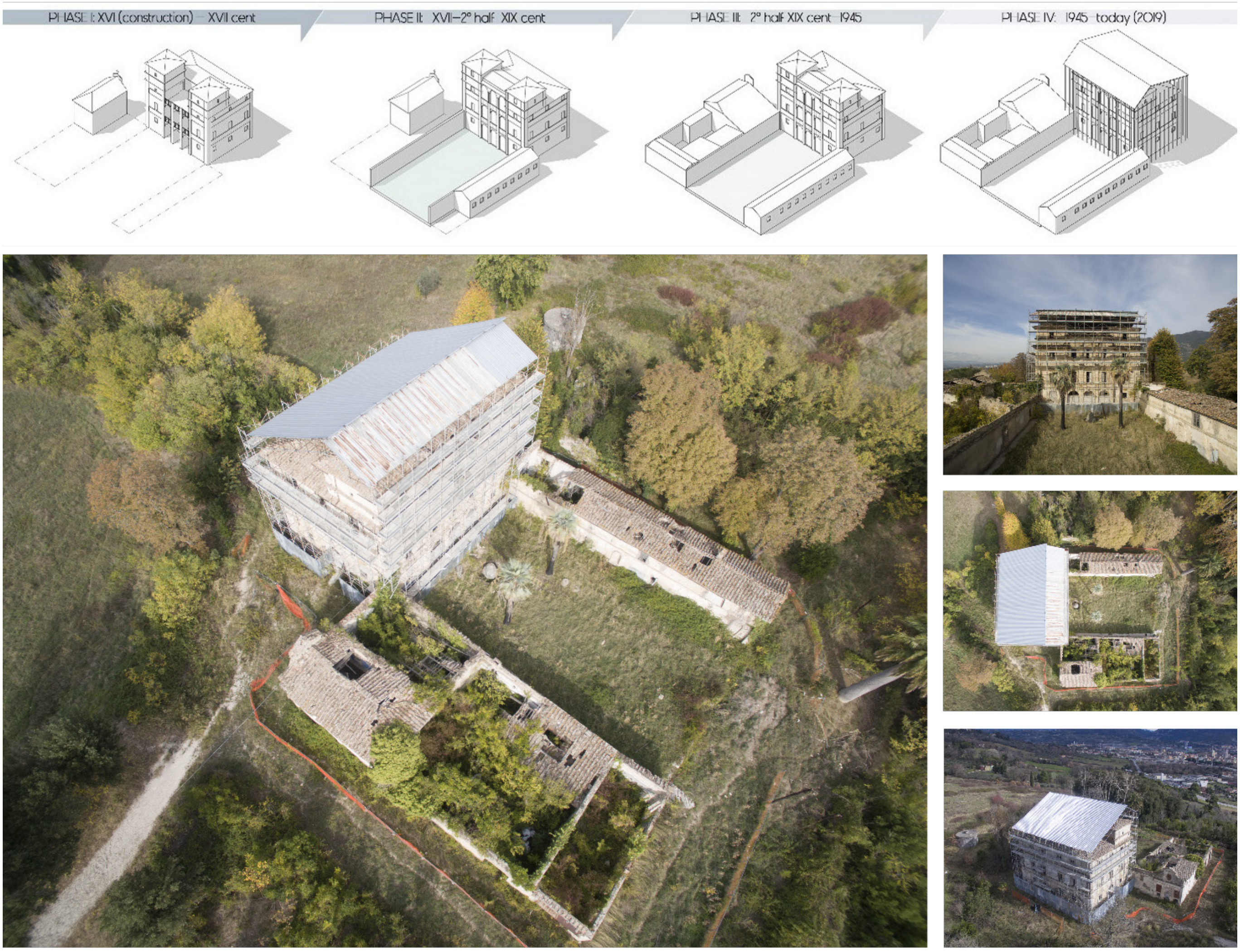


Fig. 1. *UAV photos of Villa Palma-Guazzaroni.*

degradation of materials in all sub-systems. There is also a significant pattern of cracks, which has led to the collapse of some of the ceilings. Before modelling, it is essential to carry out a historical archival knowledge recognition (Preliminary collection of knowledge, PKC [14]), in order to obtain geometric-spatial and constructive information. This is preliminary to a more detailed post-observation analysis.

To set up the historical investigation of the Villa, it is necessary to examine the *Catasto Gregoriano* (the cadastral register pertaining to the Papal States and named for Pope Gregory XVI), which provides information from the 1820s onwards, and the updates available for consultation at the Terni State Archive [15].

In the cadastral map of 1824 (Phase II, Fig. 1) the two wings of the Villa had a smaller extension than the current ones. In particular, the west wing only arrived as far as the chapel and was not yet joined to the main body of the Villa. An update of the map, showing expansion projects carried out by the Manni family, dates back to the 1890s. These expansions brought the Villa to its maximum extension, with two defined wings (Phase III, Fig. 1). Following the cadastral changes, the sale by the last Prince Ruspoli to the civil engineer-architect A. Guazzaroni dates to 1924, and subsequently Guazzaroni completely restored the Villa, together with the gardens.

The Villa, already noted as being of important interest in 1913, was governmentally listed as a protected building of historic interest in 1984, and its park was added in 1990. As for the main body of the Villa, the current plan extension is unchanged since the plans of 1824, and the cadastral survey does not in itself allow a spatial reconstruction of the historical evolution of the Villa. In addition to the required archival study, critical considerations regarding constructive and stylistic-typological analysis have allowed a return to the original state of the complex, consisting of an isolated block with a loggia on the south front, and with two soaring towers (Phase I, Fig. 1).

The hypothesis is confirmed by a view of the Villa in the sixteenth-century frescoes that constituted the frieze of the walls of the main hall. These were once hidden by a mirror vault added in the nineteenth century by the then owners, the Bonaparte-Ruspoli princes [15]. These frescoes are now once again visible following the collapse of the vault. The closing of the loggias, the elevation with the third order of blind arches, and the definition of the Italian garden in the internal courtyard all date back to this period. After further changes in ownership, a period of abandonment began, which continues to this day, and in 2014, the collapse of part of the roof requested an extremely urgent intervention. It focused on the protection of the attic level and of the frescos by the construction of a metal sheet roof supported by a scaffolding structure (Phase IV, Fig. 1). This was both a complication and a stimulus for identifying the most appropriate survey methodology.

To obtain an executive survey of geometric and constructional features, an integrated digital survey was carried out both for the exterior and interior spaces. It was not possible to perform a complete direct survey of the exterior, as the Villa is surrounded by scaffolding, which does not allow closer access. Even the indirect survey with TLS would have required carrying out too many scans to take advantage of the parallax angle, files of excessive size, and with blind grey areas to the metal scaffolding. Given these preliminary concerns, the choice was oriented on the photogrammetric survey with full-frame mirrorless Sony A7, and with UAV DJI Phantom 4 for the higher floors and to also document the dilapidation of the Villa's roof [16]. As for the interiors, the integrated potential of digital photogrammetry and TLS were exploited, also giving rise to a comparison applied between the two techniques.

THE INTEGRATED SURVEY AND NON-DESTRUCTIVE TESTS

The image processing pipeline followed the rigorous photogrammetric data processing scheme [17]. A total of 1909 photographs were taken, of which 1309 from the outside and 630 from inside. The external photos are divided into 136 realized with UAV (resolution 3992x2992 pixels) and 1137 with Sony full-frame Mirrorless A7 (6000x4000 pixels). A number of 691 photos concern parts of the building covered with scaffolding, out of a total of 1309 external photos. With the aim of obtaining a point cloud cleaned of scaffolding, the pre-processing of photos was carefully studied to obtain a point cloud cleaned of scaffolding. The photos were processed on Agisoft Metashape v.1.5.4 (Fig. 2) by applying appropriate masks, to process only the visible parts of the building. In this way, the work of removing the scaffolding was not postponed to a subsequent post-editing phase. As for the TLS survey: the 46 scans performed were registered and oriented in the final reference system with 3D rototranslation with ICP (iterative closest point) algorithms used by the JRC Reconstructor software, thus minimizing registration errors between pairs of point clouds. Furthermore, the use of TLS was fundamental for the study of underground environments with a rapid and precise survey despite the absence of natural light and dangers posed by recent collapses. The scans were performed

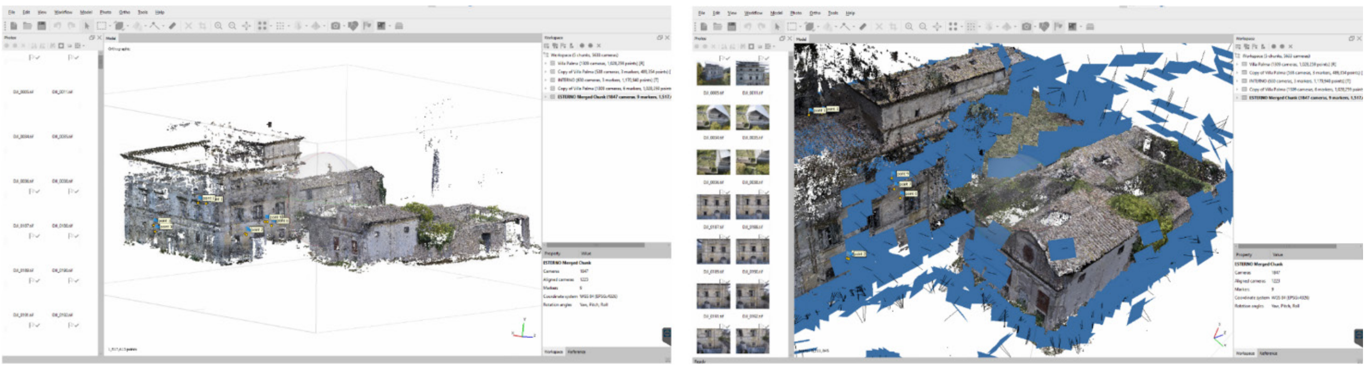


Fig. 2. *Sparse cloud elaboration within Metashape software (interior and exterior).*

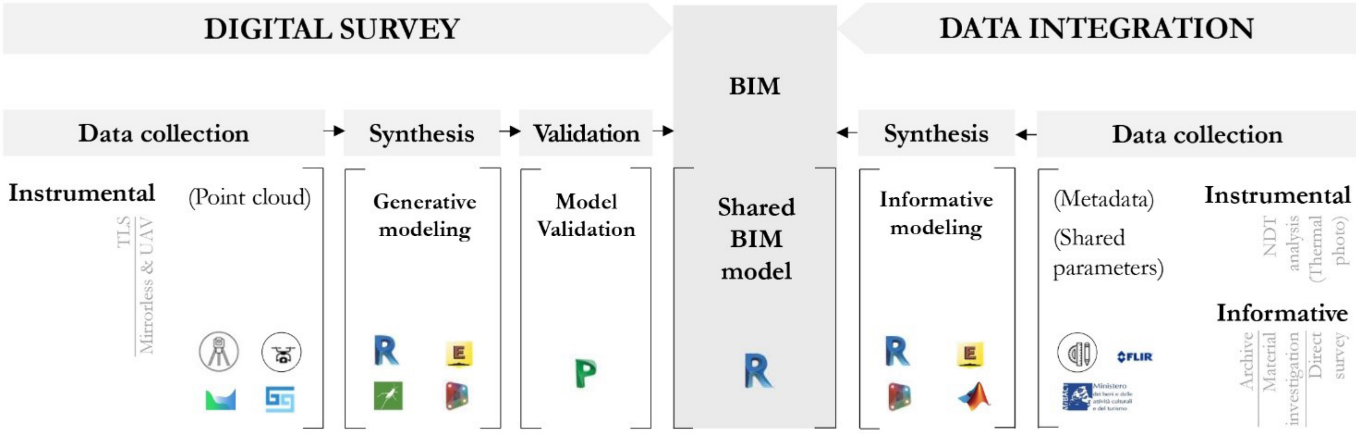


Fig. 3. *Research workflow, from digital survey and data integration to the information repository of HBIM model.*

in the dark, with Faro Focus 3D-s 120, obtaining clouds with the brightness of the only reflectance produced by the laser, without the glare that would have been generated by artificial lights on invested damp surfaces [16]. The digital survey was supplemented by direct measurements of individual construction elements and ornaments.

The fundamental part of the methodology presented is the setting of diagnostic tests to confirm, or not, the hypotheses of constructive characterisation, also inherent to the state of degradation. In particular, for this study the potential of thermal photos (Fig. 6) was exploited to identify any closings of doors and windows, study the crack pattern, or the presence of bolted end-plate inside the wall section.

The HBIM model allows the creation of a system for linking the different information and, with appropriate tools, setting the structural model in order to verify the congruence between structural analysis and deformations detected. The point cloud generated (Figs. 3 and 4) was imported to the modelling environment of Autodesk Revit, after the format conversion from .e57 to .rcs performed in Autodesk Recap.

Following the Scan-to-BIM methodology [2], the cloud was used as a scaffolding for the creation of the HBIM model of Villa Palma-Guazzaroni, integrating the architectural survey and the historical reconstruction in the various evolutionary phases. For the geometric characterisation of the HBIM model, the different height, width, or thickness parameters have been inserted for all types of slab, walls, beams, and openings. With a focus on the openings, attention has been paid to the splay, threshold, and sill (spandrel in structural analysis Section 5), linking them to a reference plane with a strong reference. We have thus allowed an easy input and modification of the values, based on the point cloud.

On the constructive characterisation side, the work proceeded in parallel between Autodesk Revit and ACCA Edilus. This step allowed further characterisation of model families by inserting some technical and mechanical specifications for the consequent analyses (Fig. 5). We used the BIM Tool ACCA Edilus, as a BIM Authoring software for the possibility offered to characterise all of the model elements according to the parameters of the NTC 2018 (Norme Tecniche Costruzioni - Construction Technical Standards, rev. 2019). Land stratigraphy was modelled based on data from the available geotechnical report of 2008, which is part of the initial investigation documentation.

The method allowed specific parameters to be inserted in the modelling of single components: in the ceilings the parameters relating to shape, thickness and filling

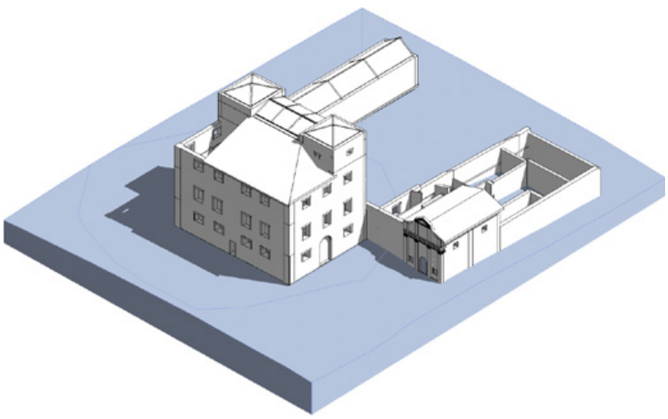


Fig. 4. *HBIM model elaborated within Autodesk Revit.*

were inserted; in the floors those relating to materials, thickness, stiffness, load analysis, and the type of clamping to the walls (defining the ability or not to prevent overturning); in the openings those relating to the insertion of the side jamb and solid thresholds, to have evidence of the construction component.

Moreover, the masonry type has been defined based on reference values for the wall types from table C8.5.I NTC 2018 (ex C8A.2.1 da NTC 2008), depending on the level of knowledge acquired. In this regard, reference was made to the criteria for describing masonry techniques for the preparation of codified scheduling modules [18] to set an objective recognition procedure, with a shared order to the information to be provided. In Figure 6, two different outputs for the constructive survey are shown: on the right, the cabinet axonometry graphically represents all building information regarding masonry elements; on the left, all data are parametrised in each Revit model instance in order to include both the geometric and constructive parameters described above.

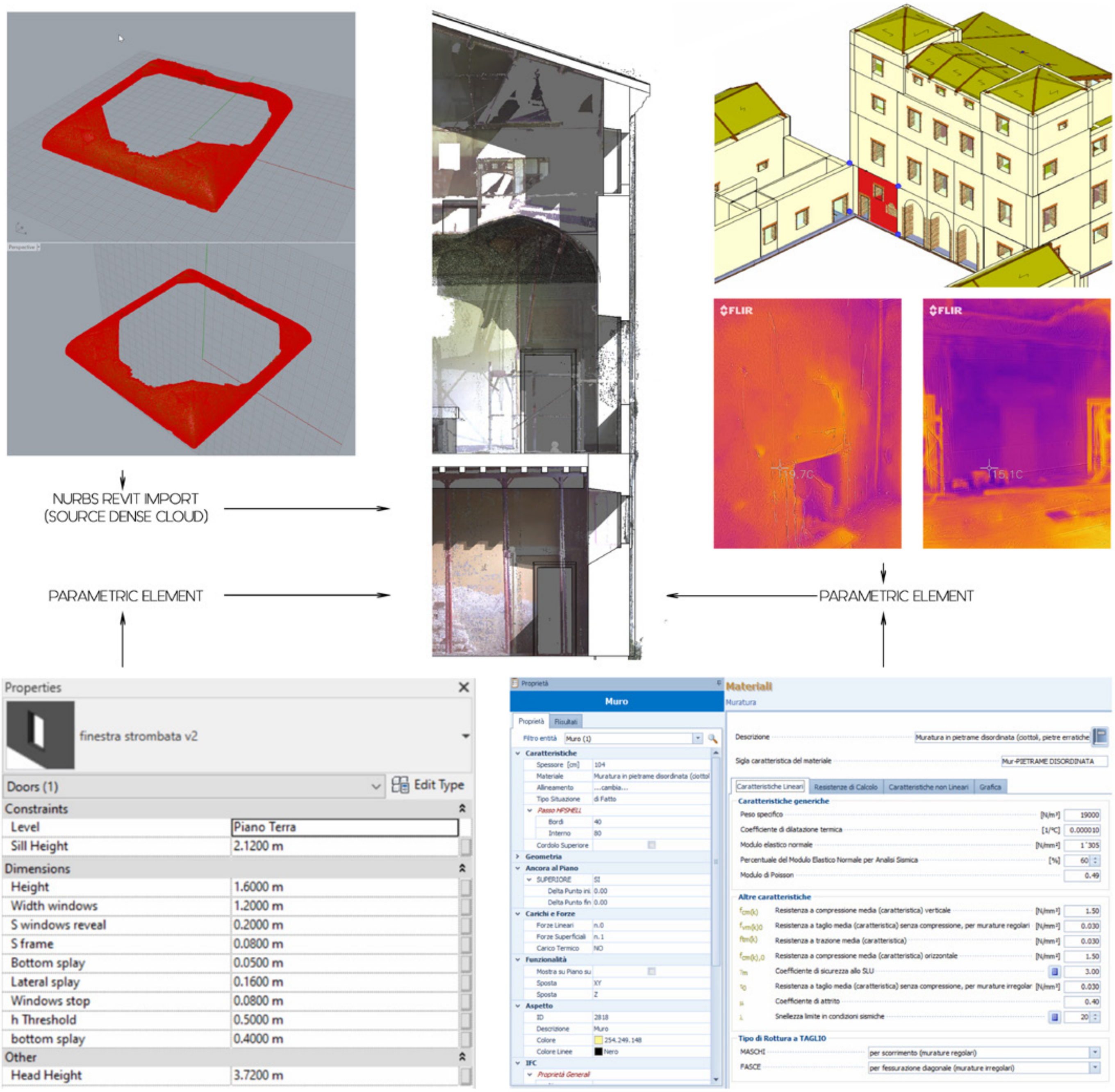


Fig. 5. *HBIM elements parametrization and Structural parameters in Edilus family. Specifications for an external wall and a floor.*

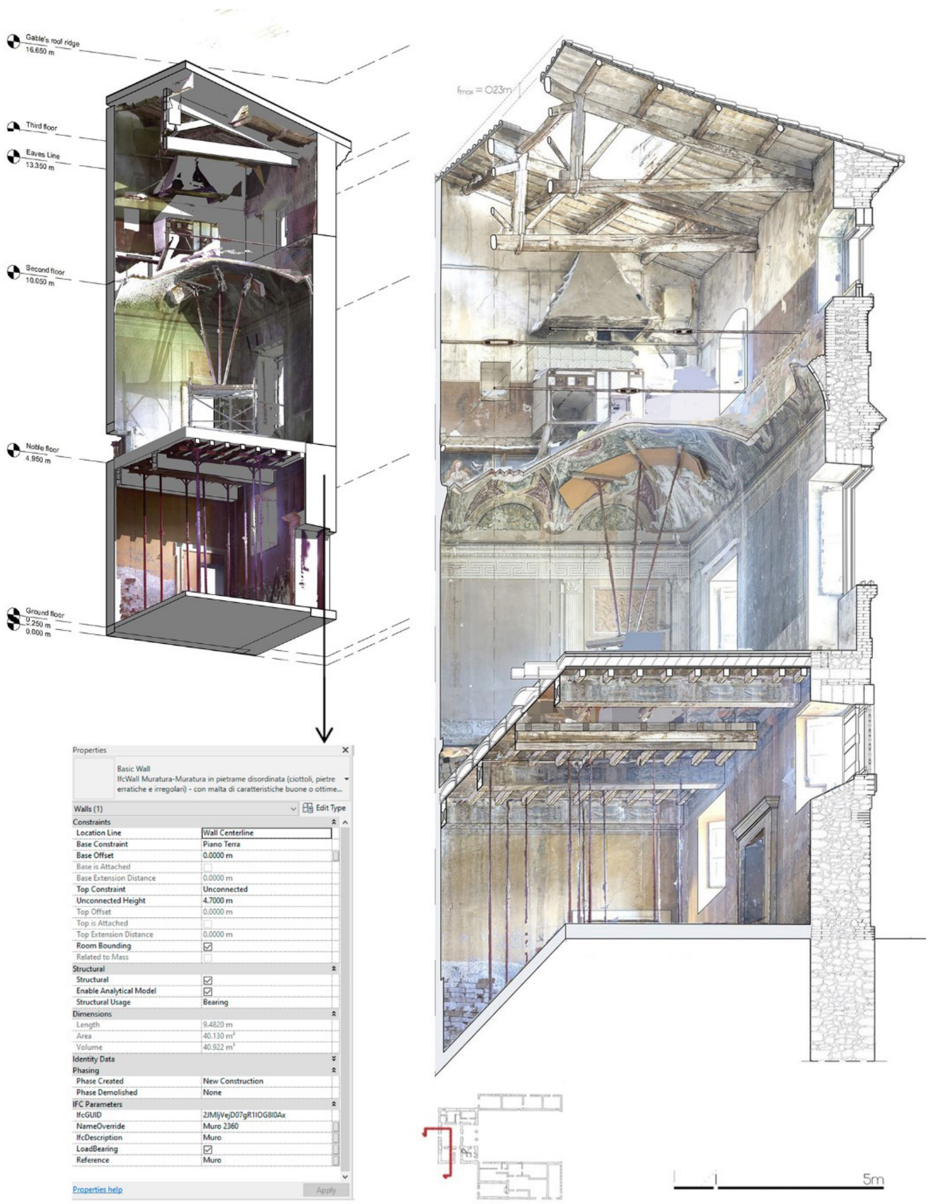


Fig. 6. *Constructive axonometry. On the left, the one from the HBIM model with specification on information about the masonry wall, on the right, the one elaborated with traditional methods with CAD.*

LEVEL OF DEVELOPMENT AND RELIABILITY OF THE HBIM MODEL

The reliability of the information is the base for the validation and reliance of an HBIM model. Therefore 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, LoR (Level of Reliability) has been proposed [19]. As well as LoD, LoR is also characterized by two parameters: the Level of Accuracy (LoA), concerning the geometric accuracy measured as the 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 [20]. As regards the quantification of LoD and LoR, while the first follows a consolidated standardisation, with numerical quantification in the international context (LOD from 100 to 400) and quantification in alphabetic classes at the national level (from A to G, UNI 11337 2017), the second is proposed with a numerical qualitative scale that varies from 0 to 10. In the case study, both LoD and LoR were assessed for individual construction elements, according to

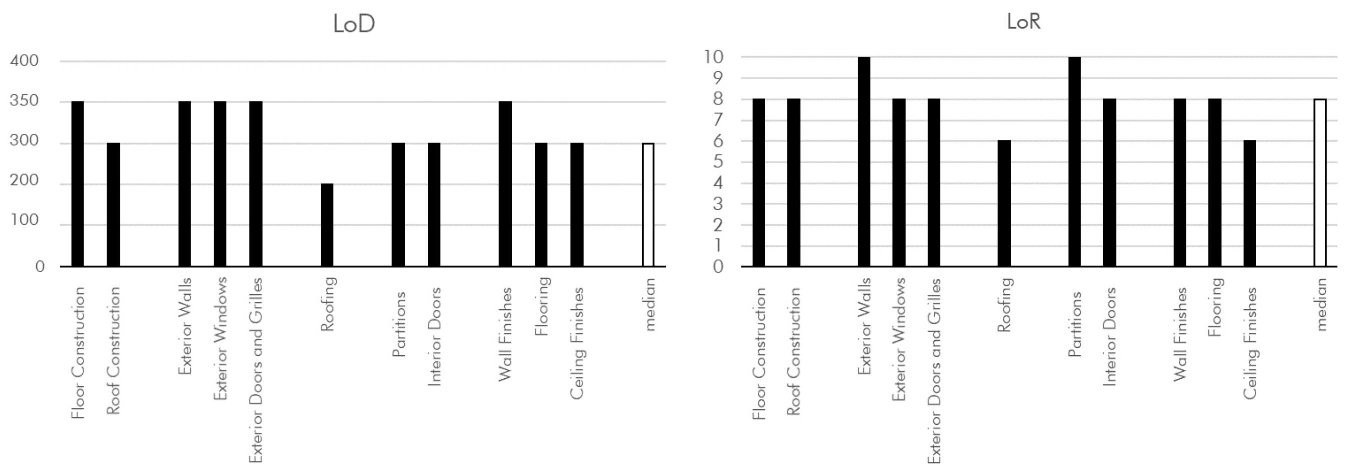


Fig. 7. *Representation graphs of the LoD and LoR achieved, respectively with respect to the references of the international standards of BS EN ISO 19650 and BIM Forum for the LoD, and Bianchini & Nicastro, 2018 for the LoR.*

the Uniformat classification. The subcategories analysed are: superstructure, external vertical closures, external horizontal closures, internal construction, and internal finishes. The LoD value varies from 300 to 350, while the LoR has an average value of 8/10, considering the consistency checks, the intrinsic geometric characterisation and the operative indication with 1 point and the other parameters with 2 (Fig. 7).

4. HBIM VALIDATING AND STRUCTURAL USE

In the context of building and civil plans, four fundamental disciplines are commonly identified to which as many project models refer [21]: Architectural Discipline, Structural Discipline, MEP Discipline, and Infrastructural Discipline. As highlighted by Vilutiene et al. [21] the number of publications strictly linked to the structural aspects of BIM emerged significantly in the scientific literature only after 2014, and it is possible to identify some applications strictly related. Some of these are already consolidated and others are in development, such as: the design and construction, as well as the identification of coordination problems between the structural elements and those other disciplines, monitoring the performance and life cycle of structural elements, optimising seismic retrofitting [22], and assessing structural damage following seismic events [6, 23]. To date, most vendors offer BIM software that incorporates the three features required for structural engineering: geometry, material properties, and load conditions for mechanical analysis. Below is a selection of BIM Authoring software (Tab. 1) and BIM Tools (Tab. 2) significant for their application in the structural field. The first ones are software capable of producing completed and informed 3D project models with specific characteristics and properties with respect to the discipline for which they were designed; while the second ones are operational tools supplied with BIM authoring software (and connected to them) that allow you to implement some specialised analyses and/or "aspects" that you would otherwise not be able to manage (in this case structural calculation and/or cost management).

There are also a series of research projects that are developing tools that are particularly interesting for this discussion, but which have not yet found an official place in the commercial field. This is the case of the study conducted by the research group of the Federico II University of Naples [23] and by the Open Project group [6] on the detection of post-earthquake damage. In both cases, the aim is to return a digital crack picture. In the first case, new design parameters are defined as being associated with specific elements of the model (i.e., collapse, detachment, lesion) and modelling of each lesion, defined as a "generic model" (such as the Revit family), obtaining a specific abacus downstream of the modelling. In the second case, the approach used is that of computational design through a Dynamo algorithm, used within the Revit interface, single lesion is "hosted"

BIM AUTHORING SOFTWARE

Product Name	Manufacturer	BIM Use	category						
			Structural	MEP	Performance	Productivity	Conversion	FM	BMC
Revit	Autodesk	Creating and reviewing 3D models	✓	✓	✓				
Bentley Architecture	Bentley Systems	Creating and reviewing 3D models	✓	✓	✓				
SketchUp Pro	Trimble (now Google)	Conceptual 3D modelling	✓	✓	✓				
ArchiCAD	Graphisoft	Conceptual 3D architectural model	✓	✓	✓				
Vectorworks Designer	Nemetschek	Conceptual 3D modelling	✓	✓	✓				
Edificius	AccaSoftware	Conceptual 3D modelling	✓	✓	✓				
Allplan	Nemetschek	Creating and reviewing 3D models	✓	✓	✓				

BIM TOOLS FOR STRUCTURAL USE

Product Name	Manufacturer	Relative BIM Authoring	Main functions	category		exchange formats			
				Processing Reviewing	Structural	import IFC file	COBie	Certified software building smart	Direct link
Teklastructure	Tekla	Revit	Conceptual and structural design modelling	✓	✓	✓		✓	✓
Structural WorkSuite	Bentley Systems		Structural analysis, detailing, quantity take-off, building performance	✓	✓	✓			
SDS/2	Design Data		3D structural modelling and detailing	✓	✓	✓		✓	
RISA	RISA technologies		3D structural modelling	✓	✓	✓			
Robot structural analysis	Autodesk	Revit	3D structural modelling	✓	✓	✓			✓
Edilus	AccaSoftware	Edificius	Architectural and structural model creation	✓	✓	✓		✓	✓

Fig. 8. *Table 1 (above) Identification of BIM Authoring software, elaboration of data by the authors. Table 2 (below) Selection of BIM Tools software in the structural field, elaboration of data by the authors.*

by the specific element, establishing a relationship of dependency that is impossible to replicate with a two-dimensional representation, as used in other studies.

5. RESULTS: VALIDATION OF THE HBIM MODEL TOWARDS HBIM STRUCTURAL USE

The above analyses imply that the HBIM model could be used to understand structural functioning and tests were conducted on our HBIM model for the different BIM Authoring and BIM Tools. Three cases are reported for example. The first is an analysis with the Revit plug-in Autodesk Point Layout, performed for the validation of the HBIM Model at a constructional level. The addition of another attribute to the wall surface permits to describe the distance between the HBIM model and the point cloud with a colour map. Indeed, with spatially registered and scaled point clouds, the deformation deviation analysis can be performed using a cloud to model (C2M) distance computation method.

The type of adopted survey allowed the characterisation of the object from a geometric and constructional point of view, in order to describe and interpret the strain and crack pattern (Fig. 9). Focusing on the chapel, the picture shows the results of analysis elaborated on a portion of the west wing of the Villa. The threshold of deviation chosen is [min -0.16m; max +0.16m] (on the right of Fig. 9) in order to better display the out-of-plane behaviour of the historical masonry and, in particular, the Rondelet second mechanisms.

A second test has been conducted to understand local mechanisms with the structural calculation software ACCA Edilus. Within Edilus, the details deriving from the constructive analysis of the Villa, LoI were implemented and reported in the original HBIM model. Among all verifications, local mechanisms identified during the construction analysis of the building require attention. i.e., the mechanism identified through the validation process on the sidewall of the church, does not seem to be a simple free overturning, but an overturning along the diagonal of the wall, due to the possible toothing be-

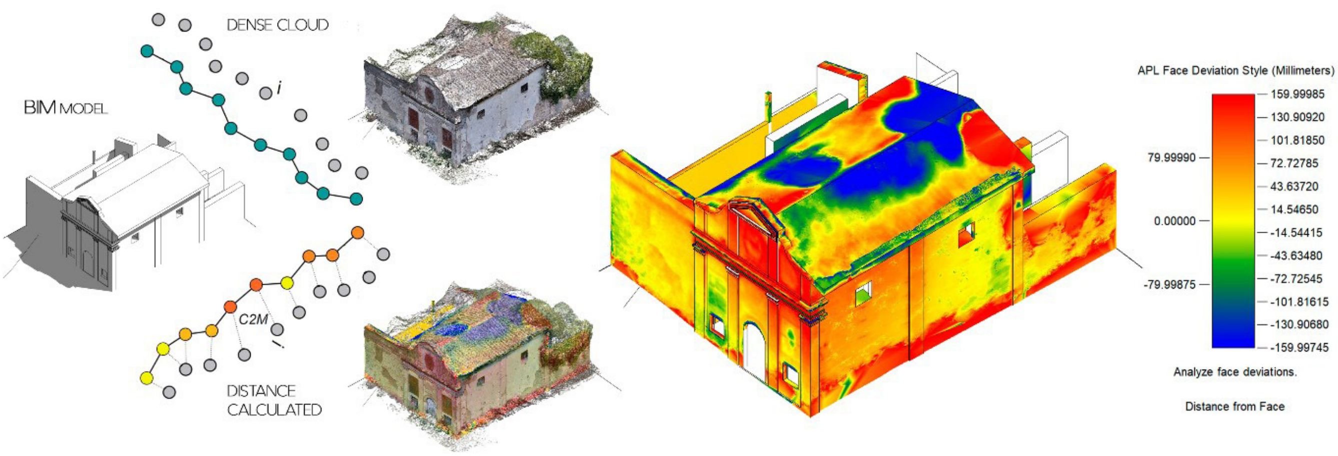


Fig. 9. *BIM model of the chapel with the cloud2model (C2M) analysis performed directly in Revit by means of Autodesk Point Layout plug-in.*

tween the two walls. Indeed, it is a second mechanism defined by Rondelet, consolidated in the analysis practice of historical masonry building, already highlighted by Giuffrè [24]. The ACCA Edilus software (Fig. 10) allows evaluating the activated wedge angle. In this case, we proceeded to verify both the simple overturning and the one along the wall diagonal, as well as verifying the correspondence both with the principle of virtual works (PVW) and through mechanical simulation (MS) within the ACCA Edilus software. The collapse multiplier α obtained are:

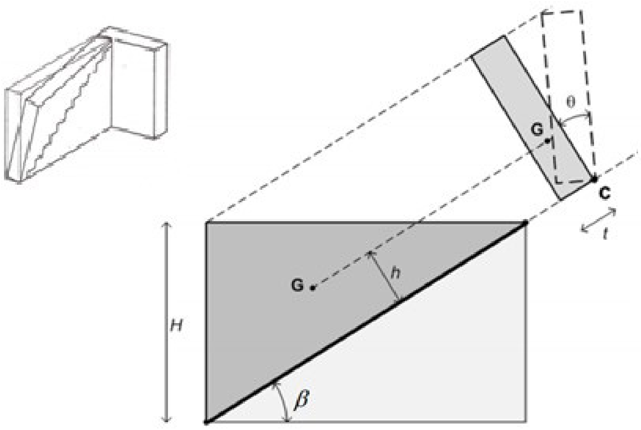
1. PVW: α '= 0.15 (for the diagonal wedge θ = 1.39°)
2. PVW: α'' = 0.1 (for simple wall overturning)
3. MS: α'= 0.22
4. MS: α'' = 0.12

The MS calculation, although not perfectly coinciding with the method of PVW, shows its coherence in the verification of the difference in the values of the collapse multiplier α, and therefore of the accuracy of the analysis, which can be achieved by taking advantage of a detailed constructive survey on the artifact.

6. CONCLUSIONS

The research delineated and partially tested a kind of workflow for the development of the HBIM model as a data repository for the structured exchange of knowledge acquired on the existing building.

According to the methodology, the pipeline of the constructive survey for an HBIM As-Built configuration



	Dis_0	CS_{SLV}	CS_{SLD}	M_{Ed}	M_{Stbl}	α_0	a_0 SLV	a_0 SLD	a^*_0	e^*	M^*	d_G X	d_G Y	θ_U	δ_U
	[m]			[Nm]	[Nm]				[m/s²]		[Ns²/m]	[m]	[m]	[°]	[m]
1	0.25	1.01	1.16	5'838'882	697'338	0.12	1.185	1.034	1.20	0.723	155'770	0.33	3.01	7.00	0.33
2	0.25	1.75	2.00	8'631'702	1'928'924	0.22	1.185	1.034	2.07	0.785	220'702	0.70	3.38	13.00	0.70

Dis_0 hinge position (related to the base of the structure) that determine the overturning mechanism.
CS_{SLV} safety coefficient for SLV state
CS_{SLD} safety coefficient for SLD state
M_{Ed} design bending moment
M_{Stbl} stabilizing moment
α_0 load multiplier that activates the overturning
a_0 peak accelerator of seismic demand
a^*_0 spectral accelerator of mechanism activation
e^* participating mass fraction
M^* participating mass
d_G coordinates of the center of gravity of the façade subject to kinematics
θ_U ultimate rotation angle
δ_U last displacement of the center of gravity

Fig. 10. *On the left, principle of virtual works explanation scheme of the chapel wall, on the right, overturning analysis elaborated with ACCA Edilus software. 1 = simple overturning, 2 = with wedge.*

is articulated and integrated. Nevertheless, this has led to different LoD and LoR for the different components of the building organism.

Whit a review of the different potentialities, which have emerged from the structural use of BIM, the paper reported a few examples of structural use. The workflow proposed permits to highlight mechanisms already triggered in the building organism, the specialisation of the model for these purposes, and the illustration of the results. Going through a case study allowed us to test this path and to analyse the results proposed for Villa Palma-Guazzaroni. Mostly, by assessing the presence of the toothing between the sidewall and the main façade, and therefore the diagonal overturning of the wall, and the recognition of the activation of the local mechanism is undoubtedly one of the application results of a proper cognitive and constructive investigation in the realisation of an HBIM model aimed at the existing built heritage recovery, and this case study in particular.

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