Laura Carlevaris, Graziano Mario Valenti

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Digital & Documentation

Reading and Communicating Cultural Heritage

Volume 3

PROSPETTIVE MULTIPLE
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Reading and Communicating Cultural Heritage

Volume 3

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The volume consists of a collection of contributions from the seminar *Digital & Documentation. Reading and Communicating Cultural Heritage*, realised on online platform on December 4th, 2020. The event, organized by Department of History, Representation and Restoration of Architecture, Sapienza University of Rome, promotes the themes of digital modeling and virtual environments applied to the documentation of the tangible, intangible and natural Cultural Heritage. The event has provided the contribution of external experts who are engaged in the management and conservation of the most important Italian cultural assets.
The scientific responsible for the organization of the event is Prof. Graziano Mario Valenti, Sapienza University of Rome.

This publication is made with the contribution of DSDRA, Department of History, Representation and Restoration of Architecture of Sapienza University of Rome.

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Filippo Calcerano (architect and researcher at the Institute of Heritage Science of the National Research Council of Italy, ISPC-CNR) is an expert in sustainable built heritage conservation, building and microclimate performance simulations, Heritage BIM and interoperability. Thanks to his national and international professional and academic experience, he developed and consolidated a particular sensitivity to interdisciplinary research and the role xof knowledge-gaps closer between different research fields and stakeholders in order to streamline innovative efficient and sustainable digital workflows applied to the AEC industry, mainly on the cultural heritage.

Letizia Martinelli is a research fellow at ISPC (Institute of Heritage Science) of the National Research Council, her work focusing on energy improvement of historical building and contexts. In 2013 she earned her Ph.D. in Environmental Design at Sapienza University, with a thesis on sustainable urban open space renovation and on outdoor thermal comfort. She continued her work with a 10 months post Ph.D. scholarship at the Urban Microclimate group of Freiburg University, where she took part in the European project UHI (Urban Heat island), funded by Central Europe programme. Since 2010 she has carried out an intense research and professional activity in Italy and abroad, participating in national and international conferences and publishing numerous articles in international journals, focused on sustainable design, environmental renovation of buildings and historical urban contexts, decision support based on multicriteria analysis.

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06 DIGITAL SURVEYS FOR THE IMPLEMENTATION OF HERITAGE BIM

MICHELE CALVANO, FILIPPO CALCERANO, LETIZIA MARTINELLI, ELENA GIGLIARELLI

Abstract

In a Building Information Model, "the Level of Information Needs should be determined by the minimum amount of information required: anything above this minimum is considered WASTE"[1].
This is stated by EN ISO 19650-1, which also defines the concept of 'federation of models', able to express the information complexity that characterises built heritage. In the current research, digital survey procedures are applied for Heritage BIM, whose information system is implemented through Visual Programming Language (VPL) procedures; the survey phase takes into account the quality, quantity and granularity of information needs, avoiding excessive 'waste'.

In un modello informato «I livelli di fabbisogno informativo dovrebbero essere determinati dalla quantità minima di informazioni necessarie [...]. Tutto ciò che va oltre questo minimo è SPRECO»[1]. Questo è quanto enunciato nella EN ISO 19650-1, in cui tra i diversi argomenti si parla anche di "federazione di modelli" con cui è possibile esprimere la complessità informativa che caratterizza il patrimonio storico costruito. Nel lavoro esposto le procedure di rilievo digitale restituiscono modelli che completano il sistema di contenitori informativi attraverso procedure VPL; la fase di rilievo prende in considerazione la qualità, la quantità e la granularità del fabbisogno informativo evitando di eccedere nello "spreco".

1. Model Information Needs

The ever-increasing need for documentation of cultural heritage has led, in the last two decades, to a digital revolution in the field of data capturing and knowledge representation; a condition achieved through the simplification of processes, the miniaturisation of sensors, the change in the use of acquisition devices [Bianchini, Senatore, Catena 2019]. The limits to this advancement have been the storage and sharing of huge amounts of digital data; while the pandemic period has further accelerated the development of infrastructures for fast communication and content sharing, one of the last remaining barriers is the mistrust in new technologies and tools by users [Katz 2020].

Architectural modelling has benefited from digitisation processes, especially in the survey field, thanks to increasingly advanced space capture systems: for instance, LIDAR systems for creating point clouds using laser stations, Structure from Motion (SfM) to generate numerical data from a multi-image process and the Simultaneous Localisation and Mapping (SLAM) technologies used in mobile mapping. All of these technologies can quickly produce an immense amount of data, often redundant for the purpose and use of Building Information Models (BIM). EN ISO 19650:2019 points out that BIM is based on a clear definition of the actual information needs of models, and therefore it has made explicit the concept of Level of Information Need, which, on the one hand, emphasises the importance of information content and, on the other hand, demands information to be limited to what is essential, outlining a conceptual framework for data management by controlling the quantity, quality and granularity of information. Granularity refers to the deconstruction of information to the minimum terms (high granularity) to obtain more effective digital processes when querying BIM models [Succar 2010]. These considerations also involve BIM processes applied to Heritage BIM (HBIM) [Pocobelli et al. 2018; Radanovic, Khoshelham, Fraser 2020], which belongs to a more complex information context, involving several actors of various cognitive domains ranging from history, restoration, technology, diagnostics, etc., whose work produces information to be included and shared by the model (fig. 1).

2. Methodology

The most common BIM tools are object-based modellers [Eastman et al. 2018], able to represent standard building categories of modern architecture (walls, floors, roofs, etc.), but also to implement, via parametric modelling, typical elements of historical buildings (portals, columns, vaults, mouldings, etc.) for HBIM. The advancement of Scan-to-BIM approach [Biagini et al. 2016; Bolognesi, Garagnani 2018; Lo Turco, Mattone, Rinaudo 2017; Santagati et al. 2021] facilitated by the evolution of software, strengthening the connection between the editing environments of both acquired data (point cloud) and BIM, consolidating the following workflow: semantisation of survey data, critical 'construction' of HBIM objects and information enrichment of the HBIM model, as a result of the integration of HBIM objects.

2.1 Segmentation processes for the semantisation of captured data

The point cloud supports the definition of parametric model objects which, in addition to express the aesthetic instance of the building, assume the role of information containers covering the cognitive domains related to heritage [Quattrini, Pierdicca, Morbidoni 2017].

The geometric survey provides meaning to the signs and components that structure the building's representation. In the past, experts proceeded implicitly, recognising archi-

tectural elements according to a shared graphic nomenclature; today, BIM forces researchers to deal with 'disambiguation' operations, whereby elements are univocally recognised in a hierarchical system that conveys their formal value as well as their constructive behaviour. Upstream of the process is the breakdown structure of the point cloud, with a double objective:
- converge towards the technical simulation of the building via the BIM model;
- create the support for information directly related to model uses.

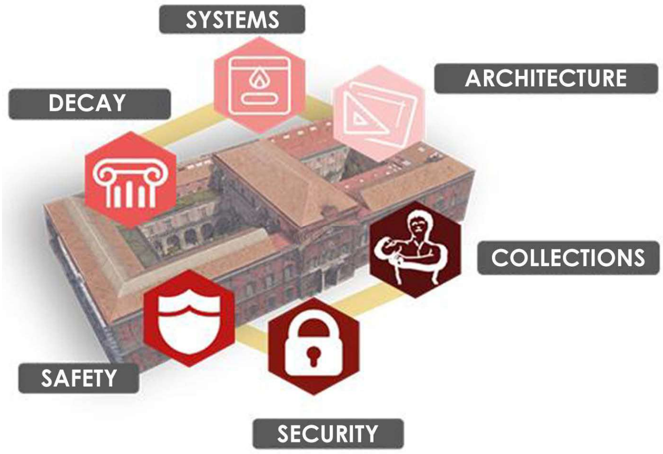
This breakdown structure, besides enhancing the building's knowledge (e.g. through annotations), simplifies Scan-to-BIM processes by reducing file size. The subsequent parametric modelling of the identified architectural elements is generally manual and still demands distinct care: the point cloud contains much more information than those required by the inputs of parametric objects, not fully responding to the principles of Level of Information Need.

To overcome these issues, we borrow from Reverse Modeling (RM) procedures – where managing the transition from point cloud to continuous NURBS surfaces is usual [Calvano 2016] – the recognition process of the 'structuring geometries', which guides the reconstruction of the surveyed building with continuous surfaces (fig. 2).

The transposition of RM procedure into Scan-to-BIM allows to identify the minimum entities in the cloud – points, lines, open and closed polylines – that define the 'geometric layout', i.e. the entities useful for placing the parametric model objects in the BIM environment [Guadagnoli 2020].

2.2 Geometric paths for placing HBIM objects

The formalisation of line tracing as an element capable of describing the algorithmic process of architectural composition was proposed in the 1980s, with the widespread



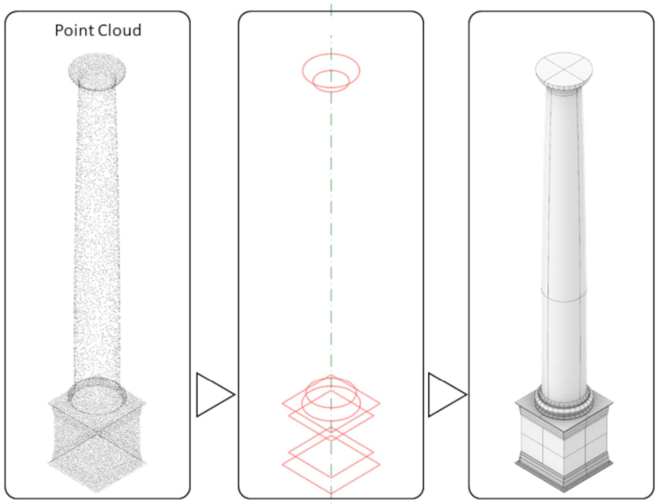


Fig. 1 - HBIM involves several actors of various cognitive domains ranging from history, restoration, technology, diagnostics, etc., whose work produces information to be included and shared within the model.

Fig. 2 - Geometric path detection from a point cloud using the Reverse Modeling process [Guadagnoli 2020].

use of CAD software. George Stiny and William Mitchell theorised the concept of 'shape grammar': a graphic and textual language (sign and metadata) used to describe the characteristics of architecture, giving meaning to a structured collection of elementary signs [Stiny, Mitchell 1978; Mitchell 1990] (fig. 3). This was an ante litteram metadata of simplified signs, in which the graphic entities were not yet associated with a data string, but everything was made explicit in a 2D graphic field.

One of their case studies was the Villa Malcontenta [Palladio 1570], where the two authors illustrated the power of shape grammar for the algorithmic deconstruction of the villa's compositional processes: a sort of visual language that progressively expressed the sequence of actions that determine the shape genesis of the building. The '2D' operations of Stiny and Mitchell are now reproducible and implementable using Visual Programming Language (VPL) procedures [Spallone, Calvano 2019]. The VPL language coupled with BIM enables architectural models consisting of parametric informed objects. The resulting workflow when associating the two tools is as follows:

- definition of the geometric framework of the model (geometric path);
- modelling and information enrichment of HBIM objects;
- association of the HBIM objects with the geometric path.

The standard workflow to link CAD and BIM environments (fig. 4) starts from the recognition of BIM components

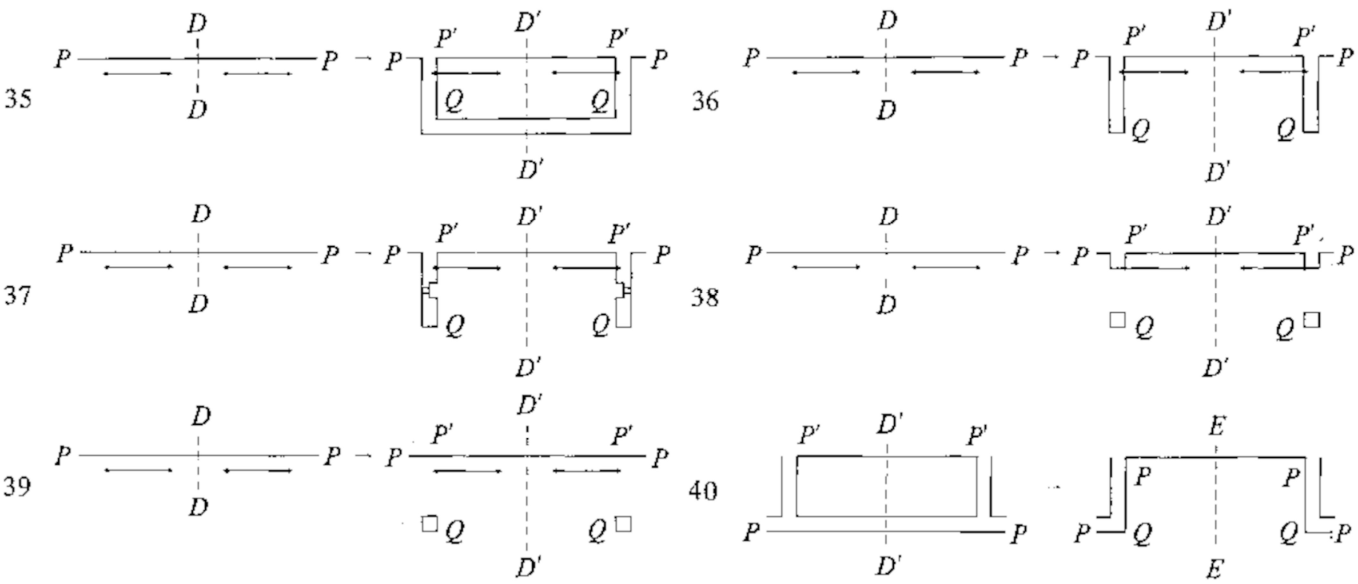
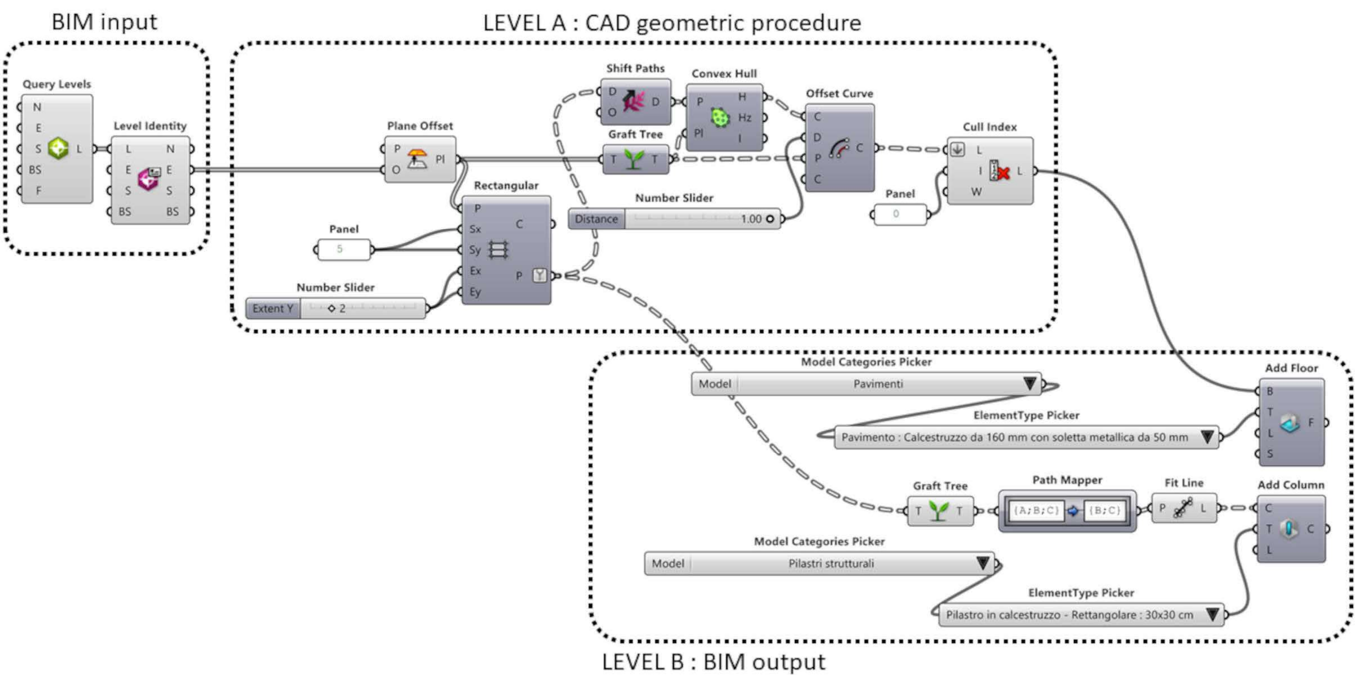


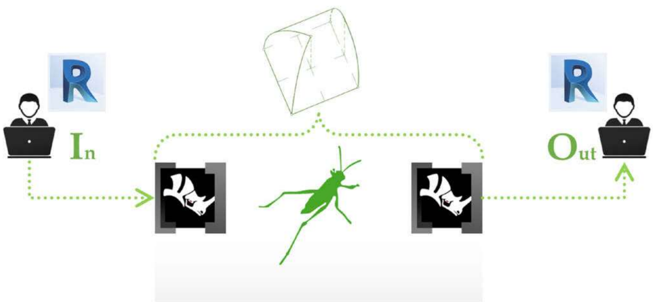
Fig. 3 - Shape grammar for the recognition of the compositional genesis of Villa Malcontenta [Stiny, Mitchell 1978].

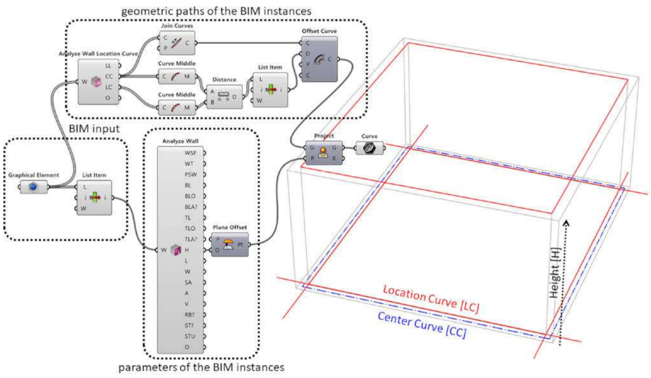
Fig. 4 - Integration of CAD processes into BIM using Visual Programming Language: standard workflows.

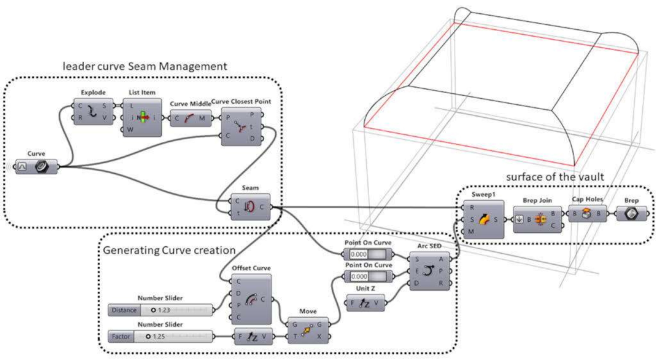
(levels, instances etc.), used to set parameters, transformations and constraints via VPL, which defines the geometric structure of architectural elements and their corresponding model objects. The added value of VPL is the responsiveness of the models created, based on two parametric levels:
Level A - configuring the geometric path and maintaining the relationship between geometries;
Level B - controlling the model objects to be associated with the geometries generated in the previous level.

2.3 Construction of HBIM objects: an example
Historical buildings are characterised by heterogeneity of materials and building systems that have been developed through time and that are not always suitable for standard BIM procedures [Gigliarelli et al. 2017; Radanovic, Khoshelham, Fraser 2020; Stefano Brusaporci, Maiezza, Tata 2018]. Preferred BIM tools are the ones offering optimised parametric modelling and dynamic information query.
Some of BHiLab's[2] experiences test the coupling of BIM authoring tools and VPL[3] to overcome the limits of BIM and automate processes [Gigliarelli et al. 2020] towards a better representation of historical buildings.
Revit divides objects into families, which are classes of geometry and information with a common set of properties and a related graphical representation. Parametric families, although well structured, often do not allow a clear description of the complexity of historical architecture; therefore, to facilitate HBIM representation, tools







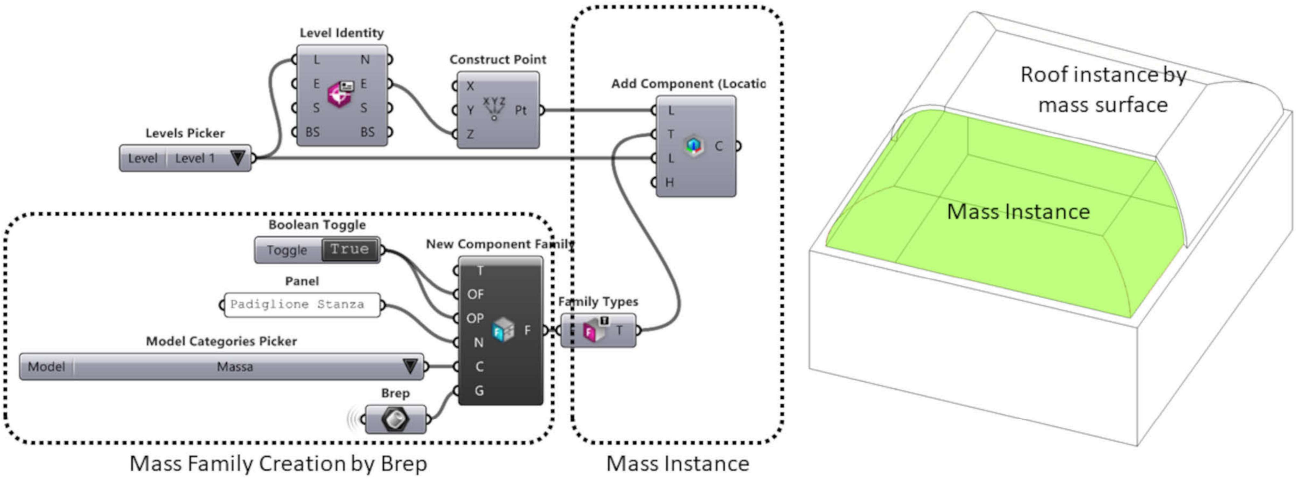


that exploit the connection between CAD and BIM can be suitable to couple the descriptive and constructive accuracy of the first to the semantic and informative aspects of the second.

To illustrate the BIM-CAD-BIM interoperability path through algorithmic operations in VPL, we show the modelling of a recurring element of historical architecture, the pavilion vault, that is not a native building element in *Revit* and therefore needs a dedicated process to get to an adequate representation of its shape and stratigraphy (fig. 5). The first part of the definition queries selected instances in *Revit*, extracting their geometric paths. To determine the vault's curve, we can start either from the wall objects that surround the vaulted room or from the shape of the room itself, if included in the model. The first method involves the identification and extraction of walls' location lines; wall objects are then deconstructed in their geometric and relational components. The extracted lines are joined in a closed curve constrained to the walls' upper constraint (fig. 6).

The *Rhino.Inside*[4] application expands *Revit* with the CAD capabilities of Rhinoceros software, inheriting the algorithmic potential of *Grasshopper*. The pavilion vault's geometry is defined from the shuttering curve, the radius of the shafts and the dimensions of the upper rectangular surface from the closed curve previously defined from walls (fig. 7).

The result is the creation of an abstract shape (called conceptual mass in *Revit*), placed in the BIM model exactly on the selected walls. In *Revit* this shape (the mass instance) can be the generative form of the 'roof' element, object able to represent a vault (roof instance by mass surface) conveyng stratigraphy and object informations (fig. 8). The second method uses rooms as input and can therefore be applied for modelling several rooms that share common boundaries, which are extracted to define the closed curves used as in the previous case (fig. 9). The two methods both



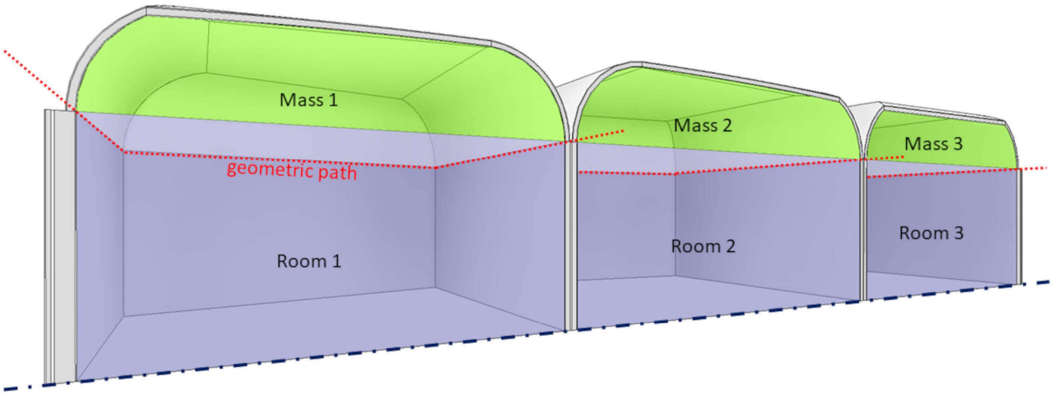


Fig. 5 - BIM - CAD - BIM data flow schematisation using the Rhino.Inside plug-in via Grasshopper.

Fig. 6 - Selection of instances in the BIM environment, extraction of the geometric layout for the construction of the vault shutter.

Fig. 7 - Management of the origin of the closed curve, placing of the vault; drawing of the generating curve of the vault; construction of the geometric mass.

Fig. 8 - Generation of the mass family from bRep, definition of the type into the design environment, application of the roof parametric instance on the mass surfaces for modelling the vaults.

Fig. 9 - Construction of several vaults from the inputs defined by the rooms, if any.

set one-dimensional entities as the input of the object to model, identifying the geometric path as the minimum data useful to trigger the modelling process.

3. Case Study: the Real Sito di Carditello

The workflow was applied to the IDEHA project (Innovation for Data Elaboration in Heritage Areas)[5] coordinated by CNR, and specifically to the Real Sito di Carditello (fig. 10). In particular, the Work Package 2 (OR2) leaded by the BHiLAB, involves the definition of a comprehensive HBIM process from data acquisition to modelling to the integration of both static and dynamic diagnostic data.
The pilot case for the current workflow is a vaulted room acquired through a photogrammetric procedure. The images were taken with a Canon EOS 750D and used for the generation of the point cloud through SfM, which involves the following steps:
- align photos and build a sparse cloud;
- build a dense cloud;
- build a mesh.

Our procedural hypothesis postulates the recognition of geometric paths directly from the sparse cloud. Figure 11 illustrates the result obtained following the orientation of the acquired images, a sparse cloud that densifies in significant places of the room's environment: the edges, the mouldings and the damaged surfaces. Such a sparse cloud, even though equipped with RGB data, does not allow the recognition of the surveyed parts; however, the same SfM software identifies as a sparse cloud the

set of homologous points present in several photos and used for their orientation in the digital space. In the 3D environment of the photomodelling software, the sparse cloud and the oriented photos from which the cloud can be observed coexist. This condition makes it possible to stand at the central point of each photo and identify a series of points that define the relevant architectural signs (paths and points). The advantage of standing on this side of the image is not only the easy recognition of elements but also the automatic projection of the targets onto the sparse cloud by the software (fig. 12). We could say that a sort of topographic survey is being carried out within the photogrammetric survey, where each oriented photo becomes a total station from which to collimate significant points, useful for the reconstruction of the two-dimensional primitives needed to place HBIM objects.
Once the target points are identified, they are exported in a vector format (e.g. .dxf) to be automatically acquired by the VPL code through a component that reads the entities in the directory where the file is placed. In this case study, the points are grouped according to their common height and interpolated by three different polylines: the ground path of the base of the walls, the elevation path of the vault shuttering and the path of the upper rectangular edges of the vault. The last two paths, providing further information on the shafts, determine the geometry of the vault which, using Rhino.inside, is classified as a mass in Revit, on which a roof with correspondent stratigraphy and information is applied.
With the same procedure, in the 3D space of the photogrammetry software, the points representing the insertion points of doors and windows are identified and enriched with metadata (fig. 13), to be recognised in Revit. The corresponding doors and windows have been modelled following a visual and geometric survey to select the constraints and parameters to define appropriate families and types. The VPL code developed with Grasshopper identifies the insertion points, reads

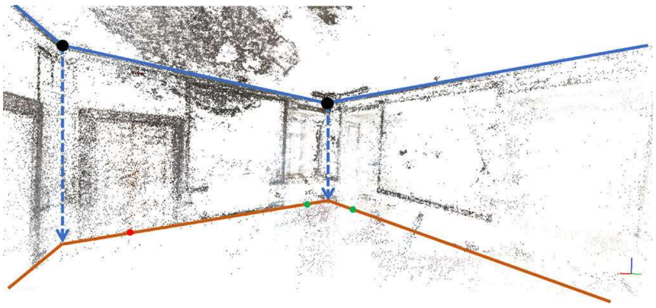


Fig. 10 - Point cloud of the Real Sito di Carditello produced with Structure from Motion process using images taken by a drone.

Fig. 11 - Outline of the geometric paths to be identified in the sparse cloud. The geometric paths will be used to locate the architectural instances in the BIM environment.

Fig. 12 - Collimation of significant points in the 3D space of the photogrammetric environment for the vector drawing of the geometric path.

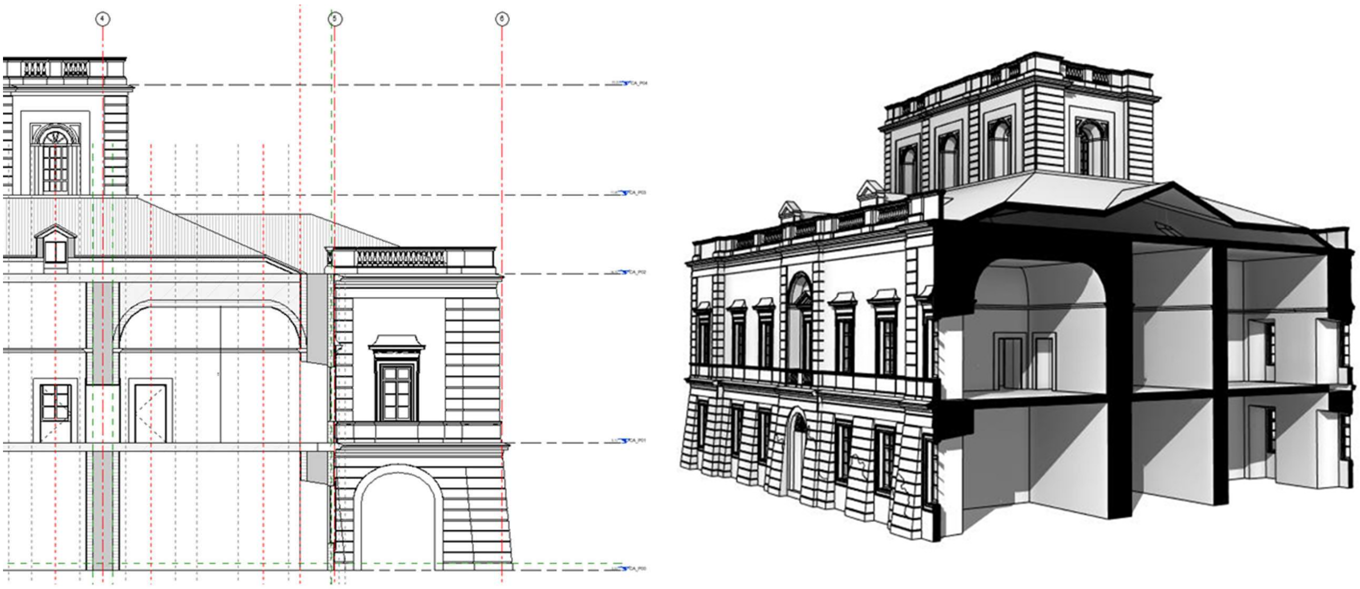


Fig. 13 - BIM model of the main building of the Real Sito di Carditello: the vaulted room has been modelled with the illustrated procedure is visible.

the associated metadata and recognises it as a door or window trace, where the correct doors and windows are automatically placed.

4. Conclusions

The workflow described allows selecting, within a Scan to BIM process, the most significant data from the complexity of information provided by a point cloud. The quantity of survey data, increasing with the evolution of the acquisition tools, is often excessive compared to the needs of BIM modelling processes. The illustrated work clearly shows how the inputs of the parametric objects of an HBIM model are also satisfied by a topographic approach. A critical/selective attitude when working remotely and not in the field, through a 360° overview of the model, allows an adequate tracing of the primitives to place and define HBIM objects.

This traditional awareness is returning at a time when BIM procedures force semantic clarity and constructive representation, bringing back the analytical approach towards architectural forms; an awareness that was being lost when the descriptive process of the surveyed forms ended with the construction of the polyhedral model from the point cloud, where the resulting mesh, although textured, was nothing more than a digital veil, more or less refined, capable of restoring the 3D silhouette of the real models.

The next steps of the research are aimed at defining tools that combine the current workflow with a 3D annotation software developed within CNR: a new application, desktop or cloud-based, to visualize the reality-based model produced by the survey and enrich it with textual annotations but also with metadata paths, according to a designed information mask; the data inserted, following defined ontologies, will be easily translated in the BIMxs environment as parameters to be associated with the model objects placed on the traced geometries, a 'pop-up' process that will allow the translation of the annotated geometric path into an informed parametric model.

Notes

1. EN ISO 19650-1.

2. Built Heritage Innovation Laboratory of the ISPC conducts applied research in the fields of knowledge, documentation and evaluation of archaeological and architectural heritage, regeneration and valorisation of monuments and historic centres, promotion and communication of cultural heritage through innovative multimedia technologies; Elena Gigliarelli is in charge of the Laboratory's coordination.

3. For the case study presented in this section (§3), we experimented with the BIM-CAD-BIM relationship using the Revit and Rhinoceros connection provided by Grasshopper and Rhino.inside to test one of the newest software technologies in AECO.

4. Rhino.Inside is a technology developed by Robert McNeel & Associates that allows embedding Rhino 7 into other applications. Rhino.Inside is also being embedded into Revit. Rhino.Inside.Revit is an addon for Autodesk Revit that allows Rhino 7 to be loaded into the memory of Revit.

5. Research funds PON - Research and Innovation of 2014-2020; lead institution CNR, Costanza Miliani, ISPC Director, is the project coordinator, Elena Gigliarelli OR2 scientific coordinator.

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