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From structure from motion to historical building information modeling: populating a semantic-aware library of architectural elements

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Abstract. In recent years, we have witnessed a huge diffusion of building information modeling (BIM) approaches in the field of architectural design, although very little research has been undertaken to explore the value, criticalities, and advantages attributable to the application of these methodologies in the cultural heritage domain. Furthermore, the last developments in digital photogrammetry lead to the easy generation of reliable low-cost three-dimensional textured models that could be used in BIM platforms to create semantic-aware objects that could compose a specific library of historical architectural elements. In this case, the transfer between the point cloud and its corresponding parametric model is not so trivial and the level of geometrical abstraction could not be suitable with the scope of the BIM. The aim of this paper is to explore and retrace the milestone works on this crucial topic in order to identify the unsolved issues and to propose and test a unique and simple workflow practitioner centered and based on the use of the latest available solutions for point cloud managing into commercial BIM platforms. [DOI: 10.1117/1.JEI.26.1.011007]

Keywords: cultural heritage; point cloud; historical building information modeling; workflow; structure from motion; data representation.

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1 Introduction

In the last decades, the use of digital technologies has completely changed and improved the working methods [from three-dimensional (3-D) acquisition to representation and modeling phases] in the architectural heritage domain. Moreover, because of new data acquisition processes, most operators believe it easy to manage complex information without having the required cultural background, we firmly believe that the real value of this research is the transfer between the cold and neutral large quantity of data to their critical interpretation, which gives them meaning and value.[1] After a scholar's interpretation, data turn into evaluated and recognizable information, distinctive for the knowledge of the studied object.

The aim of this work is to reason on and explore the capabilities of historical building information modeling (H-BIM) for historical building restoration, to effectively combine with the geometric accuracy of the survey with the parametric flexibility and wealth of the information typical of building information modeling (BIM) processes. This is a field of research that is more and more essential and critical when the copious presence of historical buildings in Europe and in Italy and the lack of BIM protocols and procedures that are relevant for this fundamental topic are considered.

One of the most meaningful definitions of BIM in international standards is a "shared digital representation of physical and functional characteristics of any built object (. . .), which forms a reliable basis for decisions."[2] However, today the suitability of BIM platforms for historical architecture is still considered a great challenge.

The first relevant issue is the conversion of 3-D data acquisition into parametric semantic-aware[3] components that are hierarchically organized.

Currently, 3-D acquisition techniques (laser scanning and digital photogrammetry) support easy and quick data acquisition. Even if the use of laser scanning is still expensive, a set of low-cost solutions for digital photogrammetry is available on the market and allows for the acquisition of architectural elements or details.

The obtained point cloud saves geometrical, material, and color data, as well as information related to the visible pathologies (Fig. 1). Nevertheless, the point cloud is not a semantic model[4] but is constituted of a large number of points that are ontologically indistinct before the geometrical restitution.[5] To this day, there is no automatic processing tool available that allows for the identification of complex shapes (such as the ones that characterize historical buildings) and turns them into geometric parametric models. Most of the software for management and processing of point clouds has advanced tools that allow one to make an "inverse" modeling.[6] They are provided with a series of two-dimensional (2-D) (plans and circles) and 3-D (cylinders, spheres, and cones) graphics primitives that are able to fit a surface to a specific selection of points (typically implemented by the scholar or automatically segmented) by means of best-fit algorithms that extract the best interpolating geometries. These algorithms take into account the typical noise of each laser scanner mediating the thickness of the cloud of points in a single geometry. Nevertheless, the complexity of surfaces in architecture reduces the direct application of this type of algorithm in a few cases.[7,8] Another possibility is to segment the point cloud and use patch surfaces.

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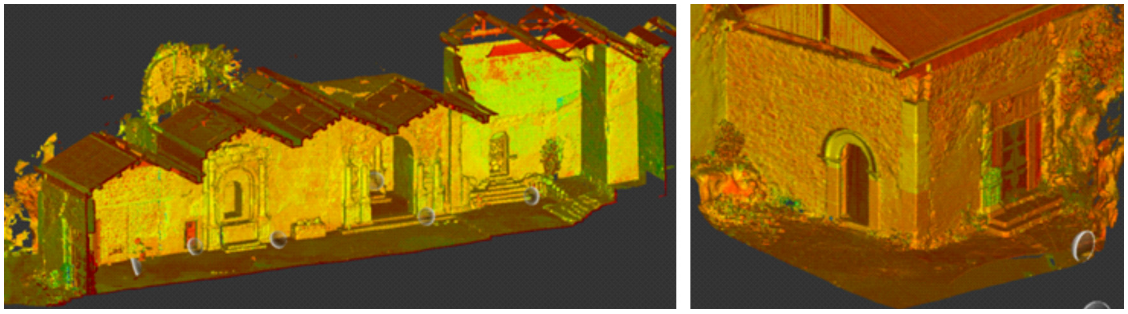

Fig. 1 View of the point cloud of the church of Maria delle Grazie in old Misterbianco

However, this procedure is not fully automatic and the user has to critically identify and extract the distinctive geometries that feature the object and then generate the patch (e.g., for vaulted systems).

It is a shared and common fact in the professional and academic community that the use of a commercial BIM package is mandatory to fulfill basic BIM requirements.[9] However, the existing BIM platforms were developed for architectural design. This means that the parametric objects inside them often are not suitable for the modeling of existing historical architecture elements such as walls, portals, windows, cornices, and string courses that use the elements of architectural language, available in many works. Another critical issue is the lack of vault components or the inconsistency in the geometric representation of the wall irregularities. As a matter of fact, the modeling tools in the existing platforms often perform very simple operations that are not always sufficient to geometrically describe the complexity of the real object, because of the high level of geometric abstraction.

Moreover, dealing with a historical building, in addition to geometrical information, a lot of heterogeneous data (original drawings, historical and recent pictures, inspection and degradation analysis to name a few) have to be organized, structured, and managed. The BIM database is able to recover such information and constitute an indispensable resource for different professionals that could be involved in the protection, intervention, or management of existing buildings.

As shown by the above, there is a need to create a shared parametric semantic-aware[10] library of architectural elements that belong to the different historical ages.[11,12] To do that, it is mandatory to create these objects through the family (Revit building component) design interface. If well modeled and generalized, these components can be reused in similar contexts. One chance is to use the architectural treatises that describe the recurrent typologies of architectural classical elements. However, not all historical architecture can be cataloged and classified into classical architecture. In this case, it is better to start from the survey of such elements.

In our research, we apply this last approach, reasoning for single architectural components, interpreting and formalizing them, developing and testing a workflow that exploits the advantages of low-cost digital photogrammetry and of a specific plug-in useful for creating parametric semantic 3-D models of an architectural element following specific workflows. We will reflect on data conversion (level of abstraction and generalization and level of accuracy), GRADE[13] (graphic detail, as the control of purely graphical contents) and LoD[14] (sometimes mentioned as level of detail[15] but here intended as the level of development, a degree of reliability of the model for data) requirements in the case of "as-built" H-BIM.

The aim is to give an answer to the discussed open issues and then to propose and test a unique and simple workflow practitioner centered and based on the use of the latest available solutions for point cloud management into commercial BIM platforms.

The paper is structured as follows: Sec. 2 will mark the state of art analyzing feasible workflows aimed at setting up new digital BIM libraries of building components, starting from the final product of the metric survey (point cloud). Section 3 is devoted to the analysis of different classifications, approaches, and the relative results in order to point out and depict our workflow. Section 4 describes the proposed workflow in detail, while Sec. 5 refers to a chosen case study. Finally, we will critically discuss the obtained results, and draw possible future research directions.

2 Related Work

Regarding the architectural design field, in recent years, the use of BIM has seen a consolidation in the procedures and the identification of standard methods.[16] However, the challenge is still open if considering the conservation, management, and enhancement of the architectural heritage. It is necessary to review and update the instrumental capture process of information, the standardization and structuring of acquired data in a 3-D semantic model, and the subsequent representation and usability of the model.

At the same time, the digital recording of cultural heritage sites using laser scanning and photogrammetry has become a topic of great interest in the field of conservation and cultural heritage. Although data collection technologies are now very efficient and automated, the processing of this data is still very time-consuming.[17]

As for image-based modeling, today, the accurate and detailed reconstruction of geometric models of real objects has become a common process. The diffusion of image-based 3-D modeling techniques through free, low-cost, and open-source packages of digital photogrammetry have drastically increased in the past few years, especially in the field of cultural heritage.[18] The low costs of these techniques as well as their attractive visual quality have led many researchers and professionals to invest their energies and resources in several tests that have shown the reliability of structure from motion (SfM) techniques for architectural elements where other techniques (such as terrestrial laser scanning) are costly, not sufficiently dense, or are not easy to access.[19,20]

Fig. 2 Some example of SfM 3-D textured models.

Referring briefly to the software used, we can distinguish between desktop- and web-based packages. If the former (Agisoft Photoscan, Zephir 3-D) needs a high-performance computer for data processing, the latter (123D Catch, Recap 360 Photo) uses the power of cloud computing to carry out a semiautomatic data processing instead of considerably slowing-down the computer. In both cases, the output is a dense textured point cloud of the analyzed object that can be easily turned into a 3-D mesh model (Fig. 2).

Furthermore, tests performed by several research teams have demonstrated that these techniques are closely dependent on the quality of the dataset (network, image resolution, ground sampling distance, and radiometric quality)[21] and are suitable for medium size objects, such as architectural elements and details.[22]

Regarding BIM methodology applied to cultural heritage, as previously stated, very little research has been undertaken to understand the potential of BIM for heritage buildings.[23–25] The efforts of researchers are currently concentrated on two primary questions:

- Can a BIM-based approach be effectively used for the investigation of historical buildings using commercial BIM platforms?
- How can point clouds be turned into rigorous BIM?

The answers to these questions are still open and will engage the scientific community for the coming years.

The first question deals with the lack of specific components/tools for historical architecture available for commercial BIM platforms. The reconstruction of complex shapes seems to be a challenging task. Once having obtained the point cloud and identified the single elements and their mutual relationship, the operator could:[26]

- build an in-place family directly in the project environment;
- create a family that could be reused in other projects (usually BIM platforms do not give the option to import point clouds into the family editor except when using specific plug-ins;[27] and
- create 3-D objects in another software and import them in the BIM model as surface models.

In literature, other works show several steps in 3-D H-BIM modeling;[12] these workflows use different software with the necessary format conversion and we mainly observe 2-D simplification with slices of point clouds to build up the 3-D model.

To answer the second question, we need to clarify the meaning of "rigorous BIM." In literature, we find several studies[9,11,12] that address the crucial transition regarding the conversion from the point cloud to the intelligent parametric object, introducing the concept of level of accuracy. In other words, the point cloud can be considered a digital copy of the object that preserves its geometric features (irregularities, deformations, and so on). Are we able to guarantee the metric accuracy captured by laser scanner and photogrammetric point clouds in the BIM modeling phase or rather is the level of abstraction too high for an appropriate geometry reconstruction? Some authors carry out a comparison—point cloud to model—(using Geomagic or Cloud Compare software) in order to evaluate whether or not the deviation is keeping with the scope of the H-BIM. Others, and this issue is directly connected to the first question, prefer to perform the 3-D modeling in other platforms (also by using procedural modeling based on shape grammar) that are able to create and manage nonuniform rational b-splines (NURBS) surfaces (that better approximate the trend and irregularity of complex surfaces);[9,12] then they use proper protocols to directly convert NURBS into parametric surfaces into commercial BIM platforms.

Other studies refer to "rigorous BIM," meaning the complete exploitation of BIM approaches for cultural heritage

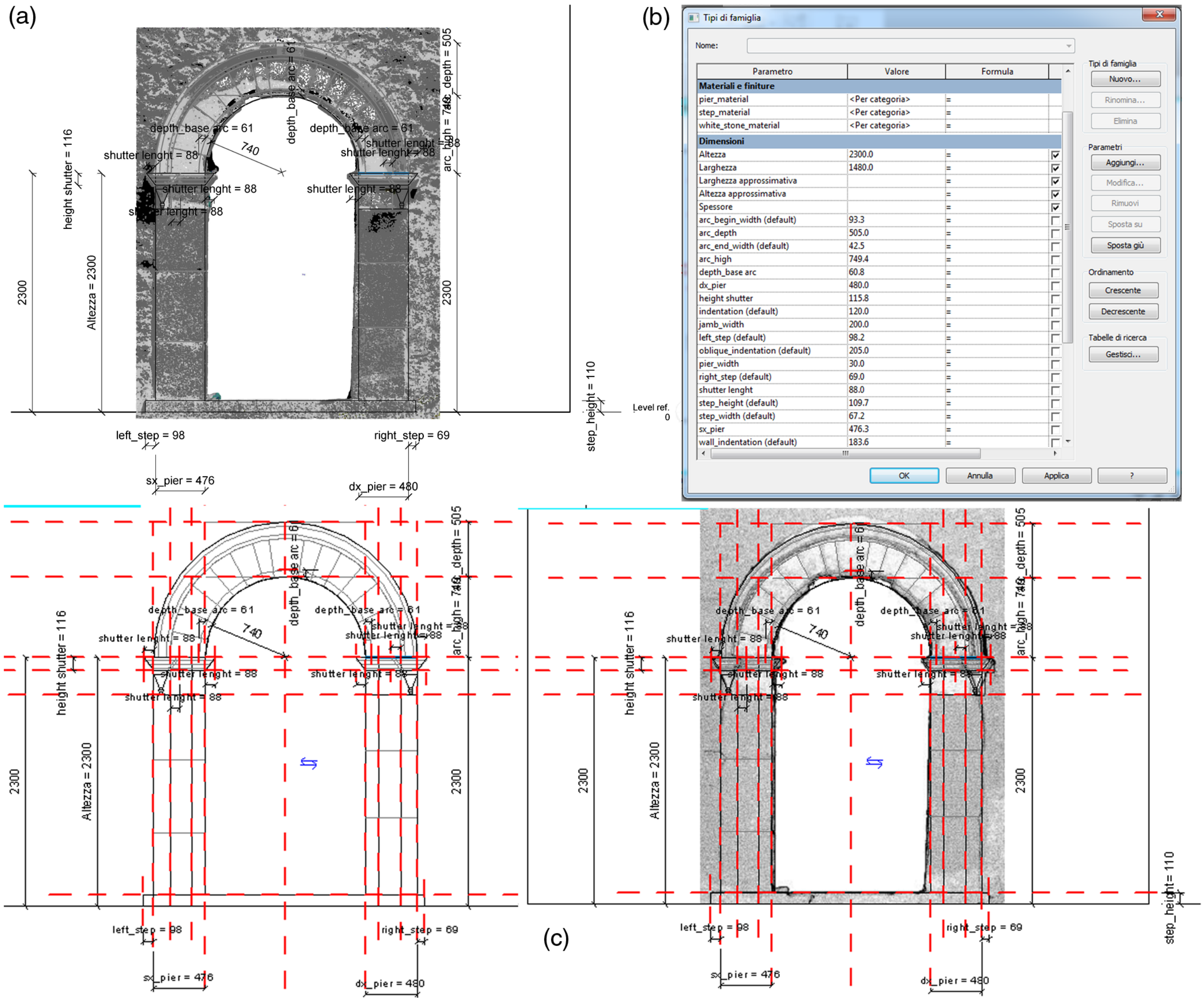

Fig. 3 (a) Modeling of the main portal through the interpretation of the data contained in the point cloud. (b) List of type and instance parameters associated with the modeled family and (c) highlighting of the reference planes that constitute the skeleton of the modeled component.

buildings not only in terms of geometric accuracy, but also considering the other aspects[28] (parametric objects, relations, attributes, and correct definitions of GRADE and LoD).

3 Process and Product Classification

In some work related to H-BIM, some samples of reconstruction of the existing condition have been described, often suggesting the generation of a semantic model[29] based on a constant comparison between the information included in the historical treatises and the profiles achievable from a point cloud. Some others are focused on the issues of accuracy between building objects models (walls, pillars, and vaults) and point clouds. Others, instead, suggest creating a historical library of building object models that currently does not exist.[26]

Once again, others propose a different classification for the whole approach, shifting the focus from general to specific issues. In this regard, "as-built" BIM characterization involves three aspects which allow one to pass from a point cloud to a structured semantic-aware 3-D model: shapes, relations, and attributes.[30]

Regarding the shape of the object, it can be classified according to three variables:

- parametric or nonparametric,
- global or local, and
- explicit or implicit.[31]

In a global representation, the entire object is described, while in a local one only a portion of the object is characterized. Another proposed classification is explicit versus implicit representation, to easily distinguish the shape of the object. Explicit representation allows for a direct encoding of the shape of the object. Implicit representation permits an indirect encoding, using an intermediate representation[30] (i.e., a histogram of normal surfaces, less used for the purposes analyzed here). Explicit representations can be divided into two categories: surface and volumetric representations. Among surface representation, boundary representation

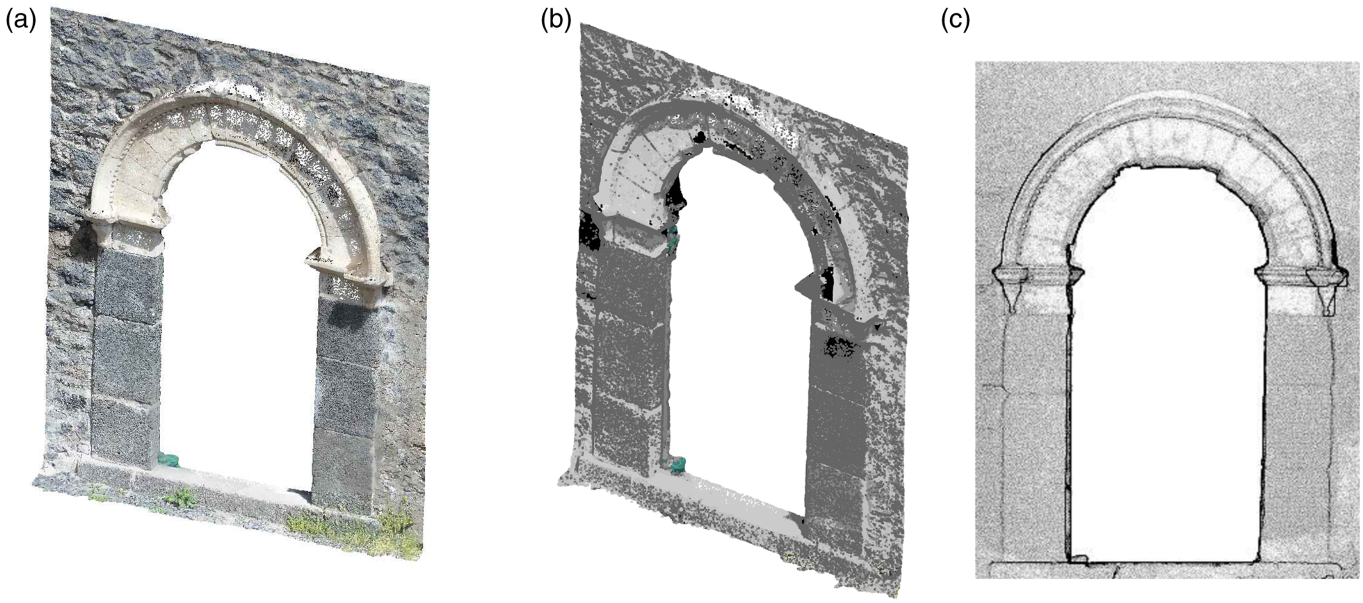

Fig. 4 (a) View of the RGB point cloud available on the Revit design interface, (b) the same point cloud loses the RGB property when imported into the Revit family interface, and (c) Pointsense can extract in x-ray orthoview to make the graphic modeling easier.

(B-Rep) describes shapes with a set of surface components, usually constituting the limits of the surface.[31] Volumetric representations describe shapes with geometric solids known as constructive solid geometry (CSG), which consists of building complex shapes starting from simple geometric primitives (such as cube, cylinder, sphere, and so on) by combining them using Boolean operators such as union or intersection.[32] B-Rep is more flexible and has a much richer operation set, such as extrusion (or sweeping), chamfer, blending, drafting, shelling, tweaking, and other operations, which make use of these. The CSG is the modeling strategy adopted for our approach.

Regarding the classification of each single building component, a further important consideration must be pointed out before developing this topic, as said, 3-D models that contain only 3-D (metric) data are not BIM models.[33] This means that a model generated from point clouds is not a BIM unless it has

a. parametric intelligence,
b. relationships, and
c. attributes.[28]

After these specifications, it is useful to summarize our personal challenge; we aim to set up a new digital component that belongs to cultural heritage, working on the parametric aspect through express modeling (CSG), and preparing the field for the corresponding data population. Section 4 is dedicated to describing how we are working on it.

4 Proposed Workflow: From Critical Interpretation of Data to the Creation of Parametric Building Components

The previous described works show a certain stiffness in the phase of graphic restitution or in the transition from the discrete (point cloud) to the continuous (parametric 3-D model, virtually rebuilt on the basis of photogrammetric surveys directly imported into the BIM platform). Trying to challenge ourselves with the restitution of cultural heritage, the first difficulty lies in the limited usability of parametric components available in software libraries and several websites that provide large amounts of material provisions drawn up by the new components production companies, thus mainly focused on new constructions.

Working on these elements, even before focusing on the modeling of the entire building, seems to be a significant field of investigation to assess the potential of BIM capabilities applied to cultural heritage, through heuristic approaches and investigating dynamic and little explored research fields. We would like to show the proposed workflow, starting from the product obtained from the acquisition phase, The point cloud survey requires a series of pre- and postprocessing stages which involve the cleaning, sorting, and combining of different sets of point cloud data. Then point cloud data can be considered as a skeletal framework, which is mapped using parametric architectural elements to shape the H-BIM.[12]

Moreover, the BIM software mostly used (Autodesk Revit 2016) does not allow one to import point cloud portions in the component design interface to be used as the basis for the virtual reconstruction of the building components (doors, windows, pillars, beams, and so on); the hypothesis to create “in-place elements” has been voluntarily discarded, because such elements, directly realized into the model, can only be saved in the .rvt project (Revit file format) without generating any .rfa external (and reusable) element (Revit component). This last step is mandatory to set up any library of reusable objects for subsequent interventions. The interface devoted to the design of these components can import vector files only with *.dwg or *.dwf file format or images.

A first available solution, though very time-consuming, consists of the use of applications that handle point clouds to make a controlled selection, a subsequent conversion into a text file, and a further file processing to obtain the file

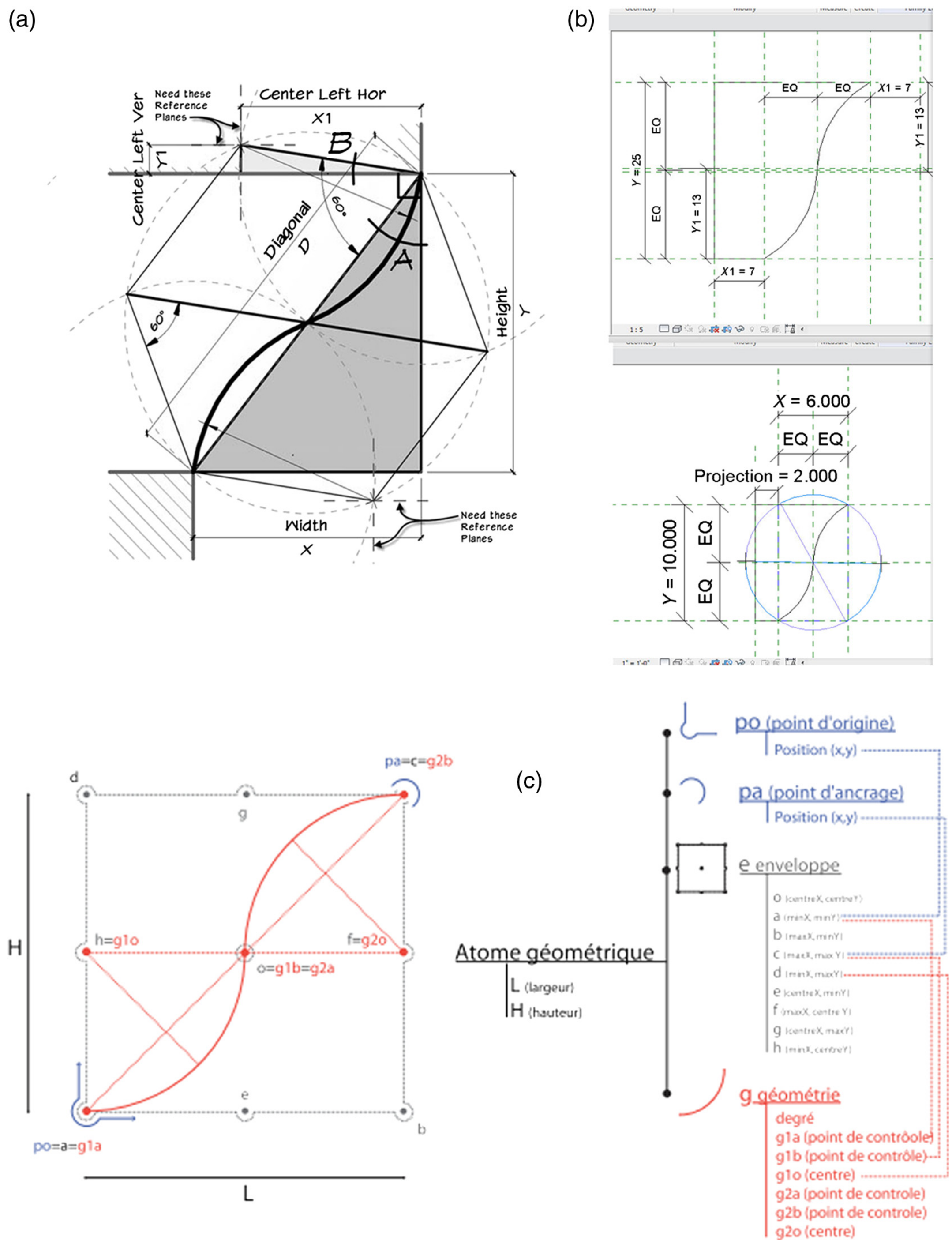

Fig. 5 Cima reversa molding parametrization according to (a) Aubin (© Paul Aubin[35]), our interpretation (b) and (c) De Luca (© Livio De Luca[36]).

format requested. Some preliminarily identified workflow can convert the point cloud into a. dwg file. This involves the use of rhinoceros and a python script used to import several extension point files (*.xyz, *.pts, and *.csv) and convert them into computer aided design files. The dwg file imported into the family design interface has some stiffness, making the virtual modeling of certain items that need to be visualized, analyzed, and measured in lateral views (sections) extremely arduous.

Recently, new tools have been released (such as Pointsense and Cloudworks for Revit plug-ins) to make the management and processing of raw data—point cloud—easier in the Revit family interface, e.g., by extracting orthophotos or segmenting point clouds. Among these plug-ins, in this research work, we tested the use of PointSense for Revit, a Kubit plug-in resell by Faro[34] that allows the user to export the whole point cloud or a part of it directly into the Revit component editor (Fig. 3).

Furthermore, to avoid visualization problems during the modeling phase, this plug-in allows one to easily extract x-ray orthoviews from the point cloud to which they are georeferenced (Fig. 4). Therefore, orthoimages and segmented

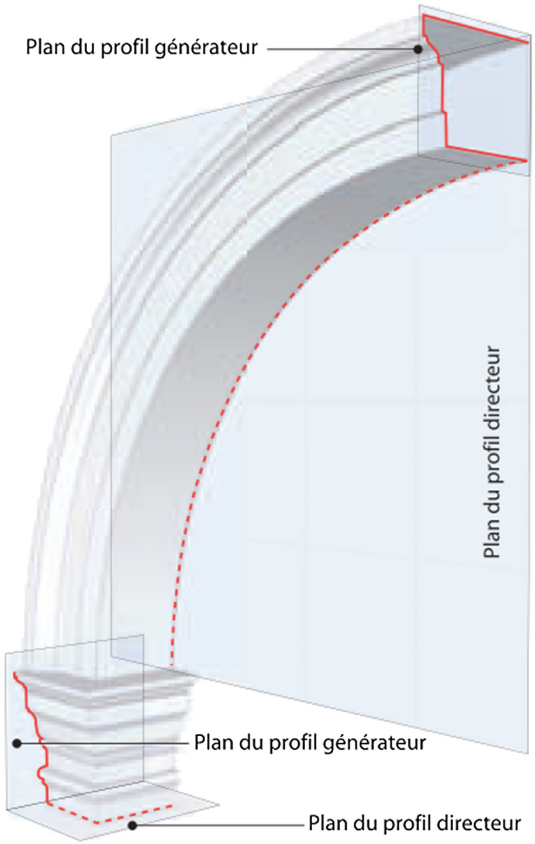

Fig. 6 Evidence of the plan of the generating profile and the plan of the directing path, © Livio De Luca (2006).

point cloud sections and elevations are the basic data imported as image and geometric data for further processing. This way, the critical interpretation of data is favored because point data redundancy is abstracted to the essential object skeleton lines. This approach is similar to the use of *in situ* eidotypes as trace, with the advantage of having a point cloud as a reference that can be visualized, cropped, and consulted in real time.

The critical interpretation of the architectural element (geometric analysis of typical shapes, compositional rules, and constraints of positioning and orientation) is aimed to formalize its semantic structure in order to make it explicit in an analytic language (parametrized).[4,15] Furthermore, keeping in mind the goal is to create reusable architectural components, it is mandatory to proceed with a formal and typological classification, in order to detect the regulatory rules, invariants, and the variation of the architectural style.

According to Murphy, a bottom-up approach is adopted that starts with the smallest building objects, such as ornamental moldings and profiles. These uniform objects are created from a shape vocabulary of 2-D shapes (Fig. 5) usable for all configurations of the classical orders.[35] Doing that, for each window, door, and all the decorations and ornaments modeled, we used a "crop cloud" very close to the element to extract 2-D profiles useful to outline complex forms drawn from classical orders (Fig. 6).

Reference planes and lines helped to trace the skeleton of the new parametric component; the following dimension and conversion into parametric variables will guarantee the geometric flexibility of BIM components.

At the end of the modeling process, we worked on the database in order to organize the different information gathered. All documents used for modeling, in fact, were linked to their virtualized components, associating an image parameter to the different element categories. This implementation allows us to link together the various original sources in a unique virtual environment. The virtual reconstruction permits multiple queries and the production of thematic drawings (such as the identification of the different measurement instruments, the evaluation of the types of degradation, the fourth dimension control, and so on). Each 3-D element is able to store a plurality of heterogeneous types of information. This can be considered the added value of using BIM instead of more established conventional approaches.

Section 5 shows a practical implementation referring to a case study of historical interest.

5 Case Study

As a case study, we chose a 15th century gothic portal, characteristic of Catalan-Aragonese architecture in the Etnean area of eastern Sicily. This portal is one of the few memories that survived the catastrophic events that occurred at the end of the 17th century in eastern and south-eastern Sicily; the disruptive Mount Etna eruption (1669) that covered and erased 16 Etnean towns and the earthquake (1693) that destroyed almost all the towns of the Val di Noto.

The portal belongs to the old church of Santa Maria delle Grazie in Misterbianco (5 km far from Catania), which was covered by the eruption of 1669 and was brought to light in the last years thanks to the excavations carried out by the Superintendence to Cultural Heritage of Catania.

This portal represents a recurrent typology of the Catalan-Aragonese architecture in the Etnean area (Fig. 7); other very similar examples can be found in Mascalucia (survivor portal of the church of Santa Annunziata in Mompilieri and the church of Sant'Antonio Abate) as well as in the remaining area (Randazzo, Francavilla, Santa Lucia del Mela, Taormina, and so on).

The recent finding of the portal in Misterbianco validates the hypothesis of a well consolidated school of local craftsmen who used the available materials, interpreting and elaborating the Spanish style of the time. As a matter of fact, the presence of the lava stone as construction material along with white limestone leads to a distinctive bichromatism typical of these areas. The portal in Misterbianco is a round-arch portal whose jambs are in lava stone. The springing cornice ashlar is realized in white limestone as well as the archivolt, the cordon, and the conclusive corbel.

5.1 *Three-Dimensional Data Acquisition*

The first step for having a good quality 3-D reconstruction by means of SfM techniques is to create a well-structured network of images. This can be fulfilled if an overlap of 70% between one image to the other is ensured and images around the object are taken with different rotations and different heights so as to vary the angle of the shoot; environmental light conditions are taken into account; the focal distance is fixed for all the data set.

The images were taken with a SONY DSC-W310 digital camera, 35-mm lens and at a resolution of 12 Mpix. The shot project took into consideration the geometrical features of the portal and the presence of the decorations for a total

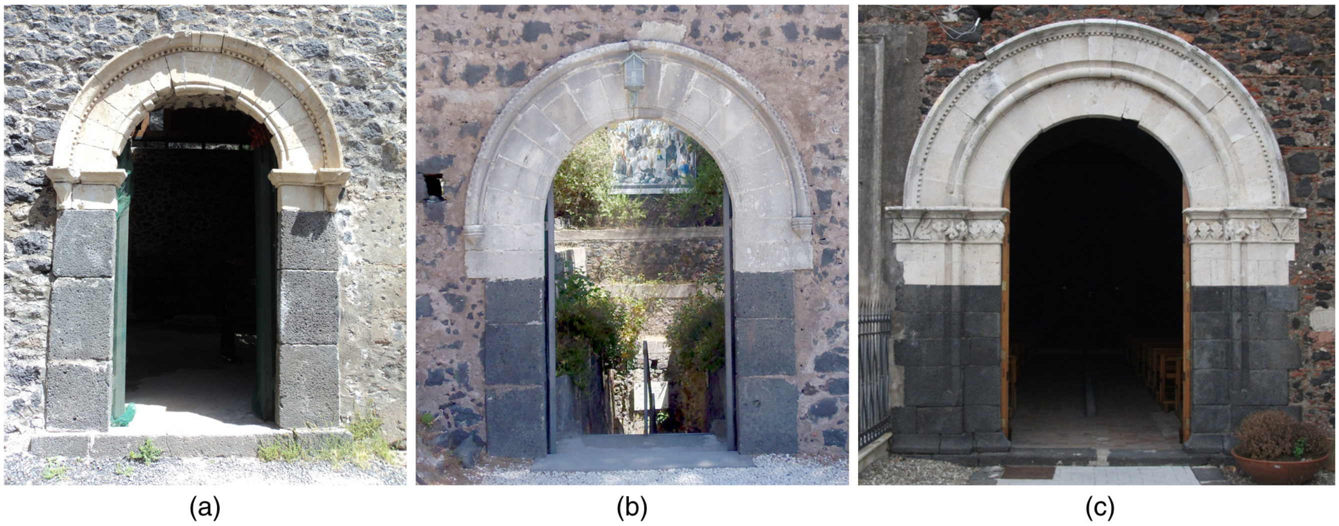

Fig. 7 Fifteenth century Catalan-Aragonese gothic portals: (a) S. Maria delle Grazie church in Misterbianco, (b) S. Annunziata church in Mompilieri, and (c) S. Antonio Abate church in Mascalucia.

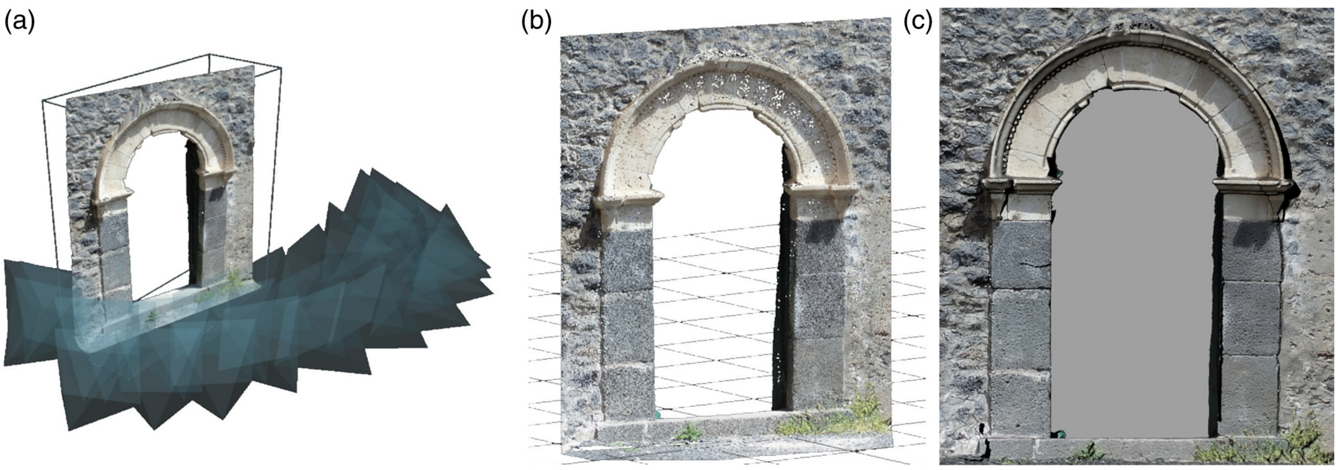

Fig. 8 (a) View of the dataset, (b) the reconstructed point cloud, and (c) orthophoto of the portal.

of 30 shots that include pictures of the entire object and details.

To formulate a workflow compliant with the most used commercial BIM platform (Revit) among all the available SfM packages, we chose Autodesk cloud-based photogrammetry service Recap 360. Taking advantage of the photogrammetric approach and algorithms of computer vision, the service reconstructs the internal parameters of the camera and the position in space of homologous points between frames starting from the correspondence between a sequence of photographic images. The user creates the project, adds survey points or reference distances to scale the model, chooses the resolution of the model (low and ultra), the smart cropping and/or texturing option, and the export format (e.g., RCS, RCM, and OBJ). Then the images are uploaded and sent to the cloud. The user is advised by e-mail when the model is ready. Then he can improve the model itself by adding survey points and resubmitting the project.

The obtained point cloud consists of about 500,000 of points; the ground sampling distance of the model is 1.3 mm. This output is congruent with the previous authors,[21] and literature tests[22] conducted on quality assessment of data acquisition and an obtained point cloud from SfM techniques.

The point cloud (.rcs format) was imported in Recap PRO where it was cropped and prepared for the following importation in Revit. At the same time, the OBJ model (mesh textured model) was opened in rhinoceros and the first orthophotos were extracted (Fig. 8).

5.2 *Critical Interpretation of Architectural Features*

The numerical model (point cloud) provides a discrete digital replica of the portal, which means a mass of raw data that quantitatively describes the object but needs to be interpreted in order to be transformed into a parametric semantic-aware model.

To do this, the geometrical rules that generate the complex surfaces have to be recognized as well as the corresponding mathematical law. The construction of the geometric model requires a deep knowledge and study of the shapes and the language of historical architecture in order to achieve a proper semantic description and connection between the elements. In this phase, the operator works consciously,

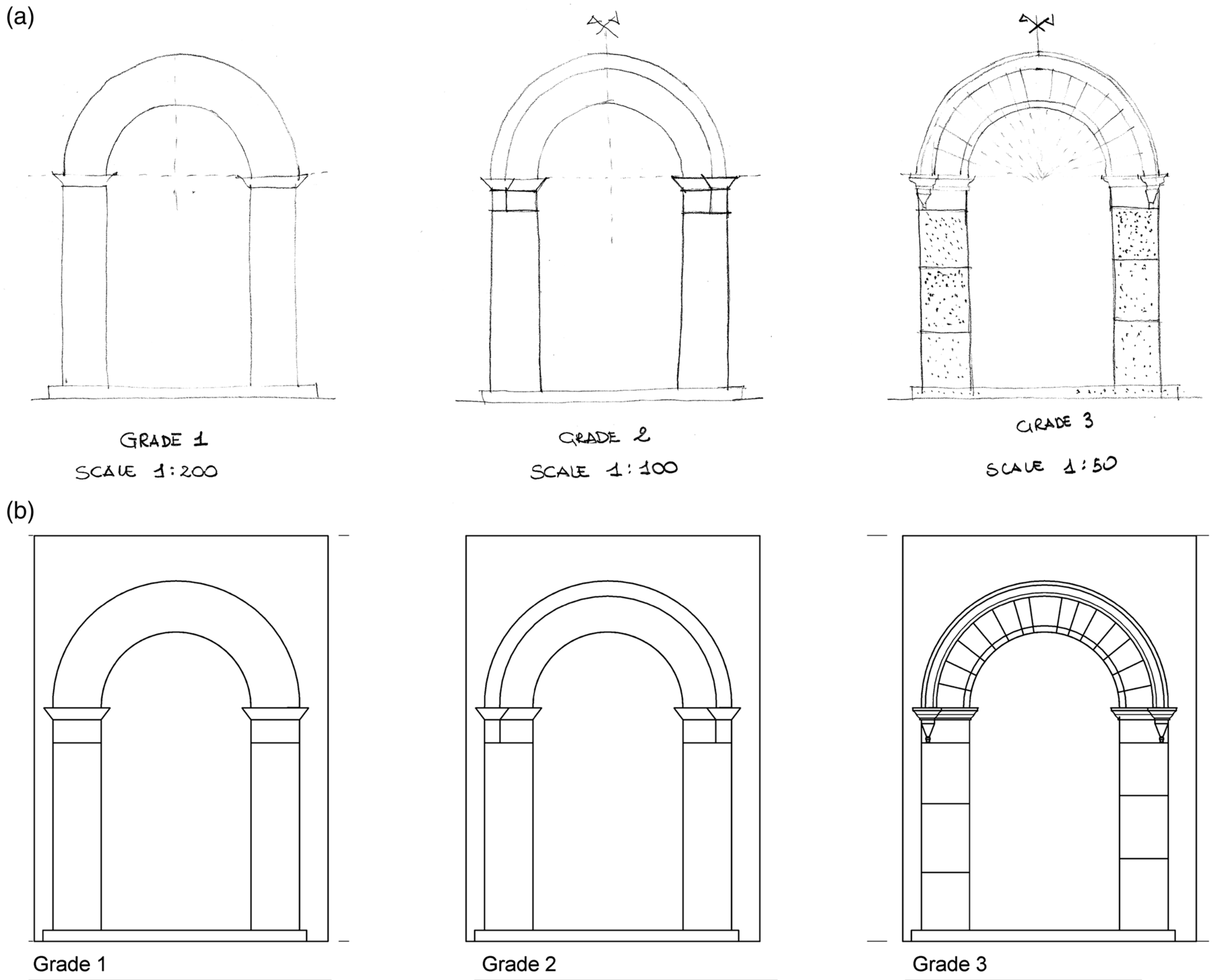

Fig. 9 (a) Proposed GRADE levels created by handmade eidotypes in comparison with (b) modeled GRADE levels.

recognizing the different elements and proceeding from general to particular by identifying the architectural elements that characterize the object of study, gradually destructuring the elements that constitute them up to the moldings—the atoms of the architectural lexicon[36]—through a conceptual abstracted process where geometry is a tool to decode the complexity of reality.

Therefore, it is necessary for:[4,11,29]

- the rigorous identification of all the elements that geometrically and mathematically describe the investigated surfaces;
- the identification of the geometric genesis of the studied surface (translation, rotation, and interpolation), and the identification of the mathematical law (Revolution, Estrusion);
- the finding of basic construction planes for each 2-D profile and path; and
- their extrapolation from the point cloud by means of a set of significant cutting planes.

The architectural element needs to be decomposed in its formal, material, and structural components. In this way, it is possible to extract the geometrical rules that generate the several surfaces/elements identifying the invariant features and the variant ones (a set of 2-D profiles).

In this case, the portal presents some relevant features of Catalan architecture: a simple round-arch archivolt ended by a cordon and corbels (in limestone), straight jams (in lava stone), and an ashlar that holds the arch spring cornice (in limestone).

Reasoning on the invariant and variant elements, we can assume that not always is the arch spring cornice present (as in the case of Mompilieri), and in some cases, the cordon profile is inside the external jamb line (once again in Mompilieri); furthermore, the cornice and cordon 2-D profiles vary according to the creativity of the craftsmen.

Summarizing, we can consider the following invariant: the presence of a limestone archivolt ended by a cordon (extrusion along a curve path), the presence of lava stone jambs (extrusion); the presence of a corbel, the use of limestone ashlar in correspondence with an arch springer; the

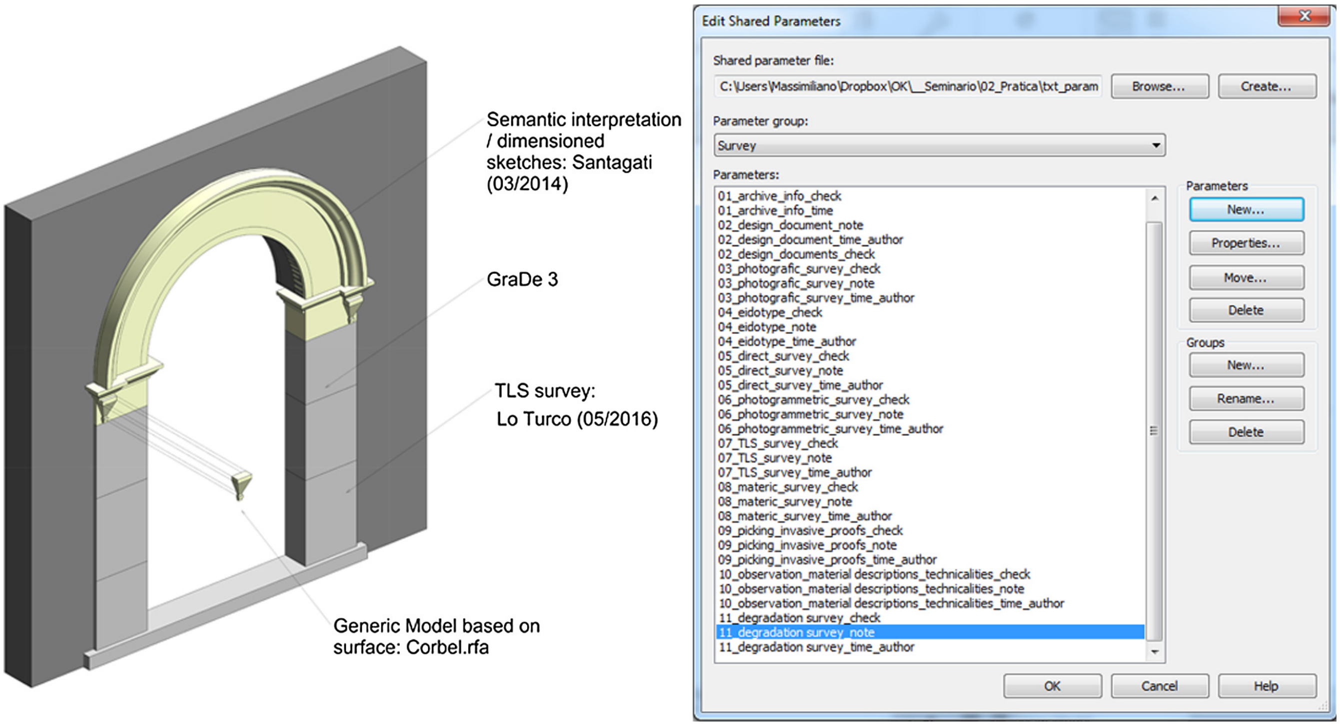

Fig. 10 List of shared parameters relating to survey procedures that can be associated with several object categories in order to define their level of accuracy.

variant elements are the 2-D profiles of the cordon, the presence of arch springer cornice, the position of the 2-D profile of the cordon (inside or outside the external jamb line).

All these issues have to be considered during the modeling phase in order to create an H-BIM component that generalizes this type of Catalan-Aragonese portal so that it can be reused in other projects.

Finally, the level of abstraction that is required during the modeling phase could be unsuitable for the specific features and irregularities of the architectural element and its scale of representation. This issue involves the so-called level of accuracy of the H-BIM model or component. The adhesion of the "mathematical" model to the numerical model can be directly checked into the BIM environment by using Point sense plug-in or using external software such as Geomagic, Cloud Compare, and Meshlab. The result is a detailed description of the deviation between the two models.

5.3 *Implementing Parameters: Graphic Detail and Level of Development Specification*

As previously mentioned, the BIM platform allows one to associate multiple data to a single virtual component. The first group control graphics output: international guidelines identify the GRADE level (expressed on a scale from 0 to 3, with increasing levels of definition: G0 = schematic, G1 = concept, G2 = defined, and G3 = rendered) to manage the graphical representation of building components in orthogonal projection and spatial views, congruent with different levels of detail, thus with different design phases.

The second set is characterized by alphanumeric parameters: the international guidelines define LoD (level of development) as the degree of reliability of information that can be expected from data contained in the digital model. According to several regulations, systems in the field of public works and different levels of LoD were identified.

As for the graphical views associated with different levels of detail, we based the modeling procedure on the basis of dimensioned sketches made during the survey, consistent with the different representation scales; it was decided to set up (Fig. 9):

- at GRADE 1: displaying the jambs, the frame of the archivolt, and the step, as well as highlight the change of material between springer cornice and jambs;
- at GRADE 2: the added 2-D drawings of corbel and cordon, appropriately schematized; and
- at GRADE 3: 3-D modeling of the corbels, cordon, and the highlighting of the ashlars of the archivolt and jambs.

As regards to LoD specification, it must be said that such classifications are particularly applicable in the cases of new buildings interventions, where the measurement of the LoD level is linked to economic checks, performances, as well as to topological, construction, and maintenance information. In the case of interventions on existing buildings, in particular on cultural heritage, it is necessary to include other variables, critically analyzing the richness of the information available. This is done to measure the reliability degree of the survey. The more the survey is complete, the greater the integration with the various stakeholders, who participated in the study, can be arranged. This procedure includes the retrieval of design archives, the photos of the state of art, the metric survey techniques, and the materials and decay surveys. Through the creation of shared parameters (Fig. 10) (therefore applicable to multiple types of components and on multiple projects), we are able to associate new parameters with the element detected and track it in the database associated with the parametric model. As previously mentioned, the added information will, therefore, be made evident in the model through labels, schedules, or thematic views.

6 Conclusions

Along with the methods for semiautomatically plotting building facades, manual plotting methods can also be used with existing H-BIM library objects. The approach used with H-BIM is to map the objects in 2-D onto segmented point clouds and orthographic images in elevation, plan, and section.

The elements (moldings, profiles, symbols, and so on) become the architectural vocabulary. The whole composition relates to a linguistic structure, offering a basis for analysis and understanding.[37]

According to this, ontology can be intended as a particular conceptual framework or as a specification of a conceptualization. It enables aggregation, as well as topological and directional relationships.

Aggregation (i.e., part of, belonging to, and so on) could be modeled with a hierarchical-based tree representation that allows one to describe the composition in a local-to-global way. Consequently, it is possible to develop semantics and management procedures in order to determine the correct LoD of the surveying and of the model. This theme is considered an open research topic, because of a current lack in the regulation systems (or guidelines) that define the levels of LoD according to the degree of reliability of the survey.

The generation of a geometric model allows for many more applications of survey data such as semantic and information modeling, which enables complex analysis, management, and visualization of heritage data.

Finally, it is crucial to make a general statement about the methodological accuracy; in this regard, the London Charter[38] defines the principles to be followed for the 3-D representation of the cultural heritage, in line with the values of transparency, communicability, and repeatability of the methods, and the results of this modeling process. We agree to state that "knowledge is the first stage of conservation"[39] and the conducted research corroborates this assumption.

This guarantees a repeatability of the scientific process where the variable element is the data, the fixed one is the process.[40] From a more scientific point of view, the application of these principles will allow us to address and define a methodology for the knowledge (and the representation) of the cultural heritage that makes the virtual reconstruction, the processing, and communication of data more transparent. We, therefore, propose a reflection on the infographic drawing, leading to a new form of design, and expanding the frontiers of our discipline. The concept of cultural dimension is thus a greater formal qualification in a permanent relationship between architectural space and information space. It, therefore, guarantees a repeatability of the scientific process where the variable element is the data, the invariant is the process.

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