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Informative Models for Architectural Heritage

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Abstract: BIM (Building Information Modeling) processes are the most effective way to know existing architectural structures, integrating the most advanced potentials of 3D modeling and the structured storage of heterogeneous information. Many HBIM (Heritage Building Information Modeling) applications lead to the systematization of survey data, even though a univocal working method is not yet clearly defined. This research considers the decomposition of architecture, based on structured criteria, and its reconstruction, through ideal models, as the main moments of the HBIM process. This hypothesis is verified through a procedure that links the survey 3D data with the characteristics of the ideal HBIM model, which allows a continuous comparison between the project model and *as-built*. The research provides for the setting up of a general methodology that, according to a growing approach to the complexity of the analyzed buildings, compares the process followed on two architectural structures. The study analyzes some important HBIM issues: The relationship between the semantic modeling and the surfaces' continuity of architectural heritage; the relationship between the elements standardization, geometric irregularities, and material heterogeneity; the reliability of the built models; and the evaluation of the gap between an ideal model and the objective accuracy of surveying.

Keywords: HBIM; built heritage; architecture; 3D model; ideal model; surveying; survey; modern architecture; archaeological architecture; Rome

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1. Introduction

The Italian territory is full of buildings with historical and cultural value, which require more or less invasive transformation. For this reason, methods and tools to store, share, and manage information on their past, present, and future status are necessary. This implies continuous updating between the methods of massive data acquisition, more and more precise in metric accuracy, and digital models, ever more complete for information quality [1,2]. The presence on the territory of a very high number of existing buildings, many of them of high historical and cultural value, which require more or less incisive transformation interventions, has favored the extension of a European directive of 2014 (EUPPD 2014/24/EU). It promotes a new approach concerning the entire building process (design, representation, construction, management, and maintenance) and invites the use of BIM not only for new construction interventions but also for restoration, adaptation, or maintenance. In this context, it is necessary to keep in mind the link between these operations and knowledge and documentation of the history and current-state of the artifacts. They are closely connected with the activities of acquisition of historical heritage data. The integration of survey data, now increasingly complete, heterogeneous, and shareable, and the HBIM systems, allows for a lot of reality-based information to be brought in. This information (metric, geometric, morphological, material, chromatic) expressed through digital models allows for improvement of the knowledge of the building and offers control using the acquired data in the development of subsequent projects.

The construction industry uses BIM for its decentralized planning and control of interventions, but it also influenced the complex management of architectural built heritage. Heritage BIM pursues the modeling of architectural elements according to their constructive and historical-artistic characteristics [3–5].

The HBIM processes allow, through digital platforms and integration with survey data, for the investigation of new possibilities of managing the cultural heritage data, from the general to the detailed scale, associating quantitative and qualitative characteristics. The first concern physical parameters, metric, geometric, morphological, and spatial information; the latter, instead, constitute all those contingent or permanent properties linked to the formal aspects of the analyzed structures. However, the possible interactions between the HBIM and the survey data are still in progress because the purposes for which BIM systems are born and used change when they are used for built heritage. Then, because of the growing up of professional figures involved in the management of the objects in question; not only designers, engineers, installers but also historians, restorers, figures in charge of the protection of cultural heritage. Furthermore, the processes of data systematization and organization for models of cultural heritage follow paths defined each time with reference to the different needs, to the prefixed objective, and the characteristics of the objects analyzed. In fact, it appears that a procedure to be followed has not yet been consolidated.

The present research consists of three phases. The first phase, cognitive, consists of a survey of the state of the art in the framework of the construction of models for the Cultural heritage, the criteria followed, and the systemization of data in HBIM processes. The second phase, analytical, is aimed at identifying case studies in the field of existing cultural heritage; based on their typological representativeness and their characteristics, the problems with which to verify application procedures are identified. In the third phase, the final phase, critical considerations deriving from the previous phases and potential elements of innovation flow together.

2. State of the Art in HBIM Processes: Different Approaches and Issues

The definition of a methodology for the switch from a numerical model to a parametric model according to BIM process is still in progress and is studied in different researches. A growing need to store and share information and models of architectural heritage has prompted scholars to test different ways to approach the HBIM. They still show some limitations, but not so much in the integration between different kinds of data. The main difficulty is the semi-automatic operation that allows transit from the numerical model—the point cloud—to the parametric model. This step consists of the construction of more or less articulated architectural elements, through the reconstruction of semantic identity, and ensuring correspondence with the real object and with its metric-dimensional aspects. Actually, point clouds record the geometric, chromatic, and material characteristics. To have information about the topology and semantic features of the architectural objects is necessary to produce other types of models, such as geometrical, architectural, or the parametric ones. It is a reverse engineering operation, in which the reading and segmentation of the point cloud, after recognizing characteristic regions, is the first step to identify surface boundaries that facilitate the modeling process. These activities are semi-automatic or completely automatic, through the progress achieved by the systems supported by the BIM processes.

The exam of progress achieved in academic research and in work experiences shows that a big step has been taken towards the automation of the process of point-cloud modeling. The algorithms and software's plug-ins are easily applicable for the segmentation and automatic modeling of point clouds that describe flat surfaces or primitive geometries. However, they generate incorrect results when trying to represent geometries of complex and irregular historical buildings. Three-dimensional modeling of any artifact implies an organized and orderly composition of digital elements but, when applied to HBIM, must go beyond the typical workflow. The ambitious purpose of the best match between the real object and the virtual model makes it necessary to structure different phases to define and optimize the workflow. The heterogeneity of the built heritage means that the definition of structured protocols is useful to represent the characteristics of the case study, because the BIM process was not created to study built heritage. To apply the BIM methodology to architectural heritage is possible thanks to continuous technological advances, but also considering its theoretical implications to propose new implementation. The scholars involved in the study of HBIM have developed different methods and used technologies for three-dimensional modeling of existing historic buildings and the use of parametric components. A careful analysis of existing literature, but also of research still in progress shows how the BIM approach for architectural heritage can be set up by three different approaches. The first category includes those studies that adopted only commercial platforms for BIM processes to create models of existing architecture creating libraries of parametric objects. The second category concerns researches, which combine BIM systems with auxiliary tools or plug-ins, including open source software or commercial data storage and management (i.e., GIS). In the third category are researches that combine HBIM with web applications.

- HBIM models

The researches belonging to the first category aim at construction of HBIM models with the creation of the related libraries. Although the software used is often different (Autodesk Revit, Graphisoft Archicad, etc.), the methodology of survey data elaboration is the same. The sections on numerical models allow for the optimization of parametric modeling operations. However, most of the cases analyzed do not state what the level of automation of the process was, which makes it difficult to understand how to implement the management processes. In addition, the creation of HBIM libraries start from 3D modeling of parametric objects based on point clouds. It integrates the primitive geometries provided by the platform used with the documentation related to the chronology of the life of the artifacts. Two problems arise from the analysis of different cases: The integration between the different formats, resolved through the GDL (Geometric Description Language) script language included in the software, and the modeling of irregular shapes, once identifying their profile on the numerical model imported in the BIM platforms.

López et al. (2017) developed this process [6] to model the Romanesque church of Santa María la Real de Mave, Palencia, Spain. The creation of the dedicated library has provided, in the first instance, the collection of information on the built space and its semantic structure, then the processing and organization of the data obtained. The sections of the numerical model, the aid of a grid that considers the characteristics of the object, the rules and the construction schemes of the architectural period to which the building belongs, have allowed the creation of simple and homogeneous surfaces. For the more complex ones, the profiles were first represented on a plane (2D), then transformed into a solid element (3D).

Del Giudice and Osello (2013) [7,8] model different architectural elements directly on the numerical model. The strength of these studies does not lie in the creation of libraries, not developed, but in the approach to temporal calculation, effective for the organization and control of projects for the management of the heritage.

Biagini et al. (2016) [9] used a similar workflow for the connection between clouds of points and tools for modeling in the BIM software. They underline how the fundamental problems are (1) the identification and separation of the components to be modeled according to their type, hierarchy, and material, and (2) the lack of flexible tools effective in modeling historic buildings.

Ma et al. (2015), Cheng et al. (2015), and Adami et al. (2016) [10–12] describe how 3D modeling of architectural components with peculiar characteristics can help scholars to learn about each real element by improving the maintenance, management, and restoration processes of the entire building.

Examination of these works shows that implementing modeling processes, particularly if using a semi-automatic approach, takes a long time. This still constitutes a weakness in the structure of a methodology, above all because software has not yet been optimized for the automatic conversion of point clouds into BIM components.

- HBIM and auxiliary tools

Some HBIM applications in the field of architectural heritage use auxiliary tools, which influence the modeling process. Dore et al. (2015) [13] base the digital modeling of the four courts in Dublin on historical bibliographic documentation and the analysis of the current state. The reading of specific aspects is useful to compose a library of parametric objects thanks to the GDL 3D ruled plug-in. The elements of the library are constructed according to two different methods: The first, used for regular components, is based on archival documents for understanding shapes and geometries; the second, set up for complex or irregular objects, includes editing operations of the numerical model by defining regions and section planes at different levels.

The study by Nieto et al. (2016) [14] proposes, instead, an innovative process for the cataloging information on artifacts of rather high complexity (i.e., archaeological architecture. The data analysis starts with the definition of grids on the surfaces analyzed for the study of the changes that the different elements have undergone over time. Other authors, such as Oreni et al. (2016, 2017) [15] and Barazzetti et al. (2015) [16] promote the structure of HBIM libraries for structural analysis, which analyze, in detail, elements of which it is necessary to know the geometry and, above all, the variations in the repetition of similar components. The research presented by Quattrini et al. (2015) [17] is interesting because it considers the numerical model as a source of information in its complexity. Therefore, it is not sectioned or fragmented, and the modeling of components takes place directly on the raw data. It guarantees quality and precision in the modeling of regular geometries, built using the Autodesk Revit parametric element libraries, and the complex ones, created through B-Rep operations of. The research group use an additional open source plug-in, Protégé, to integrate parametric data with each modeled element.

Fregonese et al. (2015) and Rechichi et al. (2016) [18,19] use open source software (3DReshaper, BIM3DGS), which are used for the processing of survey data and for the construction of parametric models, or in the integration with GIS applications (SIGEC and SICaR), such as with studies by Baik et al. (2015, 2017) [20]. In this case, the combination of the highly-detailed modeling based on the segmentation of the survey data in main parts (general portions) and secondary parts (detailed elements), allow for describing Islamic architecture, and the Autodesk InfraWorks GIS system is difficult because of the integration of information at the territorial scale with those on the architectural one.

The disadvantage of the approaches analyzed in this category concerns the integration between parametric architectural elements modeled on surveying data. The main limitations concern the auxiliary software, which, although useful and decisive in some ways, could cause the loss of information when exporting data, invalidating a deep knowledge of the building.

- Models (and HBIM) through the web

The evolution of ICT allows for the use and access of heterogeneous information thanks to technologies that can understand different languages and put them into communication. The technological advance involved, also, the field of BIM and HBIM and the creation of web-oriented interfaces that collect data within a single information model. The experience of Quattrini et al. (2017) [21] is meaningful as the group developed a methodology within a particularly complex context. The research, conducted on the Church of Santa Maria in Portonovo, succeeds in a certain way in summarizing all the problems identified to date in the field of HBIM. The work proposes a real solution to the request for (almost) total interoperability between BIM models, rich in information organized in a hierarchical way through ontologies, and their query in the context of the semantic web. The process followed is interesting for its approach at different levels of depth; secondly for the way in which a semantically-structured 3D model is shared in a commonly used environment, that of the browser. The user browses the data through queries and thus accesses 3D/2D models or parts of them, digital worksheets, and multimedia content such as pdf, video, images, or web links. The methodology followed demonstrates that it is possible to switch from the parametric representation of the HBIM to the management of the 3D web objects. This operation allows for better understanding of the single elements through thematic information on the architectural organism and allows the description of the semantic contents, connecting them with a thematic databases (construction technologies, abacus elements, etc).

Actually, the use of BIM processes for the enhancement and management of heritage influences three different aspects: knowledge, modeling, and validity of data. A fundamental difference is the role of knowledge in HBIM with respect to that required in the design process. In this case, the knowledge of the built architecture match the semantic modeling. It is a consequence of the survey data processing, and if it is set with respect to archive documents, it allows for the understanding of information through its correct interpretative context, thus it can be shared by optimizing the programming and execution of subsequent operations. Parametric and informative modeling of historical heritage is difficult, both in terms of geometric transposition of the continuity of the real world and of its qualitative description. These difficulties are also associated with the intrinsic rigidity of the parametric modeling workflow and the construction of libraries of digital objects that clash with the variability and uniqueness of the built environment, especially when it has ancient origins, or the result of the stratification of different interventions, or is in a poor state of preservation. Modeling within HBIM processes involves an important discretization operation that still faces the impossibility of using automated systems to unravel these features. The various BIM platforms allow different types of checks of the built model to highlight any collisions between interfering elements or the compliance with reference regulations. Reference is made to the clash detection functions, in the second case to those of mode checking allowed by the Autodesk Revit software, which follow in the field of design (for example, about the fire resistance of the materials used). The extension of BIM processes to built heritage has highlighted two other types of controls to validate the built models. They are the metric and geometric adherence between the numerical model and the parametric model, and secondly to the semantic decomposition of the model. On this aspect, recent academic studies have proposed the introduction of the Level of Reliability (LOR) as an indicator of the reliability of an information model, or of the digital objects that make it up [22].

Reconsidering these aspects opens up possible development scenarios to implement the consolidated methods of integrated survey and intervention in the Cultural heritage using information systems, with a view to guaranteeing an increasingly controlled structure of data that influences the scientific nature of the whole process.

3. Materials and Methods

The presented research aims to outline a protocol based on the construction of 3D information models, defined in regards to geometry and semantic, starting from massive data acquisition. It focuses on the decomposition of the architecture and its reconstruction through the operations of modeling (parametric modeling), considering them as the main moments of the HBIM process. The study foresees the setting of a general methodology, which, according to a growing approach compared to the complexity of the analyzed buildings, is representative of different historical periods and of interesting architectural typologies [23,24].

The process followed compares two case studies identifying the main troubles in the debate on HBIM. Among these: The relationship between semantic modeling and the continuity of the surfaces of the existing architecture; the relationship between the standardization of the components—typical of BIM—and the geometric and material irregularities; the reliability of the HBIM models to evaluate the gap between an ideal model and the objective accuracy of a survey.

The study analyzes the Botany Institute and the Temple of divo Claudio, both in Rome. The first is a rationalist building, according to BIM processes, due to its typo, geometric-morphological characters, and many standardized elements [25]. The second is an example of stratified architecture, dating back to 54 a.C., with a strong archaeological feature [26,27] (Figures 1 and 2).

Figure 1. The Botany Institute at Sapienza University, Rome.

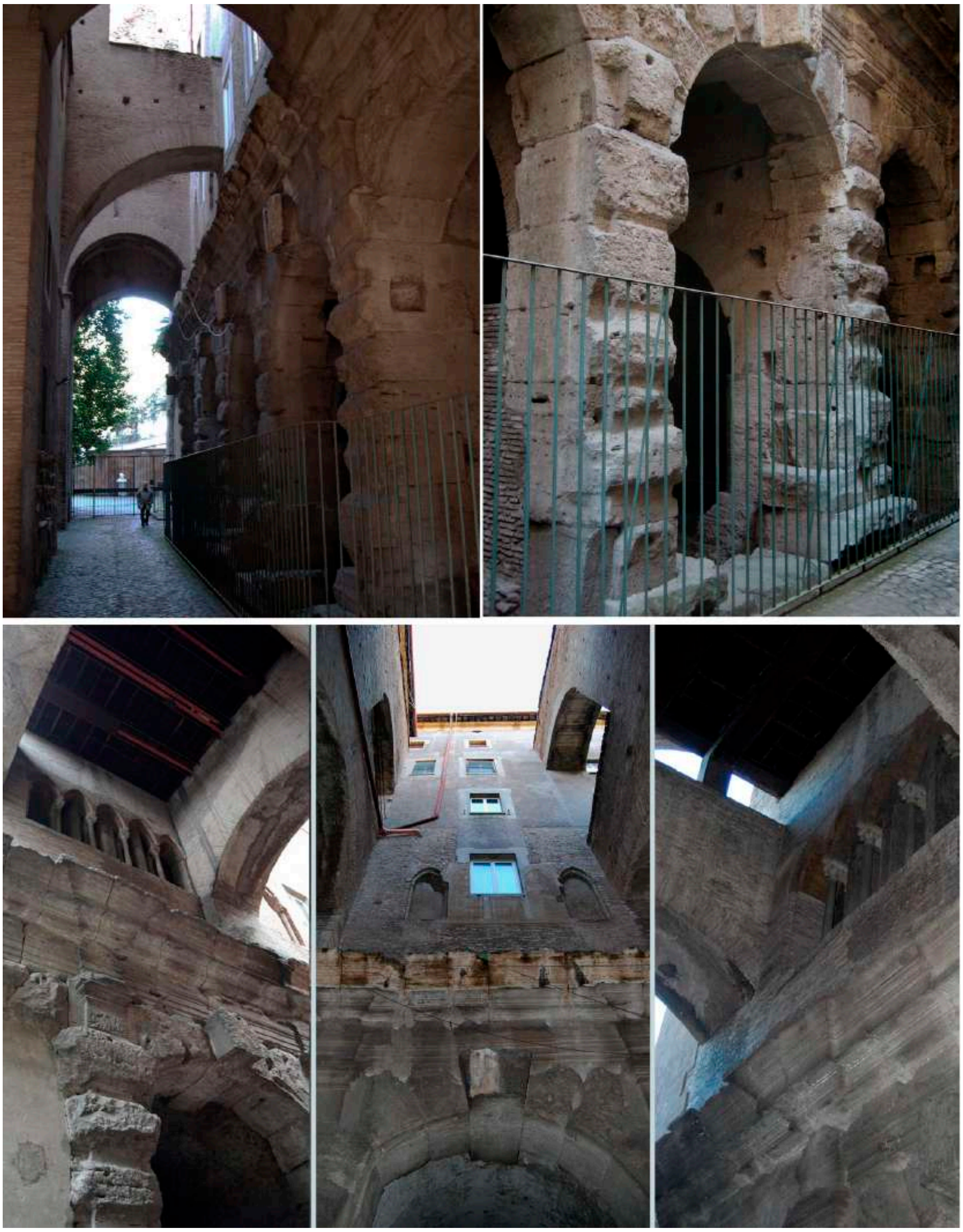

Figure 2. The Temple of divo Claudio, Rome.

The theoretical implications related to the process followed are rather complicated because the modeling of particular conformations of an architectural artefact often goes beyond its tangible, directly observable, and measurable appearance (Figures 3 and 4). This means that it was important to consider the information aimed at obtaining and communicating knowledge of the structures as wide as possible, and to be critical of the simplification choices in the modeling phase. The collection and the analysis of survey data, both semantic and typological, allowed for spatially defining the visible parts of the surfaces, recognizing the materials, and discovering the construction rules and transformations that the building had undergone. This knowledge is important for the components of the HBIM libraries: to develop the details stored behind the surfaces of the parametric objects, concerning the materials and components of the building, their cultural aspects and the historical memory, entering data storms to represent the architectural transformation of the entire life cycle of the building, provides a more in-depth reading of the state of conservation and favors the development of a more adequate maintenance program [28,29]. But even more, this allowed for the generation of digital models of buildings with similar stylistic and formal characteristics, approaching a solution for reverse engineering modeling based on the optimization of parameters and work times. Parametric and informative modeling for historical heritage clashes with the geometric transposition of the continuity of the real world, and of surveying data. The Botany Institute has several emergencies that express a formal but above all a functional unit as a whole, which made it necessary to outline a work that considered the general and detailed aspects, alongside the metric analysis of the data of the tangible material aspect. An integrated instrumental survey followed the initial phase of historical documentation. The strong solidity of the masses to be analyzed, combined with the size of the building under examination, justified a network of laser scans (1 × 1 cm), conducted with a 3D laser scanner time of flight (Leica ScanStation C10). The interior space (except for the entrance hall and connecting elements), due to the articulation in rooms intended for classrooms and offices, was surveyed through direct methodologies and through Structure from Motion (Nikon D40× digital reflex camera) for their speed of execution. These techniques were also used for the documentation of the complex of the Temple of divo Claudio. The surveying integrated 3D laser scans with a high level of detail (0.5 × 0.5 cm) and the photographic images in order to have very accurate information about the dimensions and the state of conservation of the architectural masses. The next stage of data processing was necessary because surveying data are not selective, and sometimes it is not possible to have all the necessary information [30–32]. Moreover, the construction of libraries of digital objects presupposes the inevitable comparison with the variability and uniqueness of the built environment, especially when it has ancient origins, or is the result of the stratification of different interventions, or is found in a poor state of preservation. The application of the methodology has shown different results due to the analysis of the survey and its relationship with the architecture analyzed.

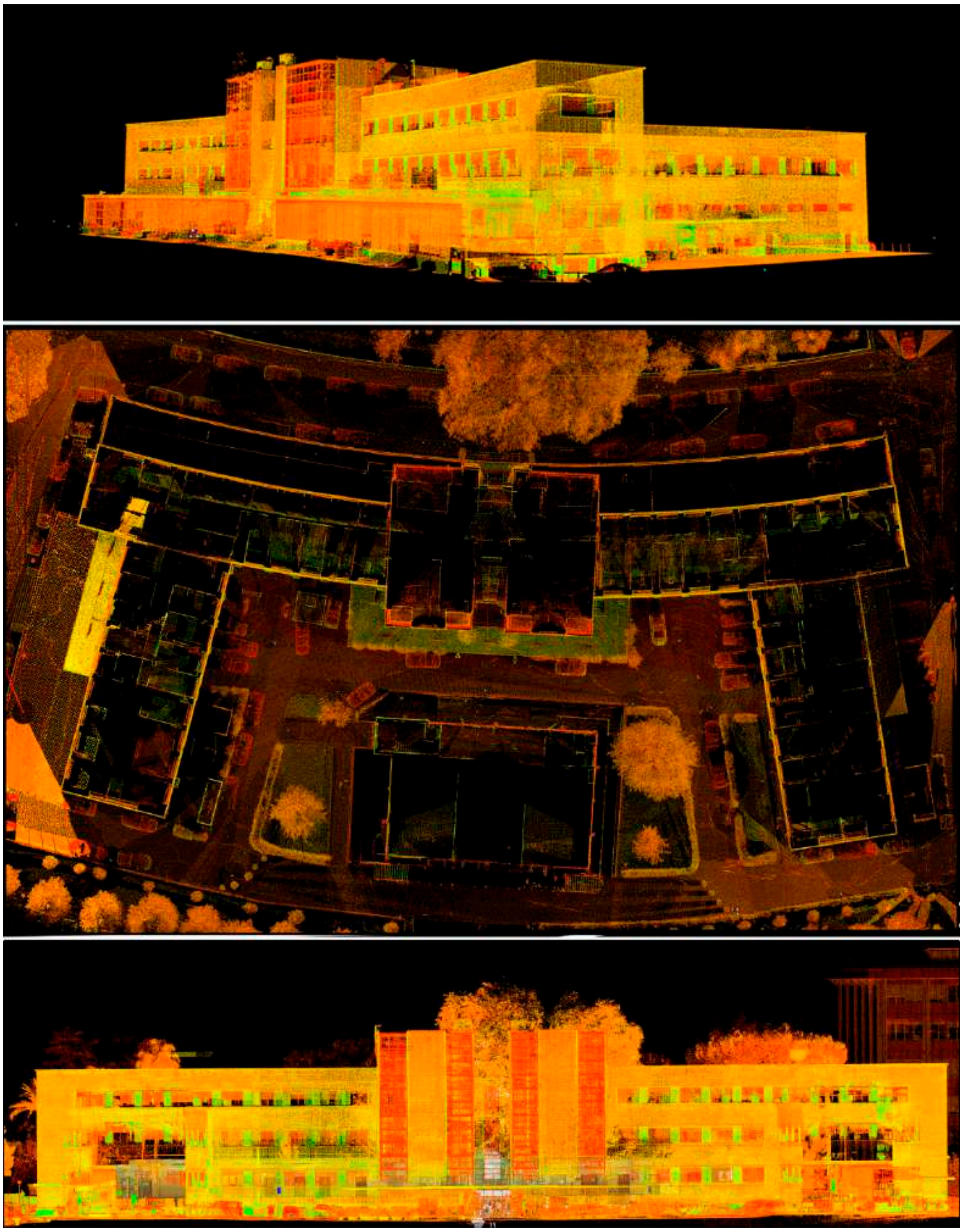

Figure 3. The Botany Institute. Views of the numerical model, RGB reflectance.

Figure 4. The Temple of divo Claudio. Views of the numerical mode RGB reflectance and RGB color.

4. Results

In the case of the Botany Institute, the classification of the elements and their modeling perfectly followed the design of the building. The HBIM process manages the serial elements by modifying dimensional parameters for the modeling of structural elements and for windows. Data acquisition comes from the 3D massive data capture technique—3D laser scanner and topography. It provides information on geometry, dimensions, materials, and their state of preservation, verifying and integrating the great amount of data deriving from the archival documentation [33,34] (Figures 5–9).

For the Temple of divo Claudio, the operations of surveying and the survey were the main elements for reading the irregularities of a stratified complex. Metrological and proportional analysis allowed for the optimization of the modeling operations, and the knowledge of the complex, just partially documented [35]. It emerged how the criterion for the decomposition of Botany's building followed the rationalist characteristics of the structure. It cannot be used for a building with a strong historical-archaeological component. What has arrived today of the Temple of divo Claudio is only a part of the ancient complex, of whose structure there are no visible traces. For this reason, its decomposition started from the identification of the structural component, which is clearly significant in the volumetric system and in the architectural components of the first building, but is less significant in the second. The shape of the Temple of divo Claudio took place simultaneously with the proportional analysis and that of the state of conservation. The proportional analysis revealed the existence of compositional rules, easy transferable to a parametric modeling environment, and the existence of a basic constructive module [36,37]. It is not only in the general construction but also in the detailed architectural components (Figure 10). The analyzed parts of the building showed a ratio of 1:3 between width and length, respectively; the unit contains 19 times the main module, identified in composition in the diameter of the pilasters, whose size is equal to twice that of the Roman foot, 29.6 cm. All the pillars of the arches of the main elevation have the same number of travertine blocks, whose geometry and dimensions correspond to multiples of the design module. The blocks maintain the same width, equal to 3 + 2/3 roman feet, but they have different heights, always multiples of the unit. The rule found in the proportions of the bays and in the blocks that make up the pillars; however, contrasted with the wall structures of the rear part, with sections and profiles in which it is not possible to recognize a geometric regularity. In the HBIM of the Temple of divo Claudio, the modeling of travertine blocks was adapted to impose constraints, so the study of dimensional variations and proportional ratios allowed the use of the generator module as a parameter. The modeling operation of hexagonal blocks, the capitals of the pilasters, and the keystone was repeated within the overall model, without considering the slight local variations. The BIM process for other architectural elements was different and linked to particular objects.

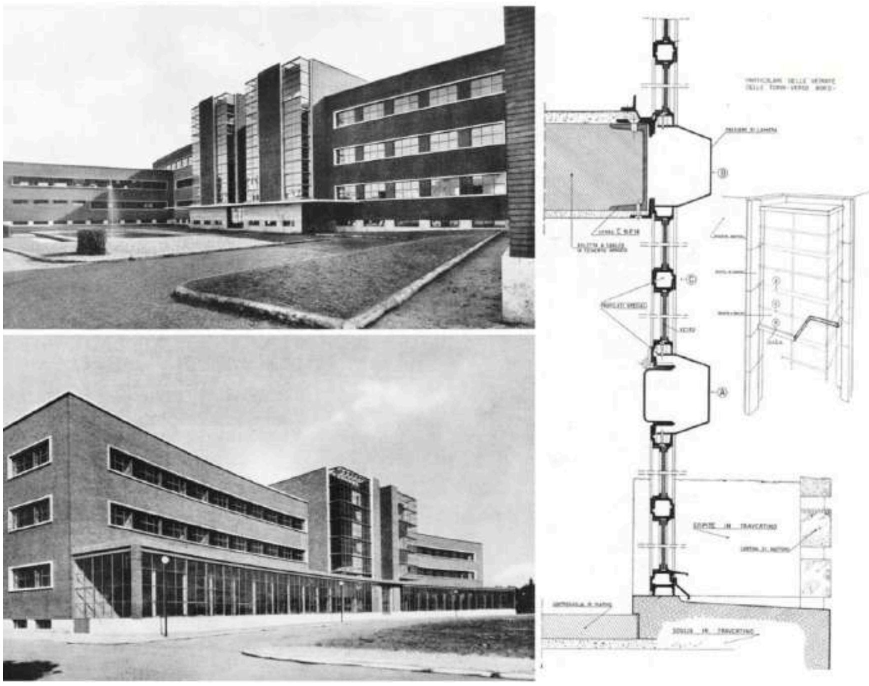

Figure 5. The Botany Institute. Archival documentation from Sapienza technical office. Photos (left) from Guidi, Francesco, 1935. L'Istituto di Botanica e Chimica farmaceutica—arch. Giuseppe Capponi. In Casa dell'Architettura di Latina, 1935—XIV numero speciale. La Città Universitaria di Roma, pp. 65–66. Detail of curtain wall, from: Guidi, Francesco, 1935. Caratteristiche tecniche e organizzazione esecutiva delle opere nella Città Universitaria. In Casa dell'Architettura di Latina, 1935—XIV numero speciale. La Città Universitaria di Roma, p. 86.

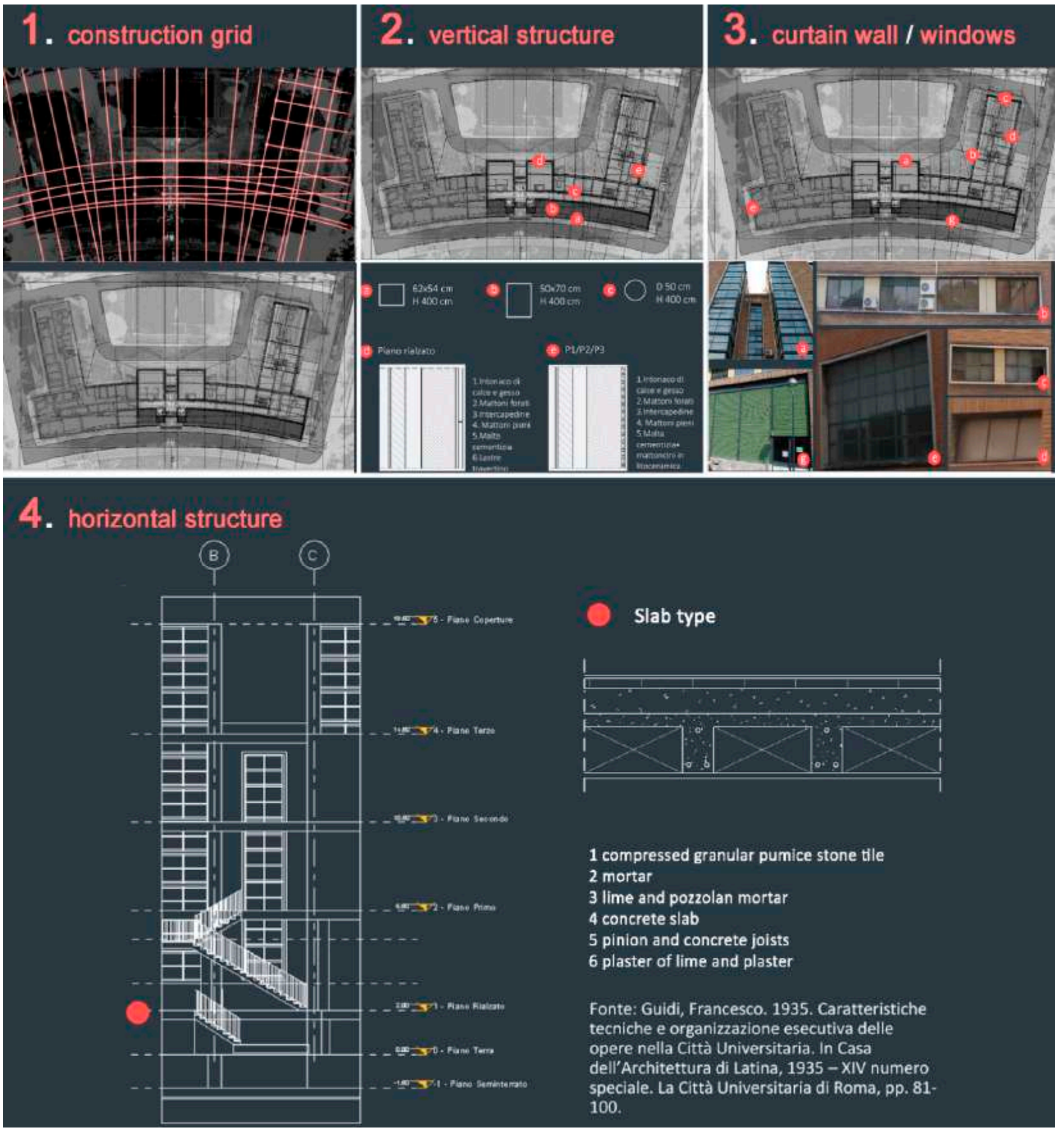

Figure 6. The Botany Institute. Breakdown of architecture.

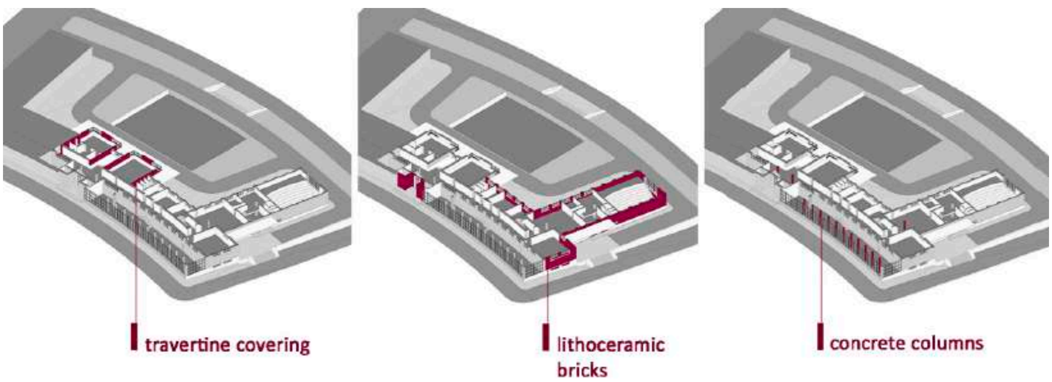

Figure 7. The Botany Institute. Architecture reconstruction through BIM processes: The structure (software: Autodesk Revit 2017).

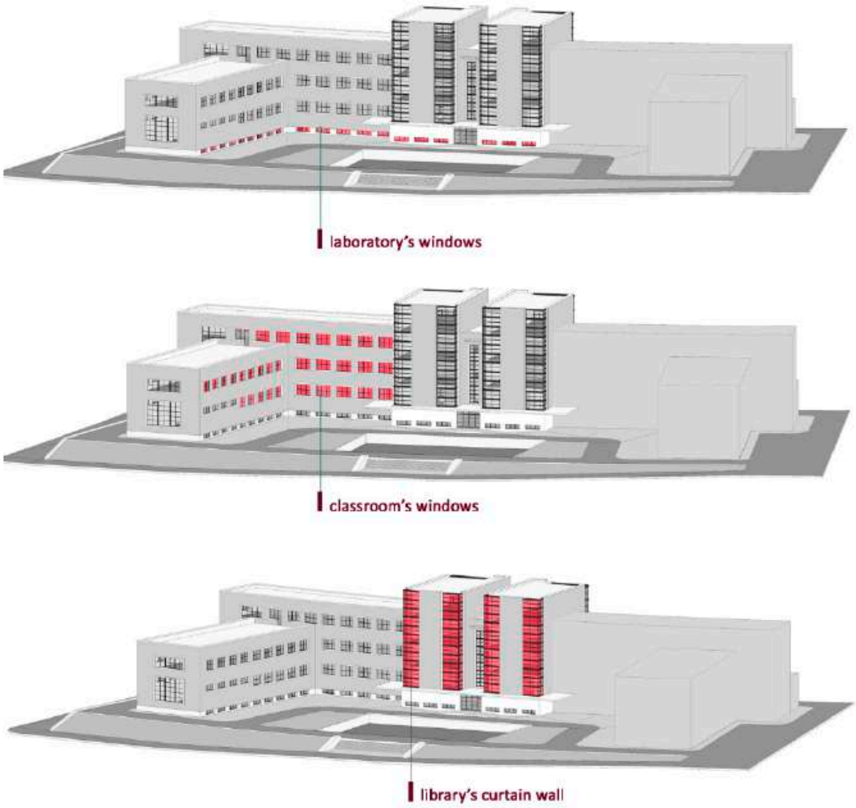

Figure 8. The Botany Institute. Architecture reconstruction through BIM processes: The windows (software: Autodesk Revit 2017).

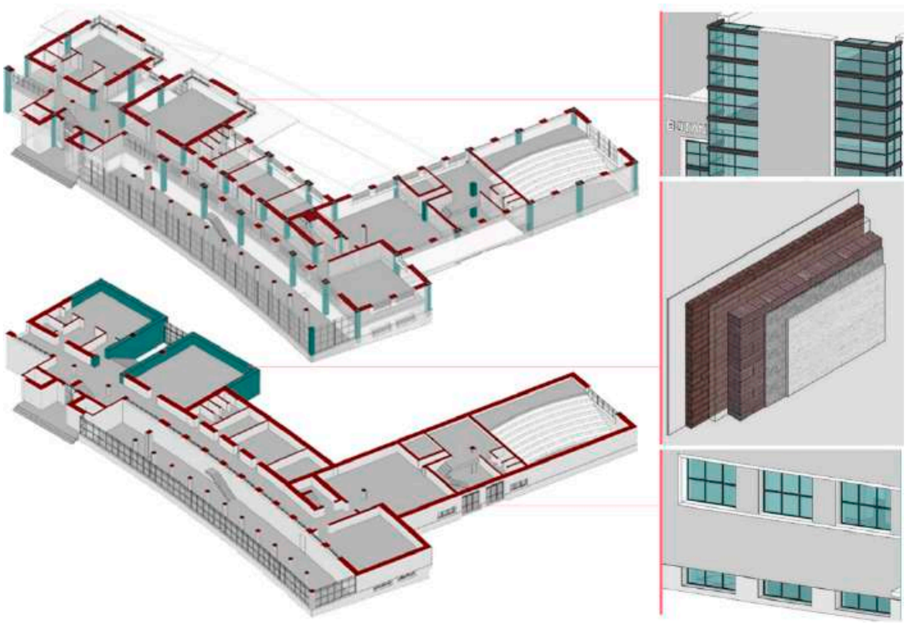

Figure 9. The Botany Institute. Architecture reconstruction through BIM processes. Details of ground floor, windows and walls (software: Autodesk Revit 2017).

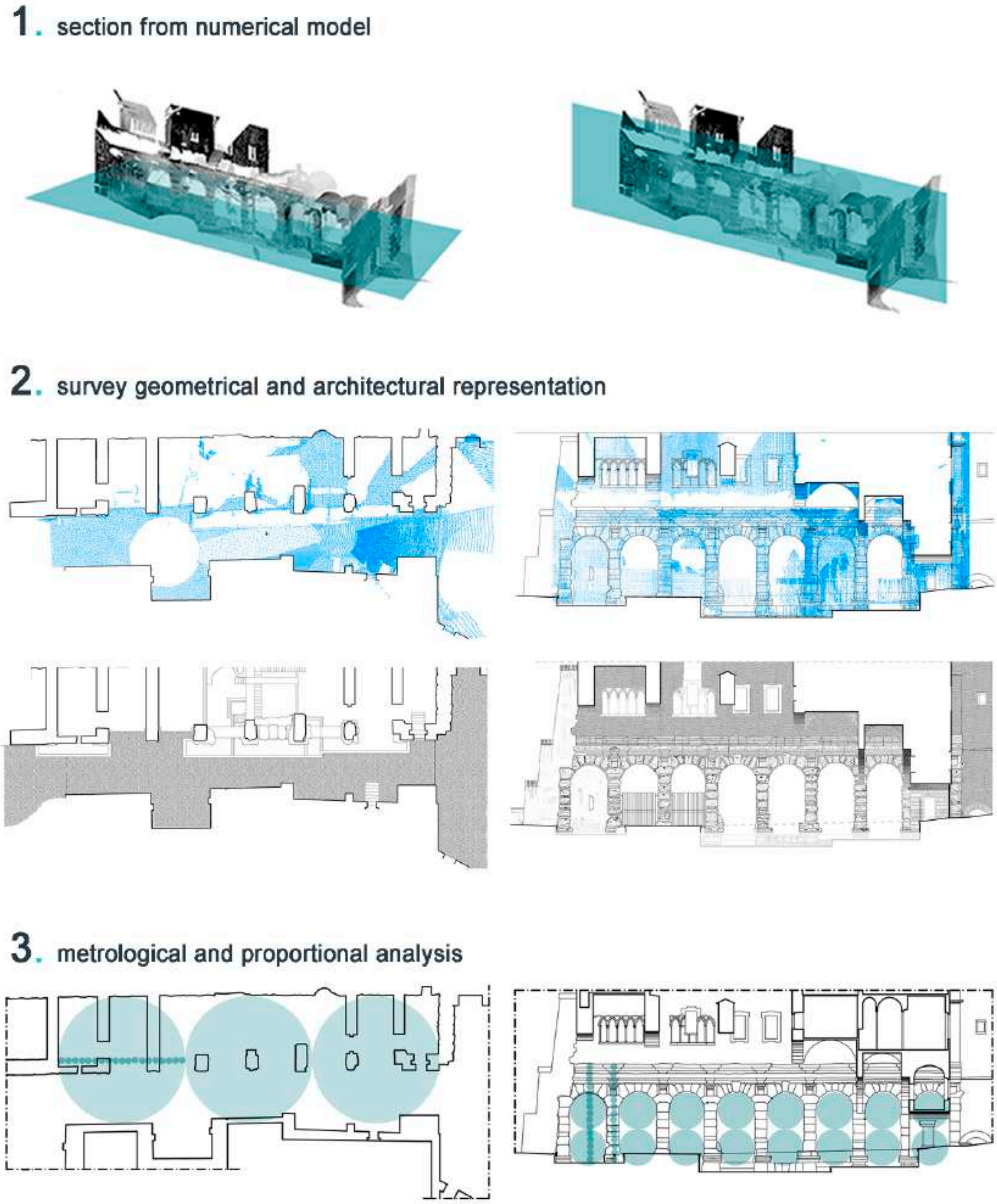

Figure 10. The Temple of divo Claudio. Breakdown of architecture from surveying data.

The capitals were built as families; the architrave was defined geometrically identifying the moldings profile in the numerical model; for the wall surfaces, with irregular sections, profiles were obtained every 20 cm; the vaults were built with the same method, changing the size and the height of the elements (Figures 11 and 12).

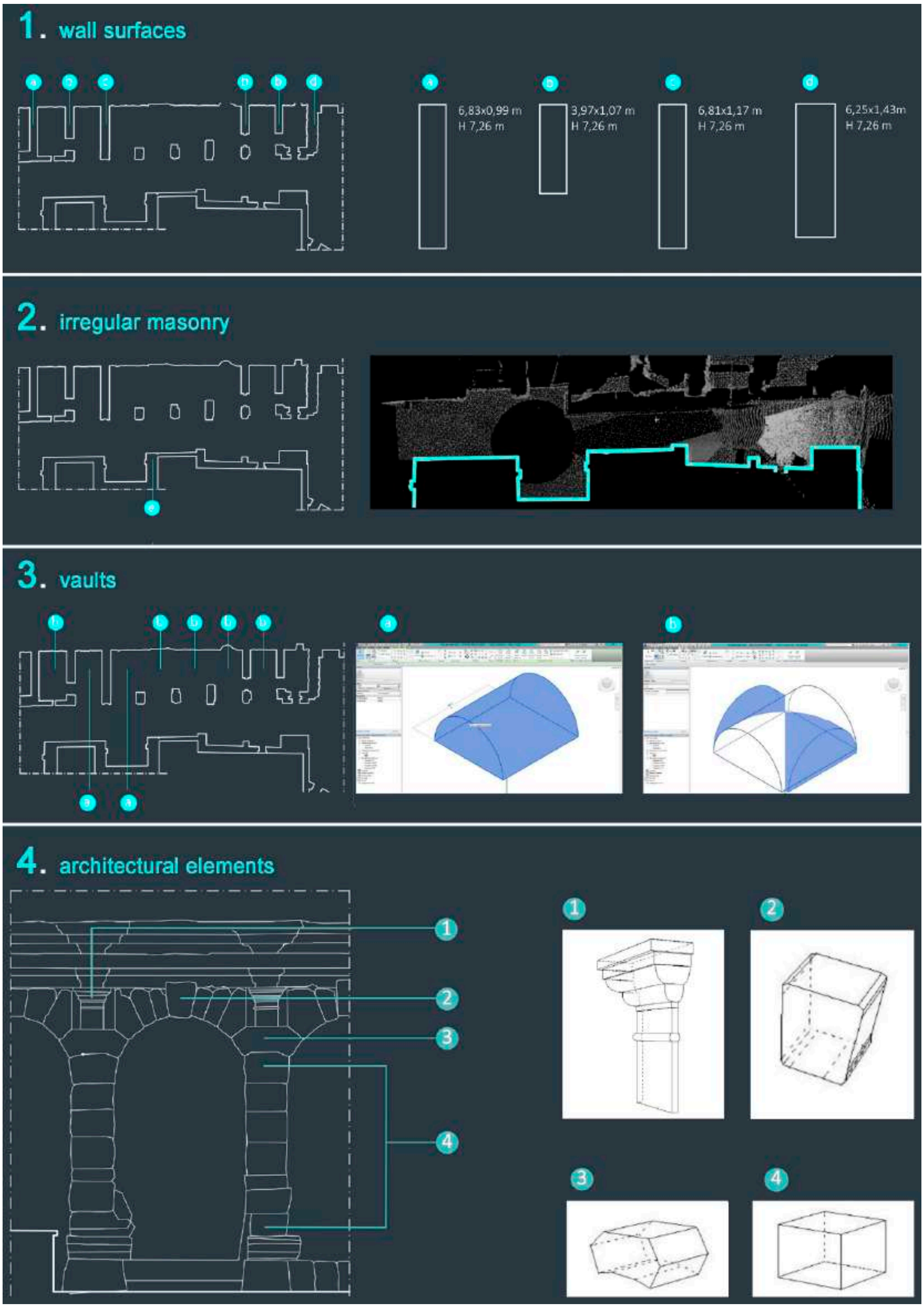

Figure 11. The Temple of divo Claudio. Architecture reconstruction through BIM processes: Structural and architectural elements (software: Autodesk Revit 2017).

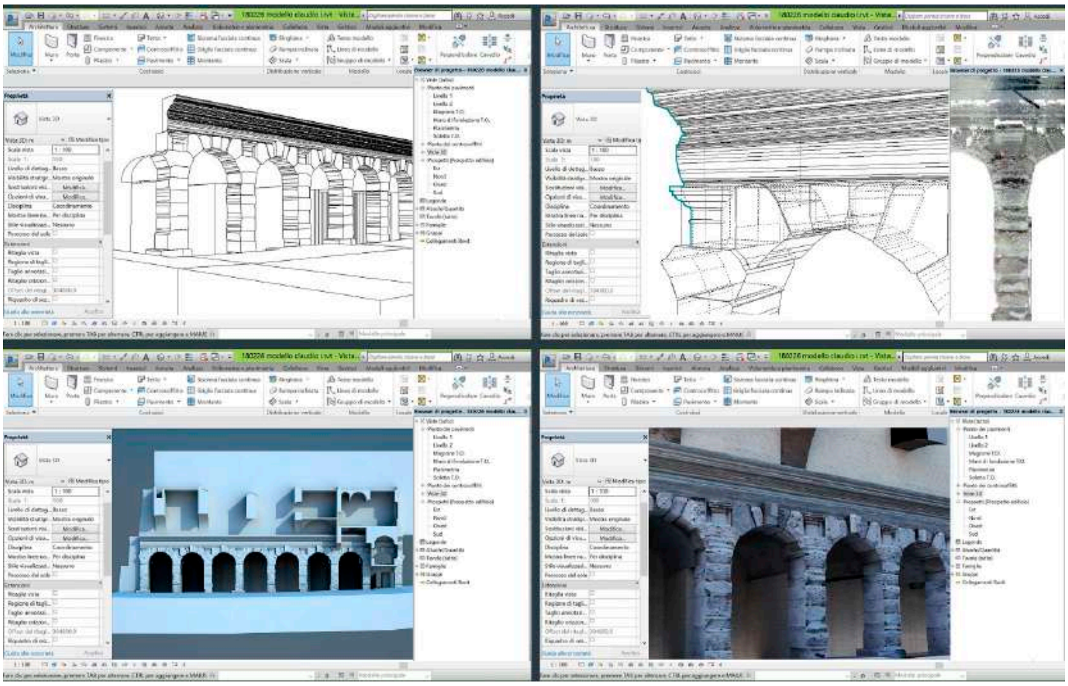

Figure 12. The Temple of divo Claudio. Architecture reconstruction through BIM processes (software: Autodesk Revit 2017).

5. Discussion

Understanding how to break down the architecture, and then reconstructing it through the BIM processes, is fundamental in order to be able to give rules as to the model's construction. To apply the process to a rationalist architecture is easy because of the repetition of the elements, the standardization of the components, the geometric features, and the possibility of finding information related to its construction. In the second case study, some troubles are related to the main problem of not being able to really and completely know the architecture, the composition of its constituent elements, and their constraints. This makes the HBIM not representative of the current state, but an ideal model. It also raises another a question, that is, the evaluation of the difference between the state of the project and the actual state. It leads to some choice required as to the elements to be parameterized and the operational methods of the modeling process.

The model of the Botany Institute represents its actual state, and the variations linked to its construction have undergone small approximation, which allows the potential of a parametric approach to be fully exploited. For the Temple of divo Claudio, on the other hand, the simplifications concerned the search for a contact point between a logic based on geometric rules, and aggregation between the elements and the contingent characters of the ancient building [38].

Assuming; therefore, that the built models do not fully represent the buildings analyzed, it is necessary to evaluate both the metric accuracy and the reliability [39–41]. The comparison between the numerical model and the geometric/parametric model (BIM) constitutes proof of any inconsistencies between the semantic structure of the model and the real object. The deviation between the two models shows the deviations between the ideal form, described in the BIM model at the geometric level, and the objective one, described by the numerical model from surveying.

The comparison between the models of the Botany Institute presents deviations of less than 3 cm for 80% of the analyzed points. These results are satisfactory, considering that also elements without certain reference plans, such as coverings, or disturbing elements, such as control, are included in the average calculation. The value was obtained both for the overall model and for the components modeled as families (structural elements, windows), which report an average distance of 0.05 and 1 cm.

The Temple of divo Claudio has submitted the same verification, in order to obtain greater deviations, in relation to the greater extent of the simplifications that characterize the model. The results show an average distance between 1 and 3 cm. Additionally, in this case, the detailed elements were analyzed, constituted by the parameterization of components within specially constructed families, such as the travertine blocks, the ashlar walls, the lintel moldings, and the pilaster capitals (Figure 13).

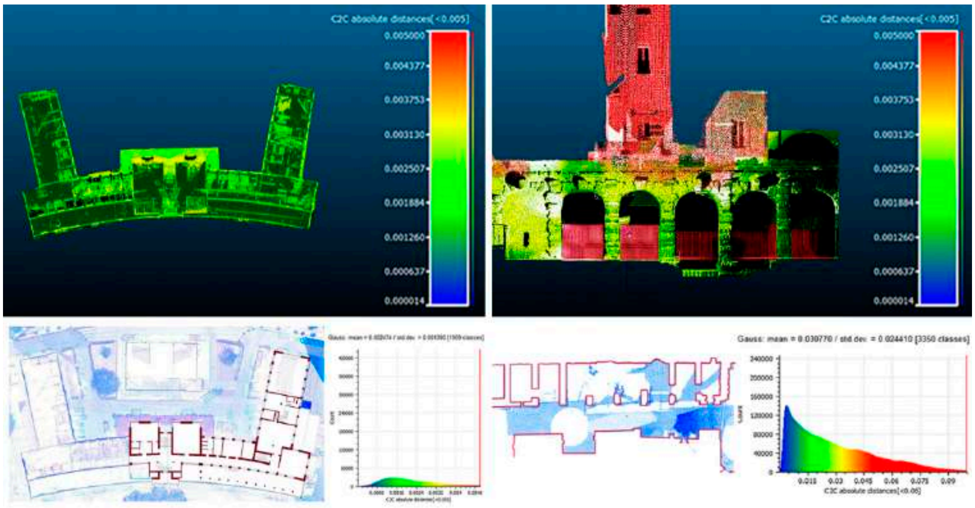

Figure 13. The Botany Institute and the Temple of divo Claudio. Comparison between the numerical model and the parametric model (software: Cloudcompare).

Another evaluation is the LOR (level of reliability). It shows how knowledge processes are always gradual, connected to the continuous possibility of new investigations and to the interpretation of heterogeneous information (Figure 14). The control of the semantic structure of digital objects implies more complex dynamics, less objective than those concerning the geometrical correspondence and the correct structural of the models. Actually, there are no applications similar to the model reviewer application that allow critical controls to be carried out on semantics within HBIM. A significant proposal in this field relates to the coding of a new parameter able to fill the insufficiency of the standard parameters that, in the BIM processes, measure the reliability of technical information. For LOD and LOI (level of information), recent research adds LOR (level of reliability), which measures reliability in terms of overall consistency of the process that defines any digital object [42–44]. The parameter relates the geometric reliability of digital objects to their ontological correspondence with the real shape they describe. Several factors influenced the geometric reliability of the model: The parameterization of the geometric shape of the elements; identification of geometric and compositional rules; and the comparison between the acquired data (through surveying operations or through archive sources) and the parametric model. The factors that influence the ontological correspondence of digital objects are much more complex to analyze because they come from subjective activities, and because they tackle the problem of overcoming the surveyed surface. In this case, data referring to the evolutionary phases of the object take over; the knowledge of construction techniques and materials used are derived from additional surveys (stratigraphy, conformation of architectural or structural elements, etc.); the identification by analogy with contemporary or similar buildings. The definition of the level of reliability is regulated by a numerical scale ranging from 0 to 10 for each digital element, with respect to the corresponding architectural element. LOR 0 represents a symbolic digital object, while the LOR 1 is reserved for known objects in very high detail. A diagram structured in this way not only simplifies the reliability of each modeled digital object, but can also be useful in the process of decomposing and reconstructing the artifact, in which the final score is incorporated into the information model as one of the attributes of the digital object (Table 1).

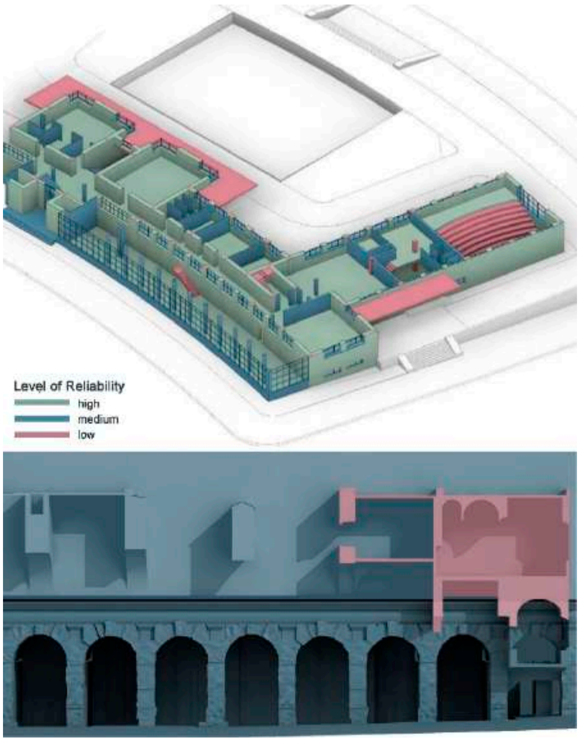

Figure 14. The Botany Institute and the Temple of divo Claudio. Representation of LOR (level of reliability) using different colors (green for high reliability: It is possible to completely reconstruct geometry, internal stratigraphy, and evolutionary phases of the modeled components; blue for average reliability: It is possible to reconstruct geometry and materials, pink for low reliability: Only the components can be reconstructed in the geometric attributes, taken from the survey data).

The comparison between the results obtained expresses the transparency and the scientific validity of a process for the knowledge and management of architectural heritage. The results, both in the case of the Institute of Botany and in the Temple of divo Claudio, were generally homogeneous and consistent with the expected performance of an HBIM. Stating that every subject presupposes a specific modeling plan, although not completely wrong from a conceptual and operational point of view, would minimize the potential of the BIM to be recognized as a process [45,46]. Both cases have shown that even existing buildings can be decomposed into recurring elements if certain geometric rules characterized them. This regularity denotes the individual building, more than with respect to its specific characteristics, as belonging to a certain architectural typology. Each architectural typo includes serial elements adhering to geometrical laws, of form and aggregation between components. Testing the process on typologically different elements demonstrates the validity and repeatability of the process. Each subject can be referred to an architectural type, whatever the historical era. However, once the geometric rules of the whole architecture—or some its parts—have been identified it would be necessary to compare the HBIM process with the acceptance of an inevitable geometric simplification.

Table 1. Type sheet to define the level of reliability of digital objects (0 < LOR < 10) [1].

Information				**Botany Institute**	**Temple of divo Claudio**
geometrical character	free form	symbolic geometry	0		
	simple or complex geometric shape	parametric geometry (typological elements) specific geometry (specific element)	1 2	2	1
surveying data	not available	hypothetic information	0		
	available	direct survey integrated 3D survey	1 2	2	2
specific diagnosis	not available	hypothetic information	0		
	available	sample survey widespread survey	1 2	0	0
archival documents	not available	hypothetic information (historical and semantic)	0		
	available	generic information (historical and semantic) specific information (historical and semantic)	1 2	2	1
material	not available	hypothetic information (analogic comparison)	0		
	available	generic information (surface) specific information (stratigraphy)	1 2	2	1
technological configuration	uncertain or undefinable	absent definition	0		
	verified or definable	generic specific	1 2	1	1
state of conservation	not analyzed	undefined	0		
	analyzed	described by external links described by digital object	1 2	1	1
congruent evaluation	in progress evaluation	not verified	0		
	available	minor deviations irrelevant deviations	1 2	2	1
				7.5	**5**

[1] The average value is multiplied by a factor of 5 to have the correspondence in a scale from 0 to 10.

6. Conclusions

An architectural model is a process that leads to discovering the truth of the construction, based on geometry but also on cultural, historical, theoretical, and symbolic characters. This widely consolidated assumption also involves current methods for the representation, both traditional and digital. Among them, HBIM processes constitute the starting point for outlining new scenarios for knowing, documenting, and intervening on the architectural heritage. The continuous comparison between new design interventions and existing heritage interventions has shown how BIM processes, which ensure greater control in the design process, often tend to exclude information that is at the basis of architecture configuration and understanding. The hypothesis from which this research starts is the possibility of effectively applying the BIM processes to the built architectural heritage, outlining the implications with respect to the field of representation and optimizing the use of data obtained from the consolidated integrated survey operations.

The two case studies belonging to two historical far epochs, characterized by a different formal approach and a different structural and technological system, has allowed for the evaluation of the validity of the process followed. The analysis of 1D and 2D data, recovered in bibliographic and archival research, and of 3D data, collected during the survey phase, allowed to structure the models by breaking down each building with respect to the architectural elements and the ontological definition of the entities that composed it. The criterion followed in the breakdown of the analyzed architectures corresponds to their design approach, and involves the processing of 1D, 2D, and 3D data in different ways and weights. Stating that every object of architectural heritage presupposes a specific treatment, although not completely incorrect from a conceptual and operational point of view, would minimize the potential of the BIM approach, whose value is recognized as a process. Both cases have shown that even existing buildings can be broken down into their recurring elements if certain geometric patterns are recognized on them. This regularity is the element that denotes the individual building, more than with respect to its specific characteristics, as belonging to a specific architectural typology which, as such, includes serial elements adhering to geometrical laws of form and aggregation between components.

Once recognized matrices or geometrical rules are deducible more or less clearly on the artifact, or on parts of it, the HBIM process tackles the issue of the (inevitable) geometric simplification. The degree of reliability of the model in terms of geometric accuracy and semantic correspondence between the acquired data and the product of their critical and subjective interpretation depends on this. In this perspective, the construction of the BIM model coincides with the construction of an ideal model.

This research allowed for the consideration of three aspects of the HBIM process. The first concerns the comparison with the commonly held thinking that the application of BIM to existing buildings is a disadvantage, to the extent that it leads to excessive simplification, far from the actual state of the building. In fact, the limits are linked to the representation of shapes that characterize historical architectures and to the parameterization of geometries that cannot always be traced back to a regularity without reaching remarkable approximations. It can be overcome through information on the elements of the considered artifact, which find their place in the 3D model space. The question is not only connected to practical operations made possible by BIM-authoring platforms, but is more purely cultural. A model that is not completely representative of its current state is a model that identifies the research process of the project status. In this regard, it should be kept in mind that any building, which today presents itself to us as a historical construction, is; however, the result of a project activity which, even centuries ago, gave rise to a new design. An existing building has to be considered as a new one, facilitating the application of the BIM processes when also the modeling of a historical architecture coincides with the modeling of a project state.

The second order of considerations examines the results of the experimental phase of the research conducted on the two architectural complexes. It highlighted how the management of the ideal model is different if the structure being investigated was built a century ago or two millennia. In the model of a modern architecture, the mutual organization of elements (pillars, beams, floors, walls, etc.) has been set according to the standards of the period and all digital objects are characterized by the attributes of BIM (materials, layers constructive, etc.), getting very close to the completed building. The model of a stratified complex, on the other hand, is the synthesis of several ideal models that represent the evolutionary phases of the building, up to the current state. The results of historical research are; therefore, essential to collect and select the necessary information from texts, images, drawings, videos, and often from other unpredictable sources, which describe the design of the original building, not only in terms of geometry but above all from a technological, material, and constructive point of view. The BIM processes, at present, do not take this aspect into account and refer mainly to the configuration of the objects in the present. However, the main software applications contain tools to represent the temporal location of an object through graphic substitution rules, widely used in the design field to identify demolition and reconstruction operations. In HBIM processes, these features can be used to describe each phase of the building's life using a model or, vice versa, each object that makes up the model can be distinguished by the membership attribute of a specific historical phase, or, at different times, data acquisition. The different models are connected not only from the logical, technological, semantic, and constructive point of view, but also from the temporal point of view, overlapping each other and respecting the rules of BIM processes with respect to families and connection laws. The critical and documentary value of the representation and its productive function of models allows for comparison with other models considered fundamental that, integrated by the LOR diagrams, favor and extend the deep knowledge of the architectural heritage and, consequently, the planning of interventions aimed at its conservation and enhancement.

The third order of considerations concerns the followed procedure, applicable to all case studies attributable to a specific architectural typology. The present research demonstrates that it is possible to follow the proposed indications both with respect to the analytical principle of the decomposition of the existing architecture, and with respect to its reconstruction through integrated parametric models. The area of the existing architectural heritage, despite being characterized by a vast quantity of heterogeneous examples, nevertheless offers the possibility of establishing general rules that take into consideration the peculiar aspects of the buildings analyzed. For example, the possibility of using the methods used to structure nested families for all the buildings of Sapienza, or that of using a parametric approach to model all the elements of Roman architecture characterized by proportional relationships.

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