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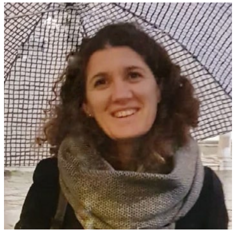

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Detect the geometrical differences: cultural heritage digital documentation and interpretation for conservation activities. Methodological aspects

The actual greater diffusion of advanced surveying and representation tools, increasingly user friendly, represent an advantage in terms of cultural heritage digitizing and knowledge sharing, but it requires a series of consideration on the quality of the procedures adopted and the possibility of qualitatively and quantitatively evaluating the results obtained.

Surveying means knowing and understanding the existing, in its geometric-morphological-constructive specificities; the different methods and tools of data acquisition must be chosen with the objective of documenting and representing the real geometries, ensuring that recognition of the differences between the stratified elements, which represents the first moment of diagnostic analysis of the historical asset. Only graphical elaborations made according to these criteria, with levels of detail according to the different scales of representation, can usefully become support for conservation project and management of restoration processes.

The characteristics of uniqueness and complexity of each historic building require an ad hoc design of the survey activities, tools and methodologies to be adopted, and of the forms and scales of representation. Nonetheless, it is possible to identify a general workflow of the surveying activities to obtain data that could be geometrically reliable, quantitatively controllable, comparable, and repeatable over time.

Keywords:
Cultural Heritage; Survey; Documentation; Drawing; Conservation

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INTRODUCTION: SURVEY AS INSTRUMENT OF DIAGNOSTIC ANALYSIS

In conservation activities, surveying means knowing and understanding the existing, in its geometric-morphological-constructive specificities and complexity (Historic England, 2016). In this sense, surveying could be considered as a tool for "pre-diagnosis" of the existing, allowing to investigate the geometric and volumetric consistency of a building, to recognize the connection between the different construction elements and to record all those geometric irregularities (for example the thickness or the alignments of the walls) and voids that are also the first indicator of transformation of the building or its parts over time (Figure 1).

In fact, the survey has the important role not only of providing data for the creation of the drawings useful for the design and management of interventions, but also of supporting the analysis of the existing, through its interpretation. This means that the documentation activities for the preservation project do not end with the classic two-dimensional representations, or the more innovative parametric models, but include the phase of analyzing and interpreting the represented geometries, in order both to reconstruct the evolution of the building over time, and to identify the criticalities and potentialities of the structures useful for a preservation and restoration project that is adherent to what are the specific and unique characteristics of that building.

Therefore, it is often from the interpretation of the survey and the following drawings that questions about the history of the building emerge, to be compared to other data, historical, stratigraphic, and material, in a continuous bidirectional knowledge path, made up of the formulation of hypotheses to be validated or refuted. In this sense, the survey constitutes the first moment of non-destructive investigation of the building and is therefore a fundamental moment in the knowledge of the built heritage.

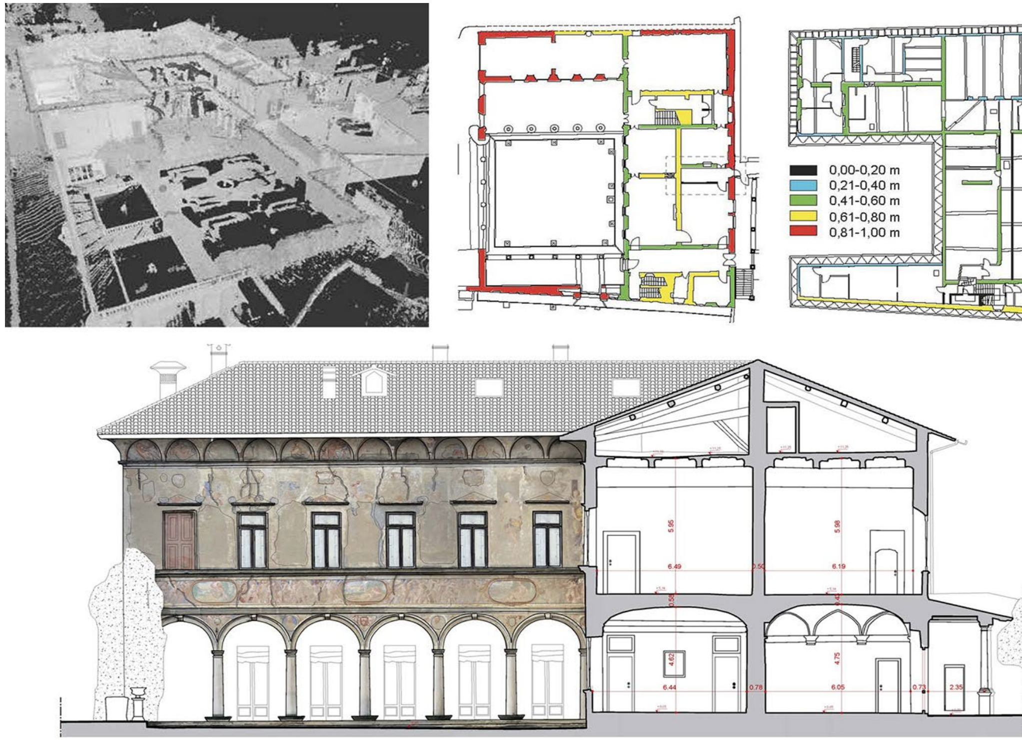

Figure 1. Villa Cicogna Mozzoni in Bisuschio (VA): from the laser scanner points cloud to the two-dimensional drawings. In the two plans above, different wall thicknesses are indicated with the colors in the legend, which are useful to begin to hypothesize different construction phases (drawings: arch. Anna Urso).

Different are the activities in the historic building documentation: a) the metric survey and data processing, that means the metric description of the facts throughout graphic representations, photographic or photogrammetric images, written reports; b) the interpretation of the data survey; c) the data collection and the data sharing.

As is well known, the quantitative knowledge of architecture, its measurement through digital registration and subsequently its representation, passes through the creation of a model; therefore, any drawing of the existing is always a representation in scale of reality, with levels of detail of the information contained that must be determined a priori, to ensure a representative consistency of all parts of the building. The levels of detail necessarily depend not only on what are the ultimate objectives of the survey and the use to be made of such data, but also on what are the geometric-constructive characteristics of the building, the accessibility of the structures, which may vary from part to part, and the environmental conditions. These parameters all contribute to defining what are the starting conditions in the planning of the metric survey and the consequent choice of the most suitable methods and tools for that given situation.

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It is then also to be considered that the moment of the geometric representation of the actual state of a building is never to be understood as a merely technical operation since it always requires an analysis and a critical interpretation of integrated data, to their final elaboration according to shared graphic conventions. Critical selection of data but also critical restitution of the same; it is the 1964 "International Venice Charter for the Conservation and Restoration of Monuments and Sites" (ICOMOS, 1964) that first formalized this need, to produce both analytical and critical documents. Infect, in art. 16, it is written: "In all works of preservation, restoration or excavation, there should always be precise documentation in the form of analytical and critical reports, illustrated with drawings and photographs". In this Charter[1], reference is also made to the need to publish and share the surveys carried out, to make them available to those who will be called upon to work on the same buildings in the future: "This record should be placed in the archives of a public institution and made available to research workers. It is recommended that the report should be published".

THE PROJECT OF DIGITAL RECORDING AND DOCUMENTATION FOR CONSERVATION ACTIVITIES

In documenting historical heritage, it is therefore essential to analyze when, where and what to survey (ICOMOS, 1990), in accordance with the needs of all experts involved in the project. Documentation must provide precise answers to precise questions and must be accessible and understandable in a short time (Letellier et al., 2007). In addition, it will be necessary to consider not only the metric performance of the measured data, but also the required quality of work needed to serve as a record and archive of cultural heritage (Quintero et al., 2017).

It follows from these observations that the characteristics of uniqueness and complexity of each historic building, whose form and material composition is the result of the layering of different constructive interventions over the centuries, require an ad hoc design of the recording and documentation activities, tools, and methodologies to be adopted, specific to those structures, the context in which it operates and its final purposes.

From a practical point of view, geometric surveying activities are often the first that are conducted on the existing building. Therefore, they must first provide the team involved in the project with graphic representations for subsequent thematic mapping, for quantifying and locating interventions, and ultimately for managing the restoration site. Information that must be appropriate and correct, timely and complete, to allow both to make decisions and design the intervention correctly, and to make changes during the course of the work, updating the surveys carried out according to new discoveries made during the construction site (e.g., following archaeological excavations or dismantling of structures such as floors or ceilings).

The possibility of updating and implementing digital recording becomes an unavoidable prerequisite, which requires that the measurements conducted be accurate (how much a measurement conforms to its true value) and precise (how repeatable a measurement is), depending on the level of detail of the scale of the survey and thus the value of the tolerance. Scale of representation that must at least correspond to that of 1:50 when dealing with a restoration project, resulting in a conventional tolerance value of 2 cm.

Today, the integrated use of advanced surveying methods and tools, from laser scanners to photogrammetry (Daniottet al., 2020),enables an ever-widening audience of users to acquire in a short time an over-abundant amount of data, with a level of detail that often goes beyond that of the final scale of representation required (Figure 2). The critical selection, analysis and interpretation of such data is left to the stage of processing, to arrive at a graphical form that is consistent with the level of detail required and with the uses to be made of such data, whether two-dimensional, three-dimensional, or HBIM models (Oreni et al., 2014).

Moreover, the different methods and tools of data acquisition, both active (the required points are selected and measured in the field, for example, using a total station theodolite) and passive techniques (involves the capture of a mass of data, from which, if required, points are selected as part of a lateral process; i.e. photogrammetry or laser scanning) (Andrews et al., 2015), must from time to time be chosen with the objective of documenting and representing the real geometries of the building elements, ensuring that recognition of the differences between the stratified elements and signs, without losing the complexity of the historical structures that represent the real value of a stratified building.

From a methodological point of view, it is possible to identify a general workflow of the different activities of digital recording of a historical building: a) preparatory work: the collection of the existing documents on the building, including any previous drawing; b) the survey planning, choosing the instruments and the methodologies; c) the critical sketches, the on field surveying activities and the systematic organization of the information gathered; d) the data processing; e) the elaboration of 2D-3D representation and reports. During both measurement activities and processing phase it must be ensured the control, the accuracy, and the completeness of the information.

As is well known, the canonical and consolidated organization of the digital registration of a complex historical building involves first the creation of a geodetic network, georeferenced locally or in the global reference system (Barazzetti et al., 2022) to which connect all subsequent measurements, carried out with different instrumentation: from direct survey to instrumental survey with laser scanner, total station, terrestrial and aerial photogrammetry, GPS station. The possibility of having all the graphic works, be they point clouds,

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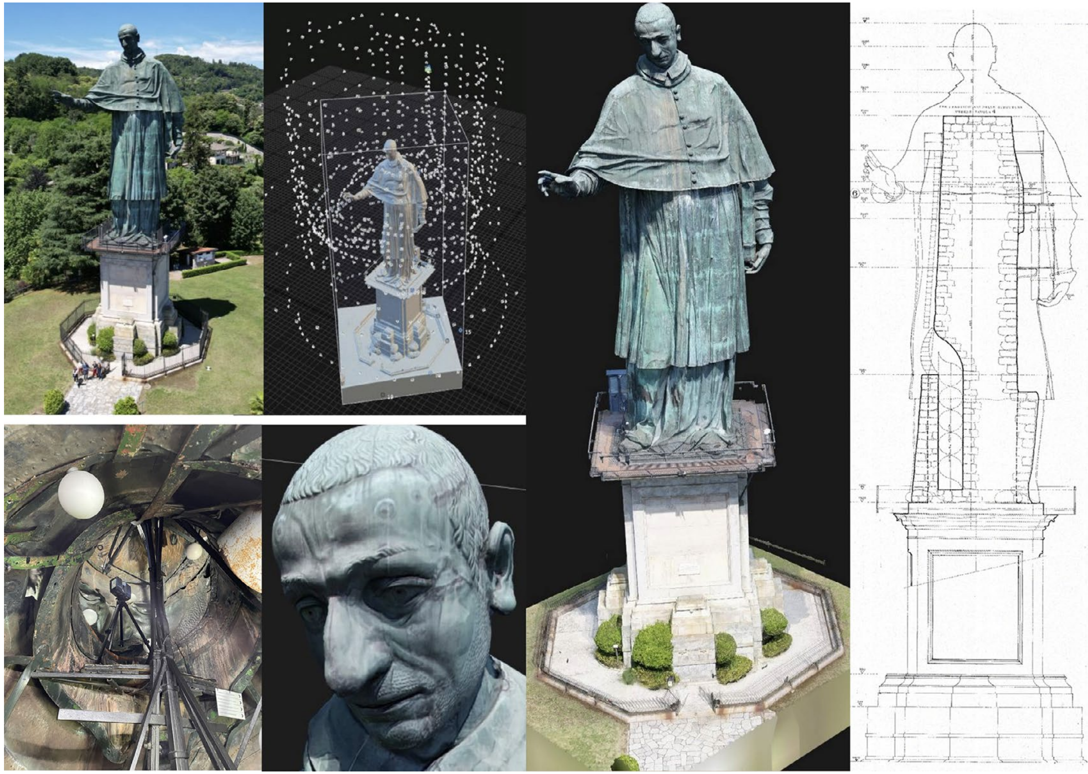

Figure 2. The Colossus of San Carlo Borromeo in Arona (NO). Top: DJI Air2s drone survey of the exterior of the statue for high-resolution ortophotos (3D photogrammetric model prof. Luigi Barazzetti); bottom, Faro CAM 2 Focus laser scanner survey of the interior of the head. Right, vertical section in scale 1:25 from 1974, made by engineer Carlo Ferrari da Passano (source: Veneranda Biblioteca Ambrosiana Archives). The purpose of the 1:20/1:10 scale 3D detail survey was the structural consolidation of the internal metal anchors of the statue's copper plates.

drawings at different scales, orthophotos and 3D models, georeferenced in a single reference system, provides the undoubted advantage of favoring the integrated use of different data, which are more easily comparable and overlapping with each other (Barazzetti et al., 2016). Similarly, the georeferencing of a survey in a global reference system makes it possible to correlate the representation of the building with its context, allowing analysis at a larger scale than that of the individual building, up to and including the urban and territorial scale; indeed, it is from the relationship with the context that important information on the state of conservation of an asset (e.g., exposure) and its reuse can be derived.

2D DRAWINGS AND 3D MODELLING AS INSTRUMENTS OF KNOWLEDGE AND REPRESENTATION OF BUILT HERITAGE

To provide real support in the advancement of knowledge of an asset and in the management of conservation activities, the drawings and three-dimensional models must be geometrically reliable, quantitatively controllable, comparable, and repeatable over time, implemented and updated, even during the site phases and by all the different actors involved in the restoration process.

Only graphical elaborations made according to these criteria, with levels of detail according to the different scales of representation, can usefully become support for thematic mapping activities, analysis, conservation, and reuse project, as well as for the dissemination and enhancement of knowledge (also using virtual immersive environments - AR/VR/mixed reality) (Figure. 3).

Working to scale means making a critical selection of survey data, which today are often overabundant compared to the real needs dictated by drawing requirements at different scales. This discretization of the real is not done arbitrarily but according to what are the levels of detail proper to the chosen scale of representation. It is particularly when working on restitution from point clouds, whether they have been surveyed by photogrammetry or laser scanner, that this concept becomes particularly evident. However dense they may be, in order to go from a "point cloud" to a section or a 3D model, it is always necessary to perform an operation of manual interpolation of the points and drawing of the position of the lines of architecture; this operation cannot be done uncritically but requires on the part of the draughtsman an understanding of the actual geometry of the building elements, comparing this data with other information, from site sketches, to details surveyed in situ at a greater scale of detail, to photographs.

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Therefore, the design of a historic building and its parts is always a complex operation, in which knowledge of the building elements and their connections cannot be ignored. Nevertheless, it is evident that when dealing with ancient buildings, some parts may be unknown and uninvestigable because they are not accessible or cannot be inspected. In the representation of a building, therefore, a certain degree of "incompleteness" and "uncertainty" of the information contained must always be considered. Information that can and should be implemented during the construction phase to be of support to the various experts involved in the activities.

Another key issue is that of controllability of the models created: while this greater diffusion of advanced surveying and representation tools, which are increasingly user friendly, is an undoubted advantage in terms of cultural heritage digitizing and knowledge sharing, it also requires a series of reflections on the quality of the procedures adopted and the possibility of qualitatively and quantitatively evaluating the results obtained. If precise reference standards exist for two-dimensional representations, the same cannot be said for three-dimensional modelling, where the question of the controllability of the result is more complex.

There are two aspects to be considered: on the one hand, the geometric accuracy of the model with respect to survey data (standard deviation, etc.), in which research has now produced excellent results with scan to BIM techniques (Banfi, F., 2017); on the other hand, the representative congruence of the elements with respect to the scale used. If about the first aspect such control and verification can take place within the modeling software, regarding the second one at the moment there are no shared and normed graphic codes that allow to do so (beyond what are the normative indications concerning HBIM modelling), although a revision activity is underway also by international organizations such as ICOMOS, through CIPA Heritage Documentation. The issue of the identification of shared standards of three-dimensional representation is fundamental also to guarantee a correct transmission of the knowledge and a real sharing of data (strictly connected to the question of the interoperability) among the different actors involved in the process of conservation and restoration of historical buildings.

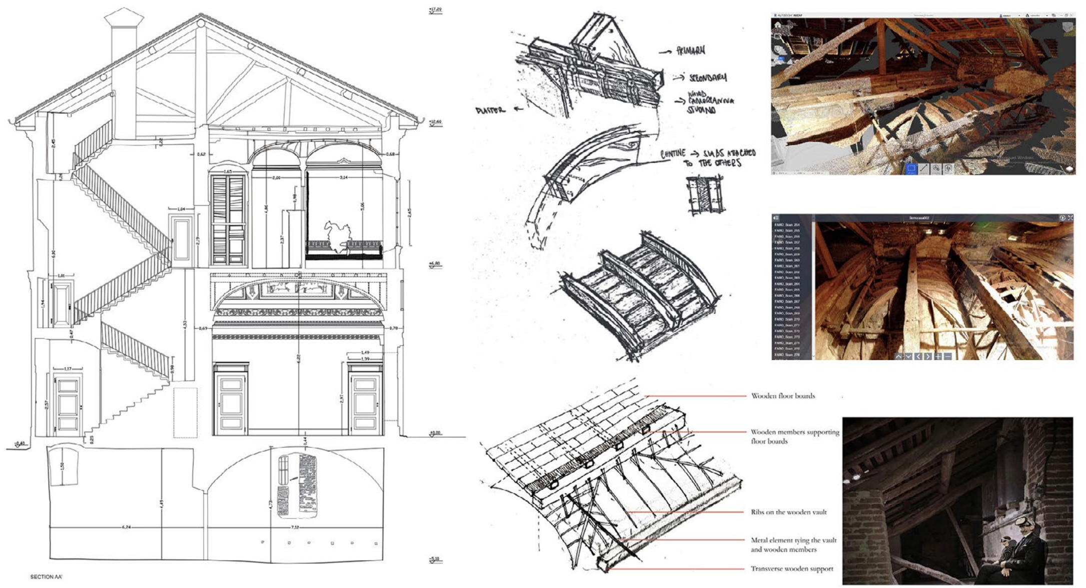

Figure. 3 Villa Sottocasa in Vimercate (MB): Use of different surveying and representation tools to measure and investigate complex covering structures. In particular, the images on the right of the point clouds render the extrados of the wooden vaults covering the nineteenth-century rooms on the second floor. Bottom right, the narrative of the building's construction history and transformations using VR.

HBIM FOR THE MANAGEMENT OF CONSERVATION ACTIVITIES

There is no doubt that the shift from two- and three-dimensional representation of historic architecture to HBIM models is a step forward in the design and management of preservation and maintenance activities. Nevertheless, there are still a few limitations and difficulties in the use of parametric models for preservation sites. In fact, as is well known, by its very nature BIM is a process management tool; in the case of historic buildings, such a tool allows for the management of all activities related to the intervention, starting from the knowledge and design phase (data collection) to site management and planned conservation. The geometric and morphological complexity that characterizes layered ancient structures and the large amount of heterogeneous data that are essential to plan the intervention still make the construction of an HBIM very onerous.

The shift from a mentality based on the centrality of the project to a process-oriented conception, concerned rather with management, also entailed a rethinking on representation and modeling, working on a composition of parametric objects functional to the specificity of individual processes (Della Torre et al., 2017), and therefore with differentiated levels of accuracy and information con-

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tent. A concept that has been incorporated in the recent Italian UNI EN 17412-1/2020 standard in which the concept of "Level of Information Need" appears instead of "LODs", emphasizing the need to always define usage before defining what information is needed, thus avoiding "information waste".

The goal in constructing an HBIM of the existing is to create a platform for exchange between different users that allows the design of models suitable for the different phases of management of a construction site. Such a platform must therefore be conceived as a three-dimensional repository in which all available information [2] can be integrated into a single database, which can always be updated, in order to facilitate dialogue and collaboration among all the operators involved: a) leading to savings in terms of time and cost of information retrieval; b) ensuring data consistency; and c) promoting continuous verification of the connection of the different phases and components and better management of the entire building life cycle.

From an operational point of view, parametric modeling of a building involves the need divide into its constituent elements, without losing the links between the parts and a necessary overview and considering the specificities of the objects to be modeled. It was the Italian UNI 11337/2018 standard that defined the need for historic buildings, to make an "As built" model; this placed the issue of geometric modeling as a central question, along with that of the accuracy of the starting survey data (Figure 4).

According to the traditional way of two-dimensional representation of a restoration project (Carbonara, G., 1990), as required by the competent Italian "Soprintendenze", the drawings must be on a scale of 1:50, with the possibility of changing in scale where necessary and delegating much more detailed information to punctual analytical sheets; transposing all this geometric, but also informative, data into a three-dimensional parametric model means first of all understanding what should be the scale of detail of the elements to be represented, by their nature geometrically complex, irregular, inhomogeneous. This issue opens the problem of modeling complex elements (Parrinello and Dell'Amico, 2021) and the real possibility of using the same level of detail for all parts of the building (Banfi et al., 2022).

Finally, regarding the question of the controllability of the parametric model, there are two aspects to consider: on the one hand the geometric accuracy of the model with respect to the survey data (standard deviation, etc.), on the other hand the representative congruence of the elements with respect to the scale used. If regarding the first aspect such control and verification can take place within the modeling software, regarding the second one now there are not yet quantitative shared parametric that allow to do so.

THE INTERPRETATION OF GEOMETRIES: COMPLEXITY, IRREGULARITIES, AND DIFFERENCES

Finally, regarding the question of the controllability of the parametric model, there are two aspects to consider: on the one hand the geometric accuracy of the model with respect to the survey data (standard deviation, etc.), on the other hand the representative congruence of the elements with respect to the scale used. If regarding the first aspect such control and verification can take place within the modeling software, regarding the second one now there are not yet quantitative shared parametric that allow to do so.

a) The reading and analysis of geometries, together with what are the different construction techniques used in different centuries, can suggest transformations, changes, demolitions, and reconstructions. In fact, the reading of the signs on the building, together with the reading of construction features, alignments, masonry thicknesses, and so-called geometric anomalies, favors the formulation of hypotheses. It is the case, for example, of masonry belonging to pre-existing buildings and partially reused, perhaps hidden

Figure. 4 From point clouds obtained photogrammetrically to the HBIM model of a vaulted room.

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within a new unitary appearance (typically this occurs in facades). Or is the case of horizontal structures varied over time, perhaps with the replacement of a wooden floor slab with a vault.

Likewise, regarding stairwells, which are often rethought and transformed over time due to a change in the distribution system (Figure 5). These are often changes that are not recognizable to the eye, moving within the building, but are evident when analyzing the graphic renderings. Similarly, the analysis of the digital recording of the existing can support the virtual reconstruction of buildings that no longer exist in their entirety or in certain parts, or not visible (Figure 6), integrating the actual state with different reconstructive hypotheses, even putting in place operations of "digital anastylosis".

In this regard, depending on of the purposes, whether they are purely for knowledge or for dissemination, the London Charter stresses the need to work with scientific rigor, ensuring effective immediate understanding between the parts of a three-dimensional model that represent the existing as opposed to the assumed. Indeed, it states in Section 4.4: "It should be clear to the user what a digital visualization seeks to present, for example, the current state of a site or object belonging to the field of cultural heritage, its reconstruction based on evidence or instead on assumptions, as well as the extent and nature of any uncertain information".

b) The identification of out-of-plumbs, deformations and overhangs of structures helps the designer in recognizing what are the critical issues in a building, identifying areas or points where further diagnostic investigation is needed. This is the case, for example, of slab or vault deformations, or walls leaning in false, to be evaluated with a structural engineer (Figure 7).

c) The identification of voids and gaps within the masonry structures (i.e., flues, interrupted stair bodies, etc.) or horizontal structures, allows the

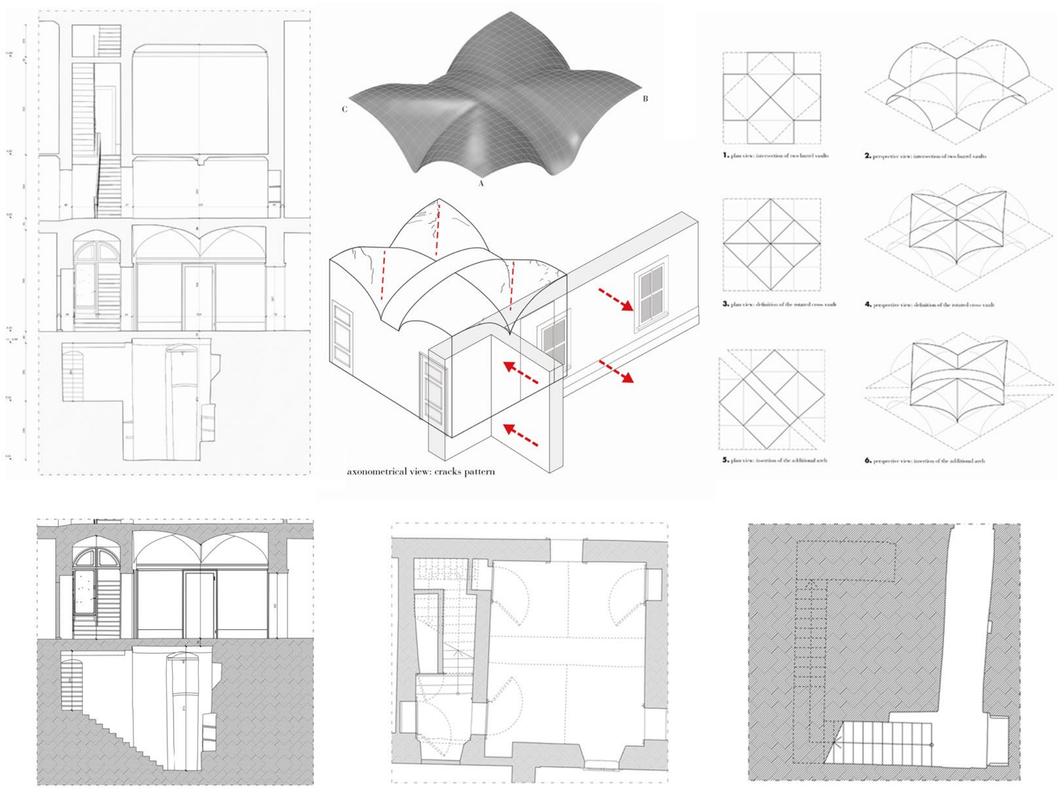

Figure. 5 Villa Sottocasa. Interpretation and analysis of geometries for understanding construction techniques and reconstruction of what no longer exists. Above, analysis of the constructive genesis of an "anomalous" vault on the ground floor; below, hypothesis regarding the positioning of the stair that connected the cellar floor with the ground floor, now no longer existent, starting from a 3D surveying data of the existing structures and stratigraphic signs.

designer to reason, for example, for the insertion of new installations and cables according to the based approach performance criterion typical of conservation projects, suggesting alternative solutions.

CONCLUSION

The digital registration and drawing of historic buildings, in all its forms, has a fundamental role for documentation, for the knowledge and conservation project, as well as for dissemination (including through the use of tools such as VR/AR) and the valorization of the results obtained (Brusaporci et al.,2020; Banfi et al.,2022).

It is clear, however, that there is no single mode of survey and representation that is always valid, as, moreover, the London Charter also points out, within which it does not prescribe "specific pur-

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poses or methods", but rather seeks "to establish, in research and communication related to cultural heritage, some broad principles for the use of digital visualization, on which the intellectual integrity of the methods and results themselves depends". He then added that "Systematic consideration should be given to a systematic assessment of the suitability of the methods to be applied to each purpose, so as to determine whether and which form of digital visualization is the most appropriate".

It is thus clear that, depending on the purposes, it will be necessary to design both the survey and the most suitable form or forms of restitution.

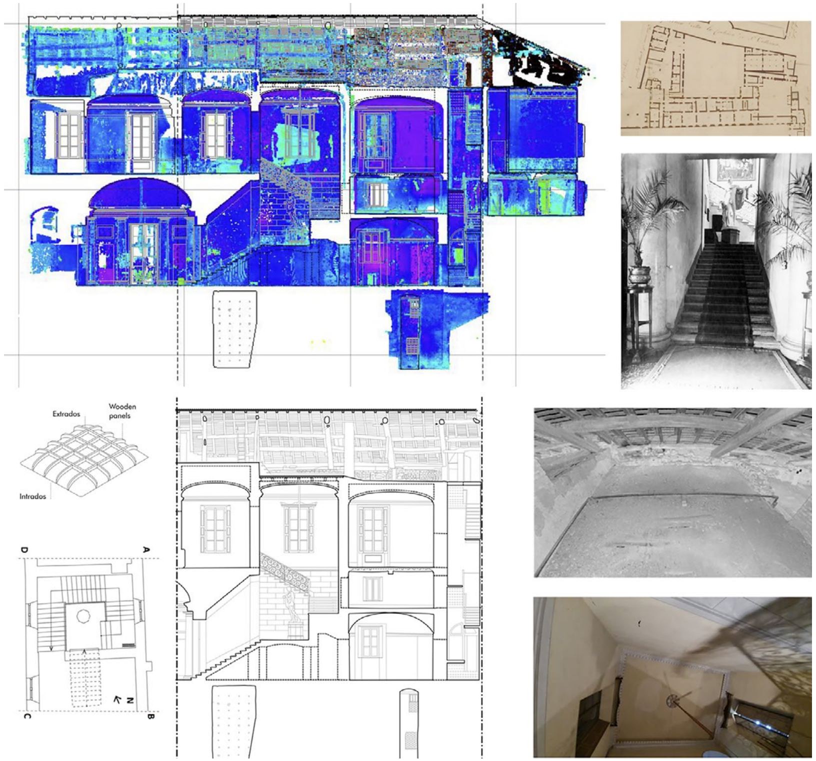

Figure. 6 Villa Sottocasa: the drawings of the grand staircase with construction hypotheses related to the pavilion vault covering it. The integrated use of geometric surveying tools, historical documents, and thermographic analysis enabled the understanding of structures not visible at the extrados.

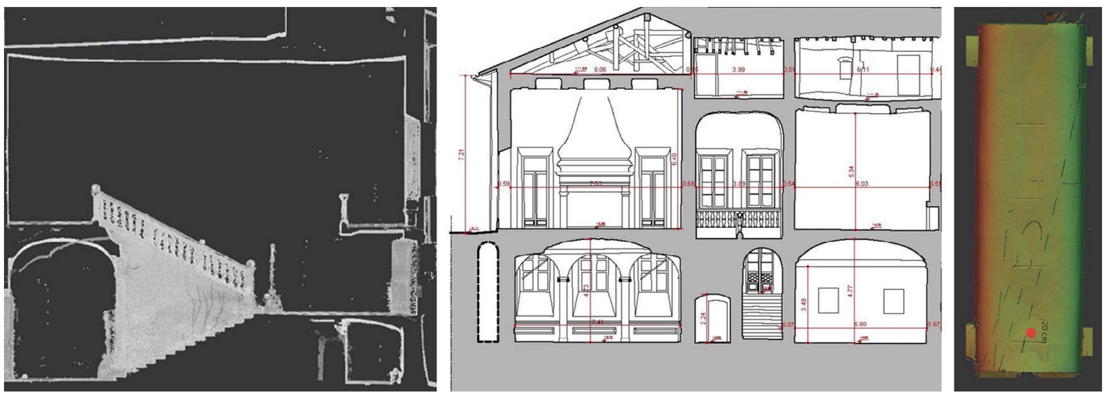

Figure. 7 Villa Cicogna Mozzoni: the laser scanner survey of the vault covering the great hall of honor showed the deformation of the wooden structure hanging, irregular in its course, toward the window (drawings: arch. Anna Urso).

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NOTE

[1] Which will be a reference of principles for the elaboration of the 1996 “ICOMOS principles on Recording”, and then also for the subsequent 2009 “London Charter for the computer-based visualization of cultural heritage” (https://www.london-charter.org/downloads.html) and the 2017 ICOMOS “Principles of Seville. International Priciples of Virtual Archeology” (http://www.sevilleprinciples.com/).

[2] In this sense, a key issue is that of ontologies. Among the Italian references: Acierno, M., Cursi, S., Simeone, D., Fiorani, D. (2017). Architectural heritage knowledge modelling: An ontology-based framework for conservation process. In Journal of Cultural Heritage, 24, 124-133; Della Torre, S., Pili, A. (2020). Built heritage information modelling/management. Research perspectives. In Digital Transformation of the Design, Construction and Management Processes of the Built Environment, 231-241.

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