Metric survey and possible representations of Historic Architectural Heritage: the case of the Santa Giustina Abbey

ARCHITECTURE HERITAGE and DESIGN

Carmine Gambardella

XVI INTERNATIONAL FORUM

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Preface

In the present era, technologies are becoming increasingly important in helping and supporting man in research, knowledge and production activities, almost as if they were smart prostheses. With the theme of the XVI Forum “World Heritage and Knowledge”, I propose to the International Scientific Community to debate and establish a comparison of knowledge carriers to communicate methodologies of good practices adopted and experiences in the use in the protection, conservation and safeguarding of cultural heritage and landscape as well as in the design of the “new, ”that, adopting in the building processes and building construction Innovative Building Modelling, can realise a non-contemporaneity of what has the same date (Giulio Carlo Argan) respectful of the values of the pre-existing, legitimate because it participated ex ante and monitored becoming all its ethical, aesthetic and performance connotations.

With the Internet of things, for example, sensors that are used to produce data autonomously that widen the processes of knowledge on all levels, from the territory with its infrastructures, to the environment, to the artefacts entering into the body itself of their physicality, or, in the case of the new, building the project as a prediction throughout physical consistency.

Nevertheless, the use of new technologies allows for economies of scale, both temporal and economical, not only for the surveying and representation of the built and the territory in the analysis phase but above all for the management of the resulting data that makes the design activity of the restoration of the historical heritage and landscape or of the newly constructed in a single process no longer divided into steps but also unitary in concrete constructions and the realisation of the works, in the intermediate checks, in the testing, in the monitoring and in the programmed maintenance.

In conclusion, it is indispensable for the scientific community to highlight how technologies, without a responsible attitude that commit man’s choices and knowledge in dealing with and planning appropriate responses to the issues and needs of the collective, can create a deception that unfortunately materialises with the subtle persuasion of uncontrolled astonishment that overwhelms the imagination.

Carmine Gambardella

President and Founder of the Forum

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Metric survey and possible representations of Historic Architectural Heritage: the case of the Santa Giustina Abbey

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Abstract
The semi-automatic metric survey techniques developed in the past years allow the recording of 3D models with an ever-increasing level of details and accuracies.
The 3D database, usually georeferenced in a cartographic system, opens the floor to different kind of representations (e.g. 2D drawings, 3D models, digital animations, AR/MR applications etc.) conceived to satisfy different requirements at different graphic scales and aimed to increasing the knowledge of Cultural Heritage.
The paper introduces some different representations that can be extracted from a 3D database: the “as built” representations, which put in evidence all the irregularities of a real building, as it today appears because of anthropic interventions and endogenous/exogenous events happened during its life.
Starting from this 3D database the main task of the representations is interpreting and synthesizing the collected information aiming to recognize the architectural values of the building, the geometric matrices of the shape, the modularity of the composition, and the relationships between architecture and decoration.
The Romanesque abbey of Santa Giustina in Sezzadio (Italy), a well preserved building, which considerable dimensions, constructive accuracy, and rich decorations testifying its territorial importance, is a significant case study for these purposes. It is a less documented architecture where metric survey and representations has been produced as a first step to support future researches.

Keywords: metric survey, architectural drawing, 3D modeling, graphical analysis, Santa Giustina Abbey

1. Introduction

The documentation of Cultural Heritage assets is one of the most intriguing and urgent needs to preserve cultural values of local and global communities. The starting points of every documentation effort are the historical evolution of the analyzed asset and the geometric knowledge of the full and empty spaces, which define the object to be documented.
The present work concentrates its attention on geometric knowledge acquisition that requires a strong metric survey and a careful set of representations able to put in evidence specific portions of the object and their spatial relationships. Both metric survey and representation cannot be developed properly without a basic historic knowledge able to inform the surveyors about the aims of the survey itself.
3D models generated by metric surveys and *ad hoc* representations of it will be the geometric framework where all the historical data could be connected by forming a database useful to transfer the basic knowledge for further analysis, restoration and conservation planning, and valorization actions.
The experience developed on the Santa Giustina Abbey represents a full example of a balanced cooperation between experts in metric survey and experts in representation to realize and communicate the achieved results.

2. Metric survey

In the last decades, many technological improvements allow the growing up of a new way to develop a metric survey from the primary data acquisition up to the management of them to obtain a 3D model, which represents the normal outcome of a metric survey intervention. 3D models generated by means of correct metric survey approach are the base for the development of different kind of representations that range from traditional 2D drawings up to BIM structures, AR/VR solutions, 3D print, etc. [1].
Despite the fact that up to twenty years ago the selection of the points necessary to start the modelling phases was performed directly by the surveyors, today the intelligence of the survey is applied on a point cloud acquired automatically by using laser scanning instruments or, more recently, by automatic digital photogrammetric methods.
The evolution of technologies and the changes in the modeling do not allow to change the correct design, execution and check of the metric survey procedure.

2.1 Design of a metric survey

The correct approach to design a metric survey can be split into four main preliminary steps. The first thing to be done is the comprehension of the goals of the metric survey by fixing the required accuracy, the deliverables to be produced and the goals that the 3D model has to satisfy. The accuracy (the maximum acceptable metric differences between the final 3D model and the real surveyed object) can assume different values for specific detail or portion of the entire object in order to minimize the costs of the survey and to give, to the final users, the needed information. The deliverables required at the end of the metric survey are of interest because they help to define the level of detail of the survey and, finally, the amount of the necessary primary data [2].
A second step of the planning of a metric survey is the recovering of already existing metric data: in case some existing data are accessible, they have to be tested in terms of accuracy and level of detail limits defined in the first step. Usually historical metric data are not completely documented and therefore not completely usable but, in any case, they could form a good base to plan the actions and to show the modification that occurred on the object over the times.
By considering the requirements and the already existing and acceptable data, it is possible to define the amount of points, which have to be acquired, and their location. That information are of fundamental importance during the selection of the usable metric survey techniques.
The fourth and last step is the selection of the techniques to be used in all the different phases of the metric survey: control network establishment, and detail survey. The use of some of the possible metric survey techniques requires, sometimes, also the establishment of a second order control network: in these cases, also this step must be carefully planned.

2.2 Detail metric survey techniques and strategies

The technology development occurred in the last years caused the almost disappearing of traditional metric survey techniques based on manual distance measurements and the traditional topographic methods using total stations, and also the use of photogrammetry based on stereoscopic plotting. All these three methods ask for the selection of the points to be measured by a skilled operator: the amount of recorded data are reduced to a minimum size and the modelling is done, step-by-step, by the surveyor itself during the point survey.
The introduction on the market of laser scanner devices, push the normal approach of the detail survey towards an automatic (and therefore not intelligent) acquisition of a big amount of points irregularly distributed (the point clouds). The main reason who justify this result is the possibility to generate a big amount of geometric analysis when they are necessary (not during the acquisition period), and to reduce the time needed to acquire the primary data.
Actually, this advantage was true for photogrammetry also since its beginning: the images and some metric information (such as for example a network of Ground Control Points or some distances) constitute the implicit 3D model to be investigated when necessary also years after the acquisition of those primary data. In the same way the point clouds acquired by Laser Scanning Systems form a stable set of metric information that can be used for geometric modelling when necessary and stored for successive uses. The automatic procedure used to generate those point clouds guarantees the objectivity of the primary data (as the images used in photogrammetric surveys) for a subjective interpretation developable in a second step.
The research developed in the last years, shows that a strong integration between Laser Scanning Systems and Photogrammetry can give the best solution: the images acquired by the most recent Laser Scanning instruments allow coloring the point clouds and increase the quality of the interpretation required during the modeling phase.
Point clouds are not 3D models because the points are not topologically connected: points are independent geometric entities and the metric survey cannot be considered totally developed until a real 3D model with defined topological relationships (e.g. line, surface and volume definitions) is built.

The simple use of mesh solutions (e.g. Delaunay triangulation) could be a possible answer for very irregular surfaces where sharp edges are not present, but especially in architectural objects, this approach do not give appreciable results. Geometric break-lines have to be detected to drive the mesh algorithms towards a correct description of the shape of the object. Today no automatic tools can give those results and a huge work of geometric segmentation has to be performed manually by using specific software platforms.
To realization of traditional 2D drawings (e.g. planes, sections, and elevations) is done by cutting the point clouds with the selected section plane, and the point nearest to this plane inside a specific tolerance, are projected onto it and then topologically connected to define the intersection line: this draft line constitute the starting point for the 2D representation.
Recent developments in automatic digital photogrammetry allow generating dense point clouds similar to the ones acquired by using Laser Scanning devices allowing to skip the heavy manual plotting by using stereoscopic vision and to produce an intermediate primary dataset of points starting from the acquired images.
In case of terrestrial applications, the use of drones to acquire stereoscopic images allow today to solve the problem of surveying vertical surfaces facing narrow streets, roofs of buildings, sub-horizontal assets like archaeological excavation sites, etc. The acquired images are used by means of standard photogrammetric tools to complete the point cloud generation.
The density of the point clouds could be different in some part of the surveyed volume due to different requirement for correct representations: the surveyor has to be aware of these requirements in order to be able to realize a 3D model useful for the specific representations defined with the final user.

2.3 Metric survey of the Santa Giustina Abbey

The aim of the metric survey of the Santa Giustina Abbey is to support historical studies and to constitute the metric base for a documentation of the complex. A survey scale of 1:100 was adopted and traditional 2D drawings (e.g. plans, sections and elevations) were chosen as a first way to represent the achieved results.
The Abbey of Santa Giustina has not be documented in acceptable ways during the past. Only one survey made in 2001 during the structural restoration could be partially recovered but the level of detail is not considered sufficient for the aims of the new investigation: in addition, there is not access to the primary data therefore is not possible to certify the metric quality of the recovered drawing. It was decided to use those drawings to describe the interior roof structures and those parts that are not of main interest for the investigations.
The level of detail required to form a metric base for geometric analysis and wall analysis that the researchers would performed, suggest adopting the Terrestrial Laser Scanning technology for interior and exterior walls, and the aerial photogrammetry for the exterior surfaces of the roofs by using a UAV. These aircraft allow the acquisition of the needed images at the sufficient distance to reach the accuracy required by the adopted scale (e.g. tolerance of ± 2 cm).

Fig. 1 – The control network (left) and the Laser Scanner station points (right)

A control network has been established (see Fig. 1) and the survey has been performed by using the scheme of a free network: planimetric measurements have been done by using a total station and levelling by using the differential levelling technique.

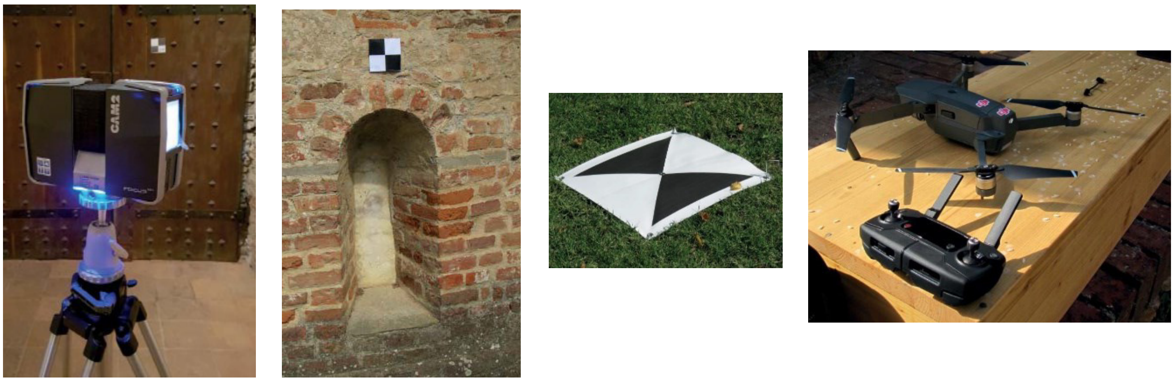

Fig. 2 – The FARO FOCUS3D X330 used for the point cloud acquisition and a marker (left) and Marker used for GCPs materialization and the MAVIC PRO UAV system used to acquire aerial images (right)

A second order control network has been realized to allow the registration of the point clouds and to estimate the exterior orientation parameters of the stereoscopic images. The Ground Control Points (GCPs) for the registration of the point clouds have been materialized by traditional signals (see Fig. 2): a total amount of 169 points have been surveyed, by using a total station, in order to allow the registration of the indoor and outdoor point clouds. Almost half of them are used to check the obtained accuracy to certify the metric quality of the final model.
All the scans obtained by using Terrestrial Laser Scanners and automatic matching of acquired images have been oriented in the coordinate system defined by the control network. The mean discrepancies on GCPs used to orient the terrestrial point clouds are less than 1.5 cm and the observed discrepancies of the GCPs used to orient the images acquired by the UAV system (see Fig. 3) are less than 1 cm. The discrepancies on the Check Points not used during the orientation steps are less than 2 cm.
Both these results allow certifying that the final point cloud used to extract 3D metric information have the necessary metric quality defined during the design of the metric survey.
Once the point clouds have been registered, the basic metric information have been extracted to generate the required representations.
The strategy in these cases is to cut the point clouds by considering all the points present inside a volume having a thickness of about two times the required accuracy. All the points contained in this volume are than projected on the needed projection plan and topologically connected to for the draft line that define the required section (see Fig. 4) or elevation.

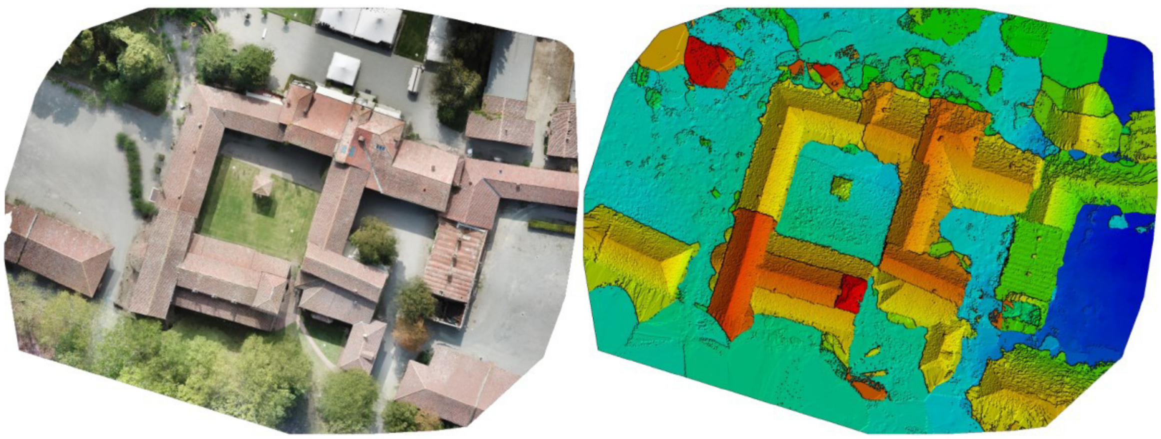

Fig. 3 – One of the aerial images used (left) and the obtained point cloud for roof metric survey (right)

3. Issues of interpretation and representation of the data

The interpretation of the acquired metric data implies a constant and rigorous attention to the formal, structural, and stylistic peculiarities of the building, to the historical period in which it was realized, also in reference to coeval buildings and to the context in which it rises, to the constructive materials used, and to transformations and events happened over time. Documentary materials, archival, bibliographic and iconographic sources contribute in a fundamental way to this knowledge.

Therefore, the architectural survey arises as an open system of knowledge whose documentation is aimed at safeguarding the cultural heritage [5].

The aims of the survey, to be established in the design phase of knowledge operations, guide at all times the representation methods and the contents that they must highlight.

The representation is established as a tool for the synthesis of the acquired knowledge, making a critical selection directed by the pre-established aims.

Fig. 4 – Elevation (left) and section vector-based extraction (right – Top: point cloud – Middle: section line – Bottom: complete section vector-dataset)

The digital revolution has led to an extensive availability of tools: for architectural representation - through drawing, modeling, animation, up to prototyping -; for communication - through virtual visits, interactive explorations, AR, VR, MR -; and for sharing - through websites and open-source platforms-.

3.1 The educational value of the work on Santa Giustina Abbey

The Abbey complex of Santa Giustina in Sezzadio, founded in 1030 by Marquis Otberto and soon the seat of the Benedictine order, has as a fulcrum the church subject of the present study [6], which closes the perimeter of the northern cloister.

The building, described by Porter in 1917 [7] as a minor edifice of the Northern Italy, has considerable dimensions (max length of about 39 m, max width of about 27 m, max height of about 22 m) which testify its relevance in the territory.

It is a Romanesque church, masonry bricks built, having a *crux commissa* plan with three naves delimited by three apses beyond the transept. The crypt occupies the space below the presbytery which is consequently raised. The salient façade is broken in the central part by a watching tower built somewhat earlier than the construction of the Gothic rib vaults on the three naves in the fifteen century [7].

The recognition of the importance of the Abbey led to the hypothesis that there could exist design criteria of a modular nature at the base of the planimetric tracing and, in general, of the spatial concept of the project. These practices, identified in Cistercian buildings of the twelfth and thirteenth centuries [8], together with the knowledge of geometry in Gothic architectural works, documented in the book by Villard de Honnecourt [9], but also found in previous solutions [10], would have in the Abbey in Sezzadio a really early application.

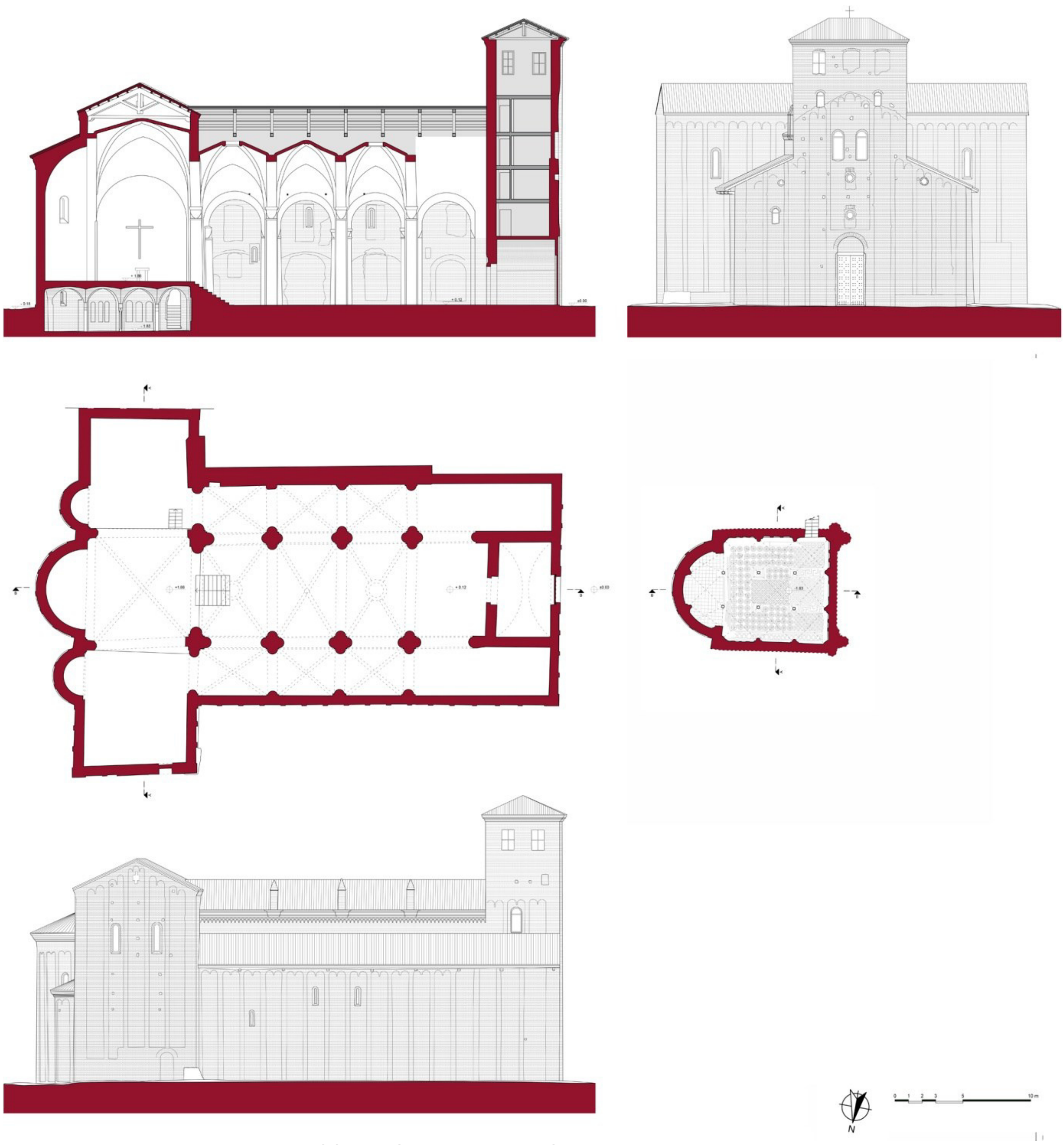

Fig. 5: Plans, elevations, section of Santa Giustina Abbey. Original scale 1:100. Drawing by Alessandro Piovano.

Moreover, the absence of updated representations metrically based on acquisitions realized with the most recent technologies and represented through digital tools, led to the choice to draw up those synthesis drawings essential for an exhaustive description of the object, which also constitute the basis for graphic hypotheses on modularity.
The selection of the cut planes and the reference planes of the point cloud to generate the most significant sections is an operation that is conceptually very complex and didactically particularly educational.
In fact, this selection forces the student to move the section plane parallel to itself in the different levels of the building, in order to intersect the most significant elements, such as keystones, as was done in the case of the present work, for the longitudinal section of the crypt and the central nave.
Similarly, the horizontal section that gives rise to the main plan had to be set at an unconventional height in order to pass on the presbytery floor and intersect the largest possible number of openings at the entrance level.

In addition, the selection of the reference plane in relation to the section plane, which allows visualizing the elevation beyond the section plane, completing the orthographic projection, involves some problems: indeed, when between the two planes many elements are interposed, the reading of the elements on the posterior plane can be difficult.
The passage from the raster image obtained from the point cloud to the vector drawing generates further issues. The selection of the points through which the break-line must pass has to take into account those punctual elements (cracks, thickening of plasters, tie beams) for which the section plane could accidentally pass that could compromise the understanding of the conformation of the artefact (see Fig. 5).

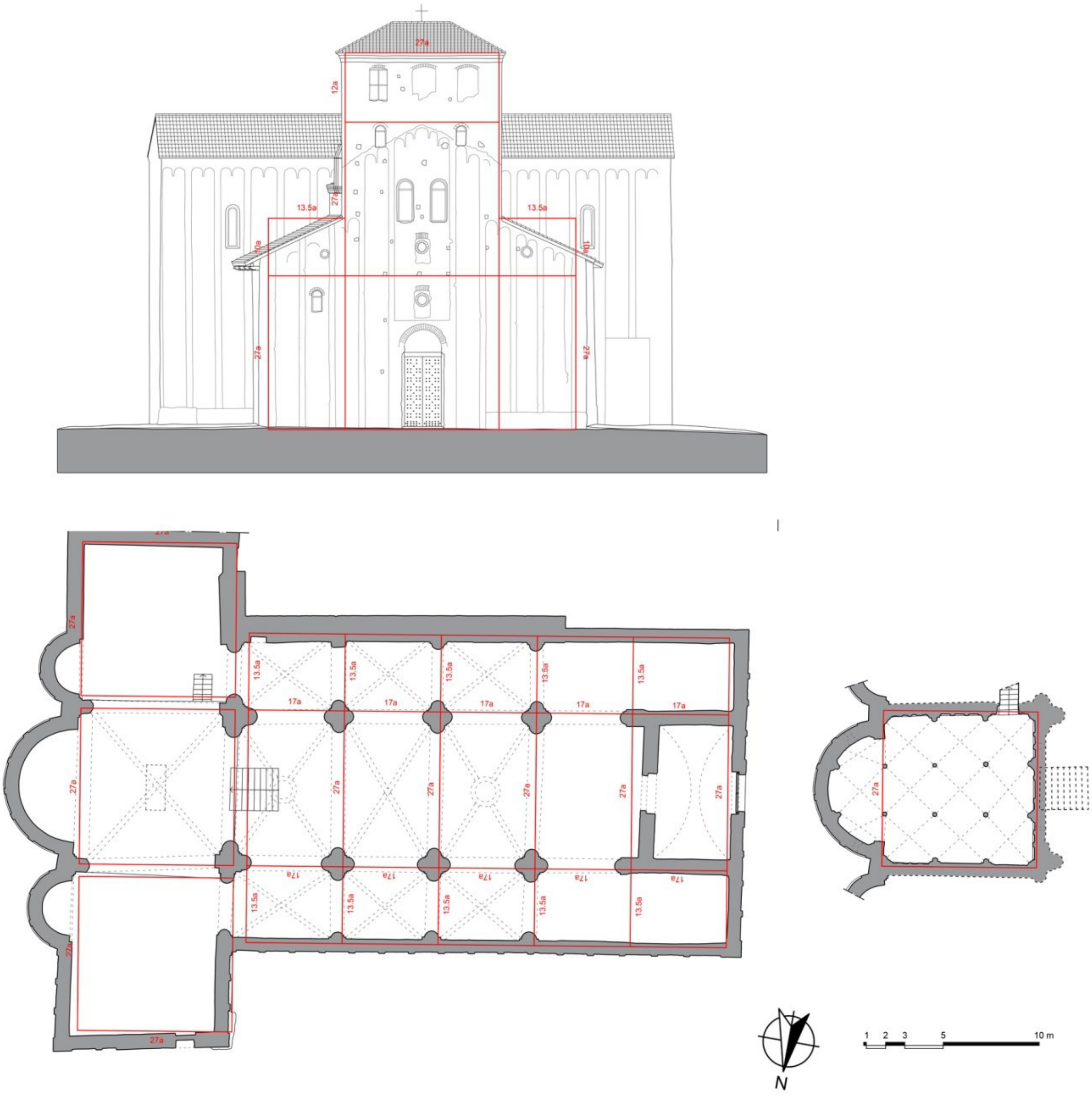

Fig. 6: Graphical analysis of Santa Giustina Abbey. Original scale 1:100. Drawing by Alessandro Piovano.

Vice versa, the points intended as projection of geometrically significant elements: edges, intersections between surfaces, imposts and keystones, must necessarily be taken into account.
In addition, the scale of representation designed for the drawing and the printing suggests the minimum distance for the selection of points, to avoid increasing of time during the work.
The potentiality of printing devices for digital drawings has progressively led to the creation of more detailed drawings than analogical ones, both in the design drawing and in the survey drawing. The relationship between scale of reduction and contents, established by centuries of pen representations on paper and by a series of indications by the standardization bodies (UNI, ISO, EU, CEN4) [11], today sees a search for the detail superior to the past.

At present, distances between parallel lines even below the millimeter are appreciable, and in the 1: 100 scale established for the restitution of the Abbey, they are equivalent to 10 or less centimeters measured.
Then, the problem is of a cultural nature, and respecting the criterion of the minimum distance between two lines is not sufficient: for instance, the identification of the main partitions of an architectural order can lead us to decide to draw a line rather than another, in order to communicate a univocal message to the reader of the drawing.
In the examined case study, it was decided to add the geometric information with the architectural ones, such as the virtual projections on the plans' section planes of the vaulted and roof systems.
Furthermore, it has been established to represent elements of recognizable particular value, such as the mosaic flooring of the crypt and to highlight, using a symbolic hatch, the tiles and the visible brick textures in the internal and external façades. The decorations characterized by chromatic variations that do not involve geometric discontinuities have not been taken into consideration: such as the alternating bands, painted in black and white on the pillars and the apparatus of the frescoes, already effectively documented in the point cloud.
Finally, on the synthesis drawings realized with such attentions it has been possible to propose modular readings that refer to the well-established methodology of the graphical analysis [12] [13].
Graphical analysis, in the field of the project's reconstruction, could be recognized as a privileged instrument of architectural criticism because it provides new contributions of knowledge in respect to the only original drawings, the old pictures, the project reports and the critical essays. Graphical analysis, with a translation of practices and meanings, can be fruitfully applied also to the survey drawings. Indeed, in the present case study, it contributes to highlight the figurative reasons of architectures' visible conformation, affirming its heuristic value.
In the abbey, the recurrence of proportional ratios of areal type (square, semi-square) and linear type (M, 1/2 M), that is more convincing in the analysis of the plans and main elevation, seems to rule the whole composition. These relationships also highlight a plausible correspondence with the unit of measurement probably used, the Roman foot (see Fig. 6).

3.2 Beyond the didactic experience: from a point cloud to several possible representations

As mentioned, the availability of the database generated by terrestrial and aerial scans can be the basis for generating multiple types of digital models and drawings, obviously paying attention to the reduction scales provided in the survey project.
Digital geometric models represent a relatively new product, compared to traditional analog representations by orthographic projections. Agreeing with Bertocci and Bini, this model is the product of a synthesis operation performed by the operator who, pursuing a specific communication objective, selects the information of what "is nothing other than a geometric figure representing an architecture" [14].
A particular category of modeling tools that can be used in the survey representation is that of parametric modeling, distinguished in geometric and BIM tools.
The first, by means of form-making strategies seems to be a suitable solution for the studies conducted on existing historical architectures [15] [16]. Anyway, the procedure, that is not comparable to a graphic reproduction gesture but to a real research activity, required the construction of a precise methodology that frames explicit correlations between shapes of an artefact, their geometric properties and the conditions bringing to its formation [17].
The second applied to the historical architecture (HBIM) allow, among other prerogatives, to build families of architectural elements to draw from during the modeling phases and, above all, to manage a series of information associated with the model, aimed at stratigraphic analysis, restoration, static consolidation, energy qualification, management, allowing to record changes that occur over time [18].
Starting from digital models different products can be created, such as animations and scaled physical models make through 3D printers. These products can be a link between representation and communication, triggering processes of perceptive fruition and facilitating the three-dimensional understanding of the artifact by an inexperienced public.
Further steps in this direction, aimed at valorization through the promotion of cultural tourism, can be accomplished by creating virtual visits, interactive explorations, experiences of virtual reality, augmented reality, mixed reality, available *in situ* or shared through websites and open-source platforms.

4. Conclusion

The presented experience is a fluid process within which different knowledges are composed in a multi-disciplinary perspective aimed at the analysis, interpretation and enhancement of Cultural Heritage. The realized database and the first graphic elaborations resulting from its interpretation offer an important contribution to further research involving the disciplines that operate in the field of the safeguard and enhancement of historical architectures of recognized value, not yet adequately documented.

Credits

Paragraphs 1, 2, 2.1, 2.2, 2.3 are written by Fulvio Rinaudo and Alessandro Piovano, paragraphs 3, 3.1, 3.2, 4 are written by Roberta Spallone, figures 1, 3, 4, 5, 6 are processed by Alessandro Piovano.

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UNESCO Chair on Landscape, Cultural Heritage, and Territorial Governance; President and CEO of Benecon SCaRL Research Centre on Cultural Heritage, Ecology and Economy (Consortium of five Universities: University of Campania "Luigi Vanvitelli", Pegaso University, University Federico II of Naples, University of Salerno, University of Sannio). Pro-Rector at the European Polytechnical University, EPU. Professor of Drawing at the Pegaso University and at the University of Campania. President of the International Forum of Studies 'Le Vie dei Mercanti' since its first edition in 2003. Honorary President of the Italian Committee of the Nation Fulbright Sector on Cultural Heritage Sustainable Development, Urban Planning, Architecture and Management of UNESCO World Heritage Sites. Editor and Founder of the series "Surveying is/or Project" and "Knowledge Factory", "Architecture, Heritage and Design". Component of the Scientific Committee of International Class A Magazine 'Abitare la Terra'/ 'Dwelling on Earth'.

During his academic career he has covered various roles including the Pro-Rector of Institutions, Academic Senator, Member of the Board, Director of the Department of Architecture and Industrial Design Luigi Vanvitelli, Dean of the Faculty of Architecture Luigi Vanvitelli, Director of the Department of Culture of the Project, Director of Doctoral School in the Discipline of Architecture, Coordinator of the PhD in Protection, Safety and Representation of the Environment and Structures and Territorial Governance, Coordinator of the PhD Program in Surveying and Representation of Architecture and the Environment, President of the Course Degree in Industrial Design. He has also been scientifically responsible for noteworthy national and international research project. He is author of numerous scientific papers on the important issues of the surveying and representation of the built and natural heritage.

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