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Digital Survey and 3D Geometric Interpretation of Complex Vaulted Systems. Palazzo Valperga Galleani di Barbaresco in Turin

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***Abstract* – The present contribution proposes the study of the 'a fascioni' vaults, which derive from Guarini's experience, that characterized, between the seventeenth and eighteenth century, part of the baroque architectural production in Piedmont. Such unitary vaults are characterized by the subdivision, through twisted arches, of the intrados into regular fields, covered by secondary vaults.**
The case study presented, Palazzo Valperga Galleani di Barbaresco in Turin, aims to deepen, through 3D representation digital tools, the links between the realizations, the references to treatises and manuals and the geometric matrices behind the articulated spatial configurations.

I. INTRODUCTION (MV)

The present contribution proposes a study on 'a fascioni' vaults, which derive from Guarini's experience that characterized, between the seventeenth and eighteenth century, a significant part of the Baroque architectural production in the Turin and Piedmont area.

The 'a fascioni' vaults are configured as unitary vaults (designed to cover rooms, even large ones, without intermediate supports) in brick masonry, often used in the civil architecture to the covering of atria and halls. They are characterized by the subdivision of the vault in regular fields, through weaves of arches. Those fields are covered by secondary vaults, whose intrados reveals the geometric complexity of shapes generated by the composition of different surfaces, aimed at obtaining effects of movement and lightness, even in cases of small rooms and reduced heights.

The research starts from previous studies, oriented to the geometric-spatial analysis of other types of complex vaults [1] and deepens the investigation – previously developped on other case studies [2] – on the geometric aspects of the primitive reference surfaces of the 'a fascioni vaults', in their relationship with treatises, manuals and historical studies.

Starting from the study carried out in the historical center of Turin, aimed at identifying unitary vaulted atria subdivided into classes referring to the geometric configuration, it was possible to catalogue more than dozen entrance spaces of palaces covered by 'a fascioni' vaults, designed and built almost all during the reference period 1690-17305 (fig. 1).

These examples constitute a significant homogeneous repertoire, characterized by defined geometry that can assume a great variety of conformation. The initial phases of the research have been set up to formulate hypotheses on the geometries supporting the constructed architecture, that can be verified through intrados survey operations, the representation of which employs digital modeling tools. Here we report some formalized results of the work carried out on the atrium of the Palazzo Valperga Galleani di Barbaresco in Turin, in order to compare survey data, geometric-spatial analysis and sources.

II. SOURCES: TREATISES AND MANUALS (MV)

The analysis of architectural literature, treatises and manuals, reveals the theoretical and applicative relations aspects established in the past between geometry, architecture and construction.

The 'a fascie' vaults, locally (in Piedmont) defined also 'a fascioni', are introduced, in treatises, by Guarino Guarini: in the *Architettura Civile* [3] for the first time he makes a rigorous examination of the vaulted systems, which is interwoven with aspects related to the invention, construction and calculation of surfaces and volumes also illustrated in the *Euclides adauctus* (1671) and in *Il modo di misurare le fabbriche* (1674). In the Trattato III of the *Architettura Civile*, Capo Vigesimosesto, *'Delle Volte, e varj modi di farle'*, he dedicates the Osservazione Nona and the Osservazione Decima to the 'a fascie' vaults and to 'a fascie piane' vaults, claiming their authorship: "This sort of Vaults is my particular one, and I have put it into practice not without much variety, and with the satisfaction of the people". Regarding the spatial configuration, Guarini describes its genesis through a division of the room, "pulling from wall to wall, or into a frame, or by diagonal line various bands, which make themselves some compartments, and then the spaces that remain, I fill it of different Vaults according to the capacities of the field, that they leave […] which they make very noble sight and

Fig. 1. 'A fascioni' vaults in the baroque atria of the historic city center in Turin: building in Via Bogino 4, Palazzo Martini di Cigala, Palazzo Capris di Cigliè, Palazzo Cotti di Brusasco, Palazzo Barolo, building in via Garibaldi 53

leave fields dear far the painting". In Plate XX of the Trattato III, an 'a fascie' and an 'a fascie piane' models are described in orthogonal projections.

The systematic approach of Guarini opens the field to the experimentations and subsequent writings, which constitute a significant theoretical corpus both in relation to the refinement of the geometric description of the surfaces, and with regard to the description of the construction techniques and implementation of the vaults in masonry. In Italy, in fact, they will become the object of specific manuals only towards the end of the nineteenth century.

The studies on the vaults by Giovanni Curioni can also be used as a link between the theoretical and practical contributions. They are also favored by scientific advances in the field of descriptive geometry and mathematics.

In the *Geometria pratica* [4] he deals with the measurement of the surfaces of the vaults, minutely describing their geometric genesis and mathematical description.

As regards the definition of the 'a fascioni' vaults he recalls the general approach of Guarini, adding indications concerning the surfaces generating the arches that divide the room, imagining that "on the polygon to be covered with one of these vaults already insists the in-trados of a vault which, depending on the figure of the said polygon, can be barrel, an 'a conca', a cloister, a barrel with cloister heads, a dome". Similarly, as indicated by Guarini, working for cuts with vertical planes on the reference surface, we obtain the arches on which the geometric structure of the vault is set: "on the impost polygon there are so many lines drawn that, raising from them vertical planes, these are to cut the intrados surface according to fields; that many solid arches resting on the piers and with mutual contrast between them, are thrown on these areas; and that from the spaces not covered by the arches the corresponding parts of the primitive vault are removed in order to replace convenient vaults far which the 'fascioni' serve rather than the walls against which they support". A few years later, still in Turin's culture, Chevalley, in his *Elementi di tecnica dell'architettura: materiali da costruzione e grosse strutture* [5] collects a sum of local constructive knowledge in the framework of vaulted structures construction and enriches the it through numerous tables in which indicates the most usual brick equipment, the arrangement of the ribs and the developments on the plane of the intrados surfaces.

In the description of the 'a fascioni' vaults, he recalls Curioni's text, confirming its genesis, indicating some built examples and empha-sizing its spatial qualities: "lt is clear that brilliant architects, from the infinite variety of combinations of which the arches are suscepti-ble together with vaults, they can draw unimaginable and beautiful architectural effects"; in particular "the baroque architects used the 'a fascioni' vaults broadly in their constructions: and in the atria and halls of palaces, in the churches of the seventeenth and eighteenth centuries, we often find remarkable examples".

III. CASE STUDY ANALYSIS: PALAZZO VALPERGA GALLEANI DI BARBARESCO (MV)

The analysis of the 'a fascioni' vaults of atria identified in the historic center of Turin makes use of the theoretical contents just illustrated and confirms, through the working methodology – which provides for the recognition of the geometric characteristics of the vaults through direct survey and photomodeling –, the general approach described by Guarini and the geometrical-spatial qualities of which Curioni refers to in *Geometria Pratica* by exposing the methods for the calculation of the intrados surfaces.

The atrium examined for this contribution is one of the most significant examples among those identified in the census phase: it consists of a sequence of spaces that highlight the variety and complexity of the geometries used in the composition of an 'a fascioni' vault (Fig. 2).

The Palazzo Valperga Galleani di Barbaresco has been the subject of some historical studies that outline its transformations [6], which testify to the progressive unification of neighboring properties through important reshaping works, which lead to the current configuration (net of recent works of restoration, which took place in 2015) by Luigi Michele Barberis (1781-1784) commissioned by Camillo Galleani count of Canelli and Barbaresco.

The Barberis project distorts the structure of the building: having occupied the site of the previous garden, the building has a new monumental façade on Via Alfieri, on which the new main access is built, previously on Via XX Settembre. The entrance, defined by lateral arches, connects directly with the courtyard, distributing the atrium on the right, in a position close to the previous one (the one that saw access from Via XX Settembre): it is in a raised position from the driveway level, with consequent exclusively pedestrian use, constituting a sort of room on the ground floor which is a prelude to the imposing staircase.

IV. DIGITAL SURVEY (FN)

The hall of the building required the use of photogrammetric techniques to fully understand the architectural space[7][8].

This survey, focused on the digital representation of the vaulted apparatus, is here managed by tools such as: camera, tripod, artificial light sources and laser distance meter.

Taking care of the photographic shot is fundamental in this phase so that the right lighting conditions must be ensured throughout the photographic campaign and, whenever possible, the spatial features of the room must not be affected by visual disturbances. The quality of the images, from the point of view of the exposure, can be managed in post-production – and is almost always recommended – on *.raw* format images.

Fig. 2. The 'a fascioni' vault of the main atrium of Palazzo Valperga Galleani di Barbaresco

For this study the images were taken with a Canon EOS 1300D with an EF-S II lens 18-55 mm. positioned on a tripod adjustable to 1.80 m. height. The conformation of the space, without any physical obstacle, allowed the positioning of the camera on an ideal grid; photographs were therefore taken by placing the camera every 0.75-1 m. in its axial directions, covering the entire surface of the atrium.

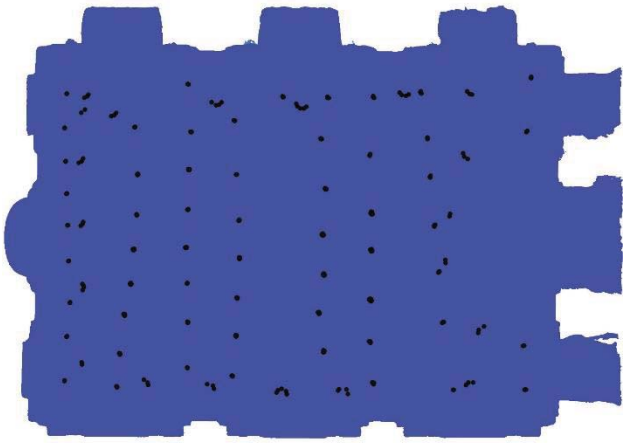

Fig. 3. Camera location in Palazzo Valperga Galleani di Barbaresco. Image extract from Metashape processing report

This method, used for taking photographs, was doubled in order to make a set facing the upper part of the room (vault and perimeter walls) and one towards the lower part (flooring). This allowed to manage the post-production corrections due to excessive exposure illumination from the openings.

For the two photosets the inclinations of the camera were also alternated for which a different GSD (Ground Sampling Distance) value was obtained, which is reported

in the following table.

Table 1. Information about images and GSD values.

General	Bottom	Top
Number of images	64	263
Focal length (mm)	20	18
Distance (m)	7,71	7,59
GSD (cm/pixel)	0,144	0,142

The results of the photographic campaign were therefore included within the Agisoft Metashape software for the processing of the point cloud and the related texturized mesh model.

The process makes the creation of different 'chuncks' depending on the type of image used: the number of photos change in the two blocks in order to better analyse the vault that is the focus of this research. The parameters entered in the software have seen a downgrade in the 'quality' privileging the first alignment phase (*Align Photos*) which has already provided a considerable number of known points.

The following table shows all the important data of the model creation phase generated by Agisoft Metashape.

Table 2. Processing parameters from Metashape model

General	Bottom	Top
Camera	70	277
Aligned cameras	64	263
Point Cloud		
Points	186.600	1.319.584
Reprojection error (pix)	0,639	0,910
Alignment parameters		
Accuracy	High	High
Key point limit	50.000	100.000
Tie point limit	0	0
Dense Point Cloud		
Point	10.876.287	2.871.835
Reconstruction parameters		
Quality	Medium	Low
Model		
Faces	1.162.398	775.500
Reconstruction parameters		
Quality	Medium	Low

From this result, manually oriented and scaled according to direct survey data, the cloud cleaning phase was exported in *.e57* format inside the open source software *CloudCompare*. This program allows a more correct management of the cloud so that at the end of the work, carried out manually, it was possible to obtain the particular sections on which to carry out the subsequent works of graphic representation.

The vision and control of the point cloud model supported all the subsequent phases of the work given the complex geometry and the wide use of plaster decoration in the vault.

Fig. 4. Mesh model of the main atria of Palazzo Valperga Galleani di Barbaresco, processed by Agisoft Metashap

Fig. 5. Isolated mesh model of the main vault's atria of palazzo Valperga Galleani di Barbaresco, processed by Agisoft Metashape

V. GEOMETRIC INTERPRETATION (FN)

The main atrium of Palazzo Valperga Galleani di Barbaresco has an almost rectangular plan of 9.24 x 6.87 m. even if the digital survey registered some irregularities.

The impost plane is positioned at 5.37 m from the floor and the vault reaches a height of 7.11 m. in the key.

This space hosts the beginning of a monumental staircase placed on the main axis of the short side, which determines a strong tripartition in all other forms.

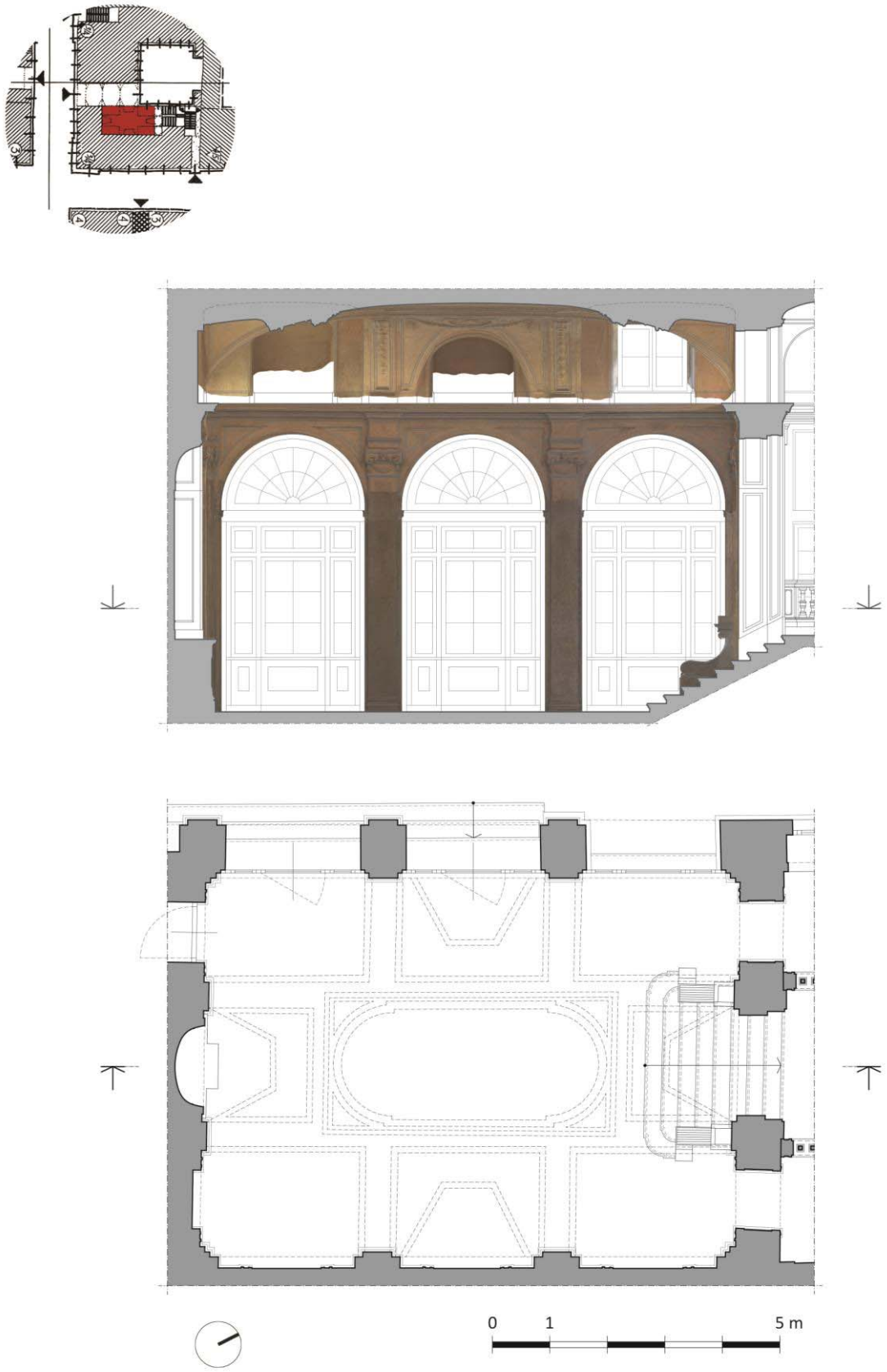

Fig. 6. Survey and graphic representation in plan and longitudinal section of the main atrium of Palazzo Valperga Galleani di Barbaresco (Drawings by Fabrizio Natta)

This division is in fact seen on all its sides: parametrically the tripartition is scanned by pilaster-strips and arched openings, they are the beginning of the bands of the vaulted system: the longitudinal bands are the principal elements of the geometric layout of the vault, where the transversal bands are interrupted.

The vault can be interpreted as a concave surface (intended as a double-curved surface with three directions – straight side and curved surface) on which vertical section planes define the tripartite scheme of arches, approximately 0.60-0.65 m. wide.

The same generative concave surface is also used to cover the axial fields of the vault, resulting almost completely flat in its central part. On the same axes, however, the lunettes are inserted on this principal surface which is cut by vertical surfaces that rise from a trapezoidal projection in plan. These lunettes can be interpreted by surfaces generated by sections that lay on the cuts of the principal surface.

The rectangular angular cuts are instead covered very low cloister-like vaults.

VI. CONCLUSION (MV, FN)

The work presented here is the first part of a research that intends to develop in the near future a deepening on the comparison between survey data and reference geometric matrices. The relationships between the survey model and the geometric interpretation model are in fact to be investigated at different levels: the first of them can be carried out punctually, comparing the main sections extracted from the digital survey with the sections that constitute the matrices of the interpretative model; the second, of more complex management, requires a comparison between the surfaces surveyed and the geometrically modeled surfaces.

Another aspect that constitutes a key element of the research is the comparison between the different case studies analyzed (as we anticipated in the introduction, in the central area of the city of Turin, more than 12 vaulted vaults were identified: for this atria a greater research group, with Roberta Spallone, Conception Lopez, Giulia Bertola and Francesca Ronco, is carrying out the operations of survey and graphic and geometric restitution), looking for recurrences in the compositional scheme, in the generating sections, in the geometric matrices.

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