Reconstruction of the wooden vault of the Synagogue of Reggio Emilia

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The contribution concerns with the reconstruction of the wooden vault of the Synagogue of Reggio Emilia, demolished in the 60s of last century, by using the 19th century carpentry techniques with which the monument had been built. The decision to rebuild the vault posed numerous challenges from the very beginning. The first step was to establish the shape and size of the demolished vault, an operation whose success has been enabled by the numerous confirmations obtained thanks to the study carried out by crossing the historical-documentary research with the analysis of data from the construction site. This first phase revealed an unusual geometry of the structure (a cloister vault terminating in a circular section without the insertion of pendentives) the fact that it was necessary to develop specific geometrical and static devices. Finally it describes the materials and construction techniques of the realization of the structure with the exclusive use of the 19th century carpentry techniques, carried out by the "Laboratory of restoration of Gazzotti Giovanni".

Keywords: *reconstruction, wooden structure.*

1. Introduction

Designed by the architect Pietro Marchelli, the synagogue of Reggio Emilia was erected by the local Jewish community in 1858. The edifice, which favoured the neoclassical style, was built in a quarter of Reggio Emilia that was as densely populated as any other ghetto. Inside, the building was divided into 4 parts: an atrium, a quadrangular hall with a giant composite order that separated it from a semielliptical presbytery housing the sanctuary. Decorated with pilasters in the ionic order, the hall originally ended in a false cloister vault with a circular lantern in the centre, through which light entered the building.

Inaugurated in 1858, the synagogue remained in use until the Second World War when the south-east corner of the vault was damaged during an air raid. After this, the synagogue was no longer used by the community but housed various different craftsman's activities until 1964 when, following a survey performed by the engineer Valli, a decision was made to demolish it down to about one metre and a half in height since it was considered to be unsafe. Emilia Romagna's regional board of the ministry of cultural heritage and environmental conservation, in the person of arch. Serchia, decided to restore the original volumes of the building by erecting a new wooden vault as part of the restoration work involving the entire synagogue, which began in the '90's. Following the proposal of "Laboratorio del Restauro di Gazzotti Giovanni", the enterprise that was assigned the works, this led to a decision to erect the new vault by using the 19th century carpentry techniques with which the monument had been built.

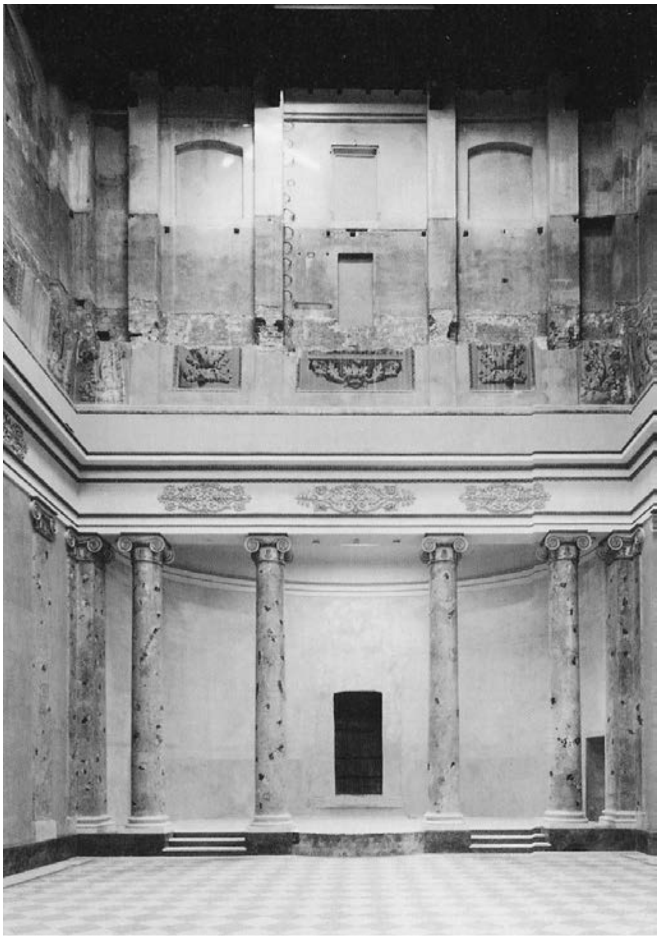

Fig.1. Internal view of Synagogue at the beginning of the work.

Fig. 2. Photograph of vault with the ring

Fig. 3. Photograph of the vault with the spring line

2. Historical-documentary reseach

In view of the complex nature of the work, it was especially important to acquire sufficient data to be able to organize the next stages. Thus, historical-documentary research was conducted with the specific aim of obtaining information about the appearance and shape of the vault. The documents kept by the Public Records Office of Reggio Emilia were interesting, although by no means conclusive when it came to the geometric definition of the vault. These documents comprised the original drawings produced by the studio of arch. Marchelli illustrating the various different versions of the project that the architect had proposed to the principal. However, the plans pertaining to the Marchelli estate only depict the solutions preceding the project that was actually used.

The more interesting written accounts include several comments by Balletti, the first historian to take an interest in the building, who described the origins of the project and the various solutions proposed by the architect. When writing about the definitive project, Balletti concluded that Marchelli finally intended to *"erect, over the hall, a large cross dome with a skylight at its summit. The work was built according to this drawing".*

Two photographs taken at the beginning of the 20th century certainly give a clearer idea of the structure (they are kept in the Panizzi photo archive of Reggio Emilia and depict the vault itself), as does a painting by A.Vitali, which also dates back to the beginning of the 20th century. The painting actually provides the only

Fig. 4. Photograph of the painting of A. Vitali

view of the entire hall and gives a glimpse of what was probably the spatial effect provided by the vault which, from a quadrangular spring line, concludes in a circular shape.

The fact of having recovered engineer Valli's report recommending that the vault be demolished was of extraordinary importance. Valli describes both the geometry *"…circular shaped central skylight about 4.4 m in diameter…"*, *"…the dome has a 6.5- 7 m rise, tangent to the vertical string and an almost circular section…"*, and construction technology *"…the ring…formed by planks nailed together" "…the thickness of the plaster vault… in the parts where it had been destroyed… was measured (14 cm)"*. When assessed with the construction site data, all this information proved to be substantially reliable, even though incorrect in certain cases.

3. Technological-metric assessment

As well as acquiring information from documentary sources, a technological-metric assessment of the building was also conducted. Although the fact that the vault had been demolished deprived us of almost all the elevation data, it did provide an extraordinary "true to life" section at an average 1.5 m height from the string line.

Covered by the recently rebuilt hipped roof, the remains of the vault featured an irregular (12.4 m and 12.7 m) trapezium shaped quadrangular string line the centre of which, calculated using the intradosal surface, failed to coincide with the centre of the hall over which it was erected.

This "true to life" section showed a wooden frame formed by 68 ribs obtained by joining 2 or 3 poplar planks together with metal nails, such planks being enclosed in a non-bearing masonry structure. The section also showed how the ribs were arranged in groups of 3 or 4 and that they were positioned so as to form the

mock pilasters, while there was only one rib in the recesses. Since they actually formed the pilasters, their directions were not parallel to each other but converged towards the apex.
Evidence of the extremely thick layers of gypsum plaster observed by Valli in the report he made prior to demolition of the vault (14 cm) was also confirmed by an examination of the structure.
Having reached this stage of the assessment, it appeared that the structure, alternatively defined by various authors as a dome, cloister vault or cross vault, featured a quadrangular spring line, was divided at the top by a circular ring, was without pendentives, had ribs that converged towards the centre and was covered with gypsum plaster. In order to proceed with the work, we now needed to acquire precise site measurements so as to define the parameters enabling the vault reconstruction work to be correctly engineered.
The survey showed how the curvature of the intradosal section, obtained by means of a plane passing through the apex and the centre lines of the two longer sides of the string line trapezium, was compatible with a semi-circular arch featuring a 6.33 m radius. This hypothesis was then assessed in relation to the positions of the trusses and was considered plausible since it allowed the spring line of the lantern to be positioned under the tie beams.
Firstly, all this allowed us to establish the height of the vault, a fundamental data item when it came to defining the structure. Although they were still to be confirmed, these data items allowed us to draw the curvatures of any section passing through the centre of the hypothetical vault using the projective method. This method was therefore used to design the first ribs and we found that the curvatures obtained in accordance with the geometric rule were absolutely compatible with the existing ones (with the exception of the diagonal ribs, which had probably been corrected to prevent them from penetrating too far into the outside walls). The fact that the existing structure complied with the geometric rules adopted confirmed that the hypotheses were correct.
We were thus able to construct a cloister vault using the data in our possession but in order to complete the structure, we still had to decide how to fit the circular opening into the apex. The method Marchelli used to cover the hall was certainly unusual and was that of a cloister vault terminating in a circular section, all without the insertion of pendentives.
In practice, the quadrangular string line of the structure had to turn into a circular section otherwise a circle fitted into a quadrangular shape would have created a sinusoidal profile where the two shapes joined.
A survey of the existing section, reaching up to 2.5 m in height on the west side, failed to show signs of a progressive change in section from quadrangular to circular (the position, nearer to the centre, of the corner ribs was not enough to confirm the hypothesis of a progressive curvature, but being localized merely on a level with them, showed that the corners had been corrected for static reasons, as mentioned above). Thus the layout was that of a normal cloister vault with horizontal quadrangular sections at each level. This meant that the point at which the quadrangular part met the circular shape had to be the result of a correction to the curvature that had only been made at the higher levels.
We then concentrated on finding a method for correcting the curvature of the ribs that was not arbitrary but that possessed a geometric consistency. We decided to use the semiellipses obtained with the projective method and to modify the last arc of circle by using the rule by which one single circle passes through 3 points. To do this, we progressed each time by choosing two fixed points belonging to the previous arc of circle without correction and considered the required point of arrival at the ring as the third point. This allowed us to modify the curvature of the vault in a proportional and imperceptible way.
The result produced by correction of only the last arc of circle seemed to be correct as it appeared to be compatible with the presence of the inspection walkway, but was especially confirmed by a close examination of the early 20th century photograph depicting the southwest corner. By observing the decorations shown in this photograph, we were able to perceive the level at which the arris of the vault still remained visible and to consequently assess the degree of correction at that point.
Lastly, we felt that correction to the terminal part of the ribs could lead to static problems, especially the ribs subjected to more extensive correction such as the diagonal ones for example, as it would create a curve that sloped to a lesser extent with consequently less than optimum compressive stress and shearing force.
We therefore decided to increase the section of the terminal part of the ribs so as to correct the axis and achieve more slope. This allowed us to obtain a better compressive stress-strain curve.

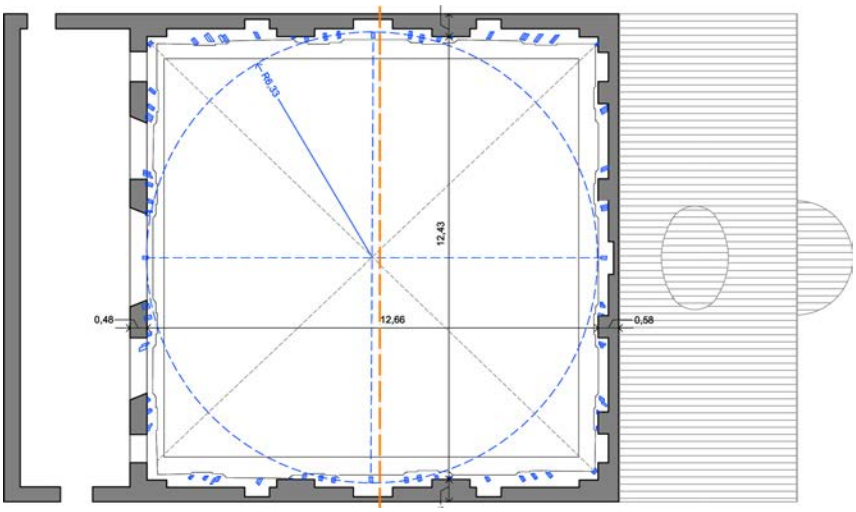

Fig. 5. Plan view showing the positions of the ribs.

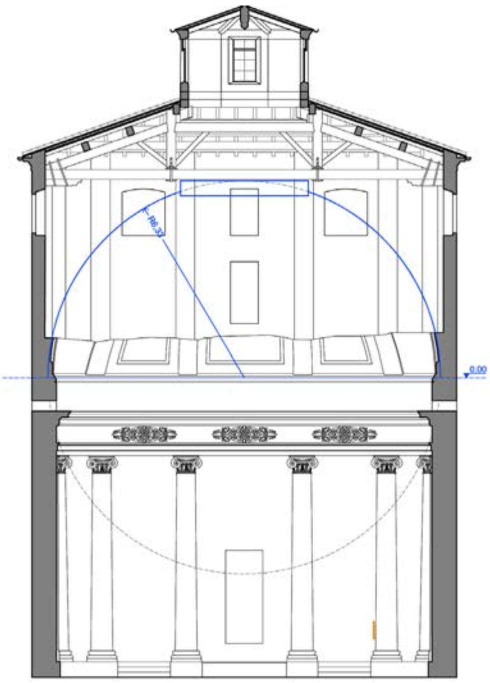

Fig. 7. Vertical section showing a curvature compatible with the intradosal curve

Fig. 6. The " true to life" section showing the wooden frame.

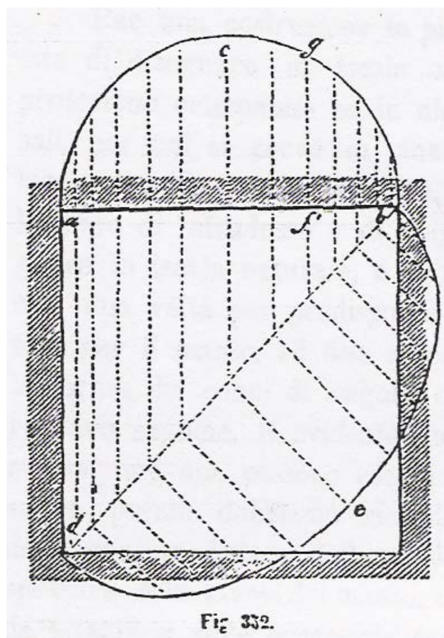

Fig. 8. The projective method.

(Breymann, G.A. (2003). "Archi, volte cupole". Editrice Librerie Dedalo. Roma).

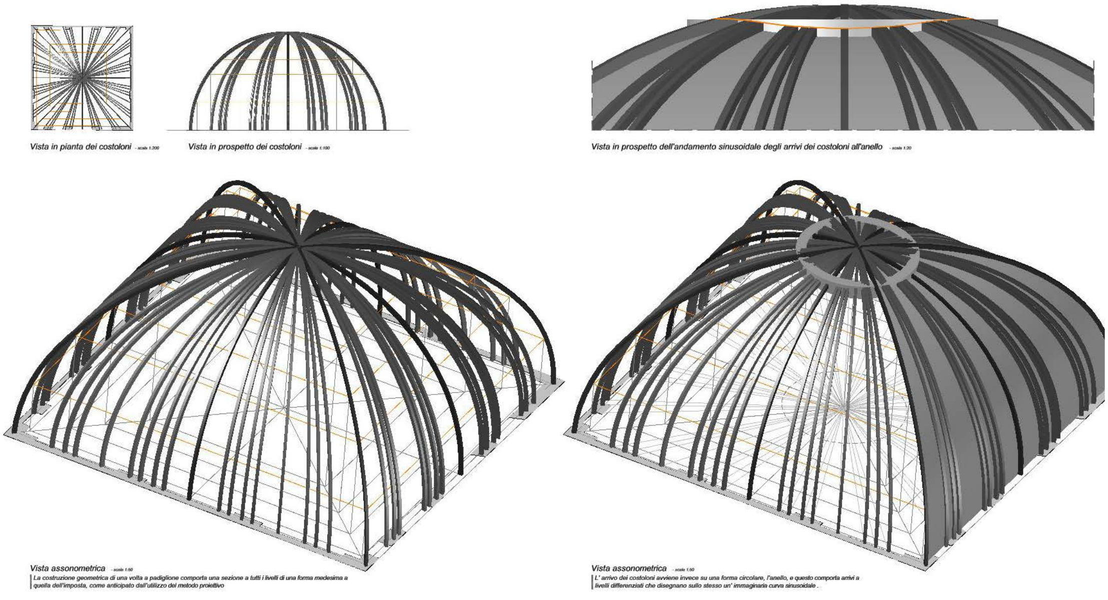

Fig. 9. The cloister vault with sinusoidal profile where the two shape joined

*Fig. 10.
The wooden frame.*

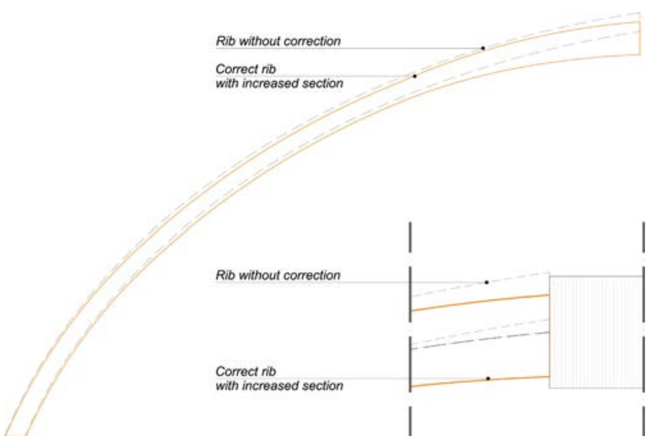

Fig. 11. Correction method of the curvature of the vault.

4. The materials

Choice of the materials was the first fundamental step:
Timber: The poplar wood chosen was already sawn into planks 110 to 135 cm wide at the base of the tree, 5-6-8 cm thick, with a good grain, already air-seasoned for 5 years and stored for a further 2 years in the construction site prior to use. The durmast oak of German origin had been seasoned in the same way.

Metal parts: Hand-crafted in the forges of "Laboratorio del Restauro", over 5,000 nails were used in lengths varying from 6 to 60 cm.

Gypsum: The gypsum was obtained from a special production method without the final grinding process.
Lime: "Laboratorio del Restauro" produced all the lime putty and milk of lime by calcining quarried calciferous limestone in wood-fired kilns followed by curing for 3 to 8 years in a trench.

5. The construction work

In view of the experimental nature of this intervention, a clear distinction between the planning phase and the executive phase was impossible, so it became natural for the designing work to be performed in the construction site with the aid of portable computers.
The work began by drafting each individual rib on the computer, after which it was immediately made and installed on site. All this was done by the same work team. The result of this method was that the two phases combined together to become almost indistinct, while it also facilitated the execution, correction and adjustment of each individual aspect of the construction.

5.1 The stringcourse

The initial idea whereby the remains of the old ribs were to be removed so that the new ones could be inserted in their place soon proved to be impracticable, especially as we did not wish to damage the existing decorations.
We therefore decided to create a new string line about 1.5 m from the original one on 3 sides and 2.5 m on the fourth side. The string line was made by forming a stringcourse in durmast oak that did not bear on the

Fig. 12. Poplar boule used for the construction of the vault.
Fig. 13. The handmade forged nails in the forges of "Laboratorio del restauro".
Fig. 14. Calcining of the limestone in the wood-fired kilns of "Laboratorio del restauro".

Fig. 15. The trench of "Laboratorio del restauro"

Fig. 16. The stringcourse.

Fig. 17. The stringcourse with wooden nail.

Fig. 18. The ring.

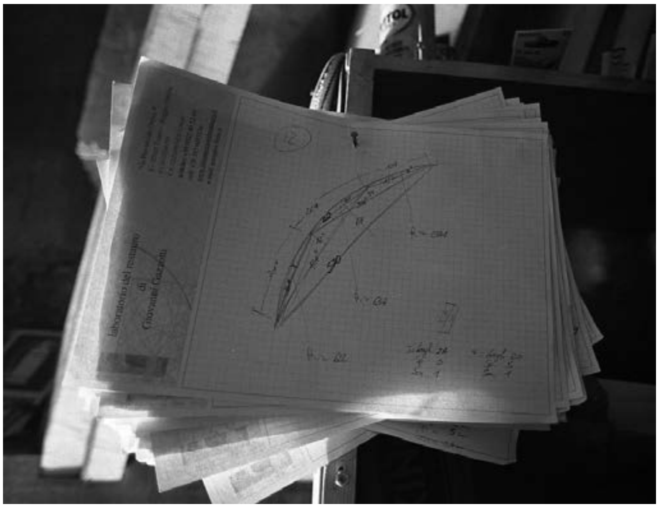

Fig. 19. The ring.

Fig. 20. Control measures of the ribs

Fig. 21. Positioning of the ribs.

structure underneath since it rested on brackets in the same type of wood. Shaped on site to follow the same curvature of the vault, the stringcourse was made by means of wooden joints with the addition of pegs, also made of durmast oak.

5.2 The ring

There were lots of indications as to the construction of the ring in engineer Valli's report, which gave the size (outer diameter 4.4 m) and explained how it was made of poplar planks nailed together. Having examined other buildings and historical texts, we defined a ring formed by 6 discs 8 cm thick with arc of circle shaped parts dovetailed together. Each disc was joined to the others with wooden pegs and everything was firmly fixed with clinched metal nails. The discs were only secured with hand-forged nails 60 cm in length after a long period of time (about 1 year), during which the ring was held in place by over 40 periodically adjusted clamps to help it to adapt to the microclimate.

5.3 The ribs

Once the profiles of the ribs had been established with the projective method (using a CAD process) and their radius of curvature had been calculated, the various different pieces were cut and assembled. Particular care was taken with every aspect of the construction: the widths of the pieces cut from the planks were similar to the original ones and varied from 20 to 27 cm, while the lengths were between 1.5 and 2 m. To ensure that each element contained as much long fibre as possible, the pieces were cut from the planks so than the main grain of the plank itself was tangent to the curvature of the actual piece. We were also careful to choose the parts of timber to suit their use on site. Thus we used the parts which, in the standing tree, mainly act in compression (internal fibres or those at the base of the tree) for the points in which the ribs would mainly act under stress; vice versa with the outermost fibres or those at the top of the tree, which mainly act in tension. The planks were secured with hand-forged nails, inserted in pairs in opposite directions every 50 cm or so and then clinched so as to hold the rib planks in place and fasten them as firmly as possible. Great care was also taken with the positions of the nails so as to prevent them from being inserted through the same fibre, while an appropriate

Fig. 22. The wooden frame

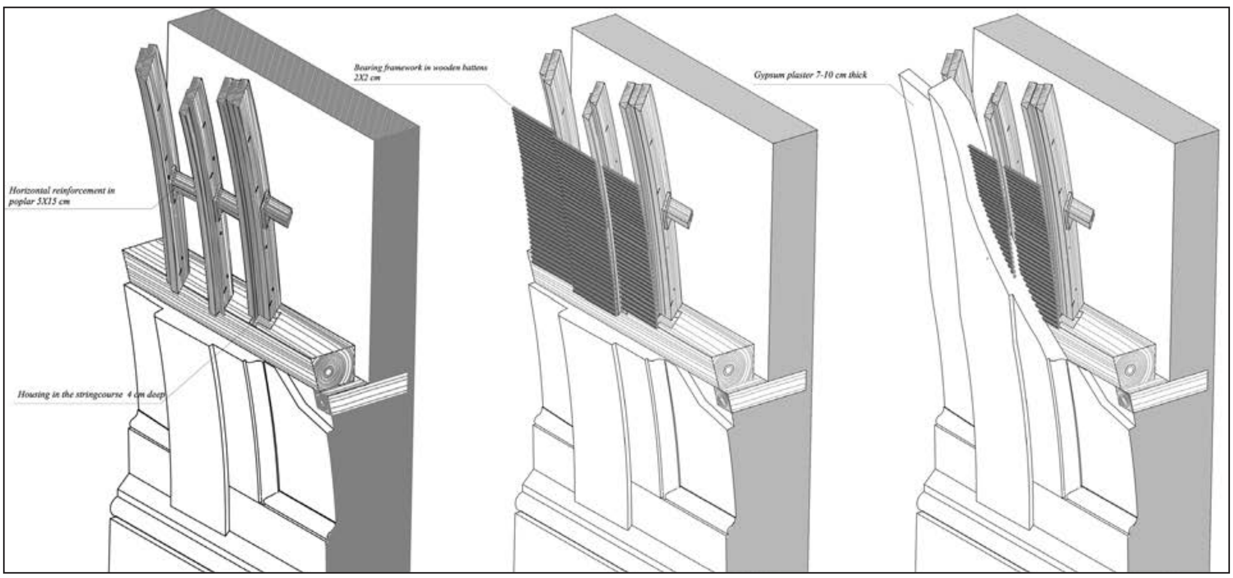

Fig. 23. Axonometrics of the sping line.

Fig. 24. Plastering the vault

distance (at least 8 cm) was maintained from the end of the piece.
After being assembled in this way, the ribs were then raised and arranged in their correct positions by means of alignment cords.
When the ribs were positioned, we had to ensure that after they had been installed, all 68 would be loaded to a fairly uniform extent. If certain of them were loaded only slightly or not at all, this could have given rise to dangerous overloads in other ribs, which would have subjected the ring to unwanted tensile strain.
To overcome this problem, we decided to fit the ribs into the ring with the utmost precision. This is why the operation was not performed on the ground, but with the rib already in its correct position. We created an assembly method which, by forming a housing in the stringcourse, allowed us to achieve a joint both between the rib and ring and between the rib and string line. This meant that the rib could only be inserted by forcing it into the housing in the string line, thus slightly pre-tensioning the element and allowing it to act as soon as the load was applied to the structure.

5.4 Plastering

Plastering the vault was certainly not an easy job. As mentioned by engineer Valli and subsequently confirmed by examining the remains on site, the vault was covered in very thick layers ranging from 6 to 14 cm and the plaster was made from gypsum alone, applied to a bearing framework made of wooden battens. The problem was how such thick layers of gypsum could be worked but more especially, we were worried about how the considerable load applied to the wooden framework would affect the static behaviour of the structure.
To achieve a more workable material, a special batch of gypsum was produced without the final grinding process so as to achieve a coarser grain containing whole crystals, i.e. gypsum that resembled the sort used in the past and that took longer to set. To lengthen the application time, we decided to opt for tannin after having consulted historical texts about the use of setting retarders.
The answer to our worries about the static behaviour of the structure was to assess its static action from the opposite viewpoint, i.e. instead of considering the vault to be a wooden framework plastered with gypsum, we now thought of it as being a gypsum vault “armoured with wood”. The intention was to create a gypsum structure that was at least partly self-supporting and no longer a structural load. To achieve this result, instead of applying the gypsum in several coats, we applied one single thick layer working on both the intrados and extrados at the same time. Each plastered

Fig. 25. Comparisons

portion was therefore like a single block that set as it incorporated the wooden bearing framework in the layer, and each other layer was like another block bearing at least partly on the structure underneath.
The mass of gypsum was finally finished with a coat of lime putty and sand applied with a trowel.

5.5 Painting

According to the indications provided by arch. Serchia, the ground colour of the structure was applied with lime wash and natural earth pigments while the plaster was still wet, without covering the decorations so as to allow the new restoration work to be clearly identified. Painting emphasized the structure of the vault through use of shadowing effects and underscored its various different levels with progressively darker shades.

5.6 Ventilation

Lastly, we made ventilation grilles in the lantern windows as the work proceeded. These, along with the frameless brick shutters in the windows of the outside walls, provided permanent and constant ventilation for the entire structure thanks to the "stack effect". The essential thermohygrometric conditions able to preserve the wooden structure were therefore guaranteed by this simple and economical solution.

6. Conclusions

Just two very brief notes about the reason for this intervention:
The motivation that led to reconstruction
In view of the symbolic significance of a dome containing both the square and circle (earth, heaven and the ascent to heaven), the decision to opt for formal completion of this edifice did not involve merely architectural implications but allowed the entire building to be completely redefined as to its meaningful aspects, and its cultural and religious core to be brought back to life.
The choice of techniques
The technique adopted for this building is age-old and was perhaps first used in Europe by Fra' Giovanni degli Eremitani. It has proved able to cover enormous spaces and to last for centuries, especially in some buildings, one of the most outstanding being Palazzo della Ragione in Padua. Was there any sense in searching for a better, more suitable or longer-lasting technique? What sort of contribution would the choice of a new technique have offered from the cultural viewpoint? We therefore felt that the most culturally fruitful solution would be to assess the material evidence and, by replicating the method, to reveal certain of the skills of this highly important technique, since, according to Confucio:

"... if I hear I forget, if I see I remember, if I do, I learn ..."

Fig. 26. Comparisons

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