The unusual dome of the Cappella Emiliana on the Island of San Michele in the Venice Lagoon

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Abstract The Emiliana chapel, built between 1528 and 1543, is hexagonal in shape and is surmounted by a hemispherical dome. The most distinctive feature of the construction is its complex roofing system. This consists of two hemispherical caps connected by a central pillar. The inner cap is made of brick masonry and the outer dome of blocks of Istrian stone, arranged in horizontal courses. The masonry central pillar is connected to the outer shell by iron tie-rods.

In the nineteenth century the behaviour of the original "tholos" structure was altered, with the consequence that the construction became more hyperstatic and more sensitive to any disturbance, such as small adjustments or differential movements, and this resulted in extensive displacement of the stone elements.

The recent restoration gave an opportunity to investigate the construction techniques of the dome and to introduce small adjustments to the structural behaviour of the roof system.

Key-words: Emiliana, Venice, San Michele, lagoon, dome.

1. INTRODUCTION

1.1 The setting

Situated halfway between Venice and Murano, the Island of San Michele is one of the best-known views of the Venice Lagoon. The forbidding profile of the cemetery walls and the whiteness of the Renaissance façade of the Church of San Michele and the Cappella Emiliana together create a uniquely striking and unmistakeable image of the landscape of the Venetian archipelago.

Fig. 1 - The Island of San Michele (p. C. Menichelli, 2009).

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1.2 Historical information

In 1528, the Procuratori di San Marco appointed the architect Guglielmo de' Grigi d'Alzano to build the chapel beside the Church of San Michele, which had recently been finished by Mauro Codussi. Work was completed in 1543. The event that led to the construction of the chapel, however, took place over a century before, in 1427, when Margherita Vitturi, the widow of Giovambattista Miani (or Emiliani, of which the commonly used name of the chapel is a corruption) decided to entrust a sum of money to the Procuratori di San Marco, so that it could be invested and ultimately used, after her death, to erect a votive building, dedicated to Our Lady of the Annunciation, in memory of her husband. She also stipulated that the endowment should cover maintenance costs.
It was Margherita Vitturi's wish that the chapel be built at San Francesco della Vigna or, if this proved impossible, on the Island of San Michele. The building had to be outside the church but communicating with it, and it had always to be accessible to worshippers from outside. The chapel was to have three altars, the main one being dedicated to Our Lady of the Annunciation and the other two to the Nativity and to the Adoration of the Magi. The prescriptions were very detailed and were scrupulously complied with when the chapel came to be built.
After the death Margherita Vitturi there passed a long period while the bequest accrued enough for the actual building work to be put in hand. Negotiations for the purchase of a plot of land at San Francesco della Vigna were begun in 1508 but for various reasons these were abandoned and the decision was taken to build the chapel on the Island of San Michele. The Procuratori di San Marco entrusted the project to Guglielmo de' Grigi, also known as Gulielmo Bergamasco after his city of origin. He had gained early experience working on the Procuratie Vecchie in St. Mark's Square and on the Fondaco dei Tedeschi. The Procuratori di Citra gave him the opportunity to prove his skills and versatility as both sculptor and architect in the altar dedicated to Verde della Scala, in the Church of the Servi, and this set him on the road to a brilliant career and numerous commissions. His other works included the Portello city gate in Padua and the San Tomaso gate in Treviso, Palazzo dei Camerlenghi in Venice, Palazzo Tasca in Portogruaro and several important works of sculpture in Venice. In 1527 Guglielmo de' Grigi presented a model for the chapel and work began in the following year. In 1529 Giovambattista da Carona was commissioned to produce the sculptural groups: three altarpieces for the interior, with depictions of the Annunciation, surmounted by a bust of God the Father, the Nativity and the Adoration of the Magi, and the statues of St. John the Baptist and St. Margaret, in memory of Giovanni Battista Emiliani and Margherita Vitturi. The six elliptical windows were made in 1533, with stained glass by Giovambattista, the Prior of the Ospedale dei Battuti on Murano. In 1539 Giovanni Antonio da Carona was commissioned to construct the altars, and Guglielmo de' Grigi himself completed the decoration of the chapel with the beautiful inlaid marble floor in 1540. Work finally came to an end in 1543.

2. THE ARCHITECTURE

2.1 Description of the building

The chapel takes the form of a small, hexagonal temple surmounted by a hemispherical dome; it is made entirely of white stone. The diameter from the outer wall surface is about 10 metres and the overall height, including the pinnacle, is 17.50 metres. The masonry of the above-ground structure is in solid brick, sandwiched between Istrian stone, inside and out. In actual fact, however, the considerable thickness of the stone facing and the presence of accentuated internal and external elements including pilasters, columns and arches, make it possible to describe the walls of the chapel as a mixed system of stone and brickwork rather than as a masonry core faced with stone slabs. An integral part of the chapel is the pentagonal vestibule that links the chapel to the church.

Fig. 2 - The Church of San Michele and, on the left, the Cappella Emiliana (p. C. Menichelli, 2011).

2.2 The dome

The chapel's very unusual roofing system consists of a double cap linked by a central pillar. The inner cap is a masonry hemispherical dome, while the outer hemisphere is a "false dome" made of blocks of Istrian stone, laid in horizontal rings and surmounted by a pinnacle. The brick masonry central pillar has a hexagonal section and tapers slightly towards the top; there is a set of horizontal tie-rods linking it to the upper cap at the height of the haunches. The system as described so far is practically the original sixteenth century arrangement; in the first half of the nineteenth century this was supplemented with six masonry ribs designed to support the Istrian stone outer cap, and with a second set of horizontal tie-rods anchored to the ribs. An interesting aspect of this roofing system is its similarity as regards structure and shape to a number of Etruscan *tholos* or beehive tombs such as those in Casale Marittimo and Casaglia. This surprising analogy, and the choice of the *tholos* model, the significance of which certainly connotes funereal constructions, suggests that Guglielmo Bergamasco might actually have seen some Etruscan burial grounds, though this remains an improbable hypothesis.

Fig. 3 - The inside of the dome between the two caps (p. S. Petrelli, I. Sartori, 1996).

2.3 Materials and finishes

The Cappella Emiliana contains an extraordinarily rich variety of fine decorative materials and finishes. The chapel itself and the vestibule are practically lined entirely with stone; not only Istrian limestone, which is the main material and establishes the overall image of the building, but as many as forty-one different lithotypes, which decorate the surface, especially inside, with complex geometrical inlaid work.

Fig. 4 - The interior of the Cappella Emiliana (p. C. Menichelli 2006).

3. THE CONSERVATION PROBLEMS

3.1 Recurrent forms of decay and instability in the history of the chapel

The fact that the construction and maintenance of the Cappella Emiliana took place under the control of the Procuratori di San Marco and that therefore every expense was carefully recorded means that we have an extraordinary wealth of data about its physical history. Study of this information provided invaluable information for analysis of the problems of decay and instability that prompted the recent restoration. The documents concerning the maintenance of the Cappella Emiliani give a clear account of the recurrent conservation problems that have affected it from the very beginning. The most important of these were rainwater leaking through the domes, movement in the foundations and the decay of the internal and external stone facing materials.

Throughout its history, the external cap of the chapel dome has always had a poor record as a waterproof cover. Just twenty years after the building was completed the joints in the dome began to need regular refilling; witnesses to the phenomenon include Sansovino, whom the Procuratori appointed to supervise the maintenance of the building. In response to this lack of efficiency as a rainproof protection, it was decided to insert a sloping tiled roof system radiating from the pillar between the two caps, to intercept any rainwater leaks and carry the water away before it could damage the internal calotta.

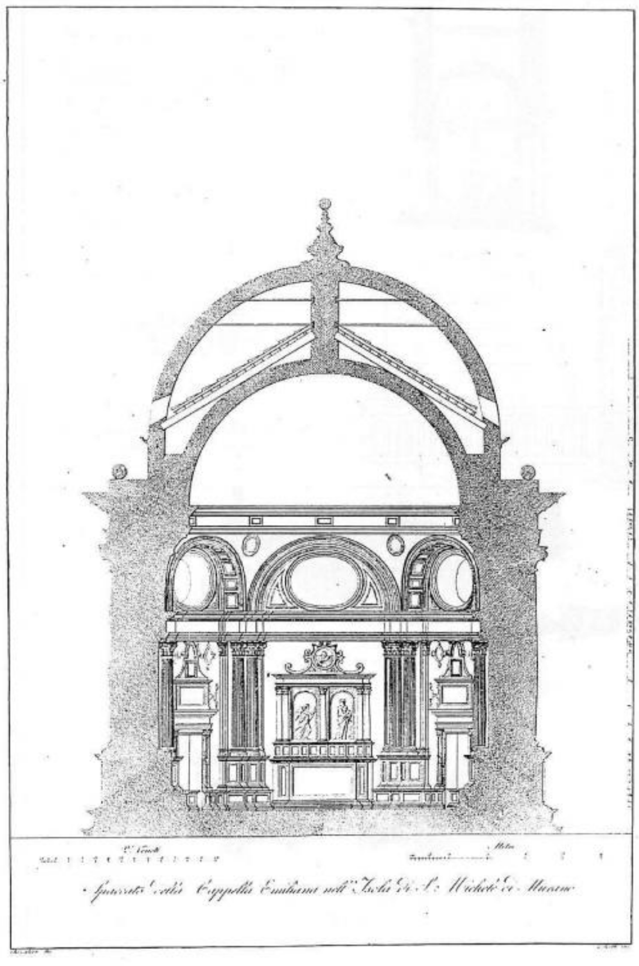

Fig. 5 - The Cappella Emiliana main section. Drawing from: Cicognara L., Diedo A., Selva A., *Le fabbriche e i monumenti più cospicui di Venezia* (1834-40).

As regards the foundations, consolidation first became necessary in the 1700s, as reported by Zendrini, Tirali and Temanza; structural work connected with deterioration of the foundations was carried out in 1827 and in 1867 huge blocks of stone were put in place to strengthen the corner of the island. Between 1969 and 1972 the Superintendency took radical action by underpinning the foundations with a ring of micropiles, and finally, between 1993 and 1995, the Magistrato alle Acque of Venice extended the consolidation of the foundations with pilework to strengthen the lagoon edge and the forecourt of the church and around the chapel.
In 1909, measures to combat deterioration of stone facing took the form of extensive replacement of marble.
Other important events reported in the archives include a violent hurricane that caused serious damage to the dome of the chapel and the roof of the church in 1819, and the major restoration work undertaken by the Municipality immediately after it became the owner of the island in 1826.
On that occasion, the many structural operations affecting the building included a total overhaul of the roofing system, with all the stonework of the upper part of the outer dome being replaced, the central pillar joining the two caps being rebuilt and above all the already mentioned introduction of six masonry ribs to support the outer dome.
An analysis of the various restoration operations carried out on the chapel during its history, with special reference to the question of rainwater infiltration through the dome, shows that the regular maintenance work ordered by the Procuratori di San Marco during the building's early years offered a more effective guarantee of adequate conservation of a delicate construction like the Cappella Emiliana, in a particularly aggressive environment like that of the lagoon, than the isolated and radical restorations carried out since the beginning of the XIX century. The historical documents also show that slackening of the maintenance regime of the chapel in more recent times was certainly crucial to the dilapidated condition into which the building had fallen.

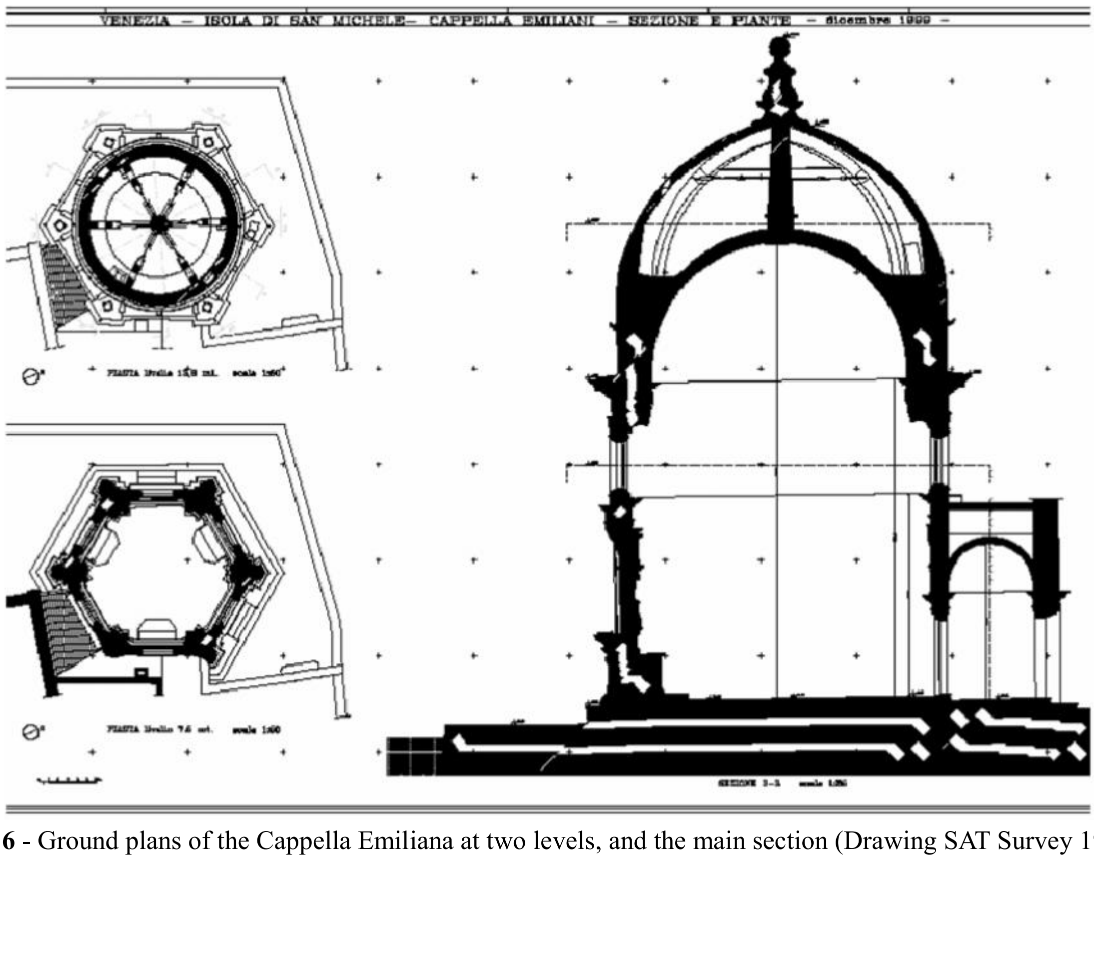

Fig. 6 - Ground plans of the Cappella Emiliana at two levels, and the main section (Drawing SAT Survey 1999).

4. THE STRUCTURAL BEHAVIOUR OF THE DOME

4.1 The hemispherical *tholos*

Perhaps also with the intention of guaranteeing a rainproof cover for the chapel, the constructional technique chosen for the outer dome involved building it of overlapping horizontal rings of Istrian stone blocks; this should, at least theoretically, have reduced the passage of rainwater between the joints. The technique was commonly adopted for tomb constructions with roofing systems in the shape of a cone or a pointed arch with a minimal curvature; it is extremely unusual in hemispherical domes.

The equilibrium of a dome develops in three-dimensional space. The arch-type behaviour of blocks laid at right angles to the stress exerted, along the meridian, is supplemented by the collaborative action of the blocks in the parallel plane, their tendency to slip towards the interior being opposed by the same tendency of all the other blocks of the same parallel. The construction technique used for the chapel dome, with joints conditioned by its horizontal ring-based structure, involves a substantially different behaviour. In the virtual absence of horizontal friction, the equilibrium of the structure can only be ensured in the horizontal plane. Each individual block (no. 13 illustrated in figure 5 is the one under the greatest stress) is subject to the force exerted by the weight of the elements above it (considered infinitely rigid) applied in the geometric centre of mass of the block immediately above.

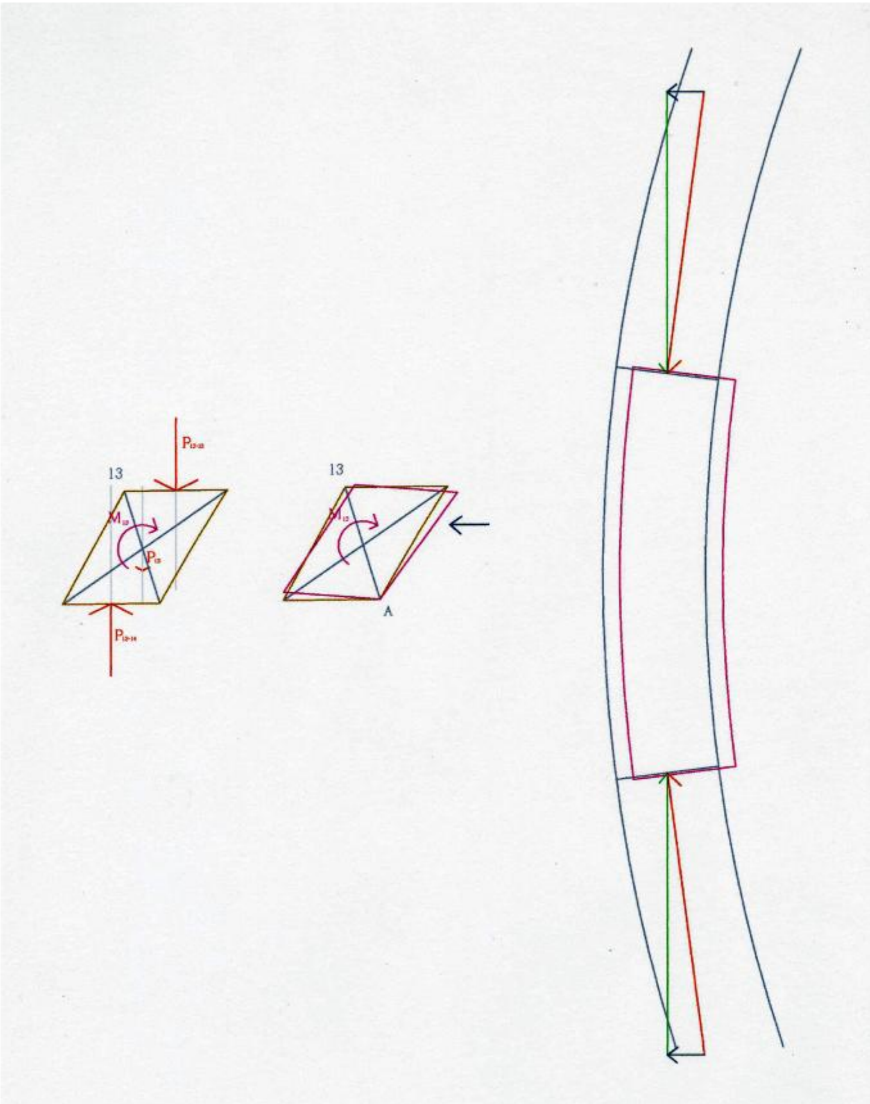

Fig. 7 - Block no. 13 (Drawing A. Lionello).

This is opposed by an equal force, increased by the weight of the element itself, applied in its geometric centre of mass. Equilibrium is guaranteed with respect to the vertical forces but the different point of application of the forces generates a moment that encourages the block to rotate around point A. The rotational force is opposed by the equal phenomenon generated in the neighbouring blocks and which, in the case of symmetrical loads, prevents the deformation of the circular crown. Opposing forces develop if the vertical joints are able to transmit forces of a magnitude which is greater than that required to prevent the rotation. It is therefore necessary for the side faces of the blocks to be coplanar and close-fitting if they are to transmit the important stresses. Any further deformation or symmetrical stress will stabilize the structure. Perhaps also in order to support the heavy stone pinnacle weighing 3.2 tonnes a central pillar resting on the inner cap was inserted during the original construction work.

4.2 Alterations in structural behaviour over time

Low expectations and lack of confidence in the unusual and uncommon technique adopted for the outer dome of the Cappella Emiliana led – maybe as early as the original construction (this too could be the reason for the central pillar connecting the two caps) but certainly in the later restorations, especially the radical work done in 1826 – to the addition of structural elements that have substantially modified the original behaviour of the *tholos* structure. For example, metal cramps were inserted to hold the blocks together and over time these have rusted and swelled, causing the stones to move and the dome to become unstable; ribs were inserted and constitute a structure in addition to the *tholos*.

Fig. 8 – The dome before restoration. At the top, the movement of the blocks caused by the rusting of metal cramps (p. C. Menichelli 1999).

They are toothed into the upper part of the central pillar and their prime purpose was probably to stabilize the pillar itself, under the strain of the considerable vertical load of the pinnacle. The structural test with load-bearing ribs and with the segments of the dome considered as webs supported

by the ribs gives positive results. The sonic tests carried out on the two sets of metal tie-rods inserted into the upper part of the dome gave insignificant results and therefore confirmed that, given their position, the tie-rods only perform the function of stabilizers.
Although on the one hand the structural disorder created by the measures described above made the construction more hyperstatic and therefore stronger, on the other it brought with it the serious disadvantage that any perturbation, such as small incidences of sagging or differential movement, had repercussions on local stability because in the configuration assumed by the dome after the nineteenth century restorations nothing acted independently any longer and everything was interconnected and superimposed. All this in time led to movements of the stone elements and they in turn prompted a number of restorations.

5. THE RESTORATION OF THE DOME

5.1 The aims of the operation

The restoration of the Cappella Emiliana, financed by the The Venice in Peril Fund of London in the framework of the UNESCO-International Private Committees Programme for the Safeguarding of Venice and conducted by the Venetian Superintendency between 2000 and 2006, provided an opportunity to study the building techniques and characteristics of the dome and to introduce a number of measures to correct the structural behaviour of the vaulting system, involving imperceptible but substantial adjustments at the interface between the ribs and the outer cap. The aim of the operation, occasioned by the need to stop rainwater leakages and to repair the structural slippages that had occurred over time, was to restore overall efficiency to the system, returning the outer cap to its orginal *tholos*-type structural behaviour but without removing the nineteenth century additions that in any case constitute a fundamental aspect of the history of the building. The objective of the project design was therefore to eliminate or significantly reduce interaction between the outer cap and the ribbing system and to recover some of the potential for general consolidation of the system that the ribs previously possessed.

5.2 Rehabilitation and “reorganization” of the static behaviour of the dome

The prime cause of rainwater leakages was the rusting and consequent swelling of the iron cramps holding the stone blocks together; as a result, the blocks tended to lift and open the horizontal joints between the courses, a worrying phenomenon that would have worsened considerably over time if neglected. The top seven rings of the dome were therefore dismantled, the iron cramps were replaced with elements of identical shape but made of stainless steel (AISI 316) and the blocks were relaid in their original positions.
Work to rebuild the cap also involved remaking the vertical mortar joints in such a way as to guarantee close adhesion between the blocks, the continuity of the rings and the establishment of the tensions needed to stop the stone blocks rotating towards the interior. To ensure greater clarity in the structural roles of the elements constituting the dome it was decided to improve the interaction between some parts and the independence of others by calibrating the mechanical characteristics of the mortars used. Mortars with greater elastic modules and resistance were employed for the horizontal and vertical joints between the stone blocks while binders with lower mechanical properties were used to remake the joints between the cap and the brick ribs. The tie-rod systems were tested; the lower set was found to be no longer efficient and was replaced with identical elements in AISI 316 stainless steel; the upper set was restored and reinstalled.

Fig. 9 – The tie-rods after renovation/replacement (p. C. Menichelli 2004).

A stainless steel hoop was inserted around the base of the cap in order to oppose the traction forces generated in those parts of the dome that lie at angles greater than 50°.
For reasons of conservation, prompted by the general wish to maintain the historical layering testifying to all the phases in the life of the building but also by the desire not to reduce the resistant components in play, it was decided to maintain the consolidation measures that had accumulated over time and which had resulted in the structural confusion described above. It was however considered necessary to restore order to the roofing system, separating the independent structural elements and enabling them to act autonomously, and creating hierarchies in the structural role of the resistant elements. Priority was given to recreating the original *tholos*-type behaviour of the dome by ensuring maximum connection and collaboration between its constituent blocks. When elements were being repositioned careful attention was paid to every aspect of the geometry of the dome. In particular, blocks were replaced not only with reference to the usual precautions of numbering and marking all items before removal but exact radial repositioning of the rings was guaranteed by reference to a highly accurate three-dimensional survey carried out with a combination of topographic, photogrammetric, direct and laser-scanning techniques.

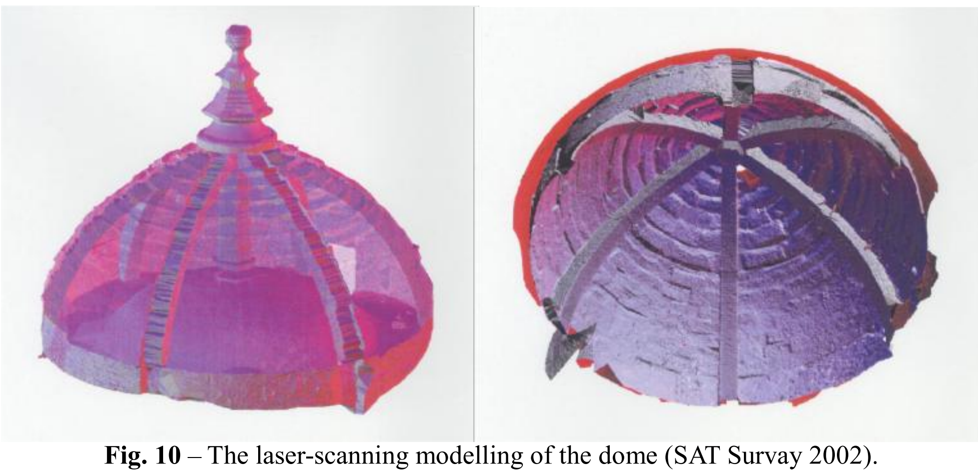

Fig. 10 – The laser-scanning modelling of the dome (SAT Survay 2002).

Special attention was paid to the interface between the outer cap and the ribs. In previous operations these spaces had been filled with chips of brick and mortar. Any stress or deformation was absorbed in part by the *tholos* structure and partly by the structure of webs and ribs, depending on their relative rigidity. The two structures did not have compatible deformations, however, and when the structural component of the ribs came into play it introduced deformations in the circular rings of the *tholos*, and jeopardized their stability. It was therefore decided that the consolidation project should establish a hierarchy for the order in which the structures came into play; first the dome must function as a *tholos*, as in the original conception, and only later, if this proved structurally inadequate should the ribs come into play and the segments of the cap function as webs. This principle was put into practice by filling the joints between the dome and the ribs, just to the edge, with relatively elastic mortar; this enables the stresses between the two structures to be transmitted only in the presence of serious deformations caused by the loss of efficiency of the *tholos*.

Fig. 11 – The dome completely separated from the ribs before the gap was filled with low elastic module mortar (p. C. Menichelli 2004).

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