UNIMED CULTURAL HERITAGE 2 PROJECT AND
HAGHIA SOPHIA IN ISTANBUL
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Abstract – The research and experimental activities started in July 2003 on the dome and structure of Haghia Sophia in Istanbul seem to be noteworthy both for their considerable acquisitions on the scientific ground as well as for the context set up in the frame of the Unimed Cultural Heritage 2 Project (Euromed Heritage II Programme - European Union funded) that actually made our campaign possible. When in all fields, efforts connected with Best Practices selection earn increasing attention, we reckon the “Haghia Sophia” case could then represent a significant up-to-date approach concerning protection and conservation of Cultural Assets.

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THE SCIENTIFIC AND OPERATIONAL CONTEXT

Byzantine architecture masterpiece, Haghia Sophia is universally renowned primarily for its enormous dome (about 30 m. in diameter) over the central space: as often happens, however, the most formidable element, the dome, has been representing since the first moment its fragile “Achilles’ tendon”. This is borne out by the many collapses and deformations that have affected the structure in the course of its long history.

After almost fifteen centuries the situation is still very much the same. In fact, the same problems affecting the building’s stability, especially the dome, but even the so-to-speak previous ones, still exist today. This depends on the fact that there is no complete and reliable survey of the structure, much less a systematic study to establish the shape and consistency of the building materials and technology used to develop them.

This situation, though, it’s due neither to want of appropriate technologies, nor to an inadequate sensitivity of Haghia Sophia Museum’s management board, nor finally to an
approximate qualification of Turkish experts. The cause is rather related to a communication failure among a variety of actors, able in equally cooperating at a super national level so to set up a kind of joint venture in the Cultural Assets sector.

The event we have been talking about actually consists in having created a common working space where all different issues have found their effective synthesis. In our experience this utopia has been the Unimed Cultural Heritage 2 Project (January 2002 – June 2005, project website: www.unimed-culturalheritage.org), led by UNIMED (Mediterranean Universities Union), while “La Sapienza” RADAAR Department was responsible for the scientific work.

It is important to briefly outline the nature and scope of the UCH2 Project:

- to unite the scientists and professionals operating in the field of the conservation and exploitation of the Cultural Heritage currently scattered haphazardly in the Euro-Mediterranean area by promoting interaction and integration between these practitioners in order to come up with concrete solutions to specific problems;
- to guarantee an up-to-date, high-level scientific profile to all the characteristic stages of management and exploitation of Cultural Assets by providing technical and operative support;
- to collect, filter and select examples of particularly important work in this field and to make this information electronically available by creating a dedicated website;
- to draft procedures and protocols for long distance communications, the transmission of relevant amounts of data and to structure interactive software allowing database consultation;
- to experiment new approaches, in accordance with established strategic technical and scientific goals, aimed at understanding, documenting, restoring, managing and exploiting these Cultural Assets;
- to promote educational activities to train experts who in turn would be able to train others in their native countries.

The UCH2 Project actually represents the general frame for the whole operation. Nevertheless it was not the only effective component: neither from a financial point of view nor from technical and scientific ones. To reach our goal, a far greater effort has been needed, involving external resources and equipment. Just to give an idea: Turkish Ministry of Culture and Tourism has closely followed all steps, actually making routine even the most complicated matters; Hagia Sophia Museum’s Management Board assured full accessibility to the site (sometimes even demoting tourist attendance) also supplying support staff beyond normal working time; Boğaziçi University has dealt with the majority of logistics in Istanbul (accommodation for all foreign staff at university guesthouse, transports, carriages, bilingual assistants, etc.), providing as well precious scientific support and assuring a widespread dissemination of survey activity among Turkish media and scientific community; UNIMED staff has attended to “Italian side” logistics (equipment shipment,
insurances, custom clearances, travels, etc.) super visioning successfully all collateral activities on the spot; RADAAR Department has provided all survey equipment (3D laser scanner, total station, etc.) as well as specialised experts for data acquisition and elaboration. UCH2 Project actually covered only a fraction of task costs (even if conspicuous): the balance was reached thanks to different funds (research, study, maintenance, etc.) belonging to all organisations involved (more information on this matter can be found on RADAAR Department Review *Disegnare, Idee, Immagini* n° 26).

**THE FIRST RESULTS**

**Structure survey and modelling**

In this framework we planned our overall activities during the short, four day period we were given. First we had to deal with a scaffolding covering more than a quarter of the site: also for this reason we immediately decided to work concurrently on the 3D scanning and on the topographic campaign necessary to determine the absolute positioning of the general model as well as of each single scan (this was to reduce, as far as possible, the risk of incongruence between the various sets of data).

For the topographic work, we used a Zeiss Rec-Elta 15 total station equipped with a laser distancemeter for measurements without a reflecting prism. Thanks to this instrument about 130 points were surveyed referring to an open polygonal line (the scaffolding effectively stopped closure), where the vertexes acted as poles. The polar coordinates of each of these detail points were transferred from the field notes to an electronic sheet and later automatically processed producing a three-dimensional CAD representation.

While the topographic and photographic campaign was underway, we also executed the 3D scan of the inner central nave and the intrados of the dome of Haghia Sophia using a Cyrax 2500 laser scanner. This instrument’s precision (6 mm. at 50 m.) and its versatility (40°x40° field angle, flexibility from 100 to 1.5 m. from the object) allowed us to carry out millimetric scans on parts of the dome’s intrados situated either at a great distance or very close to the scanner.

The alignment of the 17 models obtained from the different scanner positions (*scanworlds*) produced the overall point cloud characterised by a density of 1 point every 4 cm. In this grid, another 423 detail scans (50x50 cm. in size - density 250x250 points) surveyed the elements that, sighted simultaneously with the total station, were then used as tie points for the alignment of each shot. The whole numeric model contains 52 million points, referenced to a single absolute system which we chose to coincide with the first topographic station orientation (Fig. 3).

Once the overall model was developed, we analysed it in 2D and 3D. We then examined the model of the two piers and the West arch, separating these three elements from the rest of the structure. By carrying out a percentage reduction of the point cloud it was possible to obtain two circle arcs from the average of 10 circles drawn by selecting two points at the springing points and one at the crown. These two circle arcs give a better description of
the profile of the arch. Later on, the best fitting geometry of the main East arch and of the entire structural section (arch + piers) was reconstructed.

Over the centuries, it is the dome that has been modified and rebuilt the most. It is well known that the original, designed by Anthemius of Tralles probably with a very shallow profile, collapsed in 558. After this catastrophic event it was rebuilt by Isidorus of Mileto with a much more pointed shape and that is the one still standing today. Its history, and the numerous reconstructions that became necessary due to the many partial collapses (989 and 1346) that have taken place over time, have produced a very complex structure. To check its present geometry, we tested its 3D model by using 62 horizontal sections with a 25 cm. pitch (fig. 4). Only 45 of these were chosen as being representative of the clearest deformations and used as directrixes to study the deformations together with other radial sections located between the ribs and the vaults. This made it possible to study some critical points in the cap: the obvious disjuncture along the North-East axis of the square upon which the dome rests; the visible deformations at a height ranging between 53.5 and 49 m. above ground level. Other types of deformations can be seen at the springing points of the dome in an East and South-East direction.

While scanning a surface, the 3D laser scanner also reveals point by point the material’s response value in terms of reflectance to the laser beam. Thanks to these additional data, together with the gaps in the North part of the model of the intrados (highlighting a phenomenon called destructive diffraction – fig. 4 right, up) we could identify some areas corresponding to those areas collapsed in the 6th century.

**Structural deformations**

Undoubtedly, Byzantine building techniques played an important role in the deformations that affect the main structures of Haghia Sophia, including a number of problems to the load-bearing elements. All this partly explains the reasons for the substantial adjustments that took place, especially in the dome’s four supporting piers, both during their construction and afterwards, also due to the thrust of the dome.
Even if the piers were built with large stone blocks up to the women’s galleries, their deformation is still very visible: the two East and West transverse arches have caused an outwards deformation of the piers which, at the springing points, is now approximately 60 cm. It’s difficult to determine when the structural deformations in Haghia Sophia occurred because the structure was repaired and rebuilt many times (one of the most important restorations was carried out in 1837 by two Swiss engineers Gaspare and Giuseppe Fossati who worked on the dome and columns of the women’s galleries which were repositioned in order to re-establish their original verticality).

Even the shape of the dome at the springing plane underwent changes due to the reconstruction work, the deformations caused by the building techniques and the behaviour of the structures themselves. In fact, today the plan is closer to an oval than a circumference.

It is crucial to collect information about all these deformations in order to understand what caused them, assess the condition of the monument and be able to implement earthquake protection measures. Il profilo degli arconi ad oriente ed occidente, si presenta dunque come un semicerchio avente un diametro rispettivamente di 32.99 e 32.51 metri con il centro giacente, con buona approssimazione, in corrispondenza del piano di calpestio delle balconate all’imposta, come dimostra poi la concordanza tra il modello numerico del rilievo e la sua ricostruzione geometrica “ideale”.

The analysis of the 3D model highlights how the centre of the hemispherical structure is located lower than the springing plane. The theoretical sphere that is created by using a series of 112 points chosen from those on the areas between two ribs shows the theoretical diameter to be 33.40 m., while the centre point is 1.97 m lower than the springing plane (fig. 5). This value is higher than the one reported by other authors. The same data confirmed that the diameter of the dome at the springing plane was approximately 31.50 m. in an EW direction and 32.40 m. in a NS direction. This confirms that the four piers from which the pendentives start are wider at the top than at the base. The base square (about 31 m. its side) changed during construction because of the weight of the structure. This deformation has an overall measurement of approximately 0.50 m. in an EW direction and 1.40 m. in a NS direction. In particular, the theoretical circumference of the springing plane of the dome has deviated considerably compared to the real curve, above all in the NS direction, perpendicular to the main axis. Very probably this is caused by the greater structural rigidity caused by the two half domes that laterally support the main EW arches and the reduced thrust of the main
arches that close the NS wall. Consequently, due to the differentiated damping of the walls and the thrust of the dome during construction, the theoretical planimetric layout of the dome which would originally have been a circumference became ovoid, with its main axis in a NS direction. The deformations of some of the ribs of the dome are particularly important and are also caused by the reconstruction works: this evidence has been revealed by superimposing the horizontal sections of the intrados on the corresponding sections of the theoretical sphere to better highlight actual deviations. Chief deformations (at some points up to 80-100 cm.) are concentrated in two directions that are at approximately 45° compared to the main EW axis. This is clear proof of the reconstruction of about a quarter of the dome that took place after 1346 earthquake (Fig. 6, 7).

The survey of the two free-standing arches to the East and West has revealed a detail as yet unknown: the intrados of the arch is not an exact circular semicylinder, but a semicircular cone (fig. 8). In fact, the directrixes of the surface of the intrados has two semicircles with different radii: the bigger semicircle has a 16.81 m. radius towards the great Dome, while the smaller one has a 16.50 m radius towards the exterior (in other words towards the apse for the main East arch and towards the entrance narthex for the West main arch).

The designers were well aware they had to join two areas of different heights and soften the impact, so they probably made this correction by using a perceptive stratagem. The same solution is adopted for the North wall too; this element, in accordance with the corresponding parts of the dome, is however affected by a considerable outwards thrust. Hence, the vertical section shows a progressive upwards vertical deformation. It seems to be less in the part between the ground floor and the roof cornice of the women’s galleries (0.66 m.), while, the deviation between the plumb-line of the springing plane of the dome and the ground is approximately one meter.

What we have described must be considered as part of a more complete analysis still to come. However this first step gave as a result to outline a new perspective for Hagia Sophia: raising a new international interest for its risk condition; starting a stable cooperation among all Organization involved in this first phase (a memorandum of understanding between the Italian and Turkish institutions it’s already operative. It represents the first official act acknowledging the work done so far as well as an important step in the drafting of a final protocol for further work); showing, finally, a multilateral cooperation model. This last
feature seems even more important because of the scarce attention presently reserved to Cultural Heritage conservation.

References