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SURVEY, ARCHAEOASTRONOMY AND COMMUNICATION: THE MAUSOLEUM OF GALLA PLACIDIA IN RAVENNA (ITALY)

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ABSTRACT

The Mausoleum of Galla Placidia (built pre-450), is one of Ravenna's UNESCO protected monuments, renowned worldwide for the extraordinary mosaic decorations that cover its internal surfaces. The famous starry vault profoundly engages and inspires the observer. Its accurate representation of the real sky has been analysed and described, as has its mystical and symbolic meaning in relation to the iconographic tradition of the time.

Archaeoastronomical research was carried out on the building by Giuliano Romano, who measured its orientation. The azimuth value of 180.2° highlights a north-south bearing, unique among the other Byzantine buildings in Ravenna. This paper also examines other architectural elements beyond the orientation, with particular attention paid to the building's small slit windows, investigating their possible archaeoastronomical significance.

A functional 3D model was developed from the archaeoastronomical analysis data to display the original morphology of the building (the floor was about 140 cm lower due to subsidence), and astronomical phenomena, and to provide a multimedia way of communicating the scientific content produced. This final part of the contribution forms part of the trials conducted by the research group into interactive and non-interactive multimedia communication based on virtual models as an edutainment tool for the enjoyment of cultural sites and artefacts.

KEYWORDS: Galla Placidia, architectural survey, archaeoastronomy, edutainment, digital museum, dome

1. INTRODUCTION (M.I.)

The small, beautiful monument in Ravenna is attributed to the Roman empress Galla Placidia (c. 390 - Rome 450), the daughter of Theodosius I, and was very probably one of two sacella located at the extreme north and south of the narthex of the Basilica di Santa Croce (c. 417-425). The religious complex, built in several stages (David, 2013), bears witness to Augusta's ardent devotion to the relic of the True Cross, discovered by Helena, the mother of the emperor Constantine I, who commissioned the Basilica di Santa Croce in Gerusalemme in Rome.

Today the mausoleum is a small, isolated building in a Latin Cross shape, with wings covered with barrel vaults and a dome at their intersection. This study reflects on various aspects of the building, based on survey data collected especially for the research.

2. THE ARCHITECTURAL SURVEY (G.L.)

The survey involved the use of a FARO Focus 3D scanner and a digital SLR camera on a tripod. In a few days of work, this gathered all the data required to create a digital reconstruction of the monument. Recording the 23 point clouds and aligning the 459 photographs produced a morphometrically and chromatically reliable model, from which horizontal and vertical sections passing through particularly

important points were then extracted. These were used to analyse the measurements and geometry of the building and its decoration. Integrating the digital photogrammetry with the laser scan, now a widely used surveying technique, turned out to be essential in this case, as documenting the starry skies located on the intrados of the roofing system was one of the main aims of the whole process.

3. THE TWO STARRY SKIES (M.I.)

The mausoleum contains two starry skies, which differ greatly both in their appearance and their meaning: the dome at the intersection of the transept is decorated with a sky filled with 567 golden stars (Figures. 1, 2.1, 2.2, 2.3), while the barrel vaults of the main nave and the apse have a pattern that alludes to a more geometric and abstract starry sky (Figures. 1, 2.1). The dome, in particular, has been analysed in some detail in the past, described both as representing the real sky and a mystical, symbolic sky, in relation to the iconographic tradition of the time. Remaining in this area of research, it is interesting to compare certain aspects of the representation of stars in the mausoleum with other major archaeological sites and, in particular, to investigate the geometric rules that underpin the morphology of the stars and their distribution in space.

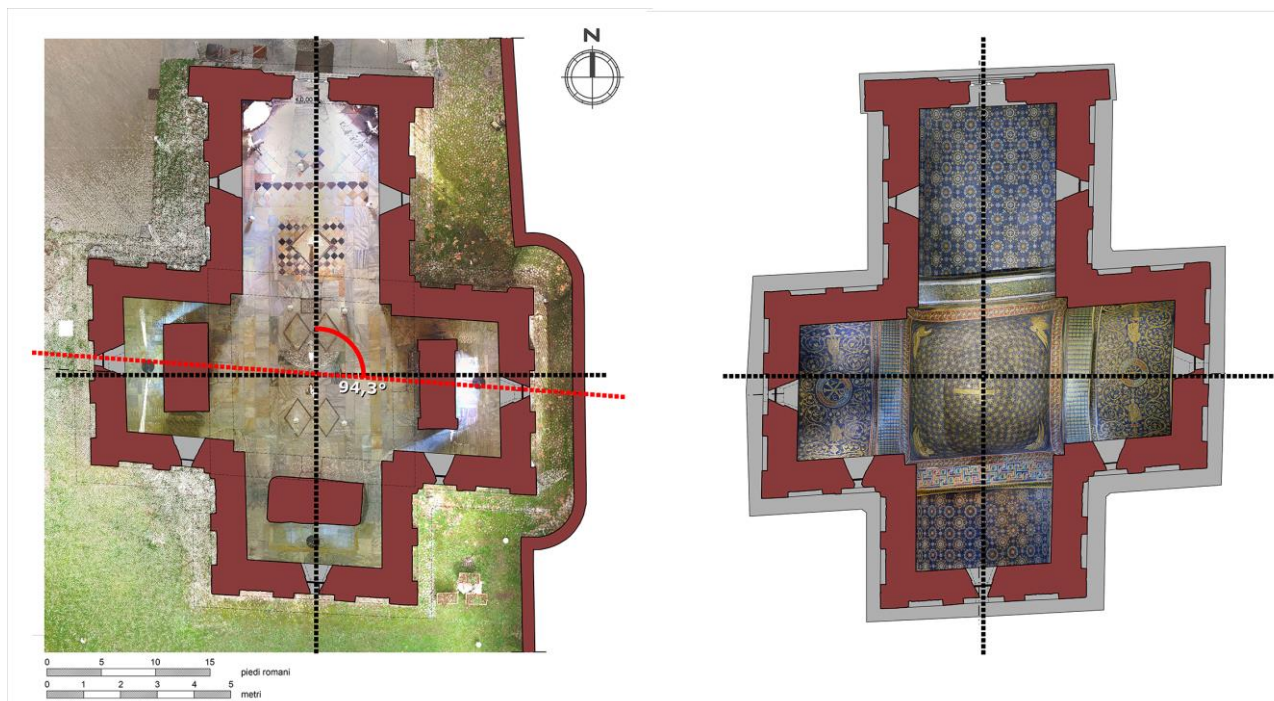


Figure 1. Plan of the ground floor, +1.20 meters (material restitution from the pointcloud) scale 1:50; plan of the dome (material restitution by photomodelling software, M. Incerti) scale 1:50 (drawings by G. Lavoratti).

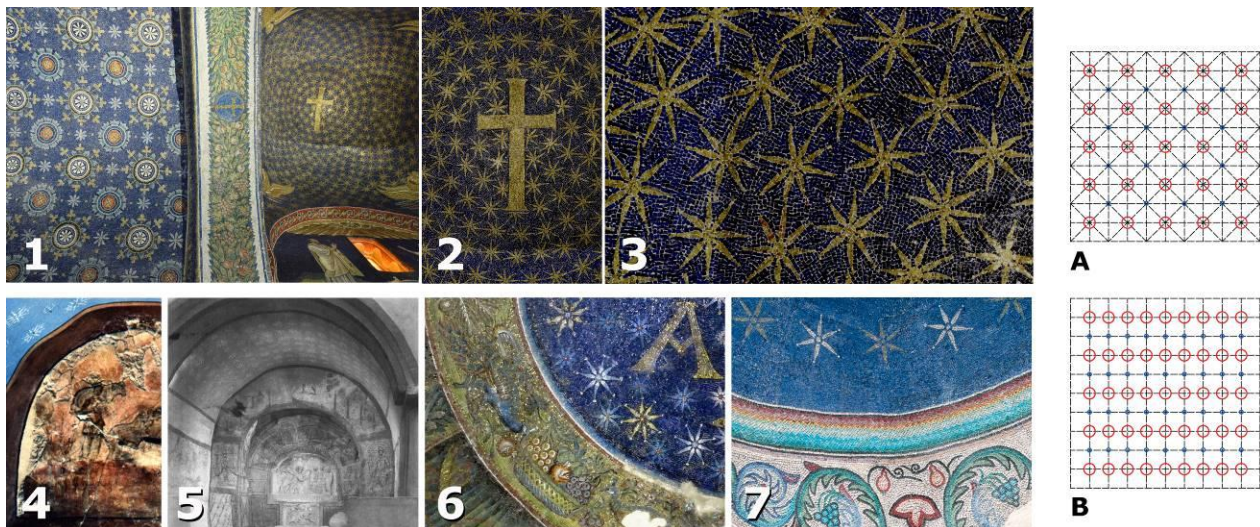


Figure 2. The stars of Galla Placidia (1-2-3, ph. M. Incerti); Baptistery of Dura Europus (4, ph. Marsyas); Mithraeum of Dura Europus (5, by Swift, and Alwis); Baptistery of San Giovanni in Fonte (6, ph. M. Cyron); Santa Maria di Casaranello (7, Ph. M. Santi Amantini); Diagram of the stars A: 45° pattern; Diagram B: 90° pattern.

3.1. Barrel vault

The pattern here is based on the alternating repetition of two figures with an octagonal form (and which therefore can be traced back to the 'rotated square') which allude to two types of multicoloured star/flower: the first has a compact corolla and a central circle in warm colours, while the second has eight long, slender, golden, tripartite leaves and cold colours at the centre (Figures. 1, 2.1). The stars follow the direction of the arch of the vault, and are staggered so as to expand the theme of the eight directions in the space: a row of eight stars of the first type is followed by a row of nine of the second type. The large stars alternate with small white flowers. The dominant lines of the square mesh pattern obtained thanks to the alternation between the two main figures are those at 45° to the walls (Figure 2.A), and evoke the precious nature of oriental silks and fabrics (Ranaldi, 2011, p. 23)¹. The design of the alternating rows of stars, intentionally drawn perpendicularly to the axis of the nave, is interrupted asymmetrically and abruptly at the arches that connect with the dome due to the morphology of the space (a parallelogram), while in the apse the direction of the alternating rows of stars is in line with the back wall.

3.2. Dome

The surface is covered with 567 eight-pointed golden stars (Figures 2.1, 2.2, 2.3), the dimensions of which get smaller as one moves from the impost to

the keystone: this is undoubtedly a figurative device used to expand the perspective effect enjoyed by the viewer, in other words making the space seem higher. Each individual star comprises a circular golden nucleus from which eight curved rays extend. The bright figures stand out against the deep blue background, which is made from tesserae laid out in well-defined circles that, although they are not visible to the naked eye, nevertheless evoke the expansive motion of the light.

Comparing the Galla Placidia golden stars with iconography of the same period immediately reveals the unique and innovative features of the work.

Although they are based on the geometry of a rotated square (eight rays), like almost all of the stars listed in Table 1, the Galla Placidia stars have an unbroken structure, with no gaps between the various elements (the centre, the rays and outer points), which are generally 'separate' in the other examples, probably to suggest the brightness of the stars and the expansive movement of the light. Here, meanwhile, this visual effect is achieved by using infinite, exquisite gold tesserae, laid out to form a compact and clean image.

From the orthophoto of the vaulted surfaces, obtained using digital photogrammetry, it can be deduced that the geometric structure of the starry sky comprises five concentric circumferences, which are used as the starting points for spherical curves. This is undoubtedly the most complex geometric layout of all the examples listed in the table.

¹ On the same topic, see the patterns of the mosaics in the church at Kartmin monastery, which also contains a jewelled cross set against a starry sky (with stars based on a square form) (Hawkins, Mundell, and Mango, 1973).

Tab. 1. The starry skies (M. Incerti).

Building	Medium	Architectural element	Number of rays	Rays/central part	Small circles outside the ray	Colours	Layout	Central element	Other elements
Galla Placidia Ravenna, before 450	Mosaic	Barrel vault		Multicoloured flowers	-	Multicoloured	Quadrangular mesh pattern at 45°, obtained using staggered rows: "n" type 1/"n-1" type 2 diagram fig. 2.A	-	-
Galla Placidia Ravenna, before 450	Mosaic	Dome on pendentives	8	Circle with rays extending from it	-	Gold	See description in text	Latin Cross (transept axis)	Corners: 4 beings of the Apocalypse
Dura-Europos, Baptistery, first half of 3rd century	Painting	Barrel vault/flat ceiling	8	Linear rays detached from the central circle (type 1, large) Pointed rays detached from the central circle (type 2, small)	Between rays (type 1)	White/clear	Quadrangular mesh pattern at 45°, obtained using staggered rows: "n" type 1/"n-1" type 2 diagram fig. 2.A (reconstruction by Yale University)	Moon?	-
Dura-Europos, Mithraeum	Painting	Barrel vault	8	Linear rays detached from the central circle (type 1, large) Linear rays detached from the central circle (type 2, small)	Between rays (type 1 and 2)	White/clear	Quadrangular mesh pattern, type 1/type 2 (same row), rows aligned with the directions of the vault diagram fig. 2.B (reconstruction by Yale University)	-	-
Dura-Europos, Synagogue	Painting	Wall	8	Linear rays detached from the central circle	At the end of the ray	White/clear	7 stars near the crescent moon, on the side opposite the sun	-	Moon, Sun
Battistero di San Giovanni in Fonte, Naples, early 5th century (before Galla Placidia)	Mosaic	Dome	8	Petal-style rays and different/same colour central circle	At the end of the ray	White/blue yellow red (centre)	Circular, just for the 2 outer rows Blue sky	Alpha and omega cross monogram	Corners: 4 beings of the Apocalypse (Bishop Sotere, after Galla Placidia)
Sepolcro Canosa Arcosolium al (first half of 5th century)	Painting	Small barrel vault	8	Petal-style rays separated from a central circle of the same colour	At the end of the ray	Alternating yellow/white	Quadrangular mesh pattern at 45°, obtained using staggered rows: "n" type 1/"n-1" type 2, with alternating colours diagram fig. 2.A Blue sky	Fragment of a clipeus	
Santa Maria di Casaranello, Lecce, 5th-6th century	Mosaic	Dome on pendentives	6	Petal-style rays detached from a central circle of the same colour	At the end of the ray	Alternating white/clear and gold	4 concentric rows on 3 strips of sky, with fading colours	Latin Cross (church axis)	Corners: 4 beings of the Apocalypse
Battistero di Albenga, Savona, c. 450	Mosaic	Barrel vault	8	Central circle with linear rays extending from it	At the end of the ray?	White	Quadrangular mesh pattern: 5 rows on each side, starting from the barrel vault impost	Christogram + alpha and omega (x 3) + 12 doves	12 doves, symbolising the 12 apostles
Sant'Apollinare in Classe, Ravenna, 549	Mosaic	Apse semi-dome	6	Central circle with linear rays extending from it	At the end of the ray	White and gold	Irregular circular layout	Jewelled cross + alpha and omega	
Santa Maria Mater Domini in Vicenza (5th century)	Painting	Dome on pendentives	6 and 8	Rosettes surrounded by a circle + 8-pointed stars	-	Red/yellow (8-pointed star)	Currently illegible	Red circle?	Sun(?), moon Corners: 4 beings of the Apocalypse

The complicated 45° quadrangular mesh pattern of the barrel vault can actually be traced directly onto the surface by dividing the generator arch into equal parts. Drawing horizontal lines (Albenga and Dura-Europos) or a series of concentric circumferences (Naples and Casaranello) is equally simple, usually confined to the upper part of the dome, and never found in the pendentives or the joins between the semicircle dome and the quadrangular volume beneath (tab. 1). The creators of the small mausoleum's renowned eye-catching and profoundly moving starry ceiling set themselves the challenging aim of creating a geometrically continuous design, perceptively similar to a ribbed vault, decorating the entire surface all the way up to the joining surfaces (the pendentives) with orderly stars. This must have

required an excellent knowledge of geometry and projection, as will be illustrated below.

At the top, inside the first circle, there are seven stars laid out around a cross, of which three are at the bottom right, three are at the bottom left, and one is at the top left². The glorious, large Latin Cross in the centre is, unusually, at 90° to the axis of the mausoleum: this golden symbol can undoubtedly be traced to the worship of the True Cross (to which the

² The same number of stars found in the Dura-Europos synagogue (Table 1) which has been posited as referring to the seven planets, but which could instead relate to various constellations.

church is dedicated)³, but also to the symbol of *Christus Victor*: indeed, the long arm faces east-west, thus forcing the observer to turn their back to the west and look east to see it in its correct orientation. The layout of this cross supports and gives significant weight to the theory that it represents the sun, something seen in the depictions of 'Christ the Sun' in the Cappella di Sant'Aquilino in the Basilica di San Lorenzo (Milan), attributed to Galla Placidia⁴, and in the Mausoleo dei Giulii (Rome)⁵. Indeed, both representations can be traced to the worship of the *Sol Invictus*, celebrated at the winter solstice (*Dies Natalis Invicti*) and promoted by Emperor Aurelian, who in 274 dedicated a temple in Rome to this divinity (Salles, 1997).

The numerous symbolic images in the mausoleum include the depictions of the four beings of the Apocalypse (on the four pendentives) and Christograms surrounded by wreaths in the transept's two barrel vaults (on the east and west sides). The latter are the Christian chi-rho symbol, formed from the letters X and P, the spread of which is tied to 'Constantine's dream' (Eusebius, 2009), where this precise symbol appeared to the emperor above the midday sun (*In hoc signo vinces*). The Christogram is also found on various Galla Placidia coins (inside a laurel wreath, the symbol of victory). Another symbol that recurs in the coinage that can be traced to her is a large Latin Cross, sometimes with a star on top (Gerke, 1966). This makes an astronomical event linked to the death of the Empress, described in Andreas Agnellus' *Liber Pontificalis Ecclesiae Ravennatis* (9th century), all the more interesting: according to the text, an extraordinarily bright star shone in the sky after Galla Placidia died. Yet another astral symbol associated with the woman who commissioned the small star-covered treasure (*Liber Pontificalis Ecclesiae Ravennatis, Vita Johannis, 42*).

4. FORM AND ARCHAEOASTRONOMY (M.I.)

The irregular forms of this piece of architecture, which are particularly clear in the plan, cannot be ascribed to a lack of care in their creation, but in-

stead must be attributed to a precise compositional aim in the tracing of the axes, which are clearly not perpendicular to one another.

Giuliano Romano (Romano, 1995) carried out archaeoastronomical research into the building, including measuring its orientation: the value of the principal azimuth, equal to 180.2°, reveals a north-south bearing that is highly unusual compared to other sacred Byzantine buildings in Ravenna. The transept is not perpendicular to the nave; it has a bearing of 94.3° (Fig. 1). The azimuth of the transept was aligned with the sunset on 26-27 March and 13-14 September at the time of its construction (before 450 AD). The former date is very close to the 25 March, the Annunciation, a feast day documented in the fourth- or fifth-century *Martyrologium Hieronymianum*. 14 September, meanwhile, is the date of the Feast of the Cross, to which the main church in the complex is dedicated.

A further aspect of the research involves the intentional creation of light effects on significant dates of the astronomical or liturgical year. The building's narrow windows were reopened as part of the restoration work carried out during the last century (Iannucci, 1995) and are divided up as follows:

- 7 windows in the lower level (2 east, 3 south, 2 west);
- 3 windows in the lunettes (1 east, 1 south, 1 west);
- 4 windows in the tholobate (1 east, 1 south, 1 west, 1 north).

The light that comes from these openings is today dimmed by the wonderful alabaster slabs donated to the building by King Victor Emmanuel II in 1911.

As the material they are made of is only partially transparent, the light conditions, while undoubtedly captivating, are completely different from how they were originally, and with them the way the colours are seen: the sun's rays are highly filtered, and it is no longer possible to observe their progress over the surfaces as time passes. Using 2D and 3D simulations limited to the south-facing windows, it is possible to establish that at midday on the winter solstice a beam of light illuminates the door of the ancient sacellum at a height of -1.4 m (lunette and vault windows, Figure 3)⁶, while the sun starts to enter at midday on the equinoxes.

The choice of this date to create a hierophanic light effect is undoubtedly linked to the iconography

³ For information on the sources and iconography behind the legend of the True Cross in Europe from the 4th to the 15th century, see Baert Barbara, 2004.

⁴ Ranaldi, 2011, p. 24. Various archaeoastronomical inferences and important examples of astral iconography have been uncovered in the Cappella di Sant'Aquilino: the Roman portal, from left to right, depicts the Sun, Jupiter, Mars, Victory or Nemesis, Venus and the Moon.

⁵ See also Christ as the sun god Helios/Sol Invictus driving a carriage (a third-century mosaic in the Vatican Grottoes beneath St. Peter's Basilica, on the floor of the tomb of Pope Julius I).

⁶ The restoration work (Iannucci, 1995; Ricci, 1914) allowed the original level of the flooring to be identified, 1.4 m below the current level. Due to major subsidence (which caused the raising of the groundwater level) it was no longer possible to return to the initial heights and, for this reason, the proportions of the current space are profoundly different from the original design.

on display, supporting the hypothesis that the effect could be attributed to the worship of the *Sol Invictus* in its relationship with the theme of the 'solstice

gates of heaven': in Roman tradition the guardian of the gates (*ianuae*) and passageways (*iani*) was the double-fronted god Janus (*Janus*).



Figure 3. Rendering of the interior of the original space (the floor has been lowered by 1.4 meters compared to today's level); on the left: view from the apse to the door (from south to north); on the right: perspective view from the top to the floor (the door is in the upper part of the image). At midday of the Winter Solstice, a ray of light illuminates the door (south facing windows of the second and third level, north-south apse, render by S. Giannetti).

5. THE GEOMETRY OF THE STARRY DOME (S.G.)

The geometry of the dome of the Mausoleum of Galla Placidia is difficult to interpret due to the lack of structural elements and its characteristic rounded corners, which hide the generatrices and directrices of its surface.

It was possible to get a better idea of its geometry from further analysis of the laser scanner survey, which involved building a mesh model obtained by

triangulating the point cloud. The following issues were encountered:

1. The dome comprises a slightly raised spherical cap;
2. The dome sits on a parallelogram at the impost;
3. Analysing the parallel sections of the dome, perpendicular to the axis, reveals an unclear course, that seems to find an average between the parallelogram of the impost and the circumference at the top.

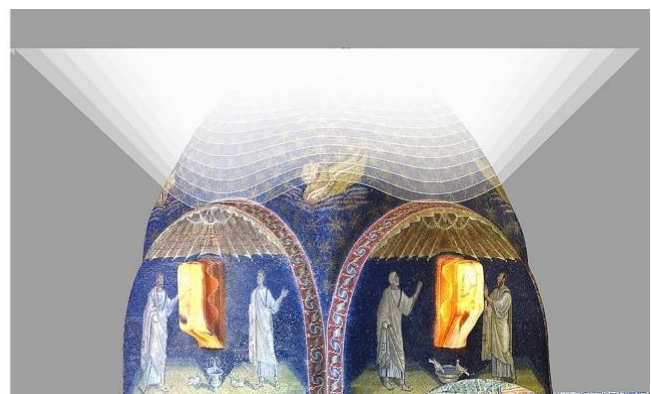


Figure 4. The orthogonal projection extracted from the textured mesh model produced during the photo modelling process. The stars do not lie on parallel planes, but instead on courses that can be defined as "festooned". These curves are obtained from the intersection of the cones and the overall surface of the dome (S. Giannetti).

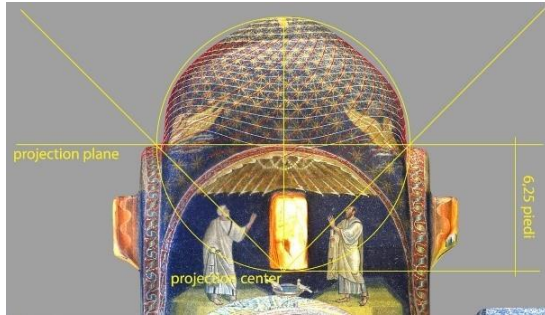


Figure 5. The diameter of the theoretical hemisphere is 12.5 Roman feet. The centre of projection (the antipodal point of the polar stereographic projection) is located at 6.25 feet from the projection plane (S. Giannetti).



Figure 6. The viewpoint placed in the centre of projection. At this point all the rings of stars, which on the surface are irregular, appear perfectly circular (S. Giannetti).

From these premises it can be established that the structure is a sort of raised ribbed vault, geometrically very different from a portion of a sphere. To analyse it, however, one must simply start from the diagonal arches. These are lancet arches, with a rounded off keystone. Dissecting the vault with a sheaf of planes perpendicular at every point to the tangents of the diagonal arch, and therefore passing through its centre, one can see that the sections of the roof are also made up of circular arcs. However, it is clear to see that the surfaces cannot comprise matching circular arcs throughout the entire quarter ceiling, or rather that the surfaces are not portions of a torus. In fact, it is more likely that these surfaces are obtained by running circular generatrices over directrices that are also curved, thereby generating surfaces with a value inside the segment, which makes up an eighth

of the ceiling. This building process is very similar to that used for the raised groin vaults typical of the later years of the Italian gothic style, when the geometry of the generatrices changed from straight to curved.

The mosaic that depicts the starry sky sits on top of this complex ceiling structure. In the 1970s the mosaic was detached from the surface and then reattached. The photos of the restoration reveal various tesserae connected by metal wire (Ranaldi, 2011), probably positioned to indicate the layout of the stars before they were detached. In its current state, seen from below, the mosaic looks like it is laid on a perfectly hemispherical surface. This effect is generated by the apparent distribution of the stars in concentric circles and aligned on loxodromic spirals on the sphere.

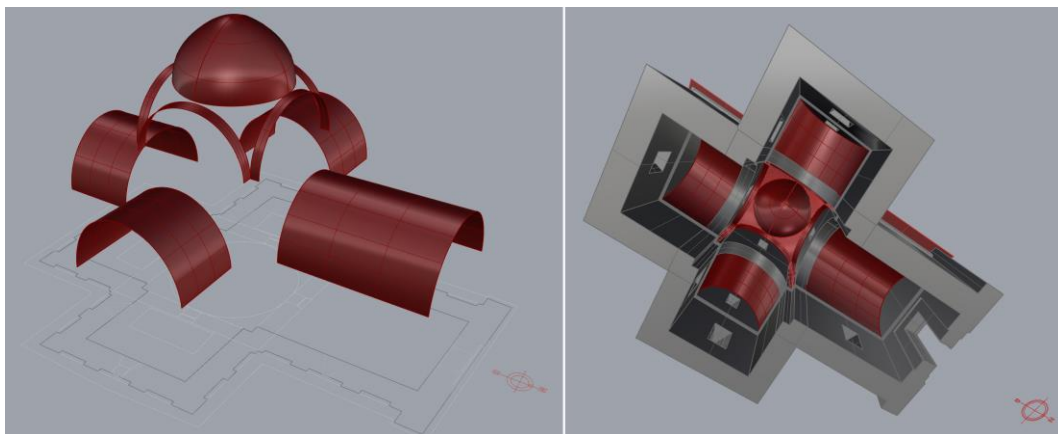


Figure 7. The model in Rhinoceros: to the left, the inner surfaces of the vaults; to the right perspective view from the bottom (S. D'Amico).

However, detailed analysis, based on the textured mesh model, of any section along a plane that passes through the axis of the dome, reveals that the stars do not lie on parallel planes, but instead on courses that can be defined as 'festooned'. From this observation it can be deduced that a central projection was used for the layout of the stars on the surface, and the particular curves along which the stars are

located are the intersection of the cones (with vertices at the centre of projection and directrices corresponding to the circles lying on the impost plane) and the surface of the dome.

Various studies, in particular Bartoli's research on the dome of the Pantheon (Bartoli, 1994), have looked at the coffers in Roman domes, noting that they were created using a polar stereographic projec-

tion. As the surface of Ravenna's starry ceiling is not really hemispherical, as stated above, the diameter of the theoretical hemisphere had to be hypothesised.

In this case this was the same as the diameter of the real dome at its impost, 12.5 Roman piedi (Figure 5). As a result, the centre of projection can be located at approximately 6.25 piedi from the 'equator' of the sphere, or from the impost plane described above. When the viewpoint is placed in the centre, all the rings of stars, which in reality are irregular, appear perfectly circular (Figure 6). In addition, the effect is heightened by the points of the stars tilted at 45° aligned with the loxodromic curves of the sphere, which in the stereographic projection look like logarithmic spirals on the plane. This occurs with a high level of reliability until the fifth ring of stars from the cross. From here on it seems that the stars, although laid out on concentric circles, are no longer aligned along spirals.

6. A DIGITAL ANALYSIS AND VERIFICATION MODEL (S.D.)

The research carried out on the Mausoleum of Galla Placidia combined various IT tools, both when managing the large quantity of data collected and in the subsequent geometric and dimensional reconstruction; following an archaeoastronomical survey, the representation of the building was dealt with digitally and also through the three-dimensional re-elaboration of its main formal features and measurements. The choice of modelling applications had to guarantee the production of a discretised digital model, which would be used for subsequent investigations and therefore had to be sufficiently descriptive, immediate and easy to consult. The studies and surveys illustrated here confirmed the benefits of systems that allow the virtual reconstruction of architectural artefacts, particularly during the analytical phases of the research. Some brief considerations regarding the geometrical characteristics of the mausoleum provide good examples of this: the building's distribution and volumetric system is effectively structured around a clear displacement, along the longitudinal axis, between the two eastern and western portions (Figure 7).

This apparent irregularity generates adaptations in the surfaces of the internal ceilings, in particular between the barrel vaults of the four wings and the central dome. The latter, set on a rhombic base, also has variable vertical profiles, so use of the model maker and a systematic comparison between two-dimensional representations and the corresponding three-dimensional transposition allowed the researchers to hypothesise the most plausible generative geometric patterns. With this in mind, it is worth pointing out that the choice of 3D software

was made based on the need to construct relatively complex curved surfaces –the internal ceilings– and particularly their formal geometric connections.

It is worth reiterating that digital three-dimensional representation has both an instrumental and investigative value: the model, in fact, makes organic and simultaneous control of the whole complex and the diversified data set resulting from the surveys possible.

7. COMMUNICATION OF CULTURAL HERITAGE (G.L)

Documenting, safeguarding and managing Italy's vast tangible cultural heritage remains a very pressing topic, of great public interest. Although the cultural heritage system extends to virtually all areas of the country, major logistical, economic, and stability (linked to sites' safety) issues mean that in reality many monuments are difficult to access, with little opportunity for them to be enjoyed by the general public.

In recent years, digital architectural models, as well as describing buildings much more accurately in terms of their morphometry and colour, have also become useful tools for sharing the results of research carried out on monuments. They create virtual environments which can be navigated and consulted, able to interact with a widespread and varied user base who, even at great distances, can freely enjoy a piece of cultural heritage that would otherwise be inaccessible. At the same time, the opportunity to continually input data makes them extremely important tools for checking and monitoring the monuments themselves.

In the specific case of the Mausoleum of Galla Placidia, the digital model allowed the actual geometry of the architectural structures to be verified, with every single deformity compared to an 'ideal' model of the building. It also allowed the extent and precision of various specific light effects that appear within the room at certain times of the year and at certain times of day to be examined, thanks to specific simulations calculated and recreated on the model. The reconstructions, in turn, have become a valuable way of publicising the work, and helped to identify further areas of research that are yet to be explored.

In the case in question, moreover, the visualisation, or indeed, the communication of the results obtained from the research itself has been beneficial: here, therefore, the virtual reconstruction has not remained exclusively a material reproduction of the architectural object but has, above all, become an illustration of different meanings, reflecting technical, cultural and symbolic parts of our historical and monumental heritage (on these issues: Kiourt, 2016).

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