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

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ABSTRACT

The Mausoleum of Theodoric (520 ca.), one of Ravenna's most globally renouned monuments and UNESCO heritage site, has been object of archeoastronomical research in the past years. This paper examines the orientation of the building as well as other elements of the architecture, especially the small openings of the building, to investigate their possible archaeoastronomical significance. The architectural survey was carried out with a laser scanner device (Faro-Focus 3D, software Scene) while the textures were extracted using digital photomodelling software. Starting from the archaeoastronomical analysis, a 3D model was developed to check astronomical phenomena and allow the communication of scientific content through several forms of media. This second part of the contribution is part of the experiments conducted by the research group (Incerti and Iurilli 2014), (Incerti and Iurilli 2015), focusing on new means of multimedia communication, both interactive and not. The research looks at virtual models as a means of *edutainment*, aiming to maximise the fruition of artifacts and cultural sites.

KEYWORDS: Theodoric, architectural survey, archaeoastronomy, edutainment, digital museum

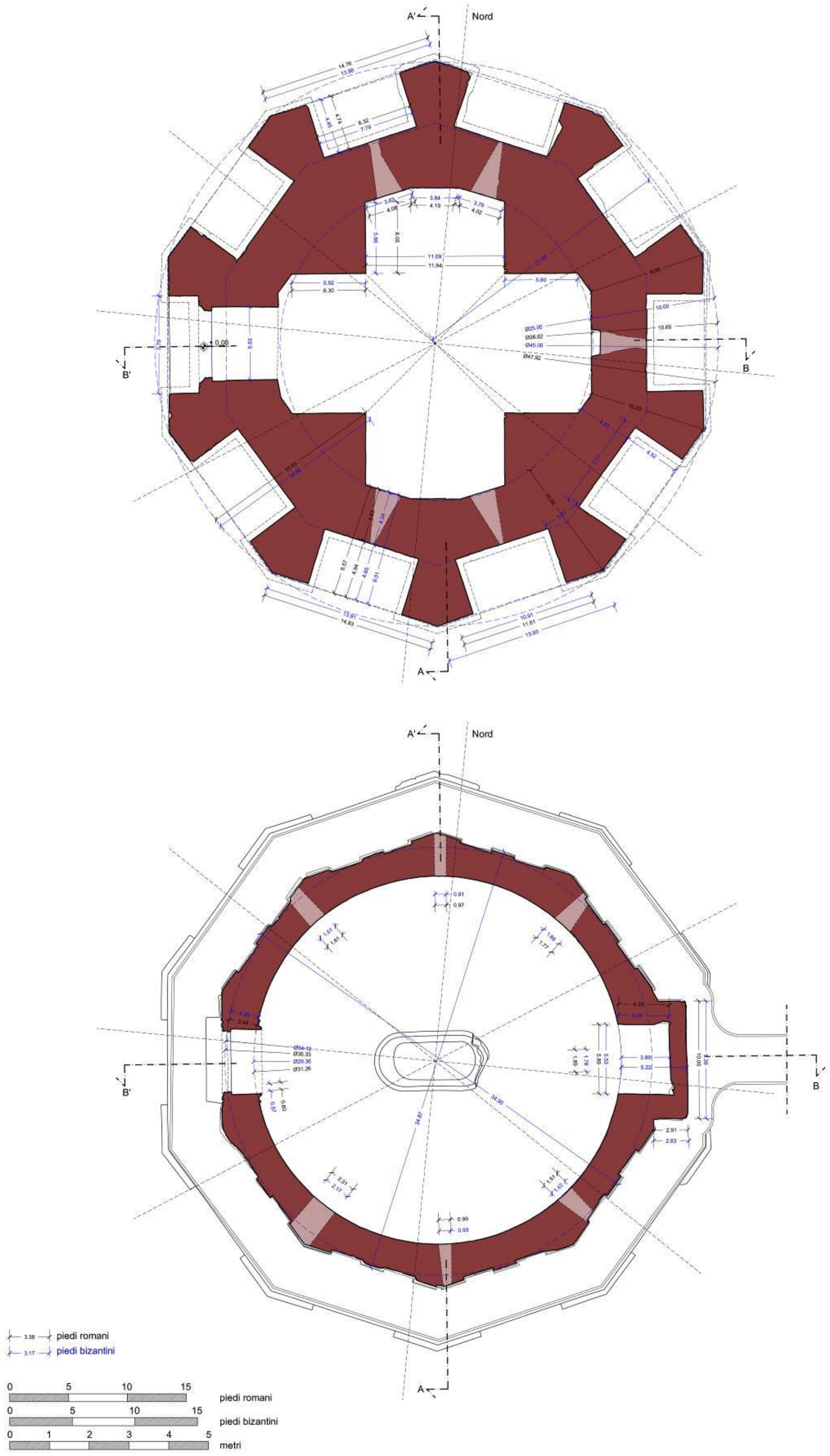

Figure 1. Mausoleum of Theodoric, Ravenna. Plans of the ground floor and first floor. Graphic elaborations of 3d survey.

1. INTRODUCTION

The most ancient information regarding the Mausoleum of Theodoric is included in a fragment of text written by an anonymous reporter known as Valesiano (*Anonymus Valesii)*, from the name of the French academic Henri Valois, who edited the piece in 1636. The second part of the text, regarding the period in which Odoacre and Theodoric ruled (years between 474 and 526), narrates the foundation of the building: "*Se autem vivo fecit sibi monimentum ex lapide quadrato, mirae magnitudinis opus, et saxum ingens quod superponeret inquisivit*".[1] Meaning *"When still living, he erected a funeral monument for himself in squared blocks, a work of marvellous grandeur, and requested that an enormous rock be found to cover it"*.[2] According to this document, the construction of the building was ordered by Theodoric himself before his death (30th August 526). It was then built in carefully squared blocks, a rarity for this time and practice, and covered with a "*saxum ingentem*", evidently purposefully demanded (*inquisivit*) by the King.

The commissioner of the work, King Theodoric was born around 454, son of Theodemir from the Amali family. At the young age of 12 he was sent to Constantinople as a hostage, and remained at the court of Leo I the Thracian until 472. Scholars do not agree on the terms and type of education he received in the East, in any case it is undeniable that during his kingdom he showed great attention to architecture. This is testified by the restoration of the ancient buildings of Rome, new buildings in Verona, in Pavia and, above all, in Ravenna.

2. THE ARCHITECTURE: HISTORICAL NOTES

The mausoleum is on two levels: the ground floor has decagonal plan in the external profile and a Greek cross interior, while the upper floor has a decagonal exterior and a circular interior space.

Like all monuments of Ravenna, now a UNESCO heritage site, the building has been the object of specialized studies (the most important of which date back to the last century,[3] and survey campaigns: the oldest, also published by Heidenreich (108-114), are those of Giuliano da Sangallo (1445-1516),[4] Baldassarre Peruzzi (1481-1536),[5] Antonio da Sangallo il Giovane (1483-1546)[6] and Giovanni Battista da Sangallo il Gobbo (1496-1552).[7]

In its long history, the small, central plan building was supported by other bodies, including a lighthouse, and later annexed to the church of a monastery (Santa Maria della Rotonda) where it was used as a "choir" (Guberti, 1952, 8-16). In 1748, a large part of the first level of the Mausoleum was still interred in an area often subject to flooding (Guberti, 1952, 17). In 1774 two flights of symmetrical stairs were built on the west side to allow access to the upper floor. Further campaigns of restoration and archaeological excavation followed in 1808, 1810, 1825, 1839, 1844 (Guberti, 1952, 19). In 1918-19 the eighteenth century stairs were removed and in 1927 the surrounding area was released as well as the first access ramp built. Further interventions were necessary in 1945 because of the damage caused by the war[8], as in 1977[9] and finally in 1998, the year in which the restoration of the stone facing stone of Aurisina[10] took place.

In the present study, some of the issues discussed relate to elements of the architecture that are possibly connected to orientation and to their archaeoastronomical meanings. It is therefore absolutely necessary to verify the authenticity and dating of the elements involved in the analysis in order to avoid misinterpretation of the data.

2.1. *The question of the "unfinished"*

Some small arches appear on the external face of the second floor, which may hint at the past presence of a loggia, perhaps lost or never finished. In this regard, the question of "unfinished" and the possible different dating of the two levels introduced by some authors do not appear to interfere with our observations. All reconstructions hypothesised for the second floor, amongst which one must remember the extremely accurate and sophisticated one of De Angelis of Ossat (very accurate graphics) (De Angelis of Ossat 1962), never involve the openings but only address the presence and shape of the portico, lower compared to the system of windows.

[1] *(Muratori, 1738), text available at link in bibliography ("Anonymus Valesianus: Chronica Theodericiana," n.d.).*
[2] *Translation in (Bovini 1977, 10-11).*
[3] *Amongst the most important and extensive works we point out (Haupt, 1913; Guberti, 1952; Heidenreich and Heinz, 1971) whose studies were actually carried out in 1938, and (Bovini, 1977). See also (Gotsmich, 1958; Johnson, 1988).*
[4] *(Sangallo, 1910), f. 38-37, see also the Geymuller codex, Uffizi, of which Heidenreich publishes an image (Heidenreich and Heinz, 1971, fig. 65, p. 63).*
[5] *Uffizi, Dis. 441 A (Heidenreich and Heinz, 1971).*
[6] *Antonio da Sangallo, Uffizi. Dis. 1406 A, 888 Av, 887 Ar, (Heidenreich and Heinz, 1971). On the same subject see also Uffizi. Dis. 875, 878, 896 (De Angelis d'Ossat, 1962, 97, tav. V)*
[7] *Uffizi Dis. 1563 Av, 1563 A, 1394 A, (Heidenreich and Heinz, 1971).*
[8] *The substitutions are highlighted by the different colours of the ashlars in the photographs of the time, see also (Conti and Berti, 1997).*
[9] *(Bovini, 1977, I-XV). Regarding restorations see (Piazza, 2013, 84-86) from the same volume see pages 24-25, 35-27, 56-57, 72 and especially the profile by Paola Novara pages 111-116.*
[10] *The recently identified construction material is the stone of Aurisina (Piazza et al., 1998; Bevilacqua, Fabbri, Grillini, and Iannucci, 2003).*

2.2. The flooring

The current flooring of both rooms, as previously mentioned, is certainly not original: in 1557 Leandro Alberti mentions traces of a mosaic floor, evidently placed in the top cell, since the bottom was buried underground. [11]

Regarding the progress of this element historians have reported a major failure of the ground on the Eastern side, which led to a drop of 14 cm in the ground floor and a 6 cm drop of the upper floor. The difference in height between the two levels led scholars to believe that an initial failure occurred during the construction of the ground floor. For this reason the upper floor was probably put in place "leveling" the already installed plan, which however, later another slight lowering. Some drawings stored in the Superintendency of Ravenna [12] show an accurate survey of the pavement slabs dated 1903, on which many measurements are noted as well as the measurement of elevation at a point indicated by the letter A. The existing pavements were put in place during the works of the biennium 1975-77 (Novara, 2013, p. 116).

2.3. The small apse

On the eastern side of the top space there is a small apse, whose function has been questioned by many historians: its height cannot accommodate an altar or an officiant or even the great porphyry sarcophagus (today placed at the center of the space). On the keystone of the arch is a large Latin cross, the only sculptural element of the interior, which highlights its relevance in the project. The small space, whose floor was slightly lower than that of the rest of the room is, according to scholars, contemporary to the building (Messina, 1980; De Angelis d'Ossat, 1962, 128-129).

2.4. The sarcophagus

According to tradition, the remains of King Theodoric were conserved in the great sarcophagus of red porphyry measuring 305x190x101 cm. The tub is characterized by four rings on the top edge and two lion heads at the bottom center of the side faces. The sarcophagus' troubled history has been well documented, its movements traced by Ambrogi (Ambrogi, 1995, 109-111), recalling its relocation to the site in 1913. There is no certainty regarding the original orientation of the object, which is however considered by scholars to be consistent with building, originally arranged in the East-West direction (the current one).

2.5. The small windows

The wall of the ground floor has a thickness of about 140 cm and is pierced by 6 splayed narrow slits, with an approximately horizontal intrados, arranged on three sides (each of which is divided into three segments). Their sizes vary in width from 11 to 25 cm, a minimum height of 40 cm, and 70 cm, and are arranged as follows:

- (1a, 2a) Northern wall: 2 small windows placed in the first and third segments (intrados lowered outward approximately 6 cm)
- (3b, 4b) Eastern wall: 2 small windows vertically aligned with the axis of the building.
- (5c, 6c) Southern wall: 2 small windows placed in the first and third segments (intrados lowered outward approximately 6 cm).

The decagonal part of the upper level ends with a series of cylindrical section bands, the highest of which is decorated by the famous "tenaglia" (pincer) shaped design. The central and receding one, about 77 cm thick, is smooth and perforated by 11 windows. Arranged roughly in the directions North-South, East-West with the two diagonals at 45 ° (directions of the compass rose), the small openings have dimensions that vary from 40 cm in height for the windows on the North-South axis, to 62 cm on the diagonal axes. Starting from the entrance, we have:

- (7-8-9-10) 4 small windows with rounded arches, combined two by two (West)
- (11) 1 small rectangular window with overhead arch between two small straight sections (North-West)
- (12) 1 small window with rounded arch (North)
- (13) 1 small rectangular window with overhead arch between two small straight sections (North-East)
- (14) 1 small Greek cross window (East)
- (15) 1 small rectangular window with overhead arch between two small straight sections (South-East)
- (16) 1 small window with rounded arch (South)
- (17) 1 small rectangular window (South-West).

The opening are almost unanimously considered contemporary to the founding of the building, excluding the rectangular South-Western one which was clearly enlarged at a later date (Guberti, 1952, 59; De Angelis d'Ossat, 1962, 94)[13]. In various pictures preceding the last restoration one can notice the presence of a twelfth opening positioned on the back wall of the small apse, probably added during the period

[11] Sources in (Fagiolo, 1972, 148-149).
[12] Dating from 1903 numbered 2080 and 2081.

[13] According to (Heidenreich and Heinz 1971, 58-60) the small windows on the diagonals are not original but date back to the Middle Ages.

when the building became a church choir (Messina, 1980, 33; Guberti, 1952, fig. 26 pp. 40 and 59).

Keeping the axes of the openings described above into consideration, the internal lighting system of the two rooms, formed by 17 openings (11 + 6) can be traced back to 12 different directions: 5 in the lower deck and 8 in the upper one. Of these, only one - the Eastern one - follows the trend of and lower system.

Below the windows is a protruding band (of about 8 cm) on which inscriptions laid out on 3 different levels have been recently found (Novara, 2013, p. 116, see also the volume at p. 85), (Piazza, 2009), investigated and restored in 2012 (results not published yet).

2.6. *The cupola*

Even the great monolith that covers the building was subject to a great number of specialized studies that have investigated physical, technological, figurative, historical and design aspects (Dyggve 1957; Bean 1972; Tabarroni 1973; Bianco Fiorin 1993).

The inner diameter is about 925 cm and the height on the springing is of about 190 cm. A large crack, which popular tradition blames on a bolt of lightning, marks the southern side where the lighthouse was built adhering to the building.

12 protruding elements are present on the outer edge of the roofing. Their triangular holes convey the image of a "royal crown". Historians have often questioned the real function of these elements and their figurative origin, (Bean 1972). The assumption is that they were used for the passage of cables and ropes necessary for its positioning, as hypothesised by Antonio da Sangallo with a drawing already published (Heidenreich and Heinz, 1971, fig. 65, p. 63), may be considered unfounded because of the enormous weight of the monolith and the common laying techniques of the time (Tabarroni 1973). What all scholars emphasize is the lack of regularity in the arrangement of the dodecagon traced by the protruding elements, for it is not aligned with any of the geometries of the building. The monolith is in fact slightly rotated in relation to the main axis of the building, which led to the unanimous conclusion of a faulty, unfixable installation due to the creation of the dangerous lesions on the southern side.

The names of the apostles and evangelists are inscribed on the vertical face of the elements in the sequence (from the door, clockwise): Lucas, Marcus, Mathias (?), Matteus, Felippus, Johannes Jacobus, Andreas Paulus, Petrus, Simeon, Thomas.[14] The elements are closed with a gable roof, almost simulating a small sarcophagus, except for one: that of San Pietro has a flat roof. This led to believe the existence of a terminal made of a different −and perhaps more valuable− material (gone missing), highlighting the figure of Peter, founder of the Church (Tabarroni, 1973, 141)

[14] *Regarding possible reasons for this sequence see (De Angelis d'Ossat, 1962, 129-131, fig. 9; Heidenreich & Heinz, 1971, p. 14; Fagiolo, 1972, 108, 119, 142, 149, 152-4; Tabarroni, 1973, 133-141).*

3. THE ARCHITECTURAL SURVEY

The architectural survey was carried out with a Faro focus3d scanner[15]; 30 stations were performed covering the interior and exterior. The individual clouds have been registered with the aid of spherical targets. At a later date two different photographic campaigns, needed for the reconstruction of the three-dimensional, textured model, were made: the first relating to the exterior, the second to the interior. The exterior shots were performed by a compact Lumix DMC-TZ7. Interior shots, due to matters of critical illumination, were produced with a digital SLR camera on a tripod. In this stage 406 photographs were elaborated and 188 targets used as follows:
Exterior: 123 photos, 38 targets
Exterior walkway details: 96 photos, 146 targets
Lower interior: 76 photos, 0 targets
Top interior: 111 photos, 4 targets.

4. SURVEY DRAWINGS: METHODS AND PROCEDURE

The pointcloud available, which is particularly dense and with limited bands of occlusion, was sectioned by horizontal and vertical planes in order to extract the two-dimensional canonical drawings (plans, elevations and sections) used to effectively describe dimensions and geometries. A thin slice (thickness of 1 cm) was extracted from the cloud for each cut-plane to represent the elements dissected, re-drawn in field vector by interpolation of the points and exported for the realization of raster images definitive 1:50 scale. The choice of using a "slice" of points so reduced yet still sufficiently detailed was possible thanks to the particular density of the pointcloud, which provided a high degree of detail, also on particularly elaborate portions such as shell decorations on the interior brackets. At the same time, the reduced thickness of the slice has guaranteed a higher precision on the section itself, likening it more to a geometric plan. The elements in the projection are obtained by re-drawing, in vector terms, screenshots specially extracted from the pointcloud and orthophotos produced by software for digital photomodelling. Particular attention was paid to the architectural

[15] *Survey M. Incerti and P. Lusuardi, dated 30/04/2015. Data handling software Scene 5.3, elaboration of data M. Incerti. We would like to thank the Compagnia delle Misure for the use of the tool as well as the Soprintendenza per i Beni Architettonici e Paesaggistici di Ravenna for the permissions accorded.*

details, for which ad hoc screenshots with appropriate definition were taken, suitable to describe even the most complex of moldings.

On the rare occlusion bands,[16] the texture has been reproduced (where possible). This has been done by integrating the gaps with specially shot photograms in order to make the final elaborate complete in all its parts. The areas treated this way have nonetheless been graphically differentiated through the use of superimposed layers and textures to emphasise the diffrent material reliability compared to the rest of the survey.

The final elaborates are therefore the result of the overlapping of parts in section and projection obtained through the procedures described above. This work format, now well established in the science world, ensures greater metric control of the architecture (through comparison and contamination of drawings obtained through different processes, distinct survey campaigns and conducted with different instruments). It also allows for detailed graphics containing material and chromatic information that a traditional survey would not have been able to render.

Plans, elevations and sections thus obtained, describing the fundamental geometry of the architectural artefact with a metric reliability that allows for the analysis reported in the next section. It also reproduces the exact wall texture, the state of conservation, the grain, color and deterioration of different materials, allowing the expert operator to perform numerous other integrated readings.

5. ARCHEAOASTRONOMIC ANALYSIS

5.1. *The orientation*

The survey of the orientation was structurally created by Giuliano Romano (Romano, 1995) who first published the Azimut value of 84,5°.[17] The building is rotated, compared to the equinoctial direction, of a considerable amount that should not be overlooked during the alignment operations. The azimut from the apse (North)[18] is aligned with the rising of the sun on the 26-27 March and the 13th of September at the time of construction (pre 526). The first date is very close to 25th of March, celebration of the Annunciation of Mary, a celebration which was already documented in the *Martirologio Gerominiano* dating back to the IV/V century.[19]

Following the correction of the slight rotation, the survey methodology involved specially processed survey drawings. By overlaying graphics to the 4 main astronomical directions (solstices and equinoxes), the small windows placed on the 45° direction were not found to be perfectly aligned in relation to the center. Despite this, it is clear that these windows allow the entry of light during the two solstitial dates.[20]

5.2. *The windows*

Only 3 of the 17 windows, those on the North side, two downstairs and one on the top floor, do not receive significant sunlight. All others are involved in important moments of the astronomical year. The behavior of sunspots on horizontal and vertical surfaces were analyzed through plans and sections, height and azimuth angles were traced, through specific software, to the ephemeris. Among the episodes we note:

- *window (14).* Cross-shaped window, the rising sun penetrates through it on the day of the Annunciation, shining on the wall placed in front, on the axis of the cell. On the day of the summer solstice, about an hour after sunrise, the light spot passes over the stone sarcophagus.
- *window (3b, 4b).* Behaves like the previous for the rising sun of the 25th March. It should be noted that the phenomenon is no longer visible due to the construction of the new upper floor access system.
- *windows (7-8-9-10).* The sun penetrates them at sunset on the days of the equinoxes, illuminating the previously mentioned emerging scripted band.
- *window (16).* At noon of the winter solstice, the light spot approximately reaches the intersection between the wall and floor. Light only enters this window around noon in the winter solstice period because of its shape.

The windows at a 45° direction still welcome the rays of the sun at dawn and dusk during solstice

[16] As previously mentioned, the pointcloud and orthophotos obtained through digital photographs are very detailed and devoid of distracting occlusion areas. It was nevertheless necessary to intervene with the described procedures to limit the parts of the architecture where undercuts and non-removable elements (balustrades, fixed decor elements etc.) would not allow a complete description of the product.

[17] At the time it was not considered necessary to repeat the measurements because of the tools used and their precision. The investigations have therefore been carried out at a second date through the analysis of the behaviour of light in the interior in relation to the theoretical hypotheses elaborated with the aid of graphic tools.

[18] The horizon was untarnished because the building was situated near the sea shore.

[19] The festivity is documented of the 25th of March (ante diem octavum Kalendas Aprilis) in (De Rossi and Duchesne, 1894). We thank E. Spinazè for the notice. On this date the Hilaria celebrations took place in Rome in honour of the goddess Cibele, mother of the gods (Vaccaj 1927, 52-65).

[20] The building was the subject of an archaeoastronomical study in 2000, today still in form of a manuscript, by the scholar M. Kerner, 2000 cited in a report of the Soprintendenza per i Beni Architettonici e Paesaggistici di Ravenna (Piazza, 2009). An image of the work is published, but not consultable, showing lunar and solar symbols, perhaps referring to lunar standstills as well as solstices and equinoxes.

dates. Phenomena of this kind may have been used for purposes of a calendar to mark the advent of a particular date of the year, or for the computation of time: in other words, to indicate a precise moment of the day.

5.3. The dome

The results of the survey allowed us to verify that the arrangement of the protruding elements follows the cardinal directions with rather accurate approximation. The item marked with the name of Paul, founder of the Church (the only one with a flat roof), is aligned to South. Aligned to the East is Jacobus, West Lucas, North Matteus. This condition is a possible explanation for what scholars consider an "executional mistake".

6. DIGITAL MODELS FOR RESEARCH VERIFICATION AND DISSEMINATION

The investigation described above, and the survey supporting it, generated a large amount of data. Their analysis and reading produced significant results, providing new information on the archaeoastronomic characteristics of the Mausoleum.

To be disseminated effectively, such results require a visual support that allows the storage of different types of data (morphological, dimensional and chromatic features, archaeoastronomical analysis, external metadata, video and processed media, etc...), and, on the other hand, facilitate an immediate understanding of complex phenomena by the addressee of the information.

A detailed 3d model of the entire building has been created starting from the digital survey, in order to allow a direct visualization of the luminous phenomena affecting the inner spaces on some particular dates of the year.

The model is a low-polygon mesh made of quadrilaterals (quad mesh), textured with a UV mapping method, whereas the high resolution textures are derived from the orthophotos coming from the SFM[21] survey. The model was ideated to be optimized for future use in real time applications.

The 3d maquette, oriented and placed in a Cartesian space reference, was put in relation with a light of the directional type, which simulates the parallel rays from a source similar to the sun, and is therefore the best suited to virtually reproduce the tour of sun around the mausoleum. The light is put on an animated path that reproduces the movement of the sun on the ecliptic. Every moment of animation (keyframe)[22] was created by parametrically inserting the values (position and rotation) derived from the calculation of ephemeris in "key" times. In particular, the exact time of sunrise has been inserted as the beginning of the path, and the sunset time as the end. This time range was then further divided into half hour fractions to cover the whole course of the day.

After setting the animation, the positional coordinates of the sun during the intermediate hours come automatically from the interpolation of the data provided, and can be read simply by moving a cursor on the timeline: the construction phase of the model thus becomes a moment of assessment and comparison of the calculations previously made (ephemeris).

The procedure was repeated for four significant dates (solstices and equinoxes). The model thus obtained was used as a kind of virtual laboratory for the observation of the effects of light within the burial cells, in an ideal condition as free of obstacles and external elements that, at present, occlude the passage of the sun rays.

The observations made experimentally on the model confirmed the results previously recorded from two-dimensional drawings with extreme precision. In addition, the simulation also provides an "emotional" component, increasing the impact of the observation of archaeoastronomical events. The high level of detail of the model and the photo textures, the use of volumetric lights and the general photorealism of the scene allow the user to observe the phenomenon of light in an accelerated form as it may observed inside the mausoleum.

The system is very powerful and effective from a communication point of view, capable of involving the user in an engaging learning experience.

Some short animated sequences −related to a specific stage− have currently been made; however in the future the program will include the creation of a complete interactive application[23]. It will display the behavior of light inside the mausoleum by interactively moving a cursor on a timeline, or simply by entering parameters such as date and time.

[21] Structure from motion (SFM) is a range imaging technique; it refers to the process of estimating three-dimensional structures from two-dimensional image sequences, which may be coupled with local motion signals. We used this technique to assemble a first version of the 3d model of the mausoleum, from which we extracted detailed ortophotos and basic morphological data.

[22] A key frame in animation and filmmaking is a still-image that defines the starting and ending points of any smooth transition. It is commonly called "frame" because its position in time is measured in frames on a strip of film.

[23] Similar experiences carried out by our research group are described in: (Incerti, Foschi, Iurilli, and Velo, 2014; Incerti and Iurilli, 2014; Incerti and Iurilli, 2015).

Figure 2. From left, counterclockwise: daylight simulation within the upper cell of the Mausoleum (vernal equinox, 21th of March, rising and sunset; summer solstice, 21th of June, sunrise) and full textured 3d model of the building.

7. CONCLUSION

To conclude, the archaeoastronomical investigation has certainly given significant results which have extended our knowledge of this extraordinary building into topics which had been previously unexplored. The database of measurements produced by the advanced survey offers additional insight, for example on the geometrical and numerical aspects in relation to units of measurement, and on the figure of Severino Boezio, imprisoned and murdered by Theodoric. Lastly, we tested the important contribution of digital models, both during analysis and in the transmission of complex, layered content such as historical and astronomical knowledge.[24]

Figure 3. The Mausoleum of Theodoric (Photo by M. Incerti)

[24] *Paragraphs attributed as following: M. Incerti (1-3, 5-7), S. Iurilli (6), and G. Lavoratti (4).*

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