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Archaeoastronomy in the Roman World

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Foreword

Past societies—not only during prehistory—made gods of celestial bodies and phenomena, including them in their mythological narratives and linking them not only to atmospheric events and seasonal cycles but also to important social institutions and the destiny of men.[1] Early on in the history of archaeology, some researchers, especially astronomers but also anthropologists and prehistorians, began suggesting that some archaeological remains (especially prehistoric ones) could be measured and examined in order to explore potential alignments with celestial phenomena. This, they claimed, would improve our understanding of the symbolic universe of the groups and societies that built these monuments. In time, this developed into an interdisciplinary subject of study, half way between astronomy and the social sciences.[2] Different terms have been put forward to refer to the discipline, including archaeoastronomy (E. Ch. Baity; M. Hoskin), astroarchaeology (Hawkins 1973), the history of astronomy and ethnoastronomy; more recently, S. Iwaniszewski (1997) and C. Ruggles (1999, 2001) proposed an all-embracing term, cultural astronomy (which can accommodate both the history of astronomy and ethnoastronomical traditions). This discipline examines how, throughout history, humans have oriented themselves in time and space through the observation of celestial bodies (Belmonte 2009: 58).

Within the field of cultural astronomy (Iwaniszewski 2009: 30), archaeoastronomy has been characterised by a lasting and intense debate around the discipline's very definition and methodological orientation. In recent decades, some degree of

[1]See, for instance, Lehoux (2007); Silva and Campion (2015). From prehistory until today (Chamberlain et al. 2005), groups and societies developed relatively advanced astronomical and calendrical knowledge, which served a variety of purposes. Calendars and programmed agricultural activities were made possible by the study of the position of celestial bodies (Antonello 2012).

[2]In general, this discipline analyses the alignment of monuments and buildings (menhirs, tombs, temples, etc.) and celestial phenomena (e.g. solar and lunar dawns and sunsets). The discipline also examines the iconographic representation of celestial bodies and phenomena and the reconstruction of astronomical events using the data gathered by modern astronomy (Krupp 1989, 1991).

agreement has been reached about the difficult question of definition. The discipline is thus described as an approach to the astronomical knowledge and beliefs of past societies (Belmonte 2000: 14) or, more restrictedly, to the astronomical practices of prehistoric societies (Esteban 2003a: 309). That is, the discipline examines astronomical, archaeological, historical, ethnographic and anthropological data in order to investigate the interaction of men and the cosmos from prehistory to the present day (Cerdeño et al. 2006: 14).

Methodological debates have also played a central role in the discipline during the final decades of the twentieth century. These debates revolved around the need to conciliate the methods followed by physicists and mathematicians (who can analyse the motion and position of celestial bodies) and those adopted by archaeologists, historians, ethnographers, etc., who can examine the cultural patterns of past societies and are in a position to ask the right questions (Silva and Campion 2015).[3] As such, the relationship between archaeology and astronomy relies on the ability of the former to provide data (gathered by means of methodologically precise astronomical calculations), the cultural analysis of which by the latter can contribute to the interpretation of the material record of past societies.[4] In addition to this, archaeology as a historical discipline has notably expanded its chronological boundaries over time, and multiple specialised period-specific archaeologies exist (Gutiérrez 1997: 25–88); it is worth emphasising that the data collected by physicists about a given period must be interpreted by archaeologists who specialise in that period.

Archaeoastronomy has a long tradition in some European countries, where there was an early interest in the interaction between past societies and the cosmos (Morellato 2011). The origins of the discipline go back to the late seventeenth century, [5] when a number of British antiquarians began to interpret megaliths as

[3]However, the twofold nature of the discipline has resulted in some degree of theoretical and methodological confusion and in the emergence of epistemologies in conflict (Iwaniszeski 1994: 5; 2003). For this reason, the interdisciplinary cooperation of physicists and archaeologists is essential for the appropriate data to be collected (Cerdeño and Rodríguez-Calderot 2009: 282–284; Esteban 2009: 69–77) and given a sound cultural interpretation. Some have even argued for the need to create a new professional category, that of the archaeoastronomer, in which the skills of both fields can meet (Antonello 2012; Belmonte 2009: 59); this is not impossible, but being proficient in the skills of both disciplines looks like a rather difficult task. Recent projects reflect the complexity of the issue, such as the *Journal of Skyscape Archaeology* (the publication of which began in 2015) (https://journals.equinoxpub.com/index.php/JSA), which aims to be a platform for the analysis of the archaeological record from the point of view of celestial phenomena, analysing the relationship between material culture, cosmos and society throughout history. The journal promotes a multidisciplinary perspective and encourages archaeologists to expand their horizons and include the sky in their cultural landscapes, while compelling archaeoastronomers to focus their study on the cultural interpretation of the material record.

[4]That is, archaeoastronomy would essentially be a technical discipline, a form of archaeometry, that is, a methodology which provides data to archaeologists for their subsequent interpretation (Cerdeño and Rodríguez-Calderot 2009: 279–286).

[5]During this period, archaeology was limited to the work of a number of antiquarians and their sponsors, while the earliest academies and museums began to open their doors; during this period, excavations were initiated in Pompeii and Herculaneum, and travellers began reporting discoveries

'astronomical observatories'.[6] Although the term 'archaeoastronomy' was used for the first time by Elizabeth Chesley Baity in 1973, the roots of the discipline are still a matter of debate. While such important physicists as Heinrich Nissen and Norman Lockyer (active in the late nineteenth and early twentieth centuries) could be considered as the fathers of modern archaeoastronomy, most agree that the discipline truly hatched in the United Kingdom, with Alexander Thom, a Scottish engineer who worked in England, especially at Stonehenge, from the interwar period to the 1970s.[7]

The 1980s witnessed the consolidation and growth of the discipline and the dispelling of numerous myths concerning various prehistoric 'observatories'. The discipline expanded into new geographical areas (the Balearic Islands, Sardinia, the Iberian Peninsula, America, Africa, etc.) and incorporated scholars from multiple countries (not only English-speaking), vindicating its multidisciplinary nature and demanding a space in the academic universe. In this context, the Leicester archaeologist Clive Ruggles, who re-examined Thom's data and arguments, and the Cambridge mathematician Michael Hoskin pushed for the creation, within the framework of the International Astronomical Union (IAU), of *The 'Oxford' International Symposia on Archaeoastronomy* in 1981.[8] Since its inception, this body has endeavoured to unify scientific and archaeological data and interpretations.

In the 1990s, the discipline underwent a phase of unprecedented growth, with the inclusion of yet more geographical regions and cultural horizons and with the publication of the earliest regional syntheses (Belmonte 1994; Romano 1992). This phase also witnessed the end of 'monumentalist' approaches,[9] and the

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in the Eastern Mediterranean; the earliest repertoires of antiquities were also published during this period, and J.J. Winckelmann outlined the principles of archaeological science as the history of Greek art; prehistory was barely defined as a discipline (Bianchi Bandinelli 1992[2]).

[6]John Aubrey (in 1678) and Henry Chauncy (in 1700) analysed some of the astronomical principles that governed the orientation of medieval Christian churches, while in 1740 the architect J. Wood and the antiquarian William Stukeley studied the astronomical orientation of the megalithic assemblages of Stonehenge, Sansen Circle and Callanis, among others, presenting the idea of British (and later European) megaliths as astronomical observatories. Their ideas would remain virtually unchallenged until the 1980s. On the other hand, in the late nineteenth century, the astronomers Richard Proctor and Charles Piazzi Smyth examined the astronomical orientation of the pyramids of Giza, in Egypt, inaugurating the archaeoastronomical study of the major pyramid-building cultures, such as the Egyptian and the Maya (Aveni 1991; Bauer and Dearborn 1998; Galindo 1994; Šprajc 2001).

[7]The early scientific phase of the discipline, which focused on the measurement of astronomical orientations rather than on historical and cultural interpretation, led to the creation of the *Journal for the History of Astronomy* (1970) and later of its supplement, *Archeoastronomy* (1979). Although his work has been subject to a profound revision, Thom's influence persists, and his statistical analysis methodology remains part of the basic toolkit of the archaeoastronomer (Thom 1954: 396–404; 1967; 1984: 129–148).

[8]This body has celebrated a total of 11 symposia to date. The twelfth one is scheduled for celebration in La Plata, Argentina, in 2020; see https://www3.archaeoastronomy.org/index.php/oxford-conferences

[9]An approach that, to some extent, has also hampered Classical Graeco-Roman archaeology until recent times.

consolidation of stable avenues of cooperation between astronomers and archaeologists, as illustrated by the Stonehenge-centred project directed and published in 1997 by B. Cunliffe and C. Renfrew (1997). Another important milestone was the foundation of the *Société Européenne pour l'Astronomie dans la Culture* (SEAC) (Strasburg 1993), by the astronomer C. Jaschek.[10] This was followed in 1996 by the inception of the *International Society for Archeoastronomy and Astronomy in Culture* (ISAAC), created in the United States with the aim of developing the academic presence of archaeoastronomy and ethnoastronomy;[11] the *Sociedad Interamericana de Astronomía en la Cultura* (SIAC)[12] was founded in Santiago de Chile in 2003.[13] In recent decades, these three associations have worked ceaselessly for the promotion of archaeoastronomical studies (Belmonte 2016: 93–101).[14]

Archaeoastronomy is currently a mature discipline practised worldwide, with a place in the academic arena,[15] awake to theoretical and methodological concerns, and capable of producing rigorous results. This maturity is also reflected in the publication of synthetic works such as the monumental *Handbook of Archaeoastronomy and Ethnoastronomy*.[16] Another important outcome of the growth of the discipline is the cataloguing of 'astronomical' sites, their potential recognition as

[10]It has been pointed out that the work carried out within the framework of this body focuses excessively on technical astrophysical matters and lacks archaeological interpretation; see: http://www.archeoastronomy.org/

[11]https://www3.archaeoastronomy.org/

[12]Constituted by professionals working in the astronomical and cultural fields, from the point of view of archaeoastronomy, ethnoastronomy and the history of astronomy; see: http://eacultural.fcaglp.unlp.edu.ar/

[13]Within the framework of the *Simposio de Etno y Arqueoastronomía del Congreso Internacional de Americanistas*.

[14]This work includes promoting the field in universities; the development of interdisciplinary cultural astronomy studies; the creation of links between international, regional and national experts; and the organisation of symposia, workshops and field schools, which have channelled most of the scientific activity of the discipline and have become the main arenas for debate and the presentation of results. Since 1993, the SEAC has organised 25 conferences (apart from the foundational conference, celebrated in 1992 at Strasburg Observatory); the 26th Conference SEAC, in Graz (Austria), is scheduled for August–September 2018. The SIAC has organised six field schools and five workshops. The *VII Escuela* and *VI Jornadas Interamericanas de Astronomía Cultural*, titled *Agua y Cielo*, to be held in Samaipata (Bolivia), are scheduled for October 2018. The ISAAC, for its part, is in charge of organising the aforementioned *'Oxford' International Symposia* and the publication of *Archaeoastronomy. Journal of Astronomy in Culture* (https://escholarship.org/uc/jac); this journal, which is based in the University of California, is open access and is published twice a year, coinciding with the solstices.

[15]After being recognised as a scientific discipline, the next challenge is to have archaeoastronomy regularly incorporated into teaching plans, for instance in Spanish universities (Belmonte 2009: 65; Cerdeño et al. 2006: 25–26).

[16]Edited in three volumes by C.L.N. Ruggles (Heidelberg, 2014–2015), it presents an up-to-date theoretical and methodological perspective, as well as including thematic approaches centred on specific topics such as cosmologies, calendars, navigation, orientation and alignments and ancient perceptions of space and time; the work also includes ethnoastronomical studies which focus on current 'indigenous' groups and some wide-ranging geographical and chronological case studies.

World Heritage Sites[17] and their protection by international organisations such as UNESCO and ICOMOS.[18]

In this context, the 1990s also witnessed the emergence of veritable national schools of archaeoastronomy and cultural astronomy. I want to emphasise two of them, because of the prominence that their members have gained worldwide, and because of the relevant role that they play in this volume. Two milestones stress the interest for the discipline in Spain (Belmonte 2009: 55–67; Esteban 2003a: 309–322): M. Hoskin's study of the alignment of Iberian megaliths, from the 1980s onwards (Hoskin 2001),[19] and Jaschek's time in Salamanca (1993–1999), which was a boost for the discipline in Spain and led to the organisation of various seminars (e.g. *Astronomía y Ciencias Humanas*), among which the celebration of the 1996 SEAC annual meeting in Salamanca (1996) (Jaschek and Atrio Barandela 1997) may be highlighted. This favourable context also witnessed the formation of the first (and to date unparalleled) Spanish archaeoastronomy team[20] in the *Instituto de Astrofísica de Canarias* (IAC) and the University of La Laguna (Tenerife). This team was led by the astrophysicist J.A. Belmonte and included the physicists César Esteban and Antonio César González, among others.[21]

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[17]See, for instance, the volumes published by the *International Council on Monuments and Sites* [ICOMOS] and the *International Astronomical Union* [IAU]: Ruggles (2017) and Ruggles and Cotte (2010).

[18]Archaeoastronomy will be considered a thematic area in the forthcoming *ICOMOS International Scientific Committee for Archaeological Heritage Management 2018 Annual Meeting*, to be celebrated in October 2018 in Montalbano Elicona (Sicily, Italy), under the title *Discover Sicily's Argimusco. A Holistic Approach to Heritage Management* (http://icahm.icomos.org/2018-icahm-annual-meeting-sicily/).

[19]Hoskins established important links with local teams, such as those led by M.ª L. Cerdeño and G. Rodríguez Caderot (University Complutense de Madrid), and M. García Quintela and F. Criado (University of Santiago de Compostela), and those which focused on Islamic astronomy (Belmonte 2009: 63) and the Iberian world (Esteban 2002: 81–100; and Espinosa Ruiz 2018: 265–278). See Cerdeño and Rodríguez (2009), *Arqueoastronomía* (*Complutum*, 20, 2), and especially the synthetic, conceptual, epistemological and methodological works by G. Rodríguez Caderot and M.ª L. Cerdeño Serrano, Stanislaw Iwaniszewski, Marco V. García Quintela, A. César González García and Juan Antonio Belmonte Avilés. For the international projects undertaken by these teams, see Lull (2006).

[20]http://www.iac.es/proyecto/arqueoastronomia/

[21]This team, which from the 1990s onwards undertook several projects in cooperation with other European and American colleagues, also organised the *VI 'Oxford' Symposium* (1999) in La Laguna and convened the organisation of the research group *Arqueoastronomía* within the framework of the IAC (Esteban and Belmonte 2000), whose main aim is to assess the role of astronomy in the cultural milieu of past civilisations, from prehistory to our days. The interests of the group go beyond the local perspective (Aparicio and Esteban 2005; Belmonte et al. 1995: 133–156), largely focusing on Mediterranean societies, from the Atlantic façade to the Middle East (Belmonte and Shaltout 2009), and especially the Iberian Peninsula. They have also carried out some work concerning Mesoamerican and Polynesian (Easter Island) societies. The prestigious work undertaken by this research group at the international level is of enormous importance; the analysis of such a wide variety of cultural horizons from an astronomical perspective involves the participation of experts with an in-depth knowledge of historical and archaeological sources as well as of the

In Italy, the interest in Sardinian dolmens, popularised by Hoskin in the 1980s (Hoskin and Zedda 1997: 1–16; Magli et al. 2011), progressively expanded to other regions (Puglia, Lazio, Veneto and Valle d'Aosta) (Aveni and Romano 1986: 23–31; Romano 1992). After a series of meetings convened by the *Accademia Nazionale dei Lincei*, a group of archaeologists, astronomers and practitioners of associated disciplines[22] created the *Società Italiana di Archeoastronomia* (SIA) in Milan in 2000.[23]

This volume is the result of the collaboration between Spanish and Italian scholars, which began in earnest during the *16th Conference of the Italian Society for Archaeoastronomy*, titled *Quis dubitet hominem coniungere caelo?*[24] As in previous meetings, the conference was a forum in which to continue exploring the relationship between the cosmos and human societies, from prehistory to our days. In addition, the organisers had—in my opinion—the felicitous idea of convening, in parallel with the main meeting, the *1st International Workshop on Archaeoastronomy in the Roman World*,[25] in response to an increasing interest in Classical, especially Roman, archaeoastronomy, over the previous decade.

In general, the current concept of Classical archaeology has transcended the limits of the Graeco-Roman cultural milieu. In this new social and chronological dimension, the field is also interested in the study of cultures that co-existed with the Classical civilisations, such as the Italian protohistoric societies and the Germanic peoples (Gutiérrez 1997: 51–52). Within this expanded discipline, Roman archaeology is now divided into multiple specialised fields (the diachronic study of the polity of Rome, the Italian Peninsula, the Eastern and Western provinces, etc.). It is, therefore, not unreasonable to demand the configuration of a specialised field, the aim of which would be to analyse the way Romans (and the societies that preceded and followed what we understand as Ancient Rome) related to the cosmos and

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operation of social processes (see, for instance, the following synthetic works: Belmonte 1999; Belmonte and Hoskin 2002; Belmonte and Sanz de Lara 2001).

[22]Including the archaeologist Gustavo Traversari and the astronomers Edoardo Proverbio, Giuliano Romano and Elio Antonello.

[23]The association is based in the Osservatorio Astronomico di Brera and was created with the aim of promoting archaeoastronomy, ancient astronomy, cultural astronomy and historical astronomy. These aims emphasise the inherently interdisciplinary nature of the field (Antonello 2003: 507–513); see http://www.brera.inaf.it/archeo/index.htm.

[24]The meeting was organised by the Department of Mathematics of the Politecnico di Milano (Italy) on 3–4 November 2016. The scientific committee was formed mainly from important members of the archaeastronomical communities in Italy and Spain and included E. Antonello, J.A. Belmonte, A.C. González-García, R. Hannah, M. Incerti, G. Magli, V.F. Polcaro and G. Rosada; see https://www.mate.polimi.it/sia2016/.

[25]Astrophysicists linked to important research institutions (concerning such fields as physics, astrophysics and heritage studies) are currently consolidating the field of archaeoastronomy in the European continent. Their work is analysing the relationship between architecture, landscape and mathematic-astronomical knowledge in ancient societies (especially concerning European megaliths, the prehistoric, protohistoric and Roman Mediterranean, Egypt and the Near East).

astronomical phenomena through the analysis of astronomical, archaeological and historical data.[26]

In a paper published in 2006, Cerdeño et al. (2006) carried out a bibliometric analysis of the papers published by the journal *Archaeoastronomy* between 1979 and 2002. They concluded that 31.8% of the papers dealt with European megaliths, and only 6.2% focused on the Classical period (Cerdeño et al. 2006: 20). These results are hardly representative, but reflect an emphasis—from the beginning of the discipline—on megalithism, especially in Europe. In recent years, the situation has changed substantially; as previously noted, over the last two decades archaeoastronomical studies have become much more widespread, covering almost every past human society, including Roman civilisation.

This volume, edited by Giulio Magli, A. César González-García, Juan Belmonte Aviles and Elio Antonello, follows a threefold diachronic, geographical and thematic structure. It is divided into several sections, dealing with Etruria—the earliest Italian culture during the Iron Age—and the Roman Empire (first to fourth centuries AD); special subsections address the *Urbs*, other Roman cities, the Eastern provinces and the application of computer methods to archaeoastronomy, which have led to the emergence of a new discipline: virtual archaeoastronomy.

We know that the Roman *libri vegoienses* contained instructions for the interpretation of electrical phenomena (the *libri fulgurales* and especially the *libri rituales*).[27] Antonio P. Pernigotti, an archaeologist at the Università degli studi di Milano, reassesses matters of orientation and ritual among Etruscan temples, which have been previously examined by different authors (e.g. Aveni and Romano 1994: 545–563; Prayon 1991: 1285–1295). Pernigotti aims to examine whether the orientation of Etruscan temples was random or whether they followed any rules regarding order and proportion. After measuring the azimuth and, whenever possible, the horizon height of major Etruscan sacred structures (28 temples in 10 different locations, 9 in Etruria and 1 in Tuscia)—and finding errors in previous measurements—Pernigotti relates the data with the chronology of, and the deity worshipped in, each temple, in order to determine possible patterns in the orientation of the temples. Based on his results, Pernigotti argues that Etruscan temples were oriented according to the Sun, rather than to the celestial dwellings of the deities (known after Martianus and the famous Bronze Liver of Piacenza). With some exceptions, temple facades were not oriented towards the dawn, and their *cellae* were not illuminated by solar rays; instead, there seems to have been a function between orientation and specific deities (Uni, Vea, Hercules ...).

[26]The inclusion of several Roman-centred case studies in the *Handbook of Archaeoastronomy and Ethnoastronomy* (e.g. González-García and Magli 2014: 1643–1650) demonstrates the consolidation of this discipline, which is also illustrated by this volume.

[27]According to Festus, these were "Etruscan books which prescribe rituals for the foundation of cities and the consecration of altars and temples, the blessing of walls and the norms to distribute city gates and organise tribes, curiae, and centuriae; to organise armies and all else that pertains to war and peace." (Festo, *Rituals*). See Bagnasco et al. (2013) for a recent account on how these texts might be related to the orientation of the sanctuary of Tarquinia. AU2

G. Bagnasco Gianni (specialist in Etruscan epigraphy in Università degli studi di Milano) combines Etruscan and Roman rituals related to the foundation of cities (Briquel 2008: 27–47; Rykwert 1988) and some cosmological principles of the Etruscan religion to re-examine (Bagnasco Gianni and Facchetti 2015: 27–56; Bagnasco Gianni et al. 2016: 253–302) the Tumulus of the Crosses, in Cerveteri, in whose corridor an Orientalising inscription containing the names of various divinities inside a celestial quadrant and a *siglum* formed by a cross inside a circle was found. The pictogram is divided into 16 regions, one for each deity, as also reflected in the previously noted Liver from Piacenza. Based on the differences and similarities between the information conveyed by the Liver and other written sources (especially Pliny and Martianus), Bagnasco Gianni concludes that the north-western orientation of the wall associated with the access ramp, where the inscription was found, allows for the beginning of the sequence of divinities mentioned in the Liver (and Martianus) to be established in the north-eastern quadrant. As such, the division of the Liver which contains the expression *Tin Ciles*, to the east of the division which contains the expression *Ciles* alone, could signal the increase in sunlight (*Tin*) that follows the sunrise at the summer solstice.

Concerning the Early Imperial period, some attention has been paid over the last decade—by Magli, Belmonte and González-García, among others—to the astronomical orientation of cities and buildings, especially in Italy and the western provinces, in relation to rituals and government propaganda.[28] Deliberate sunlight effects, as a way to stress hierophanies, most prominently found in the northern sector of the *Campus Martius* and in the triangle formed by the *Ara Pacis*, the *Horologium* and Augustus' Mausoleum (Buchner 1976; Hasalberger, 2014; Rehak 2006), can be attested in many more constructions in both Rome[29] and other regions.[30] Three case studies are analysed in this volume—specifically, in the sections dedicated to the *Urbs*, virtual archaeology and archaeoastronomy. A team integrated by V.F. Polcaro, S. Sclavi, S. Gaudenzi, L. Labianca and M. Ranieri (from the Universities of Ferrara and Roma La Sapienza and the Soprintendenza Archeologica di Roma) reassess (Labianca et al. 2008) the study of the so-called Neo-Pythagorean basilica of Porta Maggiore, an underground complex dated to the first century AD and located in the city suburbs. The complex has been interpreted as being related to Neo-Pythagorean cults, or otherwise as the funerary mausoleum of the consul *T. Statilius Taurus*. The evening sunlight penetrated the complex through a skylight in the vault of the vestibule (this was especially intense around the summer solstice) and, less directly, through a window in the main nave, projecting a point of light upon an altar. The authors argue that, by placing a light-reflecting surface on the

[28]Bertarione and Magli (2015); Esteban (2003b); Espinosa-Espinosa and González-García (2017); Ferro and Magli (2012); García Quintela and González-García (2014: 157–177); González-García and García Quintela (2014); Magli (2008: 63–71); Magli et al. (2014); Rodríguez-Antón (2017).

[29]For instance, in the Neo-Pythagorean basilica in Porta Maggiore, the Mausoleo degli Equinozi in the Via Appia (De Franceschini 2012), the Pantheon (Hannah and Magli 2011) and Adrian's mausoleum (De Franceschini and Veneziano 2015).

[30]For an illustrative example from Spain, see the studies about the orientation of the sanctuary of Torreparadones (Córdoba) (Abril Hernández and Morena-López 2018: in press).

altar, this point of light would fall upon a painting interpreted (not without some doubt) as the 'Rape of Ganymede'. According to the authors, this hierophany would be at the centre of the rituals celebrated in the complex.

Based on an allegorical interpretation of a text by the Neo-platonic philosopher Porphyry, who—inspired by the Mithraic mysteries—assimilated the nymphs' cavern described by Homer (Od. 13.102–112) to the cosmos, R. Hannah (University of Otago, New Zealand) suggests that solar equinoxes were points of balance in which gods and (deified) emperors were enthroned and that northern and southern solstices opened 'passages' for the transit of souls. According to Hannah, these ideas found reflection in public architecture, in which domes were used to represent the cosmos. The Pantheon, rebuilt in the centre of the *Campus Martius* during Hadrian's reign, was originally an *augusteum* and a temple consecrated to the divine pantheon, but later it was also used to determine the agricultural cycle, and its interior operated as a giant sundial (*hemiciclum*); on the equinoxes, at noon, the Sun entered the building and fell above the entrance, and this also happened on anniversaries meaningful to Imperial propaganda (e.g. 21 April, the day of the foundation of Rome). This use of light can also be attested in Nero's *Domus Aurea*; several poetic and historical sources recount that the entrance to the Octagonal Room was hit by sunlight on the equinoxes, also at noon (Hannah et al. 2016). Some evidence suggests that these effects were similarly used in Domitian's palace, in the Palatine. Finally, Hannah tries to picture the celebration of these hierophanies, based on the analysis of a number of Eastern Byzantine churches; in these churches, geometry, light and cosmology were used to provide light effects for solemn parades and processions, as a symbol of the divine will. According to Hannah, these light-infused rituals could be inspired by, and provide evidence for, Imperial ceremonies, also known to have taken place in Villa Adriana (De Franceschini and Veneziano 2013).

Finally, the effect of sunlight on the Mausoleum of Santa Constanza, dated to the second half of the fourth century AD and located in the archaeological complex of Sant'Agnese fuori le Mura in Rome (Rasch and Arbeiter 2007), is examined for the first time, in this volume. Based on the Mausoleum's azimuth, calculated with satellite technology, Flavio Carnevale and Marzia Monaco, from the Università degli studi di Roma La Sapienza—who have also made interesting contributions to the study of the orientation of Greek theatres, Etruscan funerary *tholoi*, the *Portunnus* temple in the Forum Boarium of Rome and the Mithraea of Ostia Antica—have attested two phenomena: (1) after the construction of the skylight (late fourth century), the Sun illuminated the interior between 8 and 25 February, during the festival of the *Parentalia*; this heliophany was similar in character to that attested in the Pantheon every 21 April; and (2) the sunlight would hit directly the centre of the Mausoleum, where the porphyry sarcophagus of Costanza was originally located.

The foundation of Roman cities and buildings was rooted in mythology, and religious formulae were essential for the projection of the celestial order upon the landscape and the spaces ritually arranged by the magistrates (Rykwert 1988). Various research projects, especially in the western provinces, have analysed the orientation of cities (an issue already mentioned by various classical authors such as

Hyginus Gromaticus [*Constitutio*, I] and Frontinus (*De Agrimensura*, 27]), the methods used to calculate these orientations and their symbolic meaning. This method, along with other similar practices, became especially popular during Augustus' reign and has been thoroughly studied in Hispania and the western provinces by the members of the archaeoastronomy team of the IAC (Belmonte et al. 2016: 65–77; González-García 2015: 141–162; González-García, et al. 2014: 107–119). Several members of this team (A.C. González-García, A. Rodríguez-Antón, and J.A. Belmonte), in cooperation with D. Espinosa-Espinosa and M.V. García, analyse the landscape of western Augustan cities (measurements have been taken in 64 of these cities, in Hispania, Gaul, Germania, Italy and North Africa). These measurements are compared with the celestial landscape, and increasingly clear orientation patterns have begun to emerge. The evidence suggests a preference for orienting cities towards dawn on the winter solstice and, to a lesser extent, on the equinoxes and the summer solstice. The study also aims to define with more precision than has been possible hitherto the 'solar model' that identified Augustus with the Sun and Apollo, a relationship that the *princeps* used regularly for propaganda purposes. Also in relation to this, several of these authors (A. Rodríguez-Antón, A.C. González-García and J.A. Belmonte), this time in cooperation with M. Orfila (archaeologist at the University of Granada), address the use of the geometric measurement technique known as *varatio* (Orfila et al. 2014). Based on measurements taken on 81 Iberian cities, it is concluded that this technique may have been used to calculate azimuths. However, the authors admit that, although it may be argued that *varatio* was used in order to organise urban and rural landscapes, which would indicate a direct link between technique and symbol when celestial phenomena were not available for direct observation, a larger sample of case studies is necessary.

The eastern provinces, which were thoroughly Hellenised and which maintained strong links with the Near East, have also been analysed from an archaeoastronomical perspective. These studies, which have been particularly intense in the Mediterranean Levant and Egypt, generally focus on the orientation of architectural features and the occupation of the landscape. Again, the team from the IAC, led by Belmonte, González-García and Rodríguez-Antón, analyse the so-called Khirbet et-Tannur Zodiac (Hurawa), which they suggest should be relabelled as an 'almanac' or 'parapegma'. This feature was found on the main altar of the sanctuary of Djebel Tannur (Jordan) (*Arabia Adquisita*) and depicts an impressive astral cycle dated to the Roman period. Despite the persistence of Nabatean traditions, Roman domination led to the adoption of the Julian calendar in the region, although the different months were still named after the lunisolar Nabatean calendar. This is the origin of the so-called *Era Provincia Arabia*. In this volume, the feature is interpreted as a calendric guide to the rituals celebrated in the sanctuary, and the measurements indicate that it was oriented towards dawn three days prior to the spring equinox, on 22 March, that is, day 1 of Nisan (New Year's Day in the Arabian Calendar). This could mean that the complex was regarded as a national sanctuary and the destination of the pilgrimage of Djebel Tannur. A small temple in Petra, erected between AD 106 and 114, and dedicated to the imperial cult, presents the same orientation (Belmonte and González-García 2017), suggesting the capacity of the Nabateans to adapt to the Roman domination.

In the following chapter, G. Magli undertakes the study of the orientation (which has not been measured to date) of the temple *podia* of the megalithic sanctuary of Jupiter in Heliopolis (Baalbek, Lebanon) (Kropp 2009; 2010; Segal 2013). The Sun aligns with the temple on 1 May and 12 August, dates with no special implications in the solar cycle, which could challenge the solar associations of the temple. However, Magli's results indicate that the temple was aligned with the Pleiades (the Seven Sisters) during the reign of Herod the Great, which could confirm the temple's association with Jupiter and the agricultural cycle. Magli also suggests that both *podia* may have been built at the same time, during the reign of Herod the Great.

C. Rossi and G. Magli undertake an analysis of Late Roman fortified settlements in Egypt's Western Desert (Rossi and Ikram 2018), which illustrate how Romans interacted with the landscape, following well-known precepts by such authors as Pliny and Vitruvius. These settlements seem to have been oriented towards the dominating winds, from the north-west, the azimuth of which was calculated by measuring the axial axles of the surrounding sand dunes. It is unclear whether this 'weathervane orientation' responds to pre-Roman traditions or whether it answers to astronomic concerns and the desire to adapt as much as possible to local environmental conditions (wind, topography, etc.).

Finally, two chapters analyse the use of computer applications and virtual archaeology, a useful combination for the analysis and dissemination of the historical and archaeological features of ancient buildings. The first of these chapters addresses the virtual reconstruction and archaeoastronomical analysis of the Mausoleum of Theoderic, in Ravenna, built during Theodric's reign and heavily transformed from the eighth century onwards. After examining the original elements, M. Incerti, G. Lavoratti and S. Iurilli (architects at the Università degli studi di Ferrara) explain the development of a 3D model of the exterior and interior of the building and use its astronomical orientation (measured in 1995 by G. Romano) to analyse the effects of sunlight at different times of the year. Specifically, light entered through some of the windows on the solstices, illuminating important elements in the interior, including the red porphyry sarcophagus. As noted in the introduction to R. Hannah's chapter, above, this kind of light effect was a common way to highlight special dates or times of the day. In addition, the geometrical study of the Mausoleum revealed that, rather than the mathematical calculations conveyed by *De Geometria*, attributed to Boethius, the architect of the Mausoleum used the geometrical tools contained in Euclid's *Elements*. The results also suggested that the builders of this monument occasionally used the Roman foot, although the standard measurement unit in the building was the Byzantine foot.

Finally, G. Zotti, B. Frischer, F. Schaukowitsch, M. Wimmer and W. Neubauer, who work on generating 3D models of archaeological buildings and features (Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology de Vienna, Indiana University and the Institute of Computer Graphics and Algorithms of Vienna), are currently giving the final touches to the software *Stellarium*, which will present these buildings and features in relation to celestial bodies. The result of this project is the so-called *Skyscape Planetarium*, which presents the relationship between the Earth's landscape and the sky in an accessible way. The tool can simulate the astronomic relationships of buildings with total precision, showing orientation patterns and sunlight and moonlight effects (Zotti 2015).

These tools, which were publicly displayed with great success in the exhibit *Stonehenge. A Hidden Landscape*, celebrated in 2016–2017 in the MAMUZ Museum (Mistelbach, Austria), have also been applied in two 'Roman' projects: (1) the study of the astronomical orientation of the *Antinoieon*, in Villa Adriana (Frischer et al. 2016: 55–79), which has confirmed Mari's initial theses (Mari and Sgalambro 2007: 83–104) that the so-called Temple 1 is oriented towards dawn, on the summer solstice (festival of *Fors Fortuna*), and towards the constellation of Antinoo, the heliacal configuration of which occurs around the birthday of Hadrian's unfortunate lover, and (2) the analysis of the relationship between the *Ara Pacis* and the *Horologium* (Frischer et al. 2017: 18–119; Frischer 2017–18, 3–100), which has identified the mistakes upon which Buchner's (1976: 19–65) famous hypothesis was built, and has determined that the shadow of the obelisk did not run along the equinoctial line across the central area of the altar on Augustus' birthday; the emergence of the Sun over the top of the obelisk, on the other hand, has been confirmed, which reinforces the idea that the obelisk was dedicated to the Sun, already suggested by the epigraphic evidence.

There is little doubt that these works will notably contribute to the consolidation and dissemination of Roman archaeoastronomy, while highlighting the central role played by astronomical observation and celestial phenomena for the Romans, a key factor for the symbolic and mythical aspects of their society.

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Preface

In the last decade, there was increasing interest in the archaeoastronomy of the Roman epoch and many researches were carried out on this topic. Several studies have been devoted to the possible astronomical orientation of buildings—including the light effects with symbolic meaning—to the astronomical symbolism of the artefacts, and to the possible astronomical orientation of towns. Therefore, the time was more than ripe for a meeting dedicated specifically to 'Roman' archaeoastronomy. In 2016, the opportunity was offered by the Politecnico of Milan, Department of Mathematics, where the International Meeting on the Archaeoastronomy in the Roman World took place from 3 to 4 November. The meeting was followed by the Annual (XVIth) Conference of the Italian Society for Archaeoastronomy (SIA).

This volume includes a selection of the papers presented in that event organised into parts and chapters. Part I is devoted to the Etruscan Civilisation, from which Romans took several ideas. This includes two chapters that centre on an analysis of temples and on how the cosmology of the Etruscans was related to their funerary customs. In Part II, the orientation and solar light effects at given dates are considered for the Imperial buildings in Rome. One paper deals with the motivations of the symbolic use of equinoxes and solstices during the Imperial period, and two chapters illustrate the possible light effects in two monuments: the Basilica of Porta Maggiore and the Mausoleum of Santa Costanza. Part III is dedicated to the orientation of Roman towns, with a paper on a statistical analysis of a large set of sites, from central Europe to northern Africa, while another paper describes the possible use of a practical geometrical tool for planning the orientation of an urban grid. Two chapters in Part IV illustrate the astronomy in the provinces of the Empire under the influence of Roman rule. The first chapter proposes a new interpretation of the Tannur Zodiac (Nabataea) as a 'parapegma', and the second one discusses the chronology of the complex realisation of the Temple of Jupiter at Baalbek. The case of the Kharga oasis in Egypt is discussed in the third chapter, where the importance of the wind direction for the settlement is pointed out, while the fourth chapter is dedicated to the architectural and geometrical analysis of the Mausoleum of Theodoric. Finally, in Part V the chapter describes the capabilities of the open source system Virtual

Archaeoastronomy within the Stellarium software, intended for research and outreach, and shows some examples of its application to Roman monuments.

Etruscans, people who '... excelled everyone in religious observance ...' (Livy 5.1.6), had a strong influence on political ideology and related rituals in the Roman world. The *Libri Rituales* of the *Etrusca Disciplina* also included the *Libri Fatales,* which probably contained the Etruscan founding rituals of cities and temples adopted by the Romans. The Etruscans gave large importance to the exact location of the cardinal points. According to Hyginus Gromaticus (first to second century CE), those points were the paradigm also for Romans, as regards at least (theoretical) land division. In the practical realisation, however, the Romans quite often adopted other criteria. For example, they usually took into account the physical characteristics of the places (e.g. rivers), or they used a simplified procedure to determine the East direction (and Hyginus showed why it could be erroneous). Vitruvius (first century BC), on the other hand, suggested a practical criterion for the town orientation based on the wind direction, since he was concerned mainly with the healthiness of the inhabitants, while he maintained the cardinal orientation for temples, when possible.

Things probably changed in part when Augustus introduced the (solar) cult of the Emperor. One may note in passing that he began this process with the divinisation of Julius Caesar in 44 BC by exploiting also an astronomical phenomenon, a comet that happened to appear during the period of the obsequy. It may be possible that astronomical criteria based on the sunrise at *specific* dates were then adopted for towns, temples and buildings. Many towns may be considered in this respect, since, as declared in the *Res Gestae*, Augustus settled colonies in Africa, Sicily, Macedonia, Spain, Achaea, Asia, Syria, Gallia Narbonensis and Pisidia, while Italy had 28 colonies founded under his auspices. Unfortunately, Augustus did not include the list, and historians tried several times to identify them (see e.g. Mommsen). As shown by inscriptions (e.g. OGIS 458), Oriental populations of the Roman Empire were keen to worship the Emperor (*Sebastos*). The positive attitude towards his divinity increased during the first centuries CE; for example, there are Roman coins with the representation of the Emperor as *sol invictus*. Several researchers have pointed out the light effects corresponding to solstice and equinox dates in Roman buildings of this epoch and connected in some way with the Emperor. Light effects based on specific astronomical orientations probably also were adopted later, but of course with a different meaning, for the Christian buildings.

A subtitle of the 'Joint 16th Conference of SIA and 1st International Workshop on Archaeoastronomy in the Roman World' was a quotation from Manilius' poem *Astronomica* (II.105)

> Quis dubitet [post haec] hominem coniungere caelo?,

that is, who can doubt that a link exists between heaven and man? Manilius was contemporaneous with Augustus and Ovid. In his poem, he described celestial phenomena, the zodiac and the related astrology. He and presumably many other people thought about cosmic harmony and the immanent divinity of nature. He wrote that into the soul of man God descends and seeks Himself and that the love of heaven makes us heavenly. Given that strong belief, it is therefore reasonable, not to say obvious, that present-day researchers would attempt to detect the expressions of such an astronomical link in ancient Roman artefacts and architecture, putting their results in archaeological and historical context. One can expect therefore further progress in this field.

Sadly, during the editing of these proceedings, we got the dismaying news that our colleague and friend Vito Francesco Polcaro passed away. Francesco was a polymath. He got three degrees, in mechanical engineering, aerospace engineering and mathematics; his scientific researches were mostly in high-energy astrophysics and technology, and in the astrophysics of the highest mass stars, but he also had deep interest in cultural astronomy, archaeoastronomy and archaeology. He collaborated with many professional and amateur archaeologists in the study of the astronomical content of ancient sites and artefacts, particularly in Rome and in Southern Italy. He regularly attended SIA and SEAC meetings, and he contributed actively to the organisation of several of our conferences. He was an enthusiastic man who believed passionately in science-led regulation and in the importance of the social aspects of science. Many people in primary and secondary schools and in cultural associations enjoyed his brilliant outreach talks. This volume on archaeostronomy in the Roman World is dedicated to the memory of Francesco.

As a final acknowledgement, we warmly thank the Politecnico of Milan for their hospitality and help with the organisation of the conference.

Merate, Italy Elio Antonello AU6

Contents

Part I Etruscan Temples and Cosmology

1 A Contribution to the Study of the Orientation of Etruscan Temples 3
Antonio Paolo Pernigotti
Previous Studies on the Orientation of Etruscan Temples 4
The Orientation of Etruscan Temples 7
Concluding Remarks 13
References 13

2 Notes on Etruscan Cosmology: The Case of the Tumulus of the Crosses at Cerveteri 17
Giovanna Bagnasco Gianni
A Case Study: The Tumulus of the Crosses and Its Inscriptions 17
The Epigraphic and Textual Evidence 19
The *Siglum* Formed by a Cross Inscribed in a Circle 20
What Does the Case Study Depict? 21
Connections Between Literary Sources and the Liver 22
Differences Between the Liver, Martianus and Pliny 23
Discussion of the Epigraphic Layout of the Liver 26
The Evidence of the Tumulus of the Crosses Compared with That of the Literary Sources and the Liver 30
References 32

Part II Rome

3 The Orchestration of Time in Ancient and Medieval Buildings 37
Robert Hannah
Introduction 37
The Mysteries of Mithras 38
Rome: The Pantheon 41

Rome: Nero's Domus Aurea 46
Rome: The Palace of Domitian 49
The Orchestration of Time 50
References 54

4 The So Called Neo-Pythagorean Basilica of Porta Maggiore in Rome: The Most Mysterious Roman Monument 57
V. F. Polcaro, S. Sclavi, S. Gaudenzi, L. Labianca, and M. Ranieri
The Monument 58
The Basilica Decoration 58
The Hypotheses on the Use of the Basilica 61
The Archaeoastronomical Analysis 63
Conclusions 65
References 65

5 The Mausoleum of Santa Costanza in Rome: A Survey of the Light Phenomena Through the Centuries 67
Flavio Carnevale and Marzia Monaco
Introduction 67
Methodological Approach 72
Orientations 72
The Mausoleum of Constantina 73
The Constantinian Basilica 75
The Honorian Basilica 75
Discussion 78
Conclusions 80
References 80

Part III Roman Towns

6 Establishing a New Order: The Orientation of Roman Towns Built in the Age of Augustus 85
A. César González-García, Andrea Rodríguez-Antón, David Espinosa-Espinosa, Marco V. García Quintela, and Juan Belmonte Aviles
Introduction 85
Our Hypothesis 87
Methodology 89
Results 93
Discussion and Conclusions 97
References 100

7 The *Uaratio* and Its Possible Use in Roman Urban Planning to Obtain Astronomical Orientations 103
Andrea Rodríguez-Antón, Margarita Orfila Pons, A. César González-García, and Juan Belmonte Aviles
Introduction 104
The *Uaratio*: A Proposal for Its Implementation 105
Sample and Methodology 107
Testing the *Uaratio* on Roman Settlements 108
A Possible Link Between *Uariationes* and Astronomical Positions 114
Discussion 116
Conclusions 117
References 118

Part IV Roman Provinces

8 *Arabia Adquisita*: The Romanization of the Nabataean Cultic Calendar and the Tannur 'Zodiac' Paradigm 123
Juan Belmonte Aviles, A. César González-García, and Andrea Rodriguez-Antón
Introduction: A Nabataean Cultic Calendar? 124
Inspiring Astral Deities in the Nabataean Realm and Their Festivals . . . 127
Land- and Skyscape in Petra: The 'Winter Solstice' Pilgrimage 130
The Twin Temples of Tannur (Hurawa) and Dharih (Aïn Al-La'aban) 132
Khirbet-et Tannur's New Paradigm: Zodiac vs. Almanac 136
Final Discussion and Conclusion 142
References 143

9 The Archaeoastronomy and Chronology of the Temple of Jupiter at Baalbek 145
Giulio Magli
Introduction 145
Archaeoastronomy at Baalbek 147
Discussion and Concluding Remarks 149
References 151

10 Wind, Sand and Water: The Orientation of the Late Roman Forts in the Kharga Oasis (Egyptian Western Desert) 153
Corinna Rossi and Giulio Magli
Introduction 153
The Late Roman Settlements in Northern Kharga 155
Orientation(s) 156
Discussion: A 'Weathervane Orientation'? 161
Concluding Remarks 163
References 164

Part V Roman Virtual Archaeology and Archaeoastronomy

11 The Mausoleum of Theodoric: Archaeoastronomy, Numbers, Geometry and Communication 169
Manuela Incerti, Gaia Lavoratti, and Stefania Iurilli
Introduction: The Foundation and the Main Topics 169
A Description of the Mausoleum 170
The Architectural Survey 173
Archaeoastronomical Analysis 174
The Interactive Models for the Dissemination of the Research Project 176
Numbers and Geometry 178
The Decagon and Boethius 182
Conclusions 183
References 184

12 Virtual Archaeoastronomy: Stellarium for Research and Outreach 187
Georg Zotti, Bernard Frischer, Florian Schaukowitsch, Michael Wimmer, and Wolfgang Neubauer
Introduction 187
An Open-Source System for Virtual Archaeoastronomy 189
The Scenery3D Plugin 189
Improvements for Astronomical Demonstrations 193
Outreach Result: The Skyscape Planetarium 193
Two Applications of Stellarium to Roman Archaeoastronomy 196
References 204

Author Queries

Chapter No.:	448561_1_En

Query Refs.	Details Required	Author's response
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AU2	Ref. "Bagnasco et al. 2013" is cited in corrections provided for footnote 27, but not provided in the reference list. Please provide details in the list or delete the citation from the text.	
AU3	The word "hyerophany" has been changed to "hierophany". Please check	
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AU6	Please check whether the City name retained as "Merate" instead of "Milan" is appropriate.	

Chapter 11
The Mausoleum of Theodoric: Archaeoastronomy, Numbers, Geometry and Communication

Manuela Incerti, Gaia Lavoratti, and Stefania Iurilli

Abstract The following paper focuses on the Mausoleum of Theodoric (520 ca.), one of Ravenna's Byzantine monuments and a UNESCO heritage site, presenting the results of different phases of research that begun in 2015. Starting from the instrumental survey carried out with laser-scanner and digital photogrammetry technology, the unit of measurement and the geometric properties of the decagonal shape of the design of this singular two-level building were analysed. The archaeoastronomical study has highlighted possible meanings of the orientation of the building and the positioning and sizing of small wall openings. Finally, a 3D model was developed from the survey data to verify the astronomical phenomena and to aid in the multimedia communication of the scientific content. It is increasingly clear how virtual models, both interactive and non-interactive, constitute an important edutainment tool. This element is indispensable to the development of contemporary methods of dissemination for the fruition of cultural sites and artifacts.

Introduction: The Foundation and the Main Topics

The historian known as *Valesiano* documents that the Mausoleum of Theodoric was commissioned by Theodoric himself before his death on AD 30 August 526 (Muratori 1738). Theodoric (Teodorico) was born around 454. 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; however, it is undeniable that during his kingdom he showed great attention to architecture. This is testified by the restoration of ancient buildings in Rome and the construction of new buildings in Verona, in Pavia and, above all, in Ravenna.

The Mausoleum was developed on two levels: the ground floor has a decagonal plan in external profile and a Greek cross interior, while the upper floor has a

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decagonal exterior and a circular interior space. Like all monuments in Ravenna, the building has been the object of specialized studies and surveys (Bovini 1977; Gotsmich 1958; Guberti 1952; Haupt 1913; Heidenreich and Heinz 1971; Johnson 1988). In its long history, the small, central plan Mausoleum has been the object of multiple transformations and restorations, such as those of the eighteenth, nineteenth and twentieth centuries (Conti and Berti 1997; Guberti 1952: 8–19). The last interventions date back to 1977 (Bovini 1977: I–XV; Piazza 2013: 84–86; from the same volume see Novara 2013: 111–116) and 1998, the year in which the restoration of the stone of Aurisina took place (Bevilacqua et al. 2003; Piazza et al. 1998).

In the present study deeper discussion will relate to elements of the architecture and topics concerning the form and orientation of the building. It is thus particularly important to verify the authenticity and the dating of the elements involved in the analysis to avoid erroneous interpretation of the data.

A Description of the Mausoleum

The Question of Its 'Unfinished' Nature

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 the 'unfinished' and the possible different dating of the two levels introduced by some authors does 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 by De Angelis d'Ossat (1962, with very accurate graphics), never involve the openings but only address the presence and shape of the portico, which is lower compared to the system of windows.

The Flooring

The current flooring of both rooms is certainly not original: in 1557 Leandro Alberti mentioned traces of a mosaic floor, evidently on the upper level of the building, as the bottom was buried underground (Fagiolo 1972: 148–149). Regarding the progress of the flooring 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 has 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 'levelling' the already installed plan, which however, later experienced another slight lowering.

The existing pavements were put in place during the works of the biennium, in 1975–1977 (Novara 2013: 116). The current floors of the two levels are more or less horizontal (with an incline of a few centimetres). One can still see the signs of the collapse by looking at the slight inclination of the band present in the tambour of the dome (the quotes and sources of the surveys can be found in Guberti (1952: 37, 56–58).

The Small Apse

On the eastern side of the top space there is a small apse, whose function many historians have questioned: 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, highlighting 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 with the building (De Angelis d'Ossat 1962; Messina 1980: 128–129).

The Sarcophagus

According to tradition, the remains of King Theodoric were conserved in the great sarcophagus of red porphyry measuring 305 × 190 × 101 cm. The tub is characterized by four rings on the top edge and two lion's heads at the bottom center of the side faces. The sarcophagus' troubled history has been well documented, its movements traced by Ambrogi (1995: 109–111) recalling its relocation to the site in 1913.

There is no certainty regarding the original orientation of this object, which is, however, considered by scholars to be consistent with the building, and originally arranged in an east-west direction (the current one).

The Small Windows

The wall of the ground floor has a thickness of about 140 cm and is pierced by six splayed narrow slits arranged on three sides (two on the north wall, three on the east wall and two on the south wall) with approximately horizontal intrados. Their sizes vary in width from 11 to 25 cm, and in height between approximately 40 and 70 cm. The decagonal part of the upper level presents a central receding band, about 77 cm thick and perforated by 11 windows. Arranged approximately 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. These windows are almost unanimously considered contemporary with the founding of the building, excluding the rectangular south-western one which was clearly enlarged at a later date (Guberti 1952: 94; De Angelis d'Ossat 1962: 59).

Keeping the axes of the openings described above in mind, 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 three different levels have recently been found (Novara 2013: 116, see also 85; Piazza 2009). These were investigated and restored in 2012 (but the results have yet to be published).

The Dome

The great monolith that covers the building has also been subject to a great number of specialized studies, which have investigated physical, technological, figurative, historical and design aspects (e.g. see Bianco Fiorin 1993; Dyggve 1957; Fagiolo 1972; Tabarroni 1973).

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

Twelve protruding elements with triangular perforations are present on the outer edge of the roofing, conveying the image of a 'royal crown'. Historians have often questioned the real function of these elements and their figurative origin (Fagiolo 1972). The assumption is that they were used for the passage of cables and ropes necessary for the positioning of the roof, as hypothesised by Antonio da Sangallo in a previously published drawing (see Heidenreich and Heinz 1971: 63, Fig. 65), may be considered unfounded because of the enormous weight of the monolith and the common technical operations 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 has 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 faces of the elements in a sequence (from the door, clockwise): Lucas, Marcus, Mathias (?), Matteus, Felippus, Johannes, Jacobus, Andreas, Paulus, Petrus, Simeon, Thomas. The reasons for this particular sequence have been widely investigated (Fagiolo 1972; Heidenreich and Heinz 1971; Tabarroni 1973). All elements are finished with a gable roof, almost simulating a small sarcophagus, except for one: that of Petrus has a flat roof. This has led researchers to believe in the existence of a terminal element made of a different—and perhaps more valuable—material (which then went missing), highlighting the figure of Petrus, the founder of the Church (Tabarroni 1973: 141).

The Architectural Survey

The architectural survey was carried out by M. Incerti and P. Lusuard with a Faro focus3d scanner. Thirty different survey stations were established covering the interior and exterior of the building. Individual clouds were registered with the aid of spherical targets (software for data management *Scene 5.3*, data elaborated by M. Incerti).

At a later date, two different photographic campaigns were carried out for the reconstruction of the three-dimensional textured model (M. Incerti): the first relating to the exterior, the second to the interior. The exterior shots were taken with a compact Lumix DMC-TZ7. The interior shots, due to matters of critical illumination, were produced with a digital SLR camera on a tripod. The upstairs photography was particularly problematic, as the view was obstructed by a railing which inevitably projected into the wall surface. It was also difficult to address the problem of backlighting generated by the perforated doors with cross motifs, as was the issue of artificial lighting, which created disruptive shadows.

Survey Drawings: Methods and Procedure

The thirty clouds available produced a dense pointcloud with rather limited bands of occlusion (the absence of this data is only found in small portions of the building where the height of the scanner failed to balance the overhanging parts of the structures).

For the creation of the two-dimensional canonical drawings (plans, elevations and sections), used to effectively describe dimensions and geometries, the point cloud model was divided by horizontal and vertical planes. A thin slice (thickness of 1 cm) was extracted from the cloud for each cut-plane as well as high definition screenshots. By importing the slice with vectorial software by interpolation of the points on a 1:1 scale, and exported for the realization of definitive raster images 1:50 scale. The choice of using a 'slice' of such reduced points yet still obtain a sufficiently detailed section was possible thanks to the particular density of the pointcloud, which provided a high degree of detail even on particularly elaborate portions such as the shell decorations on the interior brackets. The screenshots, mosaicized in order to achieve a high definition end result, allowed accurate control over the size and even deformations of elevation orthophotos produced by the digital photomodelling software, enabling the correct adjustments of projection elements.

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 scientific world, ensures greater metric control of the architecture (through comparison and contamination of drawings obtained through different processes, distinct survey campaigns and different instruments). It also allows for detailed graphics containing material and chromatic information that a traditional survey would not have been able to capture.

Archaeoastronomical Analysis

The Orientation

The Mausoleum has also been subject of archaeoastronomical research conducted by Giuliano Romano, who measured its orientation (Azimuth 84.5°; Romano 1995). The building is rotated by 5.5° compared to the equinoctial direction, which should not be overlooked during the alignment operations. Despite this apparent irregularity and approximation of the directions of the axes, an in-depth study of the consequences of these data seemed of interest.

Following the correction of the slight rotation, the survey methodology involved specially processed survey drawings. By overlaying graphics to the four main astronomical directions (solstices and equinoxes), the small windows placed in the 45° directions 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.

The Windows

Only three of the seventeen windows, those on the north side (two downstairs and one on the top floor) do not receive significant sunlight. All of the others are involved in important moments of the astronomical year. The behaviour of sunlight on horizontal and vertical surfaces was analyzed through plans and sections. Height and azimuth angles were traced to the ephemeris through specific software. Among the phenomena we noted (Fig. 11.1) that:

1. The rising Sun entered the cross-shaped window (second floor) on the days of the equinoxes, illuminating the previously mentioned thin band with painted writing on the axis of the cell. On the day of the summer solstice, about an hour after sunrise, the spot of sunlight passed over the stone sarcophagus.
2. The Sun entered the four narrow windows on the door (second floor) at sunset on the days of the equinoxes, illuminating the same scripted band. For other examples, see Incerti et al. (2016).

Phenomena of this kind may have been used for ritual purposes (see Fagiolo 1972, and the chapter by Hannah in this book), but also to mark the advent of a particular date in the year, or for the computation of time: in other words, to indicate a precise moment of the day (sunset, in this case).

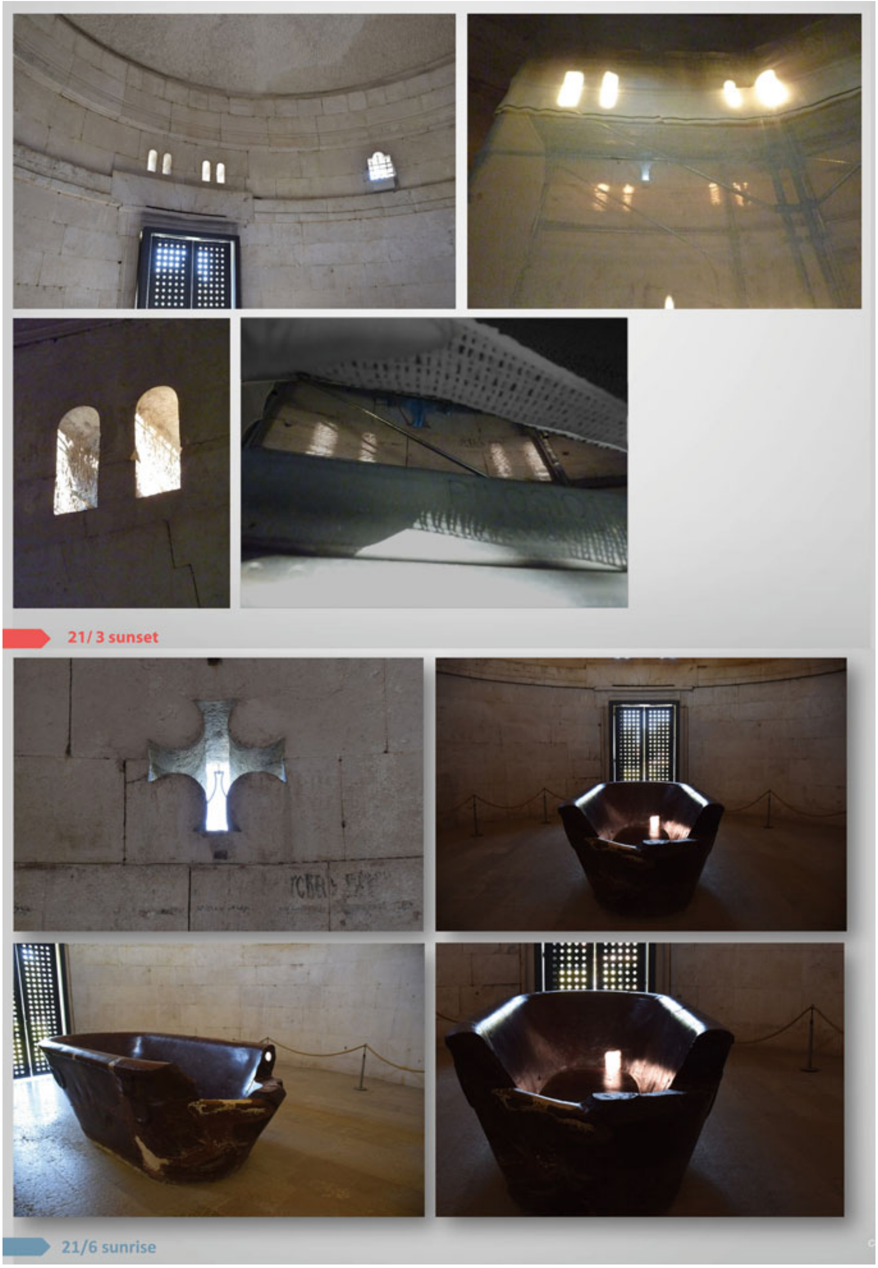

Fig. 11.1 Photographs of the effects of light (21/3 sunset, 21/6 sunrise)

The Dome

The results of our survey allowed us to verify that the arrangement of the protruding elements does not follow the directions of the decagonal geometry, but the cardinal directions with rather accurate approximation. The item marked with the name of Petrus (the only one with a flat roof), is aligned south. Aligned to the east is Jacobus, to the west is Lucas, and to the north is Matteus. This azimuth value is a possible explanation for what scholars consider an 'executional mistake' since the upper elements appear inconsistent with the main axes of the plant.

The Interactive Models for the Dissemination of the Research Project

The above study of Theodoric's Mausoleum and the instrumental survey that supports it, have translated into a multitude of results and materials of a different nature. From the massive amount of data collected, new information has emerged regarding the geometrical and archaeological characteristics of the building. The issue of disseminating and communicating the results of the research is a theme that our group has faced for some years. We have concentrated on the production of explorable and electronically searchable digital models as complementary and heterogeneous containers of information.

The 3D digital model made for the Ravenna Mausoleum can be explored in dynamic perspective on screen. This constitutes a visual support that provides the user with multiple information about the object's morphology: its colours, the materials, its state of conservation and much more. It can also be used as a visual database, useful in systematizing and making use of data beyond the range of the naked eye (dimensional data, geometrical relationships between elements, archaeoastronomical analyses, wall stratigraphy, external metadata such as video and Multimedia, etc. . . .). The interrogation of the model and reasoned structuring of information according to different levels of depth, facilitates the understanding of complex phenomena for the recipient of the information.

Starting from the pointcloud from the digital survey, a 3d model of the entire building was created, both external and internal, in order to allow a direct visualization of the light phenomena affecting the spaces on particular dates of the year. The model, designed to be optimized for real-time applications, is a textured quadrangular mesh (*quad-modelling*), texturized with *UV mapping* starting from the orthophotos extracted from the SFM survey. This model, oriented and placed in a Cartesian space for reference, has been linked to a directional light simulating the parallel rays of a source similar to the Sun, and is therefore best suited to reproduce the Sun's movement within the Mausoleum. The light has been assigned an animated path that reproduces the Sun's movement on the ecliptic, where each key movement on the animation (*keyframe*) was created by parameterizing the values derived from the calculation of

Fig. 11.2 Model and rendering of the building

the ephemeris at significant times. In particular, the exact time of sunrise has been entered as the starting point, and sunset as the end of the path. This time span was further subdivided into half hour intervals. Intermediate times result automatically from the data provided: the construction phase of the model thus becomes a test and comparison of the calculations previously made. The procedure was repeated for four remarkable dates (solstices and equinoxes). This model has been used as a kind of virtual laboratory for observing the effects of light within the burial cells in an ideal condition, since the light has no obstacles and external elements which, at present, obscure the sunrays (Fig. 11.2).

Numbers and Geometry

Research on the units of measurement used in both the project phase and during execution, can yield interesting results on the author of the project, identified by some as Aloisio—o Aloiosus—(Messina 1980: 33), an architect of debated Syrian origins (V. Aloisio and A. Iacobini, *Enciclopedia dell'Arte Medievale*, 1991). The initial problem of authorship, and secondly that of the possible sources of the geometrical and measurement knowledge used, is certainly an important topic to investigate. The two possible units of measurement verified are the Roman foot (rf = 0.2956 m) and the Byzantine foot (bf = 0.315 m, also called *Parmac*). The theme of the measurement of the Byzantine foot has been tackled in various papers (Ousterhout 2008: 75–76; Schilbach 1970, 1991; Underwood 1948) from which we extrapolate the values 0.312 m and 0.315 m (Martini 1883: 178). Throughout the research, both of these measurements were tested, with the result that the second value gave more 'whole' figures. The question of measurements, however, cannot be treated separately from the geometrical knowledge of the time.

The graphics elaborated by the instrumental survey made it possible to detect the presence of a geometrical design that led the metric control of the investigation. Beginning our analysis from the ground floor, the plan is based on a series of circumferences with a 'whole' radius measurement in which concentric decagons are inscribed (Figs. 11.3 and 11.4). The diameter of the circle in which the decagon is inscribed measures (Figs. 11.3 and 11.4) 45 Byzantine feet (bf), but also 47.92 Roman feet (rf), so almost 48 rf, two interesting measurements from a metrological analysis. Continuing with the measurements of the other decagons, we find that the internal line of the niches on the external side corresponds to the decagon inscribed in the circle with a diameter of 35 bf, and the diameter of the inscribable circle in the inner space of the ground floor (which can be traced back to the decagonal figure itself) measuring 25 bf. Finally, the thickness of the walls in the direction of the apothem is almost 9bf (the exact measurement is 8.9 bf).

It should be remembered that the relationship that binds the radius of the circle and the side of the inscribed regular decagon within is the irrational number 0.618, the result of the division of a unitary segment 'in extreme and mean ratio'. This numerical relationship between the parts of a segment, already present in *Elements* by Euclid (Book VI, Theorem VI, 30; Herz-Fischler 1998: 14), makes it clear that if the side of a decagon has a whole measurement (integer), the radius of the circumscribed circumference cannot have the same characteristic, and vice versa. With this binding condition comes the difficulty of calculating its area. Given the presence of an irrational number, the measurement of its surface has been subject to approximations such as those developed by Heron (Metric I, 23¸ Herz-Fischler 1998), whose formula $L^2 \times 15/2$ tries to be as rigorous as possible: $L^2 \times$ *fixed number of decagon* (the relationship between the apothem and the side), $L^2 \times 7.694$. Another numerical relationship used for the fixed number of the decagon is 38/5 (7,6) which comes closer to the exact value of 7.694 (Herz-Fischler 1998: 110).

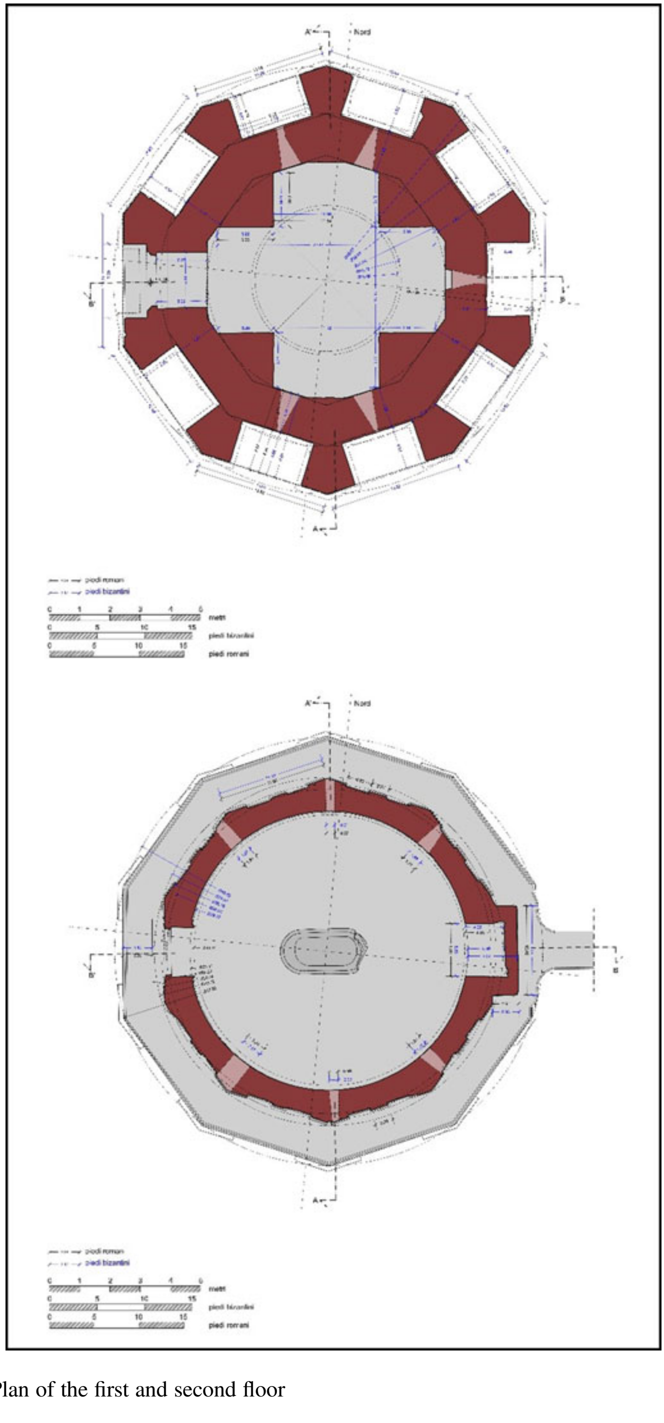

Fig. 11.3 Plan of the first and second floor

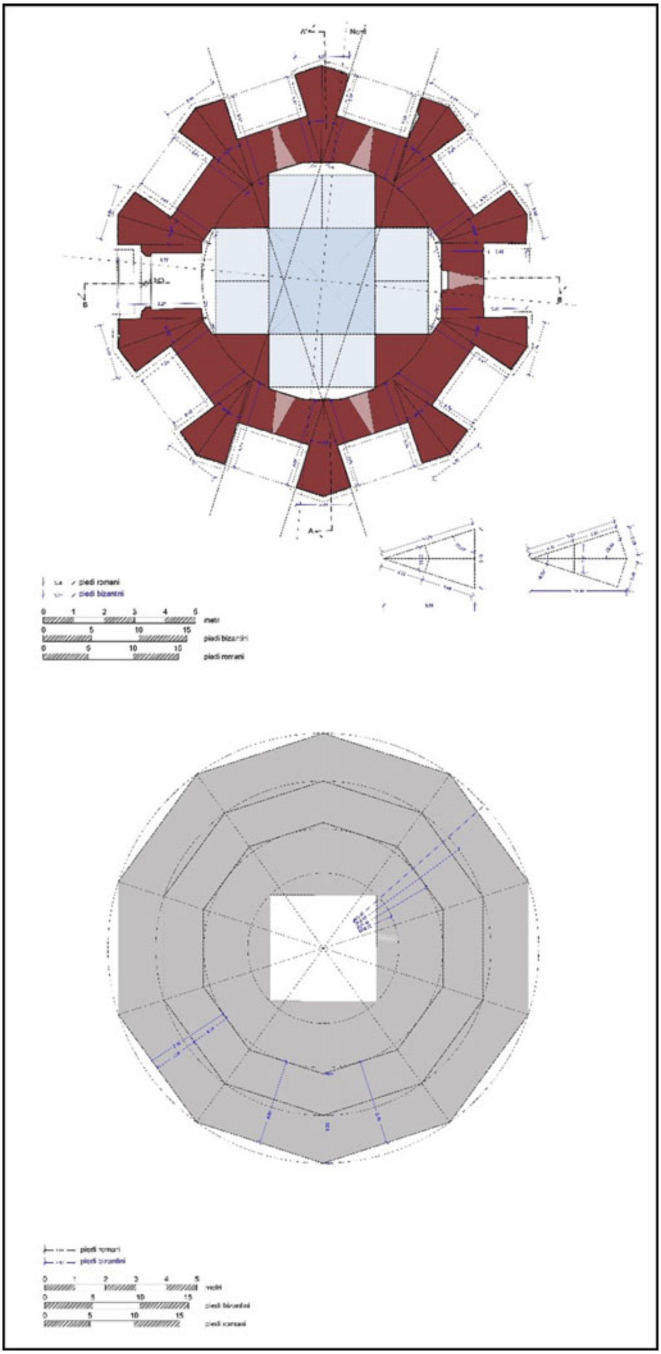

Fig. 11.4 Plan of the first floor: geometry and measurements in Byzantine feet

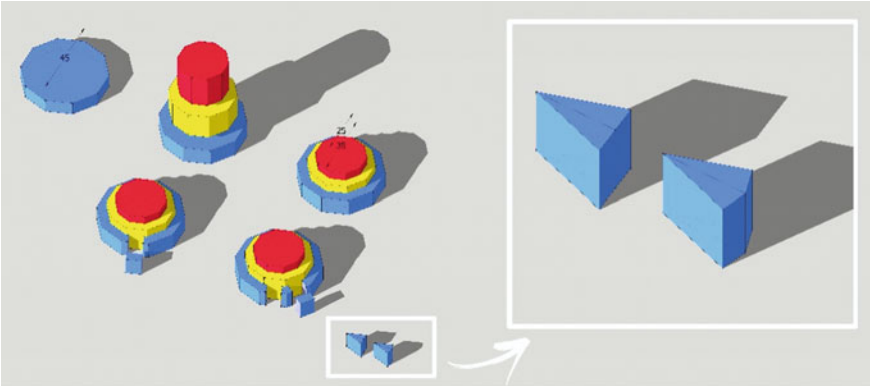

Fig. 11.5 Schematic drawing of the mausoleum volumes

An interesting geometrical quality of the decagon is that it can be divided into 10 isosceles triangles whose base angles measure 72°, and the other half of the opposite, i.e. 36°. The 10 powerful external pillars (Fig. 11.5), that are constructed on a quadrilateral made of two triangles with 10 bf hypotenuse and 9.5 bf side (angles 18°, 72°, and 90°), can be traced back to these triangles, the sum of which results in an isosceles triangle 36°, 72°, 72°, with equal sides of 10 bf and height 9.5 bf. The minimum dimension of the section of the pillar bordering the outer niches is of 3 bf (Fig. 11.4). Finally, the interior space can be easily approximated by a Greek cross, whose central square measures 11.1 bf, while the four lateral arms are rectangles with a 1/2 ratio to the square.

Regarding the upper floor of the building, it is necessary to state that the conditions of the external stone blocks do not allow, in our opinion, an accurate reading of the measurements of the existing profile. It can be hypothesised that the circumscribed circle at the base of the pilasters measured 36.65 bf, corresponding to 39 rf. The side of the inscribed dodecagon could thus be 11.33 bf, a dimension that is relatable to 12.06 rf. The upper cylinder on which the slot openings are found has an external diameter of 34 bf and an average thickness of about 2.45 bf.

The interior elevations (Fig. 11.6) are characterized by decimal measurements attributable to the unit division into 1/3, 2/3 bf. The main architecture lines of the lower floor appear to rely on a 2 × 3 square grid, while the higher one on a 5 × 8 grid (amount very close to the golden ratio). Even the arrow of the vault is attributable to the Byzantine foot and measures 6 bf. The 2 × 3 ratio is also present in the exterior elevation on the side of the decagon of the first level. In this case, the rectangle is displayed vertically and its measure depends on the side of the decagon of the plan. Its value is thus an irrational number derived from the measurement of the circumscribed circle of 45 bf.

Finally, it should be mentioned that other architectural elements are related to the Byzantine foot: for example, the maximum thickness of the cylinder on which the cupola rests is 4 bf. One must also highlight that certain measurements yield whole

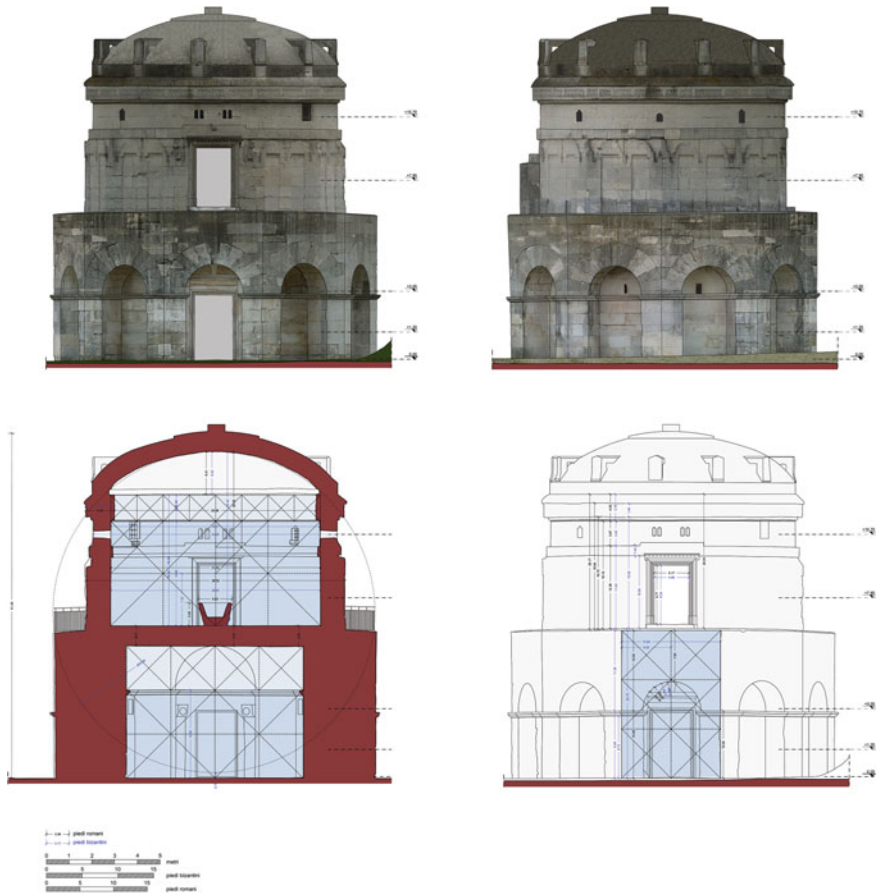

Fig. 11.6 Orthophotos; section AA' with indication of the proportions 2 × 3 and 5 × 8. 9; external elevation with indicated proportion 2 × 3

numbers in Roman feet. This is the case of the outer band decorated with a 'pincer' pattern (2 rf), the outer extent of the apse equal to 10 rf (whole number), and the pilasters of the smaller width of the gallery, which amounted to approximately 2 rf. On the ground floor the total height of the frame is 13 rf, the door height is 10 rf.

The Decagon and Boethius

In AD 526 (or according to tradition, in 524) Anicius Manlius Severinus Boethius, questor, patrician, consul and *magister officiorum* at the Theodosian court, died in Pavia, imprisoned and killed by Theodoric. The philosopher, as we know, is credited with the term *quadrivium*, a word that was used to describe the art of late-ancient scientific knowledge. The four disciplines—arithmetic, music, geometry and astronomy—have their roots in Greek tradition and constituted the 'preparatory paths of philosophy'. Architecture students had to follow such structured science, and were of course also trained in practical themes: the balance between the theoretical and the operational skills in late antiquity certainly had different outcomes in Roman society and Byzantine society (Briggs 1927; Frothingham 1909; Kostof 2000; Meek 1952; Schibille 2009; Vagnetti 1980). Within the present study, some reflections on the possible practical application (in the design phase) of the theoretical knowledge possessed by Boethius at that time certainly appear necessary.

The writings on the scientific subject attributed to Boethius have only partly reached us, unfortunately fragmented and incomplete, as attested by the relative philological studies. While the *De Institutione Arithmetica* reached us intact, the same cannot be said for other sections: *De Institutione Musica*, *De Geometria* and the Astronomy. The first work contains the knowledge of Nicomaco di Gerasa (already translated by Apuleio). The sources of the third have to be found in the documents of *Euclid's Elements*, while the astronomical works of Tolomeo were used for the fourth (see the letter between Theodoric and Boethius reported by Cassiodoro, *Variae*, I, 45, 4).

Scholars have long debated the authenticity of the two geometry books attributed to Boethius (Folkerts 1970), highlighting the incongruous traits and elements that move the dating of the earliest manuscripts to the eleventh century. However, some fragments are contained in the third and fourth book of the *Ars Geometriae et Arithmeticae* in five books (Boezio 1867). In this work, which will remain a point of reference for Cassiodorus and the measurements of the Middle Ages, a brief description of the decagon appears (book II, XXX). The short passage describes the properties of the decagon, not so much from the geometrical point of view as from the arithmetic point of view across the figurate numbers. In the book on geometry, the author associates the decagonal number 370 with the figure of the decagon (Fig. 11.7), which, although not appearing in *De Institutione Arithmetica*, can be traced back to the same arithmetic principles of the polygonal numbers (Incerti et al. 2017: 76).

It is clear that the geometric rules followed by the anonymous designer of the Mausoleum belonged not so much to the field of arithmetical calculation and the properties of particular numbers such as the decagonal ones cited in the *De Geometria,* attributed to Boethius, but to the geometric knowledge already present in the Euclid's *Elements*.

Conclusions

To conclude, an archaeoastronomical investigation has certainly yielded significant results which have extended our knowledge of this extraordinary building into topics that were previously unexplored. The critical reading of the survey measurements also allowed us to highlight the presence of a geometrical project that controlled the general

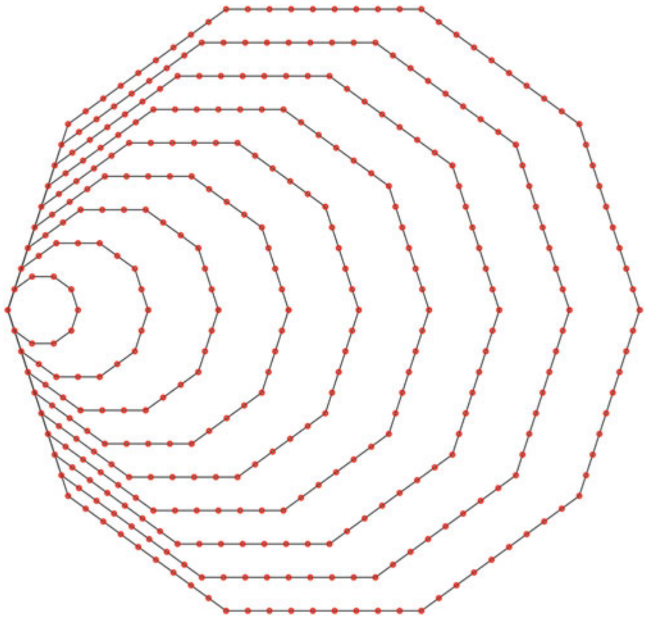

Fig. 11.7 The figure corresponding to the decagonal number 370

measures of the buildings based on Byzantine foot measurements. In addition to the encircled and circumscribed decagons, whose diameters were integer figures, other numerical relationships were found in the plans and elevations, such as: 1:2, 2:3 and 5:8. The comparison of some Roman integer measures, however, makes it clear that this second unit of measurement has also been used not so much during the project phase as during the execution of the work. Finally, we have tested the important contribution of digital models both in the phase of analysis and in the communication of complex and stratified contents such as the historical-astronomical ones.

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