RESEARCH ARTICLE

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Deciphering the Greek Temple: Verification with Software Tools of the Solar Design of the Parthenon in Athens and the Temple of Zeus in Olympia

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ABSTRACT

In Greek temples, compositional order and Pythagorean geometry were used to achieve regularity, proportion and beauty, combining exact magnitudes between the parts and the whole. It is also known that all the temples were oriented with great precision. However, the diverse reasons for their construction makes their astronomical orientation more difficult to interpret. In this research, the Parthenon in Athens (447-436 BC) and the Temple of Zeus in Olympia (470-456 BC) were analysed with solar simulation software. Comparing the results obtained, it is verified that both temples were designed and oriented following a plan: to facilitate the symbolic use of sunlight for the veneration of the goddess Athena and the god Zeus on the dates of the celebration of certain religious rituals. Verification was performed using a process that allows its extrapolation to similar analyses of any other Greek temple.

Keywords: Astronomical orientation, Greek temple, Greater Panathenaea, Olympic festival, Solar simulation software.

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I. Introduction

A. *Astronomy and Geometry in Ancient Greece*

The ancient Greeks had advanced knowledge of astronomy and geometry (Addis, 2007) and the practical application of these two disciplines was part of their daily lives. For the measurement of time they were governed by a lunar calendar and to determine the time of day they used the sundial. Stellar observations allowed them navigate by sea and to determine the most appropriate dates to carry out agricultural activities. Archaeological and literary evidence also attests that astronomy contributed to the development of the cosmological ideas and beliefs of Greek philosophy. Even today we continue to use the mythological figures chosen at that time to reference the constellations that populate the celestial vault. Although they only had basic topographical tools (Fig. 1) (Gnomon,Wikipedia 2011, may 5), the numerous investigations that have been carried out since the 19th century have demonstrated their ability to plan the layout and establish the most appropriate solar orientation in the residential architecture of new urban settlements, with the aim of improving thermal comfort through solar energy (Butty & Perlin, 1981). More recently, and in some archaeo-astronomical investigations, (Rainieri, 2004; Pantazis, 2014; Boutsikas, 2015), the importance of astronomical orientation in the construction of temples has been revealed. The geometric perfection of the Parthenon temple is well known, combining exact proportions between the parts and the whole with a series of slight adjustments to obtain regular visual effects. However, what is not so well known-and this is one of the premises of this research- is the use of solar design to achieve certain illumination effects related to religious practice. Mastery of astronomy and geometry led to numerous scientific advances. Already in the 3rd century BC Eratosthenes of Cyrene had calculated with remarkable precision the length of the circumference of the earth by comparing the altitudes of the sun at the same time in two places located on the same meridian and separated by a known distance. Thales of Miletus correctly predicted an eclipse of the sun in 585 BC. Aside from mythology, astronomy was also linked to the practice of religious worship.(Lane, 2005). The geometry and orientation of Greek temples shows us that ancient cosmological beliefs were rooted in religious practice. The main sanctuaries and temples inside which the statue of the deity to which they were dedicated was located, were positioned in a specific place. They had exact dimensions and an astronomical orientation referenced to the cardinal axes, and symbolically used sunlight to serve their religious purpose: the celebration of cult rituals on certain dates and in honour of the particular deity in question. Without precise knowledge of the trajectory of the sun and the correct interpretation of the night sky, it would have been impossible for them to choose the most appropriate astronomical orientation to achieve these purposes (4).

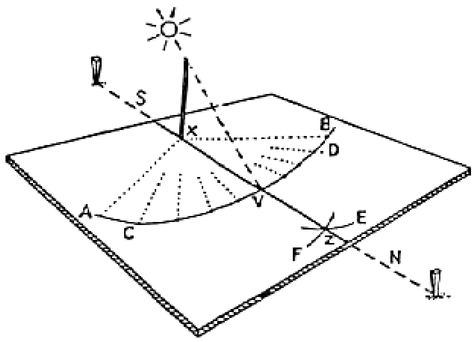

Fig. 1. Determination of the astronomical north-south axis with the gnomon was relatively simple. We marked the length of the shadow before noon (B). We drew an arc of circumference with centre in (X). When the shadow coincided with the point (C) of the arc after noon we measured the angle. The angle bisector (CXB) is the meridian line. Latitude is the arc of the meridian. In the equinoxes, the result of joining all the extreme points of the shadow of the gnomon would be a rectilinear shadow instead of a circular arc.

II. STATE OF THE QUESTION

A. The Orientation of Greek Temples

Although not always the case, in most Greek temples their main axis has an east-west astronomical orientation with a margin of ± 5, and in the broadest sense of being oriented towards sunrise or sunset.

Efforts to explain this orientation of Greek temples date back to the 19th century. The works of Nissen (1873, 1885, 1887) and Penrose (1892, 1893, 1897, 1899) are well known. Since then, many scholars, including Dinsmoor (1939), Herbert (1984), Mickelson (1999), Aveni and Romano (2000), Liritzis and Vassil (2003, 2005, 2006), Boutsikas (2005, 2007a, 2007b), Pantazis, (2008), Salt (2009, 2010) and Rainieri (2014), have addressed the problem with direct in situ measurements of azimuths from archaeological remains and provided statistical results. Their interpretations associate orientation with sunrise or sunset on the local horizon, with the position of the celestial bodies on the feast day of the particular deity in question, the founding date of the temple, or with the dates of important historical events. These interpretations are mostly convincing, although they depend on precise and demonstrable knowledge of the corresponding rituals and their dates of celebration.

In an analysis of the orientation of 113 temples carried out by Heinrich Nissen (1910) and William Bell Dinsmoor (1939), it was found that approximately 73% were oriented 60º east, 8% 60º west and 19% in other directions. Dinsmoor's general conclusion about the orientation of Greek temples was that although their easterly orientation could also be explained by Egyptian influences, their position was ultimately determined by the need to face either the rising or the setting sun (Dinsmoor, 1939) More recently, other studies using archaeo-astronomical techniques concluded that, in some cases, orientation to the east was dictated by rituals which required the interior to be illuminated only at a certain time and on a certain date (Belmonte and Hoskin, 2002)(6). However, in many cases, temple orientation is not yet fully understood and more precise research studies are required.

George Pantazis (2014) who, like many others, has studied in great detail the temples of the Parthenon and Hephaisteion in Athens, concludes that *"...both were aligned with the dawn of the day on which the festivals of their respective deities were celebrated..."* Each of these two temples was oriented in such a way that the statue of the deity to which the temple was dedicated was illuminated by the rays of the rising sun, at dawn, on their official feast day "*...the Parthenon is oriented towards the point where the sun rises on the feast day of the goddess Athena ...*" (Pantazis, 2014). To achieve these effects it was necessary to establish with great precision the astronomical azimuth of the main longitudinal axis of the building and the position of the statue inside. For this, when the building was constructed, the main axis of the temple was the line that marked its angular position on the ground.

B. The Oriented Geometry of the Greek Temple: Relationship Between the Dimensions of the Plan and the Azimuth of the Main Axis

After analysing more than 200 temples, Ranieri proposed a novel and definitive interpretation of the dimensions of the plan and the azimuth of the main axis: "*… I have often observed the clear alignment of some diagonals (and not only those of the temples) with a cardinal direction…"* He concluded that all Greek temples seem to be oriented according to a guideline referenced to the cardinal axes, either along the main axis, along a diagonal of the rectangle on the plan, or along one of the triangles that make up the rectangle (Rainieri, 1939). Cockerell had previously established this same relationship in the Parthenon (Fig. 2).

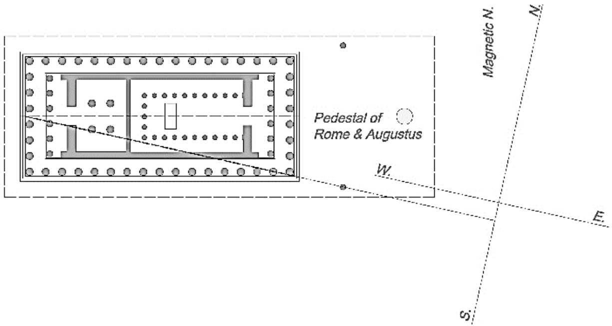

Fig. 2. Detail of the plan of the Parthenon in Athens. The temple has the diagonal of the rectangle of the semi-stylobate perpendicular to the N-S astronomical axis (meridian) and with this it determines the dimensions of the rectangle of the plan and the angle of the azimuth of the main axis. (Cockerell, 1832).

Rainieri determined that all the temples seemed to be similarly oriented, and from this premise he established four variants (Fig. 3).

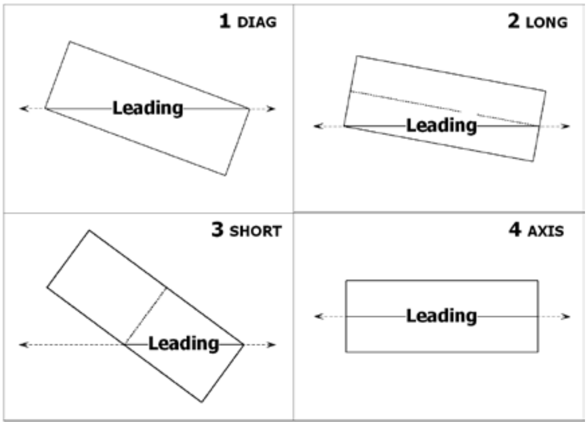

Fig. 3. The four lines of reference to orient Greek temples with the cardinal axis (Ranieri 2014).

The relationship of the Greek temple with a cardinal axis greatly facilitated the work on the ground to start its construction. Once the site had been chosen, the dimensions of the stylobate established and the precise orientation to meet the needs of the celebration of the cult of the deity in question known. The first action on the ground consisted of determining the reference line oriented with respect to the astronomical N-S axis with the desired solar azimuth angle. Once the orientation had been defined and after establishing the astronomical azimuth of the main axis, the geometric shape of the temple was defined from a Pythagorean triad. To achieve the perfect orthogonality of the rectangle that would delimit the colonnade of the stylobate, they used a well-known Pythagorean triad for the restatement, for example 3-4-5. The smallest number was associated with the shortest side, the second number with the longest side, and the largest number with the diagonal. Multiplying by the determined coefficient, the dimension of the three sides of the final right triangle was obtained.The orientation and the Pythagorean triad of the temples of the Parthenon in Athens and Zeus in Olympia (according to Ranieri) are shown in Table I.

TABLE I: COLUMN 1: TYPE OF CARDINAL ALIGNMENT. COLUMN 2: TEMPLE. COLUMN 3: GEOGRAPHICAL POSITION. COLUMN 4: PYTHAGOREAN TRIAD OF SQUARED INTEGERS (THE MULTIPLICATION FACTOR TO CALCULATE THE TOTAL DIMENSIONS APPEARS IN PARENTHESES). COLUMN 5: SOLAR AZIMUTH OF THE MAIN AXIS (FROM NORTH TO EAST).

Type	Temple	Geographicalposition	Integer triad	Solar Azimuth North-East
2 LONG	Parthenon Temple	Latitude 37.971º Longitude23.727º	2s=52-117-128(x2)	77.5º
4 AXIS	Temple of Zeus	Latitude 37.637º Longitude23.630º	2s=24-54-59(x4)	87.8º

C. Greek Temple Lighting

The Greek temples of the classical period, although they varied considerably in detail, basically consisted of simple rectangular parallelepipedal buildings that were built to house the statue of a deity. The side walls of these structures extended forward to form a portico, which was adorned with columns. The statue of the god was located inside the cella or naos and was in semi-darkness. Natural light only entered the interior of the temple when the great doors were opened on the appointed days. As already mentioned, and this is the working hypothesis of this research, the direct lighting of the statue was achieved by aligning the temple with the position of the sun to restrict the entry of sunlight into the cella to a particular day and time. This implied that at other times of the day or year the interiors of the temples remained dark or dim and their interior lighting was achieved by other means, such as lamps or torches. In some temples, such as the Parthenon and the Temple of Zeus at Olympia, the fine translucent marble roof tiles placed on the wooden framework could have allowed the passage of sunlight in a dim but constant way throughout the day, which would have been sufficient to admire the interior of the temple with its statue(Williamson, 1993). This dim lighting created a gloomy interior environment, a sacred atmosphere, as if it were another world, which increased the religious feeling when contemplating the statue of the deity.

Religious rituals were usually performed around the altar located in front of the temple and at night, when the celestial landscape was directly visible and could be related to their mythological and cosmological beliefs. Thus, in order to establish the orientation of the temple-altar complex, the exact location and its immediate and distant environment (especially the celestial landscape) were decisive. The site was chosen to facilitate observation by the participants of specific parts of the night sky that were visible on the day/night of the month of the year that the ritual in question was performed (Boutsikas, 2015).

III. Similarities and Coincidences between the Parthenon in Athens and the Temple of Zeus in Olympia

A. Architecture and Astronomical Orientations

Both temples share some common characteristics that characterize them. They were constructed in the same period, and in both cases their composition is based on the proportions of the canonical Doric order. In addition, in both temples Phidias was in charge of the iconographic program.

Inside, the monumental gold and ivory statues made by Phidias (Athena Parthenos 447–438 BC and Zeus 438-430BC), (Wasson, 2017) were venerated. The statue of Zeus was made after the expulsion of Phidias from Athens and twenty years after the construction of the temple of Zeus. (Fig. 4). In both, an architectural innovation was incorporated into the interior space that differentiated them from previous Greek temples. A sumptuous niche was designed with a double superimposed colonnade and an intermediate architrave that formed a mezzanine with a gallery to enlarge and magnify the space that housed the colossal chryselephantine image located inside. The mezzanine of the gallery of columns was accessed by a wooden staircase located to the right of the access through the main door and this allowed visitors to contemplate the statue in all its splendour.

The Parthenon temple (447–436 BC) on the Acropolis of Athens is the most important construction of the Athenian classical period. It was dedicated to the goddess Athena, protector of the city. The detailed plans were made by the architects Iktinos and Kallikrates, although the overall design is attributed to Phidias. It was built in just 10 years on the south side of the Acropolis on the initiative of Pericles, who died in 429 BC. It is an octastyle peripteral Doric temple, with 17 columns on the long side (2n+1, 2(8)+1=16+1). Its total dimensions including the stylobate are 69.5m x 30.8m and it has a maximum height of 20m. It follows the proportions of the canonical Doric temple (dimensions width-length in plan, 4:9). The main access to the cella where the statue was placed was through its east façade, oriented towards the rising sun. On the pediment located above this entrance was a clear reference to solar mythology, a sculptural group made by Phidias that represented the triumph of day over night (Sol Invictus). At the western end, the god Helios appears on the horizon at dawn with his chariot, while at the eastern end the goddess Selene disappears behind the horizon at dusk.

Housed inside was the 11-m-high statue of the goddess Athena Parthenos on top of a 1.20-m-high platform adorned with a frieze depicting the birth of Pandora. The sculpture was framed by the aforementioned niche, a gallery of 23 superimposed Doric columns with a total interior height of 12m.

The Temple of Zeus (470–456 BC) located in the centre of the Sanctuary of Olympia (Altis) in the city of Elis was dedicated to Zeus, the Panhellenic god. It was designed by the local architect Libon. Phidias completed the statue of Zeus in 430 BC, According to Pausanias, the temple was built as an offering to celebrate the final victory of the city of Elis over Pisa and served as a model for the Parthenon. It is a peripteral and hexastyle Doric temple with 13 columns on the long side (2n+1, 2(6)+1=13). Its total dimensions including the stylobate are 64.1m x 27.6m and it also follows the proportions of the canonical Doric temple (width-length dimensions on plan 4:9). Inside it housed the 12-m-high statue of an enthroned Zeus mounted on a stone platform of 6.5m x 9.8m. The sculpture was framed by a gallery of fourteen superimposed Doric columns with an internal height of 13m (13x28.7m cell). Both temples, although located in different locations, are oriented to the east, facing sunrise. The solar azimuth of the main axis is 77.5º in the case of the Parthenon and 87.8º in the temple of Zeus (they differ by 9.7º), (Fig. 4a and 4b).

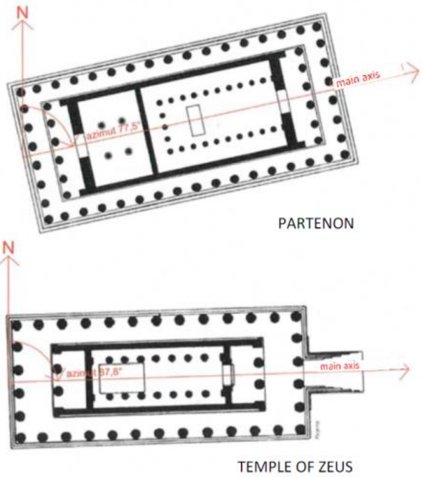

Fig. 4a and 4b. Plans of the Parthenon temple and the temple of Zeus, drawn to the same scale and with the azimuth of the main axis.

In both temples, in front of the statues, was a reservoir with a raised rime of marble which, (Pausanias, 2012), was filled with oil. Made from grey limestone, this reservoir was 6.5m^2 in the Parthenon and about 9.0m x 9.5m in the temple of Zeus. Recent archaeological studies have suggested that the reservoir served as a reflecting pool to reflect the light that entered through the gap in the open door and thus accentuate the illumination of the statue and the interior of the enclosure at sunrise on days of celebration and veneration of the deity. Both statues were built with the same technique: a wooden frame lined with bronze plates that was then completely covered with pieces of gold, ivory and precious stones (Fig. 5a and 5b).

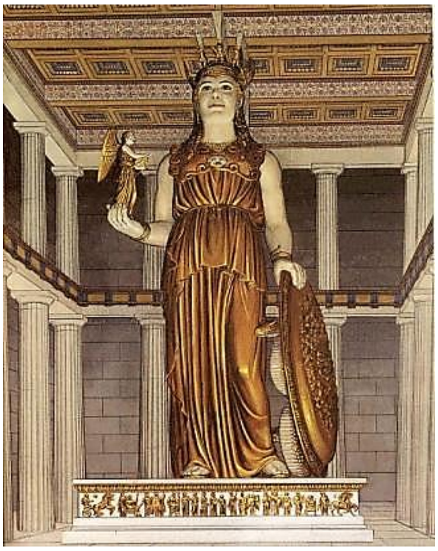

Fig. 5a and 5b. Reconstructions of the statues of Athena and Zeus made by Phidias.

IV. Religious Festivals Associated with the Two Temples

A. *Panathenaea in Honour of Athena*

The festival of the Panathenaea (founded by Athenian aristocrats in the 560s BC) was a religious celebration held annually. Every four years an expanded and more glamorous version was celebrated (Greater Panathenaea) in which athletic contests were held that probably deliberately rivalled the Olympic Games, and culminated with the presentation of the annually "woven peplos robe" on the 28th day of the month of the Hekatombaion, of the Attic calendar, which commemorated the birth of Athena. On that day, a procession was held that started while it was still night in the agora, ascended the Panathenaic route and accessed the acropolis by a paved ramp of 80x10 m. to finish in the Parthenon temple at sunrise. The doors of the temple were then opened and when the first light of day entered the interior, illuminating the statue, a ritual presentation of the "peplos robe" was made to the goddess Athena. After the presentation, the new embroidered cloak was hung as a gigantic curtain behind the statue. Next, various ritual offerings were made and a large number of animals were sacrificed on the altar of the goddess located outside the temple. It is not difficult to imagine the impression that the opening of the doors of the temple must have produced. The chryselephantine statue of the goddess Athena received the direct impact of solar radiation, shining in all its splendour and in various shades of gold and ivory. This commemoration has come down to us represented in the interior frieze of the Parthenon temple made by Phidias. There, the different stages of the procession were described in a votive relief 160 m long, which could be seen on a tour of the interior of the peristyle (Atsma, 2017).

B. Olympic Festival in Honour of Zeus

The Olympic festival (776 BC-393 AD) in honour of the god Zeus was celebrated every four years in the Attic calendar month of Metageitnion and lasted six days. The starting date of the Olympic festival (two moons after the solstice) was previously announced by sacred messengers who proclaimed it throughout Greece. The celebrations took place a few days after the end of the Greater Panathenaea, and so the rivalry between the two celebrations is evident. The Olympic Games were a show of devotion and religious worship to which the ancient Greeks gave a mythological origin. On this religious festival, athletic competitions were held between representatives of the Greek city-states, and the winners were awarded prizes that had a religious component: crowns of olive leaves taken from the trees of the Altis, the sacred grove of Zeus. On the sixth and last day of the games, the festival culminated at dawn with a religious procession to the temple of Zeus. There, the winners received their highly esteemed prize: "… *the doors of the temple opened and upon hearing their names the victorious athletes approached the central corridor to be crowned with the "kotinos", the sacred olive wreath, in a ceremony inside the temple presided over by the statue of Zeus on his throne…"* (Berbel, 2018).

V. Solar Simulation with Software Tools

A. Methodological process

In order to verify the relationship between the astronomical orientation and the dates of the celebration of religious festivals in both temples, a methodological process was used with various solar simulation software applications that allowed determination of the coincidences between these two parameters. The process was as follows:

1) Definition of the topographic horizon

Preparation of a three-dimensional model (Fig. 6a and 6b), (Sketch Up software, 2022) defining the main orientations of the building according to the cardinal points.

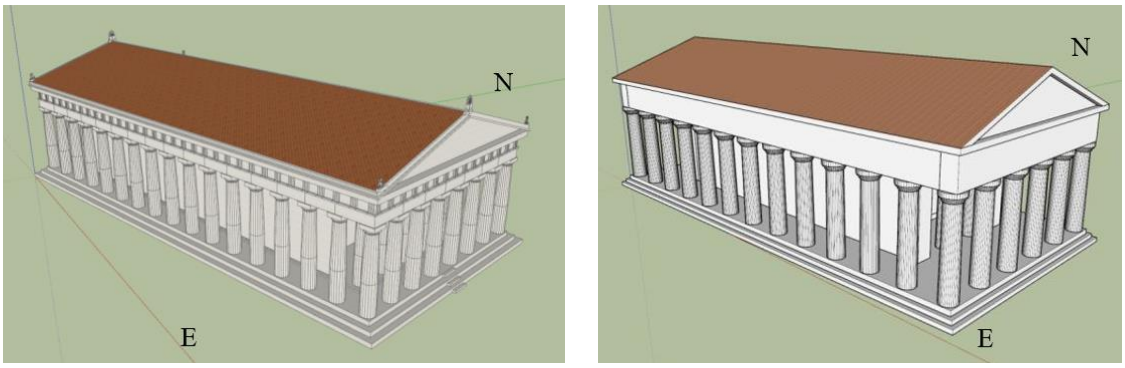

Fig. 6a and 6b. Three-dimensional modelling of the Parthenon and the Temple of Zeus with indication of the main orientation. The green axis points to the north and the other axis to the east.

Knowing the exact position of the two temples from the current archaeological remains and the azimuth of its main axis (Table I), an Epw file (Energy Plus Weather File) was created (Meteonorm software, 2022), and its topographic horizon determined. In the case of the Parthenon, for an azimuth of 77.5º the solar height to avoid the obstructions generated by the horizon is 2.27º, and in the case of the temple of Zeus for an azimuth of 87.8º the corresponding solar height is 3.2º (Fig. 7a and 7b).

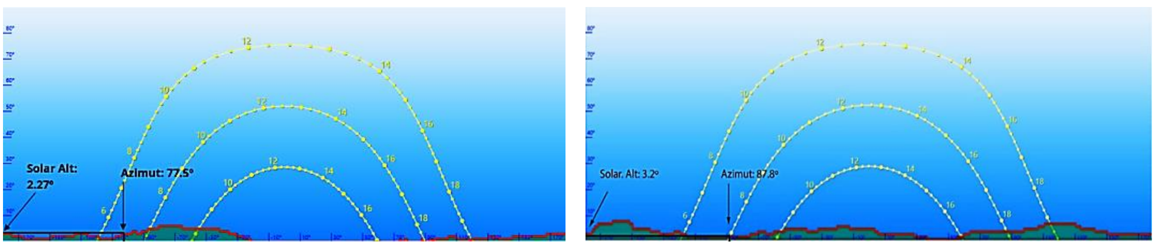

Fig. 7a and 7b. Topographic horizon of the Parthenon and the temple of Zeus,composition figures

2) Determination of the period of time in which solar radiation penetrates the interior of both temples:

After importing the data (three-dimensional model and the Epw files (Graitec Archiwizard software, 2022), it was possible to determine the days (current Gregorian calendar) on which the statues would receive solar radiation, as well as the intensity of illumination. For this, three solar receivers were assigned to each statue (Fig. 8a and 8b).

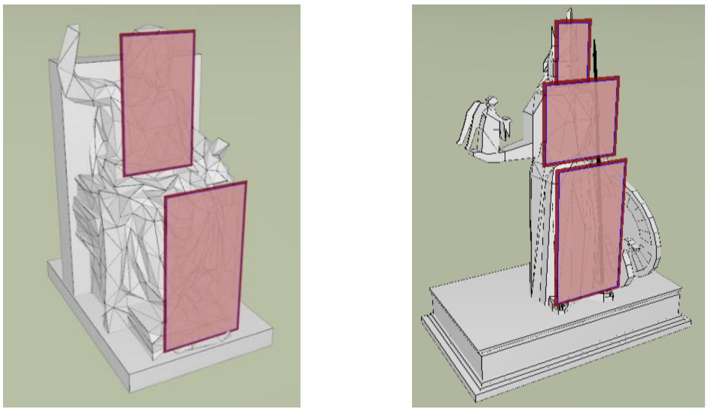

Fig. 8a and 8b. Solar receivers (surface analysis) assigned to the statues of Athena and Zeus.

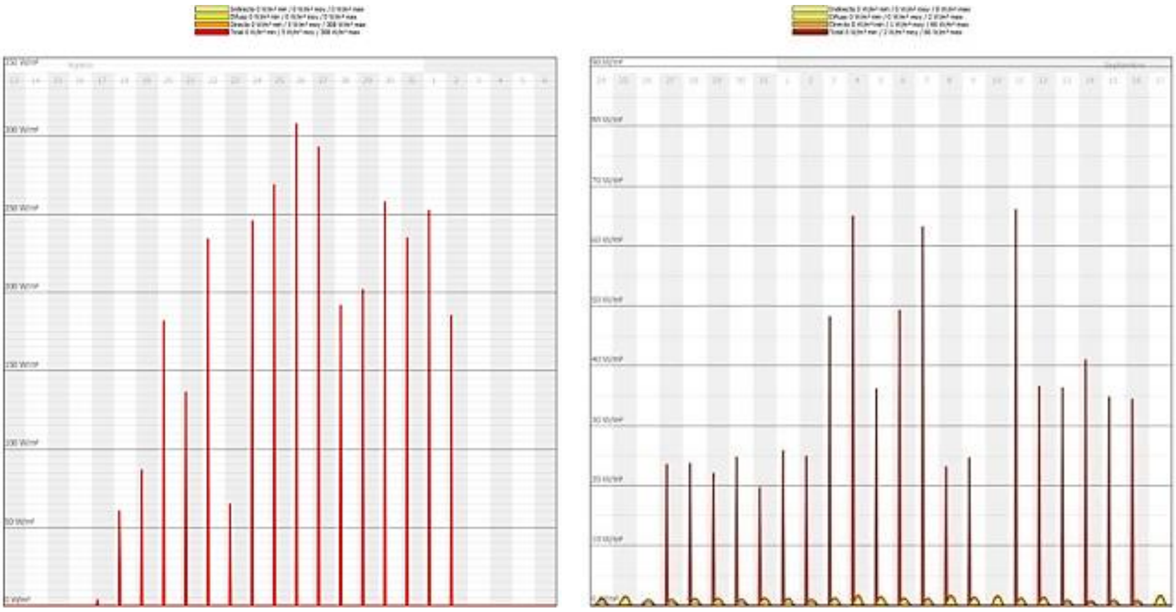

Fig. 9a and 9b. Days in which the statues receive direct radiation and lighting intensity (according to the Gregorian calendar).

The statue of Athena, with a solar azimuth of 77.5º and a solar altitude of 2.27º would receive direct solar radiation with different intensity between August 18 and September 2, (current Gregorian calendar). The statue of Zeus with solar azimuth of 87.8º and solar altitude of 3.2º would receive direct solar radiation with different intensity between August 26 and September 16 (current Gregorian calendar) (Fig. 9a and 9b).

B. Elaboration oftThe Stereographic Solar Diagram

Knowing the azimuth, the solar altitude and the days in which the statue is illuminated, we can determine when the statues of Athena and Zeus would receive direct solar radiation with the greatest intensity. In this case, the result is August 23 at 6:07 a.m. for the statue of Athena and August 28 at 6:33 a.m. for the statue of Zeus (solar time of the current Gregorian calendar (Fig. 10 and 11).

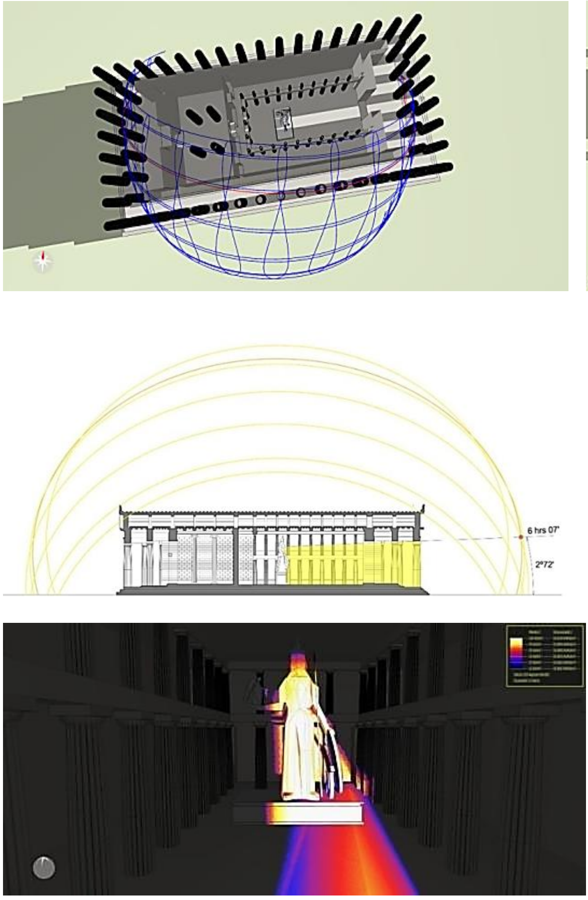

Fig. 10a,10b, 10c and 10d. Stereographic solar graph on the Parthenon with detail plan, section and direct solar radiation on the statue of Pallas Athena on August 23 at 6:07 a.m.

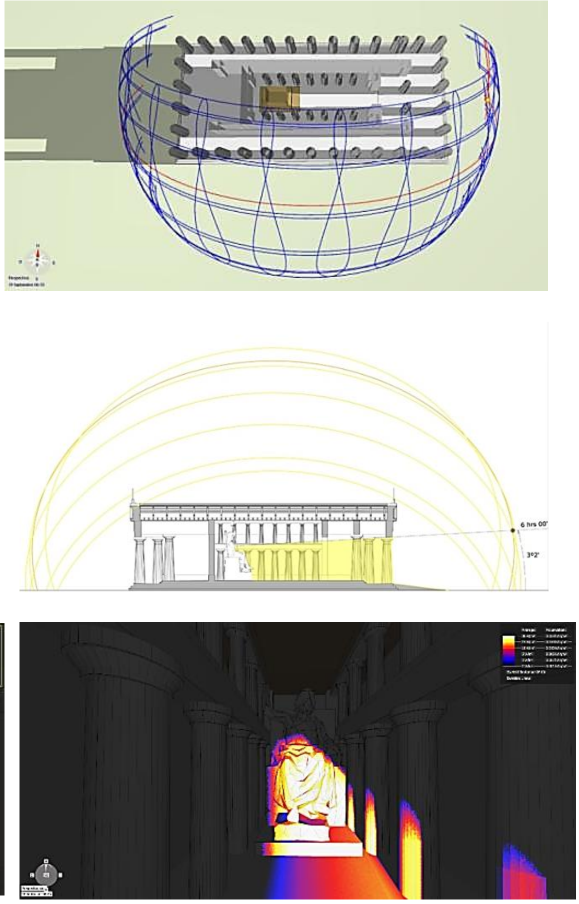

Fig. 11a, 11b and 11c. Stereographic solar graph on the temple of Zeus with detail in plan section and direct solar radiation on the statue of Zeus on August 28 at 6:00 a.m.

VI. Correspondence of Dates between the Ancient Attic Calendar and the Current Gregorian Calendar

There is no direct correspondence between the dates of the Athenian lunar calendar (Attic calendar) and our current calendar (Gregorian). The ancient Greeks used a stellar calendar to fix the dates of their religious celebrations. The Panathenaic festivals in honour of the goddess Athena took place during the month of Hekatombaion, which was the first month of the Attic calendar. The Olympic festival in honour of the god Zeus was held every four years in the month of Metageitnion. As the festivals were for such important deities, it was important to ensure that the festivities took place on the correct day and that the calendar was not out of sync. Using a lunar calendar, it was difficult to meet this requirement. The Greeks were fully aware that their lunar cycle of 12 months, approximately 29.5 days, did not conform to the year of 365 days, so every three years or so they added an extra month to make up the difference, and with each reform, a new calendar was generated with different month names and insertion times and, even though a new month always started with the sighting of the new moon, the exact determination of the best day to celebrate the rituals was always subject to the interpretation of the constellations in the night sky by local observers.

For this reason, the Attic calendar was not fixed, and the correspondence of dates between the Attic calendar and our Gregorian calendar changes from year to year. This can be verified by looking for the equivalence between the ancient Attic calendar and the Gregorian calendar in any year (Ancient Attic Calendar , Wikipedia 2022 April 23).

VII. Discussion and Conclusions

This research has been carried out with a broad vision, relating the construction of these two temples with the advanced knowledge of astronomy and geometry that the ancient Greeks had and the spatial experience that was generated in the interior of the temples during the celebration of religious rituals. This has facilitated a better understanding of the relationship between religious beliefs and the solar design of the temples and has made it possible to demonstrate the validity of the hypothesis formulated in this comparative research: that there was a direct relationship-at least in these two temples-between the astronomical orientation and the dates of the religious rituals.

The precision achieved in the solar design of both temples is noteworthy-the result of a sum of knowledge and constructive skills-to allow the generation of certain lighting effects inside the temple on the days of veneration of the deities to which they were dedicated.

Both temples were conceived, sized and oriented with great precision and with the same purpose: the veneration at dawn of the statue of the deity during the celebration of the religious rituals that were celebrated every four years, in the respective Greater Panathenaea and Olympic festivals, just a few days apart -as numerous researchers have explained- to allow enough time between the celebration of the two festivals.

The validity of the methodology and the suitability of the specific software used to simulate solar radiation have been verified. The eastward orientation of the main directrix of both temples differs by 10.3º (Fig. 12.) This different astronomical orientation delays the generation of the same lighting effects in the temple of Zeus with respect to the temple of the Parthenon by approximately one week, which coincides with the difference in the dates of celebration of their respective religious rituals (Fig. 12).

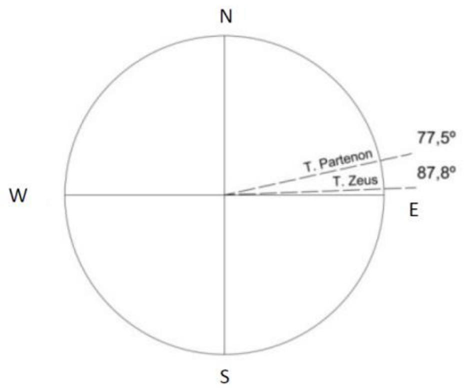

Fig. 12. Interval between the solar azimuth of the Parthenon and the solar azimuth of the temple of Zeus.

With the results obtained with the solar analysis software, it is concluded that, when considering the direct illumination of the solar radiation, the illumination reflected by the pool, the marble coating inside the cella and the diffused illumination through the roof, the interior of the temple and the statue of Athena were fully illuminated at dawn and for almost two weeks during the second half of August, with the culminating moment being August 22 at 6:07 in the morning (current Gregorian calendar) when the offering of the peplos robe was made to the goddess Athena during the Greater Panathenaea, coinciding with sunrise on the 28th day of the month of Hekatombaion of the Attic calendar.

Similarly, the direct illumination of the interior of the temple of Zeus occurs in the period that covers the last week of August and the first week of September, coinciding with the celebration of the Olympic games and several days after the end of the Panathenaic games, with the culminating moment taking place on August 28 at 6:33 p.m. (current Gregorian calendar), which also coincides with the time interval indicated by historians between both celebrations. By using a lunar calendar, the date of the celebrations varied from year to year, so a direct conversion between the two calendars cannot be made, but in any case the margin of coincidence is very significant.

Finally, and importantly, the verification methodology used in the present can be extrapolated to carry out similar analyses of other Greek temples.(Uson & Guillen, 2021).

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