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# ILLUMINATION EFFECTS IN CELANOVA AND AGÜERO SPANISH MEDIEVAL CHURCHES

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## ABSTRACT

An aspect of undoubted interest in the study of Romanesque architecture refers to illumination effects, when the sunbeams mark significant points in a church. But these lighting effects can be accidental. Any opening or hole would allow the entry of a sunbeams that could unintentionally illuminate a certain element, some day of the year. The objective of this article is to establish reasonable conditions to distinguish casual phenomena from premeditated ones. The methodology used for the study of solar trajectories and the calculation of the dates and times of the sunbeams incidence at a given point, is based on the use of solar charts. It is a simple, effective and precise method that can be used in further studies carried out even by researchers with basic knowledge of astronomy. A very simple construction method has also been analysed with the elements available to a medieval builder, which has made it possible to analyse the different solar orientations and to be able to distinguish lighting effects that have been deliberately projected from purely accidental ones. This methodology has been applied to two notable Spanish buildings: The Mozarabic chapel of Celanova (Ourense, Spain) as an example of a questionable solar phenomenon and the Romanesque church of Agüero (Huesca (Spain) as an example of a demonstrable phenomenon. This article may be a useful contribution for the study of these phenomena and to analyse their intentionality and the way in which they could have been projected by their builders.

**KEYWORDS:** archaeoastronomy, medieval architecture, solar phenomena, architectural stake out, solar symbolism, astronomy.

## 1. INTRODUCTION

The most of civilizations have tried to relate their sacred spaces with the firmament and especially with the stars those had more relevance for them, such as the sun, and sometimes the moon. This was translated in particular by the orientation of these spaces as a direct way of putting them in relation to divinity. The most frequent orientation is the solar one, although there are some interesting examples of stellar orientations, being the lunar orientations infrequent and doubtful. For example, Lull (2006) mentions various orientations to certain stars, with some notable solar orientations such as those of the temple of Horus built by Mentuhotep III (11th Dynasty) in Thebes or the great temple of Karnak (18th Dynasty), also in Thebes. In both cases, the orientation coincides with great precision with the solar ortho in the winter solstice. Nissen (1906) also mentions a notable number of Greek temples with orientations fixed with stellar criteria, although the most of them are fixed by solar criteria.

The orientation of Christian temples is fixed by the sun, specifically by the positions of the ortho and in some cases of the sunset, for clearly symbolic reasons (Hani 1996). The criteria that define these orientations are a topic widely analysed by numerous authors such as Nissen (1906), Hoare (2015), Ali and Cunich (2001), Liritzis & Vassiliou (2006), Hinton (2010), Pérez Valcárcel and Pérez Palmero (1998; 2018; 2019: 2021), González-García (2015), Lluis et al. (2021) or Giménez et al. (2018). Since the analysis methods used involve a study of solar trajectories, these same methods will be used in the calculations linked to solar phenomena, object of this article.

In addition to setting the orientation, sunrays penetrate into the temple and can cause an amazing phenomenon, which in some cases could be intentional. However, despite of their interest, they have been generally subject to more subjective than objective interpretations (Aguadé & Fuster, 2010). These are undoubtedly spectacular phenomena and, in general, they have been approached from a perspective more concerned with symbolic aspects than astronomical, architectural or simply constructive aspects. Other researchers have studied similar phenomena at other times and in very different cultural contexts, since they are not exclusive to European medieval architecture (Benfer, 2016). It can be cited some works done with the proper rigor such as those of Incerti (2012, 2001) on various alignments of Italian religious buildings, Pérez Valcárcel & Pérez Palmero (2014) who made a detailed analysis of the phenomenon of "equinoctial light" in Santa Marta de Tera (Zamora), Brown (2014) who studied the alignments of the Crossraguel Abbey in Scotland, Zabala (2015) who studied the alignments in Santiago de Agüero (Huesca) or Vilas Estévez & González-García (2016) who made a complete study of the illumination effects at the cathedral of Santiago de Compostela. However, these studies tend to focus on the phenomenon itself and its possible symbolic connotations. This work will be focused on the possible intentionality of these phenomena and the analysis of the construction systems that could be used to achieve these effects, if this intentionality exists, because can be explained with elementary construction techniques, which were undoubtedly within the reach of medieval builders.

This article has three objectives. First, some clear criteria are proposed that make it possible to distinguish whether a illumination effect caused by a sunbeam has been deliberately projected by the builder or not. Secondly, a method for calculating the alignments of the sunbeams is developed using a rectangular solar chart, which is easily obtainable on various web pages. The third objective is to study a possible staking method that could be easily used with the cultural and technical resources of a medieval master. At our level of knowledge, they are novel and useful contributions.

For this, the orientations of the building and the possible alignments and also the height of the lighting openings and the illuminated elements have been precisely measured in the studied buildings. Taking these data to the solar chart of each church, it is possible to accurately determine the days and hours in which the phenomenon occurs. An excellent correspondence between the calculations made and the observations of the aforementioned phenomena has been verified.

## 2. SOME CONSIDERATIONS ABOUT SUNBEAMS ILLUMINATION EFFECTS

The attention, with which these effects have been analysed in recent times, should not make forget its eminently simple and everyday character. In the Middle Ages, all the life was regulated according to the solar cycle and the position of the sun determined the hours of the day and the work to be carried out or the prayers in the case of monasteries. Therefore, the observation of solar paths was a daily occurrence for medieval constructors. In addition, a pre-Romanesque or Romanesque building is generally constructed with small holes, windows or oculus that let sunrays narrow enough so that its incidence at a particular point had or could have some meaning. This contrasts with the Gothic construction with large windows in which the incidence of the sun is always more widespread and diffuse, unless a hole is deliberately made.

*Figure 1. Solar trajectory in Santa María de Muro de Roda and San Miguel de Sacramenia.*

Because of this, a coincidence in the trajectory of a sunbeam does not have to imply intentionality: it can be purely casual. The trajectory of the sun goes along a wide space of the sky so that any point can receive a sunray coming from some hole at some moment of the year, if the azimuth and height of the sun are congruent with that trajectory. Figure 1 shows an example of two surely casual phenomena in the church of Muro de Roda (Huesca) and in the hermitage of San Miguel de Sacramenia (Segovia). The lighting of the sunbeam is perfectly visible and if it affects a slab of the pavement, that had some special characteristic, it could be understood that it is a calculated phenomenon, when it is most likely not.

To guarantee the existence of a deliberate solar phenomenon with some reliability, are necessary three conditions:

- **Singularity of target**: The point illuminated by the sunbeam must have some clear and different meaning respect another points. The light incidence occurs on a singular element in many cases studied, such as a capital, which also has a different theme the other capitals of the complex. An incidence on an element equal to all others can be deliberated, but it is very likely that it is not. The receiving element must be fixed, such as a capital or a relief, and must be contemporary or prior to the construction of the church. Various sunrays illumination effects have been described in which a sunbeam at one point indicates a baroque image or a gothic painting. It is evident that in these cases there has been no architectural intentionality in the building that justifies the phenomenon. It is more logical to think that someone put the image in that particular place or took advantage of a known phenomenon to perform the painting in the right place. Nor incidences in soil slabs that may correspond to subsequent burials or reuse are considered reliable. Therefore, the numerous cases in which this type of phenomenon occurs won't be analysed in this article.
- **Singularity of the date**: The day on which the phenomenon occurs must have some special characteristic or meaning. It can be a day that corresponds to notorious dates, such as an equinox, a solstice or a symbolic date such as the feast of the patron saint of the church or another date relevant to the builders or constituents. Otherwise, the phenomenon is likely to be purely casual. It is difficult to assume that a builder has taken special problem to cause a solar phenomenon in a date without relevance or that it has a symbolic meaning that justifies it.
- **Singularity of origin**: The hole through which the sunbeam penetrates must have some specific characteristic that differentiates it from the rest.

This is very evident in the case of Tera and more debatable in others. When the hole corresponds to an oculus, a concrete solar trajectory can only be produced in a few days of the year, which makes it a singular phenomenon. In contrast, the entrance of light through a window occurs over a longer period, making it more difficult to demonstrate the singularity of that phenomenon.

To set correctly the possible date of the solar phenomenon, it is necessary to take into account the Julian calendar used by its builders, the only one for them. Christian religious holidays were established at the Council of Nicea on the dates corresponding to that year, 325 AD. The Julian calendar causes an error of 3 days every 400 years, so until the Gregorian reform was regularised, the calendar was accumulating an advance in astronomical dates. Table 1 indicates some useful ephemeris for this study, with special attention to the years 950 that corresponds approximately to the Mozarabic and 1150 which is an average date of the Romanesque in Hispania. They are probable dates for the beginning of the works of the buildings studied.

***Table 1. Solar ephemeris.***

| | 46 BC<br>Julian cal. | 325<br>Nicea | 950<br>Mozarabic | 1150<br>Romanesque | 2022 |
|---|---|---|---|---|---|
| Spring equinox | 23-mar | 20-mar | 16-mar | 14-mar | 20-mar |
| Summer Solstice | 25-jun | 22-jun | 17-jun | 15-jun | 21-jun |
| Autumn equinox | 25-sep | 22-sep | 18-sep | 17-sep | 23-sep |
| Winter Solstice | 23-dic | 20-dic | 16-dic | 15-dic | 21-dic |

A question that affects, although slightly, the calculations referred to the variation of the solar declination, namely, the angle that the apparent path of the sun forms with the plane of the ecliptic. This declination varies between 22.1° to 24.5° with an around 41,000 years and shorter variations due to nutation. The I.A.U. (International Astronomical Union) adopted in 2000 a formula that allows the calculation of this value in short intervals, with T being the Julian century since January 1.5, 2000 (DJ = 2451545.0). On that day the solar decline was 23º 26 ’21.45” = 23.4392917º. The period elapsed since the construction of the buildings to be studied allows the use of the following formula (Duffett-Smith, 1988).

$$\varepsilon = 84381{,}448'' - 48{,}84024''\cdot T - 5{,}9\cdot 10^{-4}\cdot T^2 + 1{,}813\cdot 10^{-3}\cdot T^3 =$$
$$= 23^{o}\,26'\,21{,}45'' - 48{,}84024''\cdot T - 5{,}9''\cdot 10^{-4}\cdot T^2 + 1{,}813''\cdot 10^{-3}\cdot T^3$$
$$\text{being } T = \frac{DJ - 2451545{,}0}{36525}$$

***Table 2. Solar decline at the time of construction of the buildings studied***

| | Year | Julian Day | *Julian Century* | Declination |
|---|---|---|---|---|
| S. Miguel de Celanova | 950 | 2068295 | -10.49281314 | 23.5810445 |
| Santiago de Agüero | 1137 | 2136348 | -8.62962355 | 23.5560311 |

The values of solar decline were slightly higher in the 12th and 13th centuries than today. The time interval is relatively small and it scarcely affects to the conclusions, as would happen in a wider interval. In any case, the right thing to do is consider it in the calculations, as will be done.

To study these phenomena will be used solar charts. The rectangular solar charts are particularly useful in which the solar trajectories are indicated in horizontal coordinates, azimuth and elevation for each day of the year. The azimuth is the horizontal angle from a reference point, the north in this case, and the elevation is the angle measured from the horizontal plane. To analyse the incidence of a sunbeam, the azimuth of the alignment and the elevation of the lighting hollow are measured. The azimuth is taken to the sun chart on the x axis and the elevation on the y axis.

These types of charts have the advantage of being very clear and intuitive and the disadvantage that they must be drawn for each specific latitude. The figure 2 shows the solar chart of Celanova (Ourense) of latitude 42.15º N. This article will use cylindrical solar charts calculated with the PC-Solar program, version 2.0. The solar cards used have been corrected to indicate the dates that correspond to the Julian calendar of its construction period. In the Iberian Peninsula, different calendars were used, such as the Visigothic calendar and the Hispano-Mozarabic calendar. The Order of Cluny convinced the Christian kings to adopt the Roman calendar at the end of the 11th century. Sancho Ramírez introduced it to Aragon in 1071 and also to Navarre in 1076 after being named king of Pamplona. Alfonso VI introduced it to León, Castile and Portugal in 1077. However, the Hispanic calendar continued to be used for a long time. The use of one or the other calendar affects the festivities of the saints, but not the date, which was in all cases the Julian date. The Gregorian reform from which the current calendar comes out occurred in 1545, so it does not affect the calculated ephemeris.

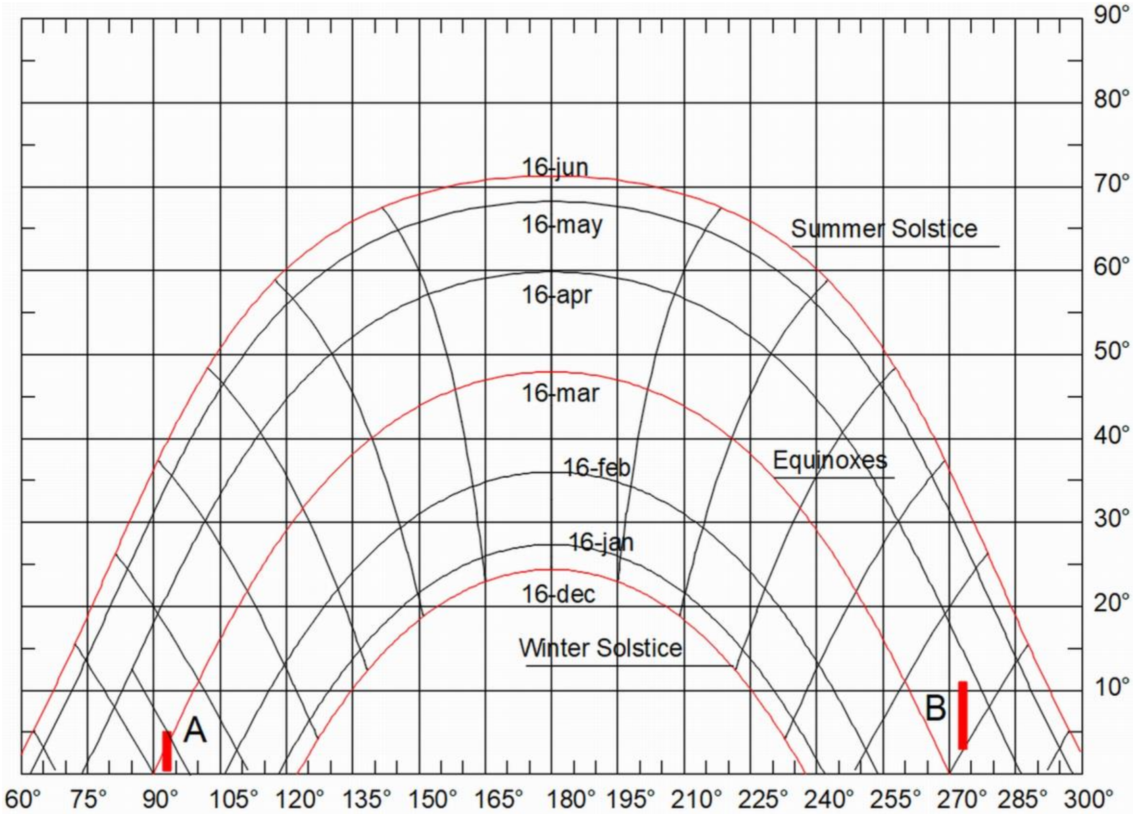


*Figure 2. Solar chart for Celanova (Ourense, Spain), 42.15º N.*

## 3. ARGUABLY CASES: SAN MIGUEL DE CELANOVA AND SAN JUAN DE ORTEGA

This study begins with a case that has had some diffusion and that, in the authors' opinion, lacks the characteristics of a deliberate solar phenomenon. This is the solar alignment at dawn of the equinox in the church of San Miguel de Celanova in Ourense (Fig. 3). It is a very spectacular phenomenon, that it has aroused a lot of interest.

*Figure 3- Chapel of S. Miguel de Celanova. The red line indicates the position of the solar rising in equinoxes.*

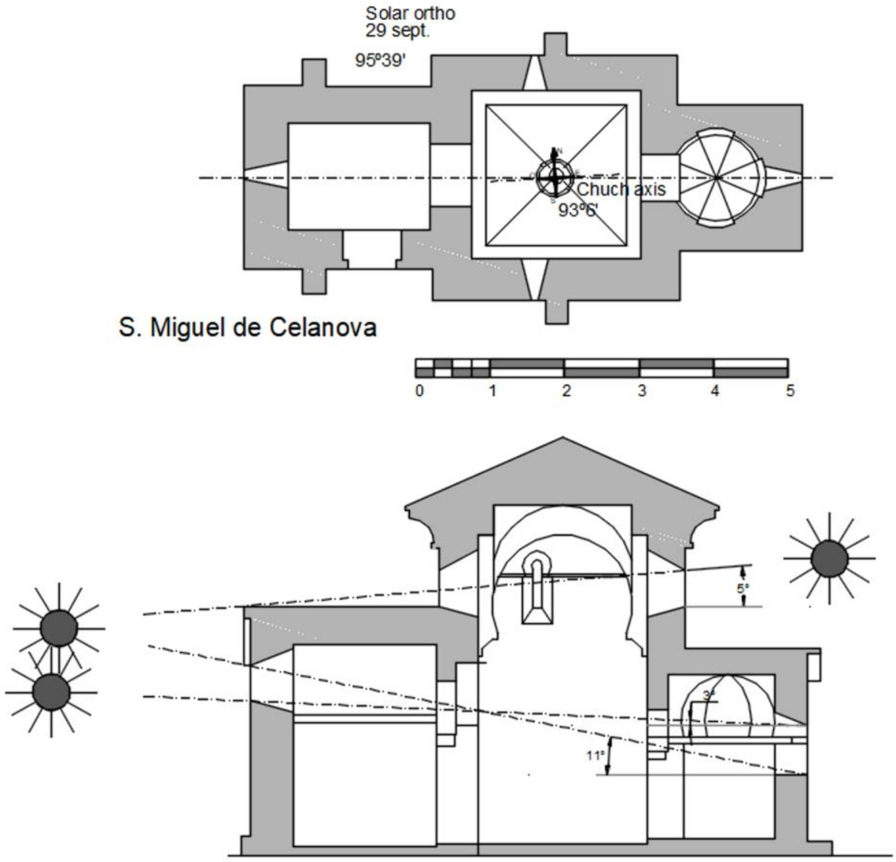


*Figure 4. San Miguel de Celanova. Orientation and trajectories of solar rays*

This church is one of the best examples of Mozarabic architecture and it is built with a high degree of perfection that suggests that nothing in it is casual (Franco Taboada and Tarrío, 2001). The church is of very small size and is formed by three volumes, of which the central one has greater height (Fig. 4). The most relevant fact for this study is the central body with windows aligned in the direction of the axis of the chapel, which also happens with the apse and the west facade that also have elongated windows aligned with the axis.

The building has an orientation of 92.5º degrees and a horizon altitude of 2.45º, so that the position of the solar ortho with altitude correction is 90.33º. Consequently, the day in which it was staked out was March 14 or September 17, according to the Julian date corresponding to the calendar in force at the time of its construction. Now this orientation corresponds approximately to the equinox (March 20 or September 23), but for its builders the date was the indicated. It is possible that someone had astronomical knowledge and could accurately identify the real equinox, which is possible, but in any case, it is a simple hypothesis.

The phenomenon in which the sunbeam crosses both windows is undoubtedly spectacular and therefore it has drawn attention and aroused all kinds of not founded interpretations. However, the same attention has not been given to consider that this phenomenon occurs not only on the day of equinox, but also on all those days when the height of the sun is between the lines defined by the edges of both windows. As it can be seen in figure 2, all solar trajectories between their boundary angles are congruent with the observation of a phenomenon of solar alignment. The boundary angles are the height of the horizon that is 2.45º as a minimum value and the altitude between the edge of the roof and the lintel of the rear window that is 5º as much (Fig. 2A). This gives us a narrow interval which would be between March 15 and 24 at the present. These dates correspond quite well with the astronomical equinox.

There is also another possible solar phenomenon. Looking at the building from the outside of the apse, to the west, there is an alignment between the two low windows that allows the rays of the setting sun to pass through the temple. The boundary angles are between 3 and 11º, so this situation occurs between March 26 and April 8 or in summer between August 24 and September 6. At the present time this phenomenon is not visible, since the current baroque church and possibly the previous Romanesque church, make the building in shadow in the afternoon. However, this phenomenon happened at the time of its construction (Fig. 2B).

It is possible that these phenomena had been deliberately foreseen, but it is much more reasonable to suppose that the windows have been simply aligned on the axis of the church, without another intention that was not a correct design. No variation in height of any of them is observed that limits the phenomenon to a narrower time interval, but has the expected proportions. The beam of light does not illuminate any singular element. For that we understand that it is a casual phenomenon that should not be considered a deliberate fact.

The solar phenomenon of the church of San Juan de Ortega in Burgos is probably the best known and the most famous. It consists of a ray of light that crosses the top of a gothic window illuminating a capital of great beauty that represents the Annunciation. It occurs at an interval of a few days around the equinoxes at 5:00 p.m. and around 8 minutes. The clear symbolism of the phenomenon means that all kinds of interpretations have been proposed, which are not the subject of this article.

It is indisputable that the phenomenon occurs, but, in the opinion of the authors, it is not a deliberate solar phenomenon, at least in its origin. It is a proven fact that the window was built after the capital. Some authors assume, without any technical basis, that there was an oculus, which if it is true could confirm the intention of the phenomenon at the beginning. However, while the existence of this supposed oculus is not proven, there is a simpler explanation. In reality, the phenomenon occurs because a wooden tribune, built much later, hides the entire window except the upper point of the ogive. It is very unlikely that the gallery was built with any other intention than to welcome the faithful and pilgrims, since the church is an important landmark on the Way of St James.

For these reasons, the authors consider that the cases cited by Celanova and Ortega, despite of their impact on the media, it lacks the necessary conditions to be considered premeditated solar phenomena, so we will exclude them from the rest of our study.

## 4. SOLAR ALIGNMENTS IN THE CHURCH OF SANTIAGO DE AGÜERO

The church of Santiago de Agüero in Huesca is one of the strangest and most surprising of Aragonese Romanesque. Its construction was started during the reign of Ramiro II the Monk (1134-1157) and completed by his son-in-law Ramón Berenguer IV, who limited its construction to the apses and the transept, leaving the rest unfinished. It is curious that in a church that was not intended to conclude, a truly extraordinary set of reliefs has been made, both in the capitals and in the frieze of the southern apse, of a very high quality (Zabala, 2015; García Lloret, 2020).

*Figure 5.- Church of Santiago de Agüero. Apses with the situation of the windows.*

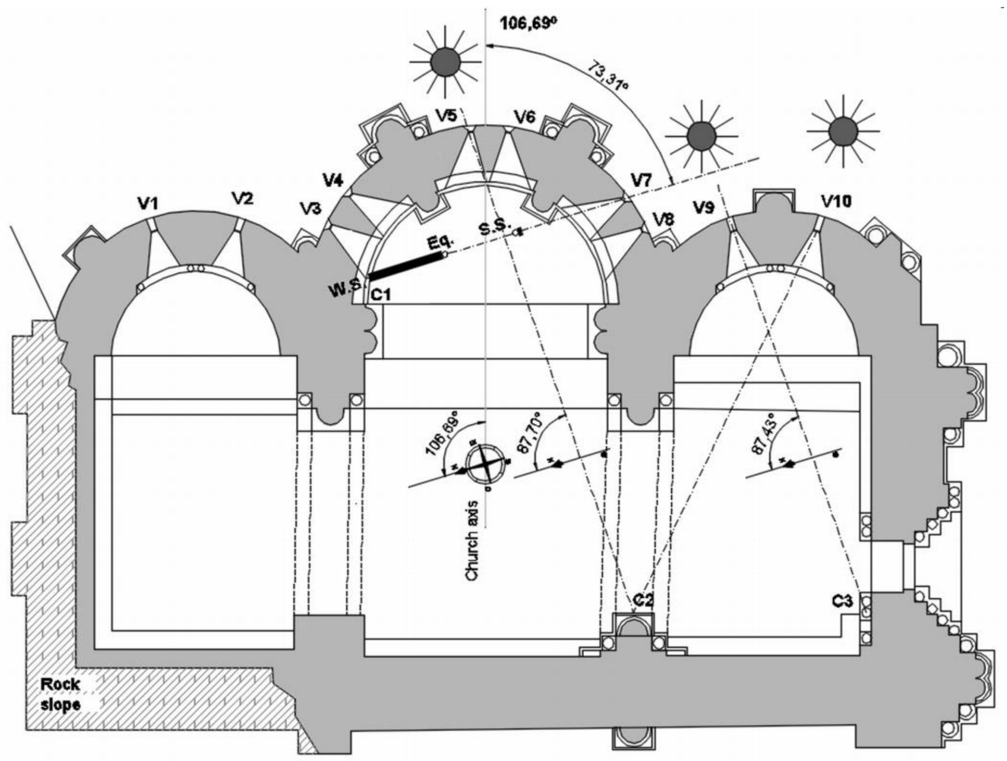


*Figure 6. Santiago de Agüero plant with solar trajectories. Drawing of the authors on data from Daniel Zabala.*

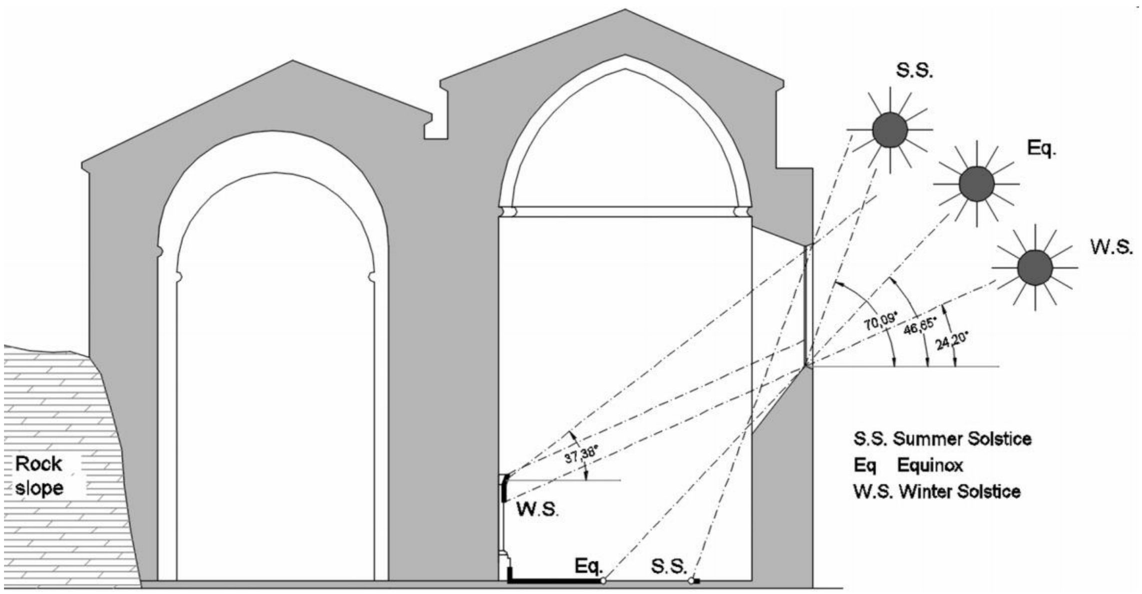


*Figure 7. Section in the N-S direction of Santiago de Agüero with solar trajectories.*

The church has a latitude of 42.35º N, an orientation of 106.69º and an altitude of the horizon of 3.35º. According to these data, the staking day that was February 16 or 17, or October 12 or 13, calculated in both cases on Julian dates of the 12th century. An autumn-winter orientation is notable in an area that it is not particularly conducive to begin a construction in these dates. However, it is possible that it has prevailed other reasons in this case. The area in which the church is implanted is topographically very unfavourable, with a ravine in the south and a rocky massif in the north. In fact, the current church has its northern apse embedded in the rocky slope. It is constructively very likely that, respecting the orientation to the east, it would have turned slightly to adapt it to the terrain. This was not always done in the Romanesque, in which many times very forced solutions were adopted to adjust the orientation of the building (Pérez Valcárcel, 2018), but it is likely that the orientation to the east would be very carefully combined in this case, with the possibilities of the available land.

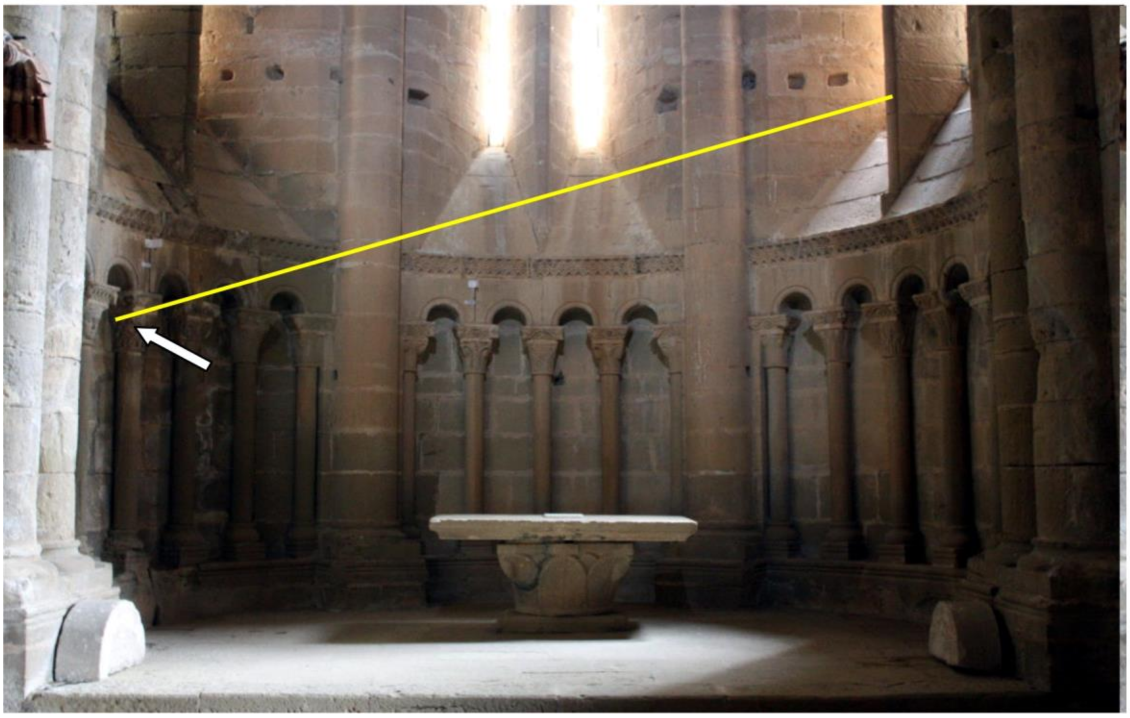

*Figure 8. Central apse of Santiago de Agüero with solar trajectory and illuminated capital.*

There are three singular elements in Santiago de Agüero: The second capital in the north side of the central apse (C1), the capital on the southwest corner of the cruise (C2) and the capital inside of the left jamb of the access door (C3) (Fig. 4). These capitals correspond to three alignments that correspond to dates with a clear symbolic meaning, Christmas for C1 and Easter for C2 and C3, (Table 3).

The capital of the apse (C1) represents a crowned head and it is completely different from all the others, which have stylized plant motifs. In this capital the most notable solar phenomenon of Agüero takes place. It is located in front of a southbound window and it has been observed that in the winter solstice a sunbeam coming from the window clearly illuminates the capital at noon solar. On the character represented, there are several theories that point to the kings of Aragon Alfonso I the Battler, Ramiro II the Monk or the Count of Barcelona Ramón Berenguer IV, husband of Petronila, heir of the throne of Aragon. The reasons provided by Zabala (2015) for this last attribution seems solid, but it is not relevant for the purpose of this article, the subject will not be delved into.

Because of its orientation, every day at solar noon, which in the case of Agüero occurs on average one hour and nine minutes later than in the official time on the winter solstice and two hours and nine minutes on the summer solstice, a ray of sun penetrates the temple in the direction of the cited column. During the summer solstice, only a small part of the light, which comes from the top of the window, illuminates the floor on the side, since most of the ray dies in the window spill. The light ray becomes larger and reaches the base of the column approximately on the equinox day and between October 2 (current October 9) and February 24 (current March 1), the sunray illuminates the capital. the rays coming from the windowsill light up the capital in the winter solstice. An alabaster plate, as was usual in Romanesque churches, closes the window, but the lower part of the plate is missing. This allows the passage of unattenuated sunrays and the phenomenon reaches the highest spectacular level. In Figures 4 and 5 the illuminated areas are indicated in plan and section according to the dates of the year. Figure 6 shows the path of the sunrays on a photograph of the apse.

*Figure 9. Illumination of the capital of Agüero (courtesy of Mr. Luis Lansac Torcal).*

The maximum illumination of the capital occurs around the winter solstice due to the lack of the bottom of the alabaster plate. It does not appear the plate has been broken, but the bottom piece has not been deliberately placed. For this reason, the illumination of the capital is produced with intensity on the dates close to the winter solstice, on Christmas time, whose symbolic meaning is evident (Fig. 9). To this it must be added that the reliefs of the extraordinary frieze of this church contain precisely the Christmas cycle. In the rest of the dates in which the capital is illuminated it does so through the alabaster, so the illumination is more attenuated, although it is clearly visible

The church of Agüero has other lines that make the sun's rays coming from different openings fall on some notable capitals that have been indicated as C2 and C3 (Fig. 2). Capital C2 is located on the pillar of the southwest corner of the transept and capital C3 is on the right inner jamb of the access door.

The capital C2 is a big representation of a male with the appearance of a naked child, and with marked sexual attributes, who is hung by two eagles that join their beaks above its head and hold his feet with their claws (Fig. 10a). The most common interpretation is that it is an "*elevatio animae*", in which the angels who usually raise the soul of the deceased towards Glory, have been replaced by eagles. Zabala considers that the use of eagles is due to the fact that "according to the Physiologist, he can ascend to the sky looking directly at the sun, which equates to Christ who can directly contemplate his Father" (Zabala, 2015; Physiologus, 1986). Such interpretations, undoubtedly very interesting, are not the object of this study. The important thing is that it is a special capital, that shares themes with others in which the solar phenomenon is very evident, as in the case of Tera (Pérez-Valcárcel & Pérez Palmero 2014; Regueras Grande, 2015). For this reason, we consider it very likely that the phenomenon has been foreseen, although the exterior vegetation prevents us from seeing it at the present.

***Figure 10. Capitals C2 and C3 of Santiago de Agüero.***

The capital C3 corresponds to a combat between a Muslim warrior and another Christian that takes place in two phases (Fig. 10b). On the outside the lid seems even, while on the inside it opts for the Christian's side, who pierces the Muslim with his spear. Precisely on the inner side, the V3 window illuminates very visibly the capital at the equinox. In this case, the capital is not as noticeable as the others described, but it raises a theme that was undoubtedly important in its time and the date is also unique. Therefore, it is considered that it should be included in the study as a deliberate alignment.

Zabala points out in his article the existence of other possible alignments. The capital C2 could be illuminated from windows V3, V5, V6 and V10. The V4 window would be at the limit so if it were occurred, which is unlikely, it would be very short-lived. The rays of light that could come from the V9 window would die in the spill of the mentioned window before reaching the capital. In the same way, the C3 capital would only have valid alignments from windows V3, V4 and V9. Alignments do exist, but not all are considered intentional.

The data of these alignments have been obtained with a Leica brand laser meter, model DISTOTM D8 with a precision of 1 mm, which has a digital clinometer with a precision of 0.05º. The orientation data has been measured with a Suunto KB-14/360 R G brand precision compass with a precision of 0.5º. These results have been verified with the data provided by Zabala in his article, showing a good agreement. With these data, the authors' Orient 3.0 program provides the following results.

*Table 3. Alignments and possible dates in Agüero*

| Agüero | Latitude: 43,35º N | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Alignment | Azimuth | Top | Bottom | Interval 1 | | Interval 2 | | |
| V7-C1 (A) | 180.00 | 17.96º | 34.95º | 02-oct | 14-dic | 14-dic | 24-feb |
| V5-C2 (B) | 87.70 | 11.68º | 0.00º | 18-mar | 07-apr | 21-aug | 11-sep |
| V9-C3 (C) | 87.43 | 13.46º | 9.37º | 04-apr | 11-apr | 17-aug | 25-aug |

Taking these values to a solar chart of the latitude of Agüero, it is easier to visualize the areas illuminated by the three alignments described.

In the solar chart and in figures 5 and 10, the studied alignments are observed with the results obtained. They are as follows.

A. Window 7 - capital 1 alignment. - It is the most notable alignment and the only one that has aroused the greatest interest. It occurs on the winter solstice day at solar noon and it illuminates the capital with the effigy of the king (Fig. 5). As indicated, some degree of illumination occurs between October 2 and February 24 (Julian dates), but the phenomenon is less noticeable.

B. Window 5 - capital 2 alignment. - It occurs after the spring equinox and before the autumn equinox, on the dates indicated in table 3 in an interval around three weeks (Fig. 10).

C. Window 9 - capital 3 alignment. - It also occurs after the spring equinox and before the autumn equinox, on the dates indicated in table 3, but in a shorter interval, of one week (Fig. 10).

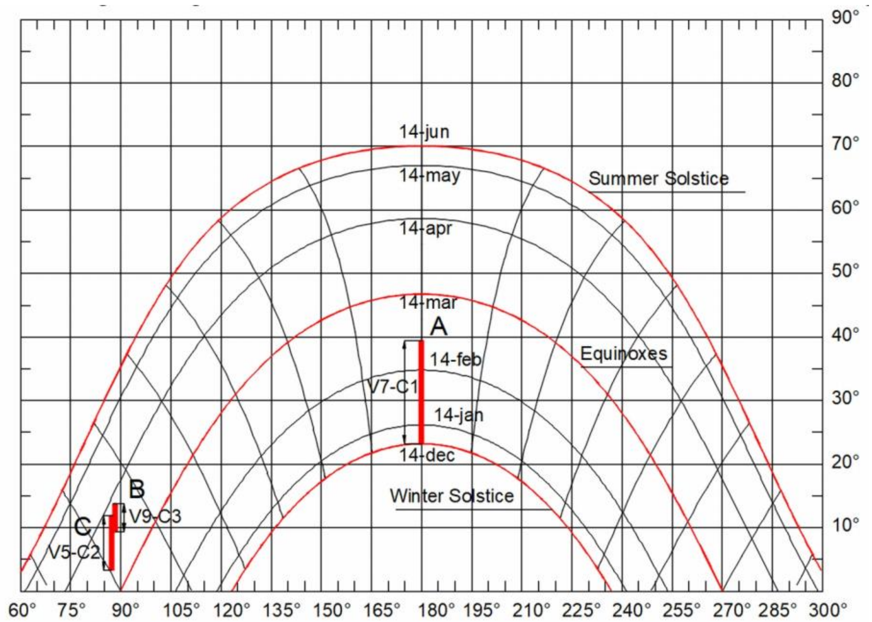


*Figure 11. Solar chart of Santiago de Agüero (43.35º N) with the analysed alignments.*

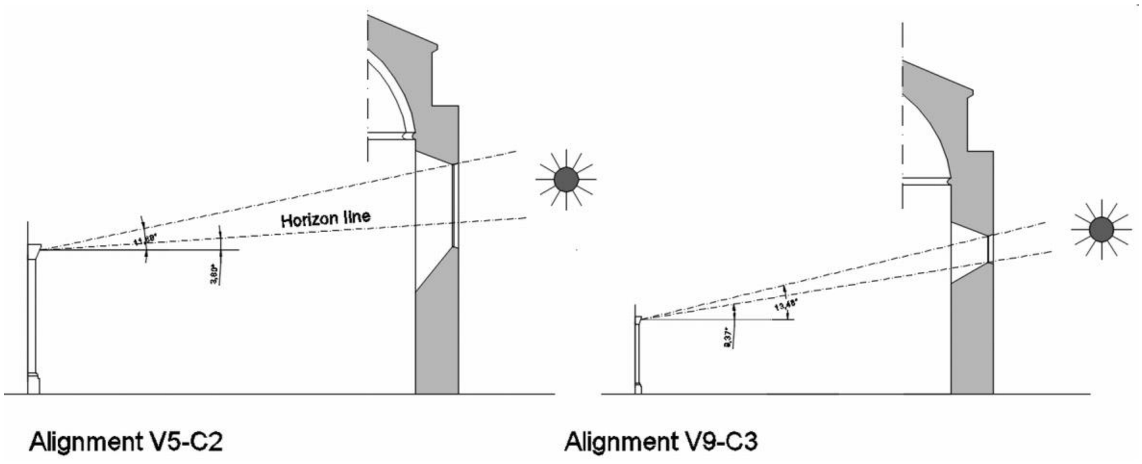


*Figure 12. Sections of the church with the alignments B and C.*

There are other possible alignments such as those of windows V3, V5, V6 and V10 towards capital C2 and those of windows V3, V4 and V9 towards capital C3. Of all these alignments, only C1-V7, C2-V5 and C3-V9 can be deliberately traced. The first one corresponds to the south direction and the other two to the east direction. The alignments to the east allow a wide range of possible altitudes, which at the latitude of Agüero are between 0º (equinoxes) and 35.29º (summer solstice). In contrast, some very clear plan alignments such as C2-V10 have such a small altitude relative to their azimuth that they cannot correspond to a true solar path. The rest of the alignments can be interpreted as normal situations in a well-designed building with reasonable regularity, both in plan and height. In these alignments, the singularity characteristics with which this type of sunrays illumination effects are identified are not appreciated. For this reason, it is considered that only the three indicated alignments can fulfil the required intentionality conditions.

## 5. STAKING SYSTEMS USED

Naturally, the calculations provided have been made with technical resources that no one could imagine in the Middle Ages. The Romans had made great advances in topography (Guillaumin, 2005) and part of that knowledge had been preserved (Moreno Gallo, 2004). The medieval builders had solid knowledge of geometry that allowed them to achieve these results with much simpler devices and systems (Mc Clusky, 1998).

It is very easy to determine a solar alignment both in plan and elevation, using only stakes and ropes. And for this, the Agüero V7-C1 alignment will be analysed in detail, which is the phenomenon that it can be considered deliberate with the greatest probability. As in the Middle Ages as today, construction work begins with the stakeout in which the orientation is fixed and contour of the building is planned. When the stakeout is done, a simple stake can be marked the desired alignment with its shadow line on the chosen day. Being calculated an adequate height, the end of the shadow on that day marks the desired point on the ground, where the building is already laid out. If we add the height of the capital to the height of the stake, the final position of the oculus or window can be precisely determined. It is a well-known construction since ancient times. In fact, the Romans used the Hellenistic lychnia for similar stakeouts. It is a simple and very effective instrument that is also drawn in the Villard de Honnecourt album, therefore we consider it is highly probable that it was used in medieval times. When the position of the hole is fixed, the solar phenomenon occurs on the required date.

As for the altitude of the loophole, when the position of the blocks has been rethought, it is enough to lay a thread from the window to the capital so that the necessary altitude is correctly defined. It is an elementary system, that it still used in current construction.

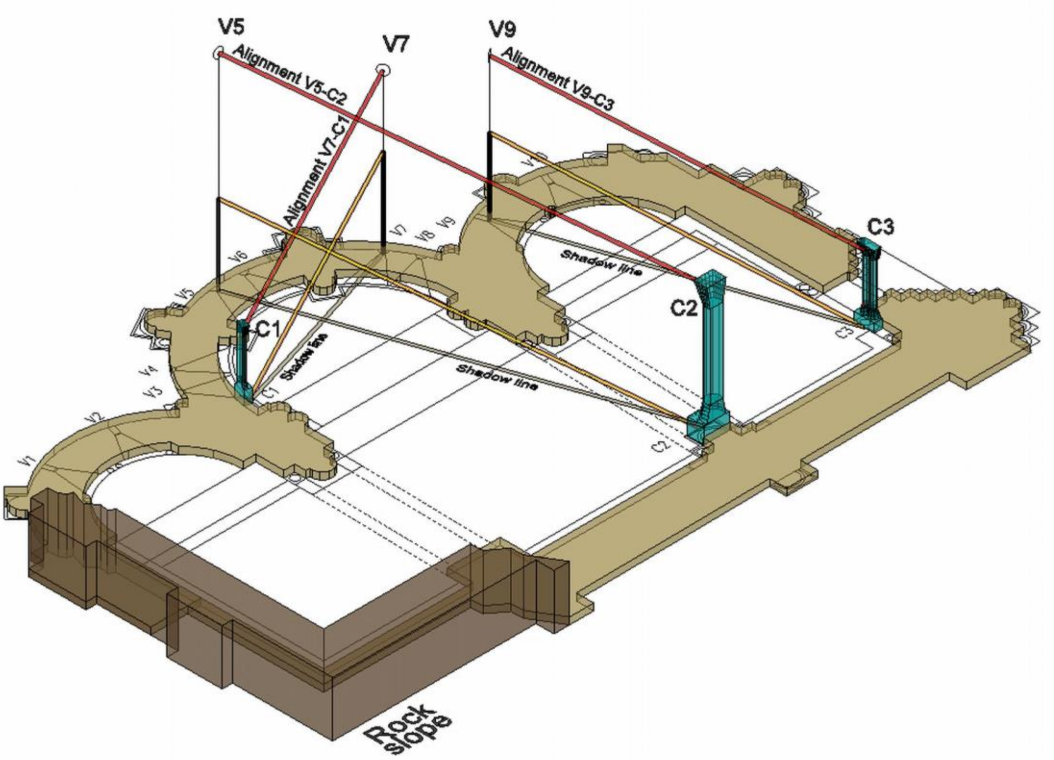


*Figure 13. Scheme of the possible stakeout of the light lines.*

Figure 13 shows the replanting process that could be used. In this case, it is not necessary a special adjustment because the light source is a window. But in the case of Tera, where the light source is an oculus, the placement of the ashlars is adjusted to precisely define the dimensions of the hole. In Agüero it was not necessary, but the strong inclination of the windowsill is notable. This implies the intention that the sunbeams can penetrate the interior of the building without obstacles.

The figures show the layout diagrams of the different alignments indicated. When the light source is a window, the margin is wider, so it is not necessary to adjust the ashlars, as it happens in the case of the church of Agüero.

## 6. CONCLUSIONS

The study carried out provides reasonable criteria to distinguish deliberate sunrays illumination effects from casual ones, such as the illuminated element, the date of the phenomenon and the light source. The illuminated element must have some singularity and form a fixed part of the temple. In addition, the date when the phenomenon occurs must have some meaning and the gap that it illuminates must have some intentionality.

These criteria can serve to rule out or at least call into question some of the phenomena that have been described. Thus the sunrays illumination effects in Celanova or San Juan de Ortega do not seem to respond to phenomena of clear intentionality. There are also many other phenomena that have been pointed out by various authors such as San Bartolomé de Rio Lobos in which the rigorous application of these criteria would allow them to be considered as simple coincidences.

The three alignments indicated in Agüero correspond to singular days and elements, although when are produced through windows their temporal margin is less clear. In the case of the capital with a crowned head C1, it is considered that the lack of the lower piece of the alabaster is deliberated, which is proof of the intentionality of the phenomenon. In any way, in authors' opinion, the three cited alignments are deliberate. On the other hand, the rest of the alignments indicated by Zabala are likely to be accidental, coming indirectly from the simple regularity of the temple's layout.

For the determination of these phenomena, the use of the cylindrical solar chart is especially useful, in which the azimuth and elevation of any possible solar path can be defined with great ease and the day and time when the phenomenon occurs. It does not have the same degree of precision as astronomical calculations, but it is sufficient for practical cases and does not require specialised astronomical knowledge, so it is within the reach of any researcher. This methodology can be successfully applied to the determination of remarkable alignments and if the indicated restrictions are considered, is available a useful system to define whether such alignments have a meaning or not.

In all cases and with a complete security, the construction system used was applied with simple elements such as stakes, threads and shadow lines. This should not seem minor. Eratosthenes calculated the size of the Earth by measuring the shadow of a stake (gnomon). Let us not forget that for a long time the gnomonic was a highly appreciated and useful branch of knowledge. On the other hand, the geometric knowledge of medieval builders is doubtless.

There is no conclusive evidence of the intentionality of these solar phenomena, but it seems that the evidence provided gives a reasonable probability to conclude that the case studied in Santiago de Agüero is not an accidental phenomenon, but rather that it has been deliberately projected by the builders, with an identical or similar staking system to the one proposed.

In conclusion, the article gives an adequate response to the three objectives indicated. The criteria established to determine the intentionality of the solar phenomena have led with reasonable certainty to conclude that in the case of Celanova it is a casual phenomenon and in the case of Agüero, to indicate from all the possible alignments those that are deliberate. For this, the use of solar charts has proven to be a simple and efficient method without the need to use complicated astronomical calculations. Finally, a completely viable staking method has been proposed that demonstrates that medieval builders had sufficient means to achieve these effects. It is considered that they are contributions of interest that can allow and facilitate investigations in other similar cases.


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