Mediterranean Archaeology and Archaeometry
2024, 24(3), 1334
ISSN:2241-8121
https://www.maajournal.com/
Research Article

Time and Culture Across the Iberian Lands: The Cathedrals' Orientation Paradigm—A Diachronic Analysis of the Orientation of the Cathedrals of Portugal and Spain

Maitane Urrutia-Aparicio [1*], Juan A. Belmonte [2] A. César González-García [3]

[1] Doctor, Escuela de Arquitectura, Universidad Europea de Canarias; Instituto de Astrofísica de Canarias; University of La Laguna, Tenerife, Spain
[2] Professor, Instituto de Astrofísica de Canarias, and University of La Laguna, Tenerife, Spain
[3] Doctor, Instituto de Ciencias del Patrimonio, INCIPIT-CSIC, Santiago de Compostela, Spain
* **Corresponding Author:** m.urrutia.aparicio@gmail.com

Citation: Urrutia-Aparicio, M., Belmonte, J. A., & González-García. A. C. (2024). Time and Culture Across the Iberian Lands: The Cathedrals' Orientation Paradigm—A Diachronic Analysis of the Orientation of the Cathedrals of Portugal and Spain. *Mediterranean Archaeology and Archaeometry, 24*(3), 1–22. 10.5281/zenodo.13382956

ARTICLE INFO

Received: 03 May 2024
Accepted: 30 May 2024

ABSTRACT

The purpose of this research is to explore the complex and evolving orientations of cathedrals in the Iberian Peninsula and associated islands, examining the interplay between cultural, religious, political and architectural influences. Employing temporal and cultural analyses alongside remote sensing tools like Google Earth and HeyWhatsThat to gather archaeoastronomical data, over a hundred structures have been documented, revealing diverse orientation patterns across centuries. The earliest cathedrals aligned predominantly with equinoctial orientations in accordance with canonical prescriptions. However, deviations to the northeast appear from the 13th century onward, challenging conventional explanations and suggesting the need for a more in-depth analysis. Results suggest that cathedrals might be oriented according to ancient Roman city planimetries, to the perpendicular of the most employed qiblas during Muslim rule, and, naturally, to the ancient Christian prescriptions. In this context, the research sheds light on the potential influence of regional idiosyncrasies and pre-existing structures in shaping cathedral orientations, emphasizing the necessity of considering diverse cultural influences. Finally, a pivotal turning point around the last Council of Trent (1563) and the Gregorian reform of the calendar (1582) is identified, marking a relaxation in orientation prescriptions. Overall, this research contributes to a comprehensive understanding of the intricate history of temple orientations in the Iberian Peninsula within a broader cultural and historical context.

Keywords: Archaeoastronomy, Church orientation, Iberian Peninsula, Cathedrals, Qibla.

INTRODUCTION

Early Christian communities adopted an eastward orientation in their rituals, symbolically connecting Christ with the rising sun, often metaphorically described as the Sun of Justice (McCluskey, 2015). This enduring liturgical practice, with a focus on the east, has aroused debates and scholarly inquiries over the centuries regarding its precise connotations. However, over time, there seems to have been greater flexibility in church orientations, especially after the last Council of Trent in 1563, as noted by Cardinal Borromeo in his work Instructiones fabricae et supellectilis ecclesiasticae (I, 10) (Borromeo, 1577): "Eius pars posterior in orientem versus recta spectet, etiam si a tergo illius domicilia populi sint. Nec vero ad solstitialem, sed ad aequinoctialem orientem omnino vergat. Si vero positio eiusmodi esse nullo modo potest, episcopi iudicio, facultateque ab eo impetrata, ad aliam partem illius exaedificatio verti poterit; tuncque id saltem curetur, ut ne ad septemtrionem, sed ad meridiem versus, si fieri potest, plane spectet". There, the author explains the relevance of equinoctial east when orienting churches, but also how to proceed when this orientation could not be achieved, marking a difference with prior prescriptions.

From the 19th century onward, researchers have increasingly delved into comprehensive studies exploring hypotheses related to church alignments (González-García, 2015), including considerations of the feast day of the patron saint (Hinton, 2006; Liritzis & Vassiliou, 2006a; Laužikas, 2015; Spinazzè, 2016; Abril, 2017), the equinoxes (Liritzis & Vassiliou, 2006b; Dallas, 2018; Čaval, 2018), or important feasts of Christianity such as Easter Sunday (Romano, 1997; Ali & Cunich, 2001; Spinazzè, 2015; Krack, 2020; Urrutia-Aparicio et al., 2021).

However, later research has revealed the significance of regional peculiarities and the impact of local topography, challenging simplistic explanations (Ridderstad, 2013; Di Paolo et al., 2020; Muratore et al., 2023). Recent studies, particularly in Spain, have added complexity to the discussion by examining factors, including a construction criterion, i.e. the day of the church layout (Pérez-Valcárcel & Pérez-Palmero, 2021), the use of the gnomon for precise orientations (Lluís et al., 2021) and the impact of pre-existing structures (García-Ortega, 2015; Abril, 2020). The latter is of particular relevance to our current research, due to the region's diverse cultural history. Roman Hispania experienced a significant transformation with the arrival of Germanic tribes in the early 5th century, eventually leading to the Visigoths' dominance over the entire Iberian Peninsula by the 6th century. The subsequent Muslim invasion in 711, followed by the prolonged Christian expansion southwards (a process often termed as 'Reconquista' in Spanish historiography), deeply changing the cultural landscape. Over nearly eight centuries, both Christian and Muslim cultures coexisted on the peninsula, fostering the development of diverse artistic styles. This prolonged period of cultural and artistic interchange left an indelible mark on the heritage of the Iberian Peninsula.

Such interchange can also be perceived at the level of the orientation of cultic buildings. An illustrative example of such behaviour is observed in the pre-Romanesque Asturian churches, where builders may have intentionally avoided orientations that could be perceived as resembling those of mosques constructed in contemporary Al-Andalus. This avoidance might be highlighting their resistance against Muslim dominance, as proposed by González-García and Belmonte (2015a). During the Reconquista, numerous mosques were converted into churches, motivated both by economic considerations and the desire for consolidation of power (Harris, 1997). This transformation often involved using the perpendicular orientation, as many churches' apses were aligned towards the east-northeast, contrasting with mosques oriented towards the southeast according to the qibla, albeit with variations (Rius, 1999a). Additionally, there are instances where "paleochristian and Visigothic temples were repurposed, with the qibla determined, by positioning the mihrab in the Epistolae wall, a practice that was reversed during the Reconquista process" (Jimenez, 1991). Therefore, as previously indicated, the existence of prior structures should be considered when studying the orientation of churches (Liritzis & Vlachos, 2022).

Given the remarkable findings observed in the late antiquity and medieval churches within the Iberian Peninsula (González-García & Belmonte, 2015b; Abril, 2020; Lluís I Ginovart et al., 2021; Pérez-Valcárcel & Pérez-Palmero, 2021; Urrutia-Aparicio et al. 2022), which exhibit distinct equinoctial or Easter orientations, among others, the question arises as to whether these traditions were preserved across time and geographical regions. To address this inquiry, we selected a complete historical sample of cathedrals that encompass a large temporal and physical scope.

METHODOLOGY

Data Sample and Methodology

In total, we studied 122 cathedrals, co-cathedrals and ancient cathedrals within the Iberian Peninsula and associated islands (Giga-Catholic Information, 1997). Details concerning their locations and dates of construction are available in Table 3 in the Appendix, along with accompanying archaeoastronomical data. Figure 1 shows some illustrative examples of cathedrals constructed at various times, in distinct styles, and across diverse locations. Cathedrals serve, in this analysis, as exemplary subjects for two fundamental reasons. Firstly, due to their relatively large structures, the margin of error in their examination through remote sensing techniques and satellite imagery is minimized. Secondly, these edifices hold significance as pivotal ecclesiastical buildings constructed over numerous centuries, dispersed across the Iberian Peninsula, the Balearic Islands, and the Atlantic archipelagos. Moreover, there has been growing interest in the orientation of cathedrals in Spain in recent years; notable studies include the investigation of illumination effects on the cathedrals of Santiago de Compostela (Vilas-Estévez et al., 2018) and Mallorca (Samper et al., 2024).

Figure 2 illustrates a map encompassing the Iberian Peninsula, Ceuta, the Balearic Islands, and the Atlantic archipelagos, displaying the orientations of cathedrals and their respective locations. We conducted azimuth measurements using Google Earth (2001), leveraging multi-year satellite imagery to mitigate undesirable effects like parallax, by taking the mean value of all measurements for each church. This study is not the first research attempt in the field of church orientation employing Google Earth for the acquisition of azimuth data. Several prior investigations, including those by Dallas (2015; 2018), have extensively used this tool and proven its capabilities.

In line with the methodology outlined by Rodríguez-Antón et al. (2018), we estimated a mean error of 1.35° in azimuth associated with Google Earth and 1° for height using HeyWhatsThat (Kosowsky, 2013). Regarding declination, we determined an uncertainty of 1.7° through error propagation. The results are predominantly presented in curvigrams, following a similar methodology to previous works (González-García, 2013). Additionally, we used a heat map representing the expected frequency for a pair of declinations and date values. This kind of image helps to visualize the orientation patterns over time within a single figure.

The sample under consideration encompasses cathedrals constructed over a broad temporal spectrum, the majority of them going from the eleventh century to the twentieth century. This presents one main problem: some of these cathedrals followed the Julian calendar when they were erected, while others adhered to the Gregorian calendar. The Julian calendar accumulates one day every 128 years due to its disparity with the tropical year. Consequently, depending on the construction date, a significant discrepancy may exist between celestial events, such as astronomical equinoxes or solstices, and fixed calendar dates.

For instance, in the year 1400, the astronomical equinox occurred around March 11, deviating by approximately ten days from the ecclesiastical equinox, resulting in a declination of about 4˚. In contrast, in 1150, the astronomical equinox happened on March 14, while the ecclesiastical equinox corresponded to a declination of approximately 3˚. Following the Gregorian reform of the calendar in 1582, both equinoxes regained synchronicity, with a declination of c. 0˚.

The challenge in establishing a correlation between a specific date and a particular declination value lies in the necessity to designate a specific year for this purpose. Therefore, a chronological analysis is imperative to ascertain the consistency or evolution of canonical orientations across different time periods. Of course, one of the major challenges is to ascribe a given cathedral to one particular period, when some of them have been subject to several reforms and rebuilding. In this case, we would ascribe a given Cathedral to the period when the largest parts of it were built. It is essential to note that this approach does not dismiss the possibility of earlier structures for which the analysed images may provide occasional evidence. For example, in the case of the Cathedral of Santiago, although the latter stages of the multi-secular building are those of the Baroque reform (especially by the construction of a new façade and towers that modified the overall outward structure, see e.g. Vilas-Estévez et al. 2018 for the effects in the illumination inside), the nave is clearly Romanesque, and therefore it was considered by this period of time. If changes manifest, understanding the nature and rationale behind these alterations becomes crucial. This demands an exploration of potential disparities in orientation choices based on the cultural milieu of the era, whether Roman, early medieval Christian, Muslim, late medieval, or Renaissance.

Figure 1. Representative Examples of Cathedrals in the Iberian Peninsula and the islands, Exhibiting Diverse Architectural Styles and Periods of Construction: (a) Santo Domingo de la Calzada, initiated in the 11th century in the Romanesque style; (b) the Gothic facade of the cathedral of Palencia, dating back to 1321; (c) Las Palmas (Gran Canaria), constructed at the end of the 15th century; and (d) the new cathedral of Malaga, which, although its construction began in 1528 in the Renaissance style, has its origins tracing back to 1486, built atop the remains of the main mosque. Images: the authors.

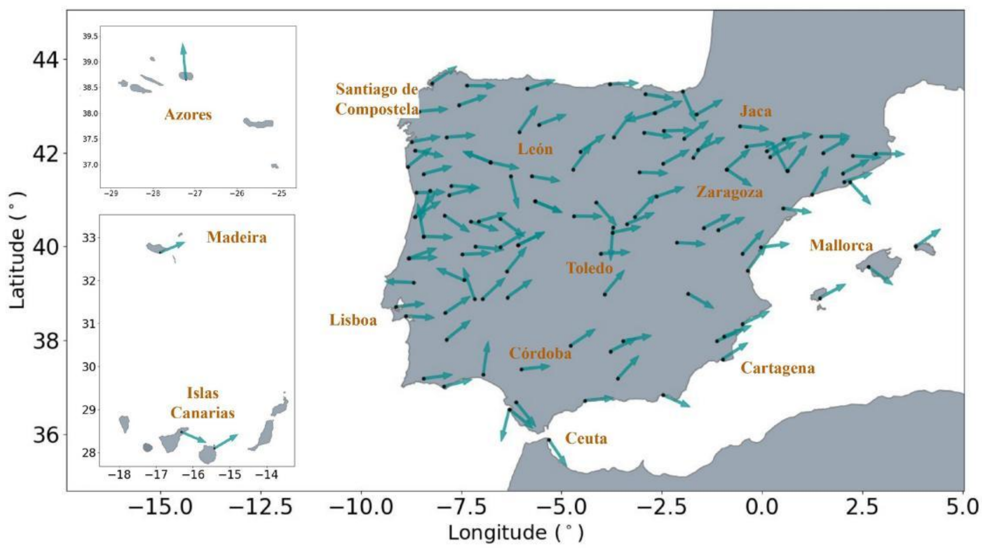

Figure 2. Map Depicting the Iberian Peninsula, Ceuta, Balearic Islands and Atlantic Archipelagos, Showing the Locations of the Cathedrals Alongside their Respective Orientations

RESULTS

The integration of the aforementioned perspectives promises a more comprehensive understanding of the cathedrals in the Iberian Peninsula and associated islands, encompassing their historical origins and evolutionary trajectories.

Chronological Analysis

This analysis will be undertaken through two distinct approaches. The initial method provides an overview of cathedrals alongside their respective dates of construction and orientations, expressed in declination values. This preliminary examination, as a general picture, aims to identify potential clusters, facilitating subsequent segregation into distinct groups for a more in-depth and detailed analysis.

Figure 3 illustrates the declination values of the cathedrals based on the century of their construction. The colour scale in this heat map denotes the frequency of occurrences for pairs of declination and date values. By doing so, significant groupings are depicted in yellow and red, while less prominent ones are represented in indigo blue and purple.

According to this colour scale, the sample reveals three notable groups or clusters. The primary and most substantial cluster shows a declination around 3°, mainly predominant in the twelfth century and extending into the following century. The second cluster spans declinations between 23° and 19°, prevalent in the 14th and 15th centuries. The third cluster appears within the declination range of 5° to 19° (in yellow) in the 12th and 13th centuries. These three major concentrations may be related to the equinox, summer solstice, and Easter, respectively. It is noteworthy that what starts as a set of orientations toward the northeast (ranging from approximately 3° to 23°) persists from the 12th to the 16th century, without any discernible concentration or pattern thereafter. Lastly, a smaller group (in green) exists outside the solar range, around 35°, primarily corresponding to the 13th century.

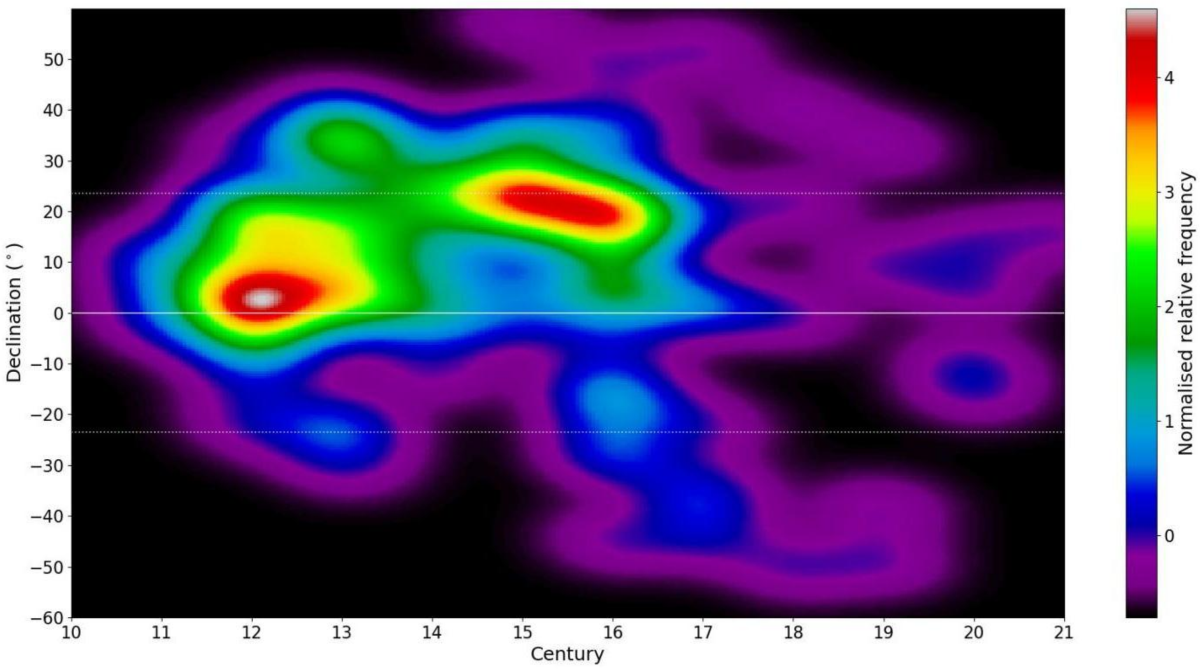

Figure 3. Declination Frequency Map Relative to the Date of Construction of the Cathedrals. The abscissa axis presents various centuries during which cathedrals were built, while the ordinate axis represents their orientations, expressed in declination values. The colour scale indicates the relative frequency with which a certain declination and time value is expected, with red and yellow denoting higher significance. Three primary concentrations are evident: around the equinox, the summer solstice, and Easter

For a more detailed analysis, we have categorized the sample into four groups based on the construction date. The first group encompasses cathedrals erected between the 11th and 12th centuries (a total of 27 measurements), corresponding to the Romanesque period. The second group includes those constructed in the 13th and 14th centuries (totalling 34), predominantly representative of the Gothic style. The third group comprises cathedrals from the 15th and 16th centuries (a total of 40), representing the transitional period from the late Gothic (Flamboyant) to the Renaissance style. Finally, the fourth group consists of cathedrals constructed from the 16th century onwards (21), a period marked by greater flexibility in the orientation guidelines (Borromeo, 1577), and the establishment of the Gregorian calendar.

Figure 4 displays the azimuth and declination curvigrams for each group of cathedrals, normalized in the usual manner to identify significant maxima (González-García, 2013), and Table 1 presents the maxima extracted from these curvigrams, organized chronologically for each specified group. Note the persistent maximum around 90° azimuth, spanning significantly from the 11th to the 14th century, corresponding to the peak at 0° declination. Additional maxima persist up to the 16th century, visible to the northeast and ranging between 64° and 77° of azimuth. Finally, cathedrals constructed between the 13th and 16th centuries exhibit a less pronounced ensemble discernible near 44° of azimuth.

Note how these results align with those presented in the heat map in Figure 3, providing a slightly more detailed insight, particularly regarding the azimuth values. The first set of cathedrals shows nearly equinoctial (or Easter) orientations, with a larger tail towards NE, perhaps related to the Easter orientations. The second set, c. 13th and 14th, do include this pattern, but now the largest concentration is close to values near the summer solstice. The northeast orientations, especially the one near 44° azimuth and 35° declination, stand out due to their deviation from the equinoctial line and even falling outside the solar range. The cathedrals of the third group cluster near summer solstice azimuths and declinations, while those after the 16th century do not seem to display any significant pattern (apart from a slight concentration close to the equinox in declination). This departure from the standard results found in churches suggests the need to explore alternative explanations, considering the historical context of the time.

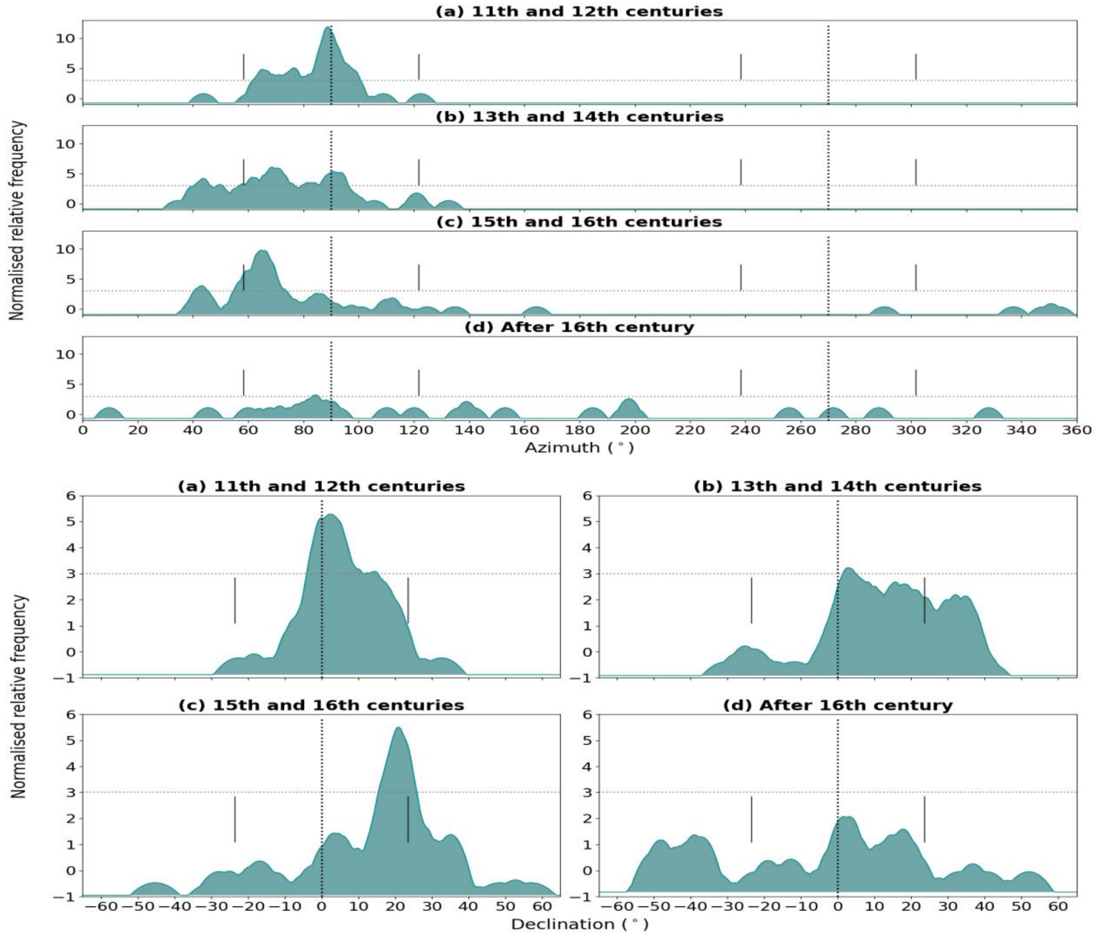

Figure 4. Azimuth and Declination Curvigrams of Cathedrals Divided into Four Groups (a) 11th and 12th Centuries, (b) 13th and 14th Centuries, (c) 15th and 16th Centuries, and (d) post-16th Century

Table 1. Significant Maxima From the Azimuth Curvigrams Associated with Each Established Temporal Group, Along with their Corresponding Declination Values

Period (centuries)	Azimuth (°)	Declination (°)
11th-12th	88.8	2.1
	76.7	11.5
	64.3	18.5-20.2
13th-14th	90.7	0.0-5.1
	68.7	14.5-18.5
	43.8	34.6
15th-16th	64.7	21.0
	43.2	35.0
>16th	84.3	1.7

Upon closer examination of cathedrals with these orientations, a notable pattern emerges. Many of them constructed in the 13th century and onwards, were predominantly located in the southern and eastern parts of the Iberian Peninsula. These observations raise the hypothesis that these cathedrals, built during the Christian Reconquista, may have been repurposing the layouts of prior mosques and subsequently rotating the apse by 90°, a concept recently analysed by Abril (2020) in the context of churches in Al-Andalus.

These findings underscore the need for a distinct analysis that delves into the interplay among the various cultures that inhabited the Iberian Peninsula.

Cultural Analysis

As previously pointed out, the findings of the temporal analysis emphasize the importance of thoroughly examining potential distinctions and similarities in the orientation patterns related to the diverse cultures that have inhabited the Iberian Peninsula and its archipelagos throughout history. Such an inquiry has the potential to provide insights into the intricate interactions among these cultures.

In an initial analysis, we attempted to represent the locations of cathedrals and their orientations, classifying them into three distinct groups. The map in Figure 5 aims to facilitate the identification of potential spatial patterns. On one hand, it depicts cathedrals that are definitively known to have been constructed on a mosque or its grounds. On the other hand, and based on the temporal analysis, those constructed after 1563—the last Council of Trent and, therefore, a potential relaxation in the tradition of church orientation (Borromeo, 1577). Finally, we indicate cathedrals that, as per available information, do not meet either of the aforementioned conditions and are presumed canonical. Additionally, Figure 6 displays the azimuth curvigrams of these three groups in red, yellow, and green, respectively.

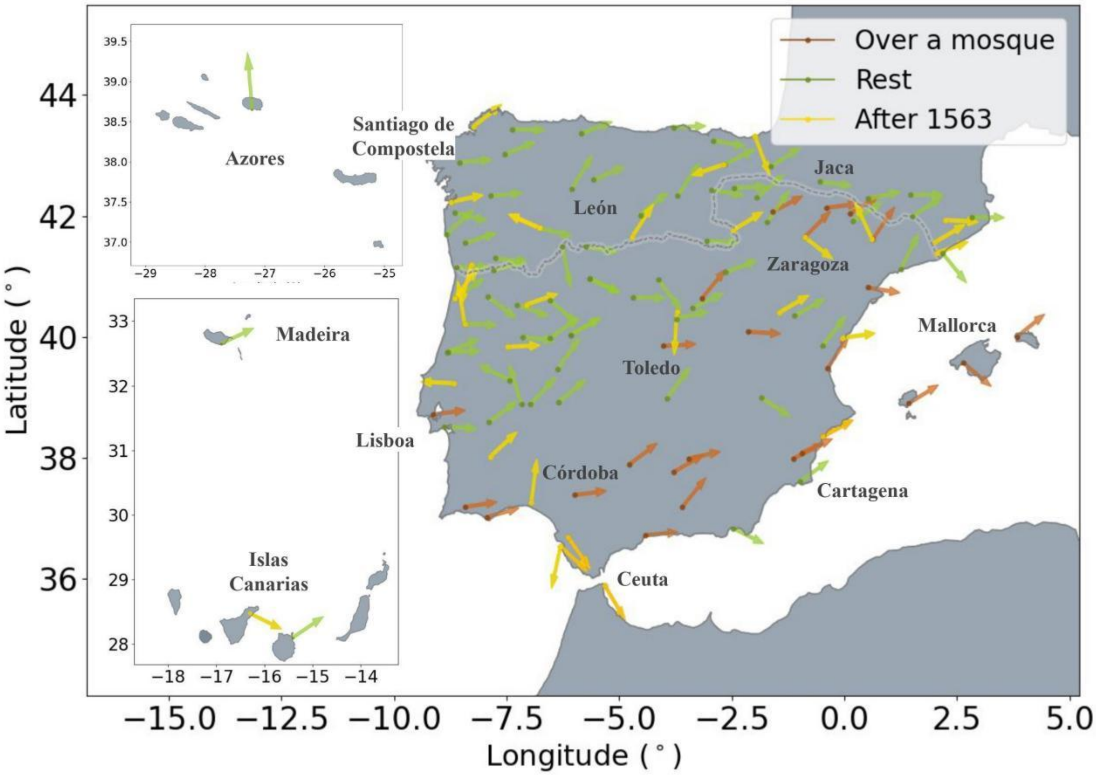

Figure 5. Map Illustrating the Christian-Muslim Border Around the Caliphate of Cordova (c. 950 AD), as an Illustrative Example of a Period of Splendour in Al-Andalus. The image presents cathedral orientations categorized into three groups: in red, those constructed over prior mosques or their grounds; in yellow, those built after 1563; and in green, the remaining.

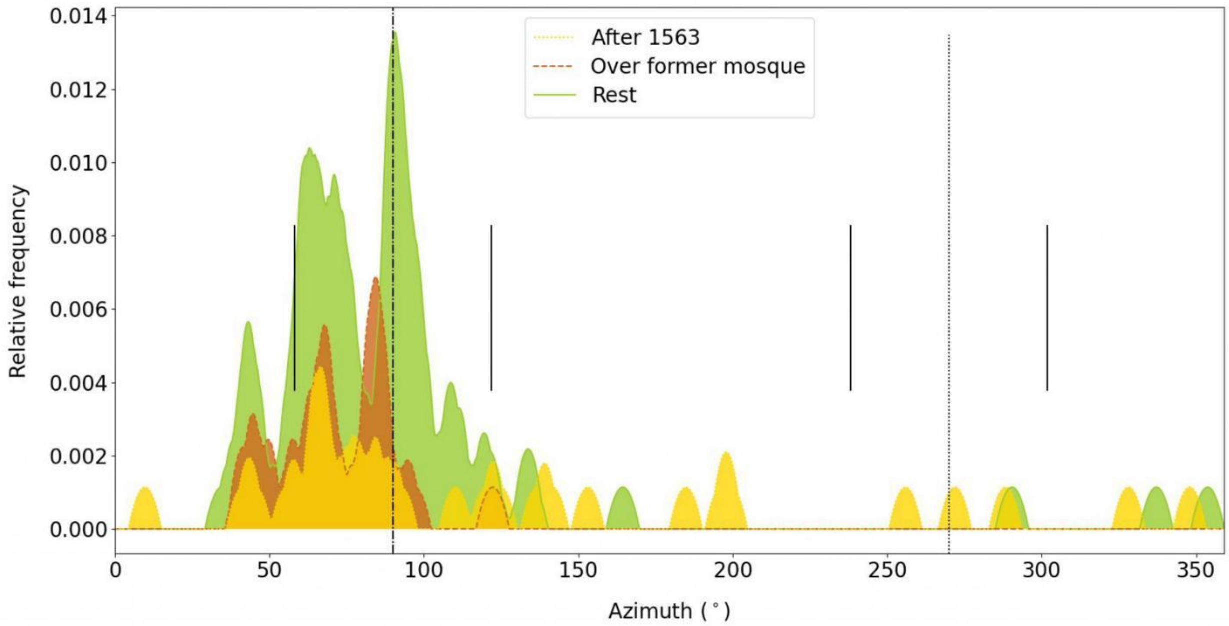

Figure 6. The Azimuth Curvigrams of the Cathedrals Divided into Three groups: in red, those constructed on prior mosques or their grounds; in yellow, those built after 1563; and in green, the remaining. Note that the curvigram for cathedrals built after 1563 differs from Figure 4d due to the inclusion of an additional 37 years into the 16th century onwards dataset. Consequently, there are eight more cathedrals represented, particularly noticeable in the peak located north of east.

Figures 5 and 6 suggest that cathedrals constructed on mosques or their layouts are likely located in areas that were under Muslim rule, at least until the Caliphate of Cordova. The majority of cathedrals located to the north of the peninsula appear to follow a canonical eastward orientation, whereas those in the south, within Muslim territories, seem to deviate towards the northeast, some even outside of the solar range. Lastly, in line with the earlier temporal analysis, recently constructed cathedrals exhibit more dispersed orientations. However, upon scrutinizing the azimuth curvigrams, it becomes evident that all three groups share orientations trending towards the northeast, with equinoctial orientations only present in cathedrals not belonging to either the group constructed on mosques or those built after 1563.

The orientations to the north of the east observed in these groups of cathedrals, notably the green one, may suggest various possibilities. Firstly, they could indicate an alignment towards the sunrise on Easter Sunday, a trend found in Romanesque churches along the Jacobean route traversing the northern regions of the Iberian Peninsula (Urrutia-Aparicio et al., 2021). Secondly, it could be due to the adherence to the planimetry of an ancient Roman city. Lastly, especially for certain cathedrals located south of the fluctuating Christian-Muslim border over the years, these orientations are compatible with being perpendicular to the qibla of a mosque. It is important to note that, as of now, there is no evidence indicating that these cathedrals were constructed upon mosques. However, this proposition gains greater validity for those cathedrals with orientations to the northeast falling outside of the solar range. The following sections will analyze these three groups, corresponding to three highly significant cultures in the history of Spain and Portugal—Pagan Rome, Muslim, and Christian.

The Roman Time

Vogel (1962) and González-García and Belmonte (2015b) proposed, in the context of Paleochristian churches, the potential utilization of pre-existing spaces, specifically certain sections of Roman cities. Since some cathedrals are constructed on churches from earlier periods, notably Visigoth, the investigation of this hypothesis involves considering available data on the orientations of ancient Roman cities upon which later cathedrals were built (Rodríguez-Antón et al., 2018b) and comparing them with the azimuths of the cathedrals. Table 2 outlines the difference between the Roman layout and that of the cathedral for these 13 cities, revealing that the majority of them do follow the orientation of the ancient Roman layout (see Figure 7). Notable is the orientation of the Cathedral of Tarragona, built on top of the Imperial Cult temple of the Roman Provincial Forum.

Figure 7. The Ruins of the Old Cathedral of Cartagena, Adjacent to the Roman Theatre, were Built in the Late Romanesque style, with an Orientation Compatible to that of the Ancient Roman city. Image: the authors

Table 2. Comparison of the Azimuths of Cathedrals for which the Orientation of the Ancient Roman City is Known (Rodríguez-Antón et al. 2018b) (*) Orientation Taken with Google Earth that Differs from the On-site Measurement

Cathedral	Azimuth (°)	Eastern Azimuth of the Roman City (°)	Absolute Difference
Cartagena	61.0	61.5	0.5
Astorga	39.4	38.5	0.9
Córdoba	62.0	59.0 (towards the river)/93.75 (centre)	1.4 / 33.35
Alcalá de Henares	70.8	68.5	2.3
Lugo	73.4	71.0	2.4
Évora	60.6	58.0	2.6
León	72.7	69.75	2.95
Zaragoza	120.1	124.25	4.15
Braga	77.1	72.25	4.85
Mérida	58.5	52.75	5.75
Barcelona	132.6	126.75 (134.0*)	5.85 (1.4*)
Tarragona	34.5	124.0	90.5 (⊥)
Beja	55.6	127.5	71.65

Interestingly, in Segovia, the Roman aqueduct runs almost parallel to the cathedral (Jurado, 1995). The measurement of the orientation of the remains of the hypothetical Forum, located in Guevara Square (Caballero et al., 2018) and assessed from a plan, suggests a nearly cardinal orientation, closely resembling the path of the aqueduct in that vicinity. Although this orientation may not fully explain the cathedral's orientation, it is plausible that multiple land plots align with the aqueduct's orientation at the cathedral's location, and this building follows one of these alignments.

Muslim Domain

During the Reconquista process, a significant number of mosques and their grounds transitioned into Christian churches (see, e.g., the case of the Mosque of Cordova, González-García & Belmonte 2015). As noted before, churches in Al-Andalus may have been intentionally designed to attain the orientation of their apse by executing a 90° counterclockwise rotation of the qibla direction. This practice reflects a strategic adaptation of existing structures to align with Christian religious practices during the period of transition. For a comprehensive overview, Figure 8 categorizes each group derived from the temporal analysis into two distinct subsets: cathedrals with a history of being constructed over a former mosque or its ground, and the remaining cathedrals.

The significant discrepancy in the number of elements between these categories is noteworthy, with cathedrals built over preceding mosques being notably less abundant (19 in total), except for those falling within the 13th and 14th centuries. (To plot the curvigrams, considering this classification and the inherent variations in sample sizes, the usual normalization approach has been set aside. Instead, adjustments have been applied based on the sample size, multiplying by the number of elements in the subsample and dividing by the total sample size of that group. While this methodology may not provide a measure of the statistical significance of the maxima due to the absence of a standardized normalization, it effectively facilitates a comparative analysis of relative abundances). This underscores the pronounced concentration of cathedrals constructed on mosques or their grounds between the 13th and 14th centuries, aligning with the zenith of the Reconquista and succeeding the pivotal Christian victory in the Battle of Navas de Tolosa (1212).

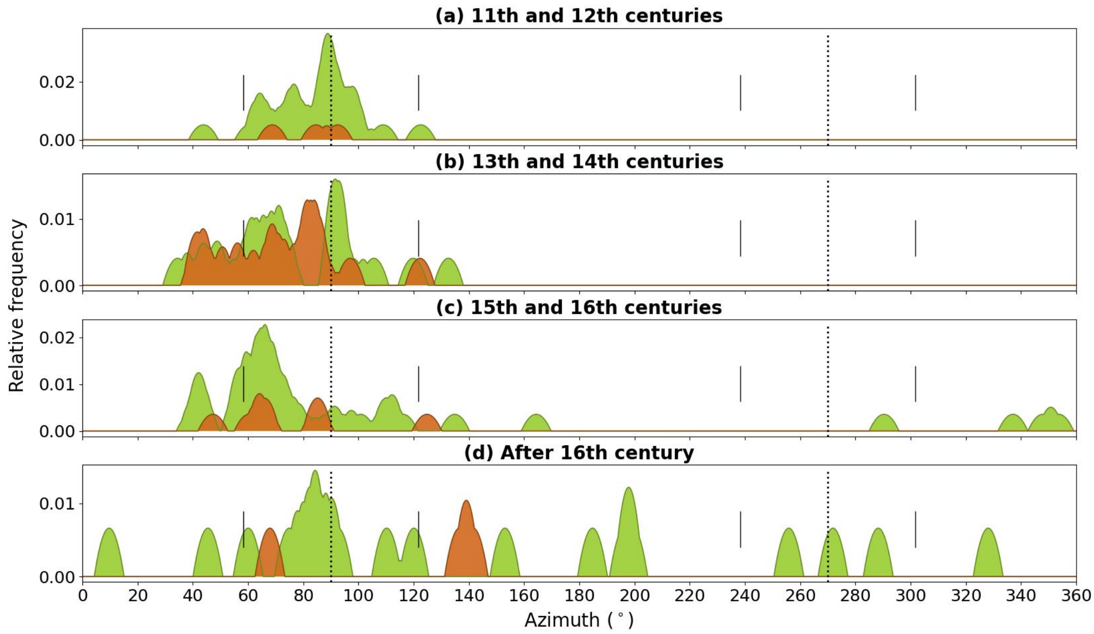

Figure 8. The Azimuth Curvigrams of Cathedrals, organized into four Groups Based on the Century of Construction: (a) 11th and 12th Centuries, (b) 13th and 14th Centuries, (c) 15th and 16th Centuries, (d) post-16th Century. Those constructed over former mosques are highlighted in orange, while the rest are represented in green. It is important to note that the curvigrams are normalized to the sample size for comparative abundance analysis

As initially noted, specific orientations towards the northeast, surpassing the typical solar range, might be linked to cathedrals constructed over former mosques or their grounds. While the peak at 44° azimuth could be difficult to explain, its perpendicular alignment would result in an orientation closely resembling the widely accepted qibla in the mosques of Al-Andalus. This so-called consensus qibla orientation is popularly acknowledged to have an azimuth of approximately 135° (Belmonte & Hoskin, 2002).

However, several cathedrals, particularly in the southern region of the Iberian Peninsula, have also been constructed over former mosques, and display orientations within the solar range but north of east (see Figure 9). Consequently, it is pertinent to consider the possibility that these orientations might be related to the perpendicular to other certain prevalent qiblas employed in Al-Andalus (King, 1995; Ríus Piniés, 2000; Belmonte & Hoskin, 2002): The orientation "like" the Kaaba (150° on its major axis); the qibla of Cordova (152°), widely imitated; the qibla of the consensus (135°, already mentioned); and the Medinan or Southern qibla (180º). The perpendicular alignment of some of these orientations could coincide with a Christian canonical orientation, particularly the latter, which might also indicate an equinoctial orientation.

In certain instances, cathedrals located in areas which were under strong Muslim influence exhibit orientations compatible with the perpendicular to the qibla of Cordova and the consensus qibla (as depicted in the map on Figure 5), even in the absence of documented prior mosques in those sites. While these cathedrals' orientations align with Christian prescriptions, the possibility of a preceding mosque should not be entirely dismissed, suggesting on site excavations. Further complexity arises with the realization that some cathedrals built over mosques were also conversions from pre-existing Christian temples, i.e. as mentioned by Rius Piniés (1999a) and Jiménez (1991). Notable examples include the cathedrals of Toledo, Cordova, and Valencia, among others.

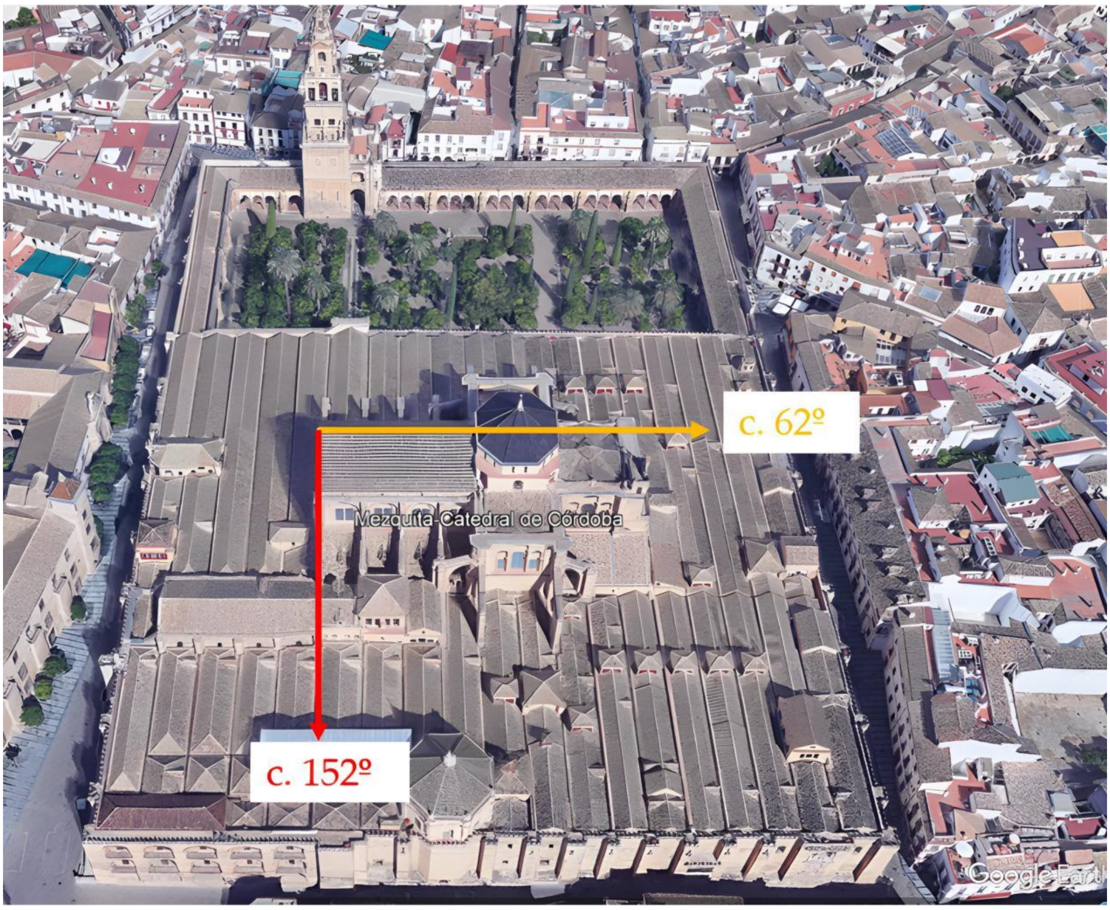

Figure 9. Example of the Qibla Rotation at the Cathedral-Mosque of Cordova. The red arrow indicates the direction of the qibla, c. 152˚, and the yellow arrow is the orientation of the Christian cathedral, built after the mosque, and perpendicular to it. Interestingly, this pattern belongs to a sector of the Roman city which was not adopted by the former Visigothic Saint Vicent Basilica, but the Muslims found a basis for an orientation not towards, but parallel to the Kaaba. Hence the qibla of Cordova became one of the most popular in Al-Andalus and Al-Magrhib (see Figure 10). Diagram from the authors on an image adapted from Google Earth (2001).

To address these potential scenarios, Figure 10 shows the comparison of azimuth curvigrams for different groups of cathedrals linked to mosques: those with documented construction over preceding mosques (or their grounds), those suspected of being built over prior mosques due to their location and orientation, and finally, those that were initially Christian churches converted into mosques and subsequently became cathedrals. To facilitate a comparison with the most frequently used qiblas in Al-Andalus, their orientations have been adjusted by a 90˚ rotation to the east.

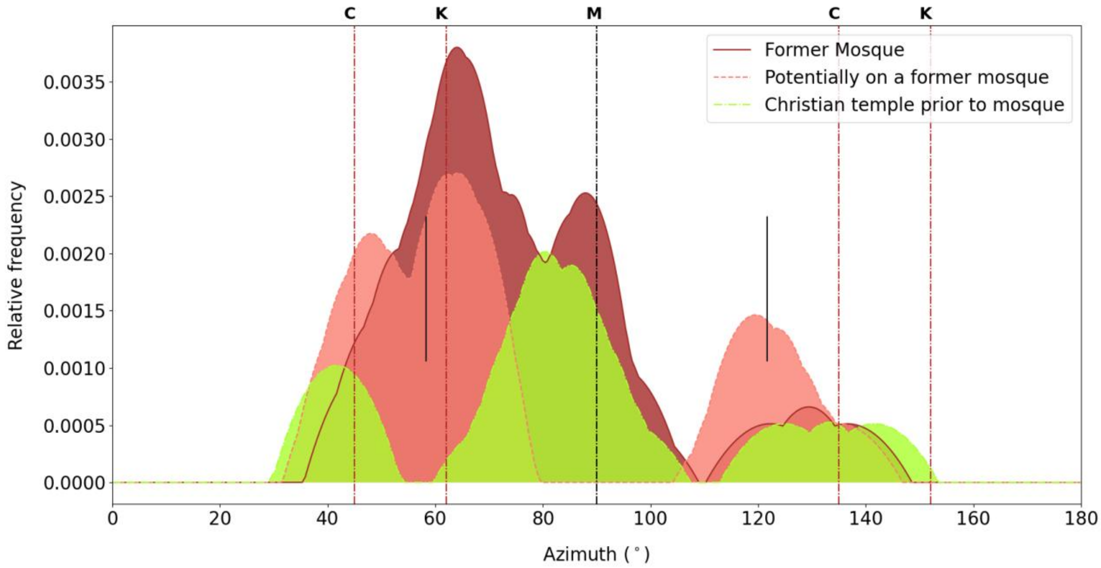

Figure 10. Azimuth Curvigrams Comparing Different Groups of the Orientation of Cathedrals Based on their Potential Origins. The plot shows cathedrals known to be constructed on mosques or the grounds of former mosques in dark red with solid lines. Additionally, it displays cathedrals without documentation regarding whether they were built on mosques, but having existed in Muslim territories for a sufficient period to make it a possibility, in salmon colour with dashed lines. Finally, it illustrates cathedrals that were originally Christian temples before being converted into mosques and later cathedrals, in green with dashed-dotted lines. The figure also marks the azimuth values corresponding to the perpendicular to the consensus qibla (C), the qibla of Cordova (K), and the Medinan qibla (M), which closely aligns with the equinox

Cathedrals built on prior mosques or their layouts display orientations consistent with the perpendicular alignment to the qibla of Cordova and the Medinan qibla, and the extended tail of the peak suggests that the consensus qibla should not be discarded. For cathedrals lacking documentation on whether they were built on mosques, but situated in areas once under Muslim rule, their orientations align with the perpendicular of the qibla of Cordova and the consensus qibla. Notably, these orientations pose challenges when explaining them within the typical or canonical orientations of Christian churches in the Iberian Peninsula.

Finally, cathedrals that were initially Christian temples before serving as mosques and later reverting to cathedrals exhibit a peak that does not conform to the aforementioned orientation patterns. Instead, it primarily aligns with the north of the east, approximately around 80°, reminiscent of pre-Romanesque churches and potentially associated with Easter. It is worth mentioning that there is also a peak on the winter solstice, which is, for example, the preferred orientation for the qibla in Egypt (King, 1984).

DISCUSSION

Chronological Overview and Interpretation

11th to 12th Centuries

Cathedrals constructed during this period are oriented towards the sunrise at some point in the year, predominantly concentrated around the equinox. However, there is an exception in the case of Tarazona, with an azimuth of approximately 45°, where archaeological remains of a late Roman necropolis were discovered. Additionally, a northeast deviation is noticeable, a feature also present in pre-Romanesque churches (González-García & Belmonte, 2015b) and Romanesque churches (Urrutia-Aparicio et al., 2022) of the Iberian Peninsula, which could be linked to Easter Sunday and, in some cases, the planimetry of a Roman city.

13th to 14th Centuries

The preference for an equinoctial/Easter orientation seems to persist during these centuries. However, there is an increasing number of cathedrals deviating towards the northeast, extending even beyond the solar rising point at the summer solstice. Upon careful examination of Figure 8, it becomes evident that there is almost an equal number of cathedrals built over earlier mosques as those that are not, possibly attributed to the accelerated

Reconquista process after the Battle of Navas de Tolosa in 1212.

Once separated into these two groups, we observe that cathedrals without known prior mosques exhibit the more precise equinoctial orientation. The latter group significantly contributes to the azimuth peak at around 69°, with some cathedrals constructed over pre-Romanesque churches or following the planimetry of the Roman city, resembling patterns observed in the 11th and 12th centuries.

Finally, a subset of cathedrals exhibits azimuth values falling outside the solar range, around 44°, with the majority being constructed over former mosques. This observation may suggest that, during the construction of the cathedral, builders opted for the perpendicular to the previous orientation of the mosque. In this case, the consensus qibla at 135˚ might have served as the reference orientation.

Likewise, a similar rationale could apply to cathedrals with azimuths around 62°, potentially perpendicular to the qibla of Cordova, one of the most replicated orientations in Al-Andalus. The orientations of some cathedrals might also be related to the winter solstice or the perpendicular to the Medini qibla at 180°. The latter interpretation would be valid only if it were confirmed that the corresponding mosque followed such an orientation since its perpendicular, at 90°, aligns with an equinoctial orientation and, therefore, conforms to Christian canonical principles.

The case of Toledo adds an intriguing dimension to this context, featuring an orientation of 88°. Its historical origins can be traced back to a Visigothic temple, potentially with an equinoctial orientation. During the period of Muslim rule, builders erected a mosque atop this temple, aligning the mihrab perpendicularly and conforming to the Medini qibla (Rius Piniés, 1999b). Subsequently, following the Christian reconquest of the city, the cathedral was established on the same site, reverting to the original equinoctial orientation.

Furthermore, the cultural analysis unveiled cases of cathedrals constructed over mosques that were previously Christian temples. Many of these cathedrals, primarily dating from the 13th century, exhibit orientations that, akin to Toledo, reflect a synthesis of both cultural influences. However, it remains plausible for a cathedral to adopt a distinct orientation, even in cases where a prior Christian temple existed before the construction of the mosque and subsequently the cathedral, as in the case of Cordova.

15th to 16th Centuries

During this period, the predominant equinoctial orientation observed in pre-Romanesque churches appears to be substituted by a cluster with orientations ranging between 19° and 22° of declination. The results suggest a plausible association with the growing cult of St. James. Despite the relatively broad range, it is conceivable that some of these orientations may align with July 25, a festivity closely linked to St. James and discernible in the orientations of pre-Romanesque churches across the Iberian Peninsula (González-García & Belmonte, 2015b).

However, the complexity arises as certain cathedrals within this group are either constructed over former mosques or are situated in territories that were once under long Muslim dominion, exhibiting orientations compatible with the perpendicular to the presumed qibla. Consider, for instance, the Cathedral of Coria in Extremadura (Figure 11) a region in the mid to southwestern part of the modern-day Spain, which remained under Muslim rule until its capture by Alfonso VII in 1142 (Clemente Ramos and Montaña Conchiña, 1992). The cathedral's origins are most relevant. While historical records indicate Alfonso VII's decree to demolish mosques within the city (Harris 1997), archaeological findings suggest otherwise, with evidence pointing to an east-west orientation of the qibla wall (Sanabria Sierra, 2015), indicating that Muslims prayed perpendicular to the cathedral's current orientation. With an azimuth of approximately 63˚, the perpendicular of the cathedral's orientation may coincide with that of the qibla of Cordova. However, according to Sanabria Sierra (2015), preceding the mosque, a Goth basilica may have existed, which was also potentially built over a Roman house discovered in the cloister, dating back to the 1st century, possibly utilized as a domus ecclesiae. This orientation might thus align with different religious beliefs and customs, exemplifying the intricate complexities arising from diverse construction periods and cultural influences within a unique place. While there isn't sufficient rationale to favor one explanation over the other, the ambiguity presents an intriguing scenario, which indicates the need for further archaeological excavations or test trenches to gain a more in-depth understanding.

Figure 11. North Façade of the Catedral of Coria in Extremadura. Its construction began between 1495-98, although this gable may have goth or visigothic origins. The case of this cathedral stands as a remarkable example of how one space could be reused throughout different cultural contexts over time. Image: the authors

The orientations of cathedrals in the Portuguese archipelagos, specifically in Funchal and Angra do Heroísmo, appear to lack a discernible pattern. In contrast, the Canary Islands present two noteworthy cases, one in San Cristóbal de La Laguna and another in Las Palmas de Gran Canaria. The latter is oriented towards the solar rising point at the summer solstice, suggesting a potential alignment with the unique significance this date held for the indigenous Canarian population (Belmonte, 2015). The orientation of La Laguna cathedral will be discussed below.

From the 16th Century Onward

The more recent cathedrals display significantly more dispersed orientations than their predecessors, extending even beyond the solar range. However, those constructed over former churches, primarily of Romanesque origin, tend to exhibit orientations closely aligned with the astronomical equinox. Notably, the cathedral of the Nivariense diocese in San Cristóbal de La Laguna, in Tenerife, appears to be oriented towards the sunrise on the feast day of San Cristóbal, the city's patron saint (Gangui & Belmonte, 2018). The observed dispersion in cathedrals built from the 16th century onwards may be attributed to the relaxation of orientation prescriptions following the decrees of the last Council of Trent in 1563 (Borromeo, 1577). Furthermore, the Gregorian calendar reform in 1582 brought about a significant shift in the ecclesiastical orientation panorama, both temporally and spatially.

Contrary to the frequent assumption that prescriptions for Christian temple orientation were abandoned much earlier, this study suggests that such relaxation did not occur until at least the mid or late 16th century. While this specifically applies to cathedrals in the Iberian Peninsula, it prompts questions regarding other periods, geographies, and architectural styles.

CONCLUSION

The overall results of this research suggest orientation patterns that are more intricate than initially anticipated. While equinoctial orientations are present, they are far from exclusive. Other north-of-east-oriented patterns emerge, extending even beyond the solar range, highlighting the necessity of approaching their study through two independent analyses. The temporal analysis indicates a discernible relaxation in orientation prescriptions, identifying this turning point around the last Council of Trent in 1563. Notably, the only recent cathedrals retaining the equinoctial orientation are precisely those built over ancient churches, primarily of Romanesque origin.

The prevalent pattern of orientations towards the equinox, and to a lesser extent, Easter, is notable in the earliest churches mainly situated in the northern part of the peninsula. Although this orientation persists until the 14th century, the emergence of additional orientation patterns during these centuries indicated the need for a second analysis focused on the diverse cultures coexisting in the Iberian Peninsula. In this cultural analysis, we consider the comparison of the Christian orientations with two significant groups—pagan Roman and Muslim. Firstly, there are cathedrals following the planetary of the ancient Roman city, some located on former Christian temples. Most of them exhibit northeast orientations, some of which could be "repurposed" as Paschal, but many fall outside the solar range.

Secondly, there is the possibility that certain cathedrals, constructed over prior mosques or their grounds, might use the perpendicular of the latter's orientation as their axis, i.e., the qibla wall. Along the same lines, it is interesting to consider those located in Muslim territories with atypical orientations, suggesting the possible existence of a former mosque, although there are little to no archaeological data to support this.

However, certain cathedrals show orientations that might align with both Muslim and Christian cultures. This is the case for some cathedrals dating from the 15th and 16th centuries, built over mosques or in territories that were once under Muslim rule. Nevertheless, their orientations could also be related to the feast related to St. James on July 25, a feature already present in the orientations of pre-Romanesque churches on the Iberian Peninsula. The variety of hypotheses explaining the orientations of the cathedrals in modern-day countries of Spain and Portugal underscores the importance of considering the possible influences of the diversity of cultures that have inhabited this territory over the centuries, particularly the Romans, both before and after their conversion to Christianity, and the Muslims.

AUTHOR CONTRIBUTIONS

Conceptualization, M.U., J.B. and A.C.G.G.; methodology, M.U., J.B. and A.C.G.G; software, M.U. and A.C.G.G; validation, M.U., J.B. and A.C.G.G.; formal analysis, M.U., J.B. and A.C.G.G.; investigation, M.U., J.B. and A.C.G.G; resources, M.U., J.B. and A.C.G.G; data curation, M.U.; writing—original draft preparation, M.U.; writing—review and editing, M.U., J.B. and A.C.G.G; visualization, M.U., J.B. and A.C.G.G; supervision, J.B. and A.C.G.G; project administration, J.B. and A.C.G.G; funding acquisition, J.B. and A.C.G.G All authors have read and agreed to the published version of the manuscript.

ACKNOWLEDGEMENTS

The research was funded by the State Research Agency (AEI) of the Spanish Ministry of Science and Innovation (MICIN), and the European Regional Development Fund (ERDF) under grants with references PID2020115940GB-C21/PID2020115940GB-C22 ’Orientatio ad Sidera V’. Contributions from the internal IAC project P310793 ‘Arqueoastronomía’ and the School of Architecture of the Universidad Europea de Canarias.

CONFLICT OF INTEREST

The authors state that there is no conflict of interest to declare.

REFERENCES

Abril, J. M. (2017). Evidence of churches aligned to the sun on the patron saint's day in southern Spain after the twelfth century. *Journal of Skyscape Archaeology, 3*(1), 29–48. DOI: https://doi.org/10.1558/jsa.31508

Abril, J. M. (2020). The orientation of Gothic-mudéjar churches in southern Spain: The rotation of the Qibla and sun-rise on the canonical equinox. *Journal of Skyscape Archaeology, 6*(2), 182–206. DOI: https://doi.org/10.1558/jsa.19629

Ali, J. R., and Cunich, P. (2001). The orientation of churches: Some new evidence. *The Antiquaries Journal, 81*, 155–193. DOI: https://doi.org/10.1017/S0003581500072188

Belmonte, J. A., and Hoskin, M. (2002). Reflejo del cosmos: Atlas de arqueoastronomía en el mediterráneo antiguo. *Equipo Sirius*.https://www.academia.edu/5233480/Reflejo_del_Cosmos_Atlas_de_Arqueoastronom%C3%ADa_del_Mediterr%C3%A1neo_antiguo

Belmonte, J. A. (2015). Pre-Hispanic sanctuaries in the Canary Islands. In C. L. N. Ruggles (Ed.), *Handbook of Archaeoastronomy and Ethnoastronomy* (pp. 1115–1124). Springer. DOI: https://doi.org/10.1007/978-1-4614-6141-8_106

Borromeo, C. (1577). *Instructionum fabricae et supellectilis ecclesiasticae*. Librería Editrice Vaticana (2000).

Caballero, S. M., González, L. J. M., García, C. M., Vielva, J. M. L., Martín, V. M. C., & González, S. Á. (2017). Datos para evaluar la evolución urbana de Segovia en época celtibérica y Romana. *Anejos de Segovia Histórica, 2*, 157-181.

Clemente Ramos, J., & Montaña Conchiña, J. L. (1994). La Extremadura cristiana (1142–1230): Ocupación del espacio y transformaciones socioeconómicas. *Historia. Instituciones. Documentos, 1994*(21), 83–124.

Čaval, S. (2018). Locating the festival, positioning the feast: Natural and calendar festivals in medieval Slovenia. *World Archaeology, 50*(2), 300-322. DOI: https://doi.org/10.1080/00438243.2018.1538814

Dallas, T. G. (2015). On the orientation of byzantine churches in Thessalonike. *Mediterranean Archaeology and Archaeometry, 15*(3), 213-224. DOI: https://doi.org/10.5281/zenodo.27748

Dallas, T. G. (2018). On the orientation of early christian churches in præfectura illyricum. *Mediterranean Archaeology and Archaeometry, 18*, 131-138. DOI: https://doi.org/10.5281/zenodo.1478013

Di Paolo, A., Gangui, A., Belmonte, J. A., and Perera-Betancort, M. A. (2020). Cuando la ortodoxia no es lo más rele-vante: El paisaje de La Gomera y la orientación de sus iglesias. *Cosmovisiones/Cosmovisões, 1*(1), 73–88. https://revistas.unlp.edu.ar/cosmovisiones/article/view/13474

Gangui, A., and Belmonte, J. A. (2018). Urban planning in the first unfortified Spanish Colonial Town: The orientation of the historic churches of san cristóbal de la laguna. *Journal of Skyscape Archaeology, 4*(1), 6–25. DOI: https://doi.org/10.1558/jsa.34336

Giga-Catholic Information (1997). *Cathedrals in the world*. http://www.gcatholic.org

García-Ortega, A. J. (2015). De mezquitas a iglesias: Formalización y trazado en los procesos de reconversión de Toledo y Córdoba. *EGA: Revista de expresión gráfica arquitectónica, 26*, 202–211. https://doi.org/10.4995/ega.2015.4053

González-García, A. C. (2013). Profiting from models of astronomical alignments to unveil ancient cosmologies in Europe and the Mediterranean. *Anthropological Notebooks, 19*, 49–66. http://hdl.handle.net/10261/137155

González-García, A. C. (2015). A voyage of Christian medieval astronomy: Symbolic, ritual and political orientation of churches. In F. Pimenta, N. Ribeiro, F. Silva, N. Campion, A. Joaquinho, & L. Tirapicos (Eds.), *SEAC 2011 Stars and stones: Voyages in Archaeoastronomy and Cultural Astronomy* (pp. 268–275). BAR International Series, 2720.

González-García, A. C., & Belmonte, J. A. (2015a). Interactions between Islamic and Christian traditions in the Iberian Peninsula. In C. L. N. Ruggles (Ed.), *Handbook of Archaeoastronomy and Ethnoastronomy* (pp. 1695–1702). Springer. http://doi.org/10.1007/978-1-4614-6141-8_172

González-García, A. C., & Belmonte, J. A. (2015b). The orientation of Pre-romanesque churches in the Iberian Peninsula. *Nexus Network Journal, 17*(2), 353–377. https://doi.org/10.1007/s00004-014-0231-7

Google (2001). Google Earth Pro. https://www.google.es/earth/

Harris, J. A. (1997). Mosque to church conversions in the Spanish reconquest. *Medieval Encounters, 3*(2), 158-172.

Hinton, I. (2006). Church alignment and Patronal Saint's days. *The Antiquaries Journal, 86*, 206–226. DOI: https://doi.org/10.1017/S0003581500000111

Jiménez, A. (1991). La qibla extraviada. *Cuadernos de Madinat al-Zahara', 3*, 189-209.

Jurado, F. (1995). Acueducto de segovia. *Informes de la Construcción, 47*(437), 5-27.

King, D. A. (1984). Architecture and Astronomy: The ventilators of medieval Cairo and their secrets. *Journal of the American Oriental Society, 104* (1), 97–133. DOI: https://doi.org/10.2307/602646

King, D. A. (1995). The orientation of medieval Islamic religious architecture and cities. *Journal for the History of Astronomy, 26* (3), 253–274. DOI: https://doi.org/10.1177/002182869502600

Kosowsky, M. (2013). *Heywhatsthat*. http://www.heywhatsthat.com

Krack, K. (2020). Die ostausrichtung mittelalterlicher dorfkirchen in mecklenburg-vorpommern. *ZfV-Zeitschrift für Geodäsie, Geoinformation und Landmanagement, 145*, 43–48. DOI: https://doi.org/10.12902/zfv-0279-2019

Laužikas, R. (2015). Church orientations in central and eastern Europe. In C. L. N. Ruggles (Ed.), *Handbook of Archaeoastronomy and Ethnoastronomy* (pp. 1727–1732). Springer. https://doi.org/10.1007/978-1-4614-6141-8_176

Liritzis, I., & Vassiliou, H. (2006a). Does sunrise day correlate with eastern orientation of Byzantine churches during significant solar dates and saint's day name? *Byzantinische Zeitschrift, 99*(2), 523–534.

Liritzis, I., and Vassiliou, H. (2006b). Further solar alignments of Greek Byzantine churches. *Mediterranean Archaeology & Archaeometry, 6*(3), 7-26. DOI https://doi.org/10.5281/zenodo.4704836

Liritzis, I and Vlachos, A. (2022). Skyscape impact to cultural astronomy. *Scientific Culture, 8*(3), 131-155. DOI: https://doi.org/10.5281/zenodo.6640243

Lluís I Ginovart, J., Lluís Teruel, C., and Ugalde Blázquez, I. (2021). Cosmology and precision in the Val d'Aran. *Nexus Network Journal, 23*, 433–451. DOI: https://doi.org/10.1007/s00004-021-00551-2

McCluskey, S. (2015). Orientation of Christian churches. In C. L. N. Ruggles (Ed.), *Handbook of Archaeoastronomy and Ethnoastronomy* (pp. 1703–1710). Springer. https://doi.org/10.1007/978-1-4614-6141-8_173

Muratore, M.F., Gangui, A., Urrutia-Aparicio, M., Cabrera, C., and Belmonte, J.A. (2023). On the orientation of historic Christian churches of Fuerteventura: Conciliating tradition, winds and topography. *Journal of Skyscape Archaeology, 9*, 1-22. DOI: https://doi.org/10.1558/jsa.22808

Pérez-Valcárcel, J., & Pérez-Palmero, V. (2021). *La orientación de las iglesias medievales en la Península Ibérica*. Universidade da Coruña, Servizo de Publicacións.

Ridderstad, M. (2013). Orientations of the medieval stone churches in Finland. *Suomen Museo-Finskt Museum, 119*, 5-44.

Rius Piniés, M. (1999a). *La orientación de las mezquitas en Al-Andalus y el Norte de África entre los siglos XI y XVIII* [Doctoral dissertation, Universitat de Barcelona]. CORA TDX Repository. http://hdl.handle.net/10803/673542

Rius Piniés, M. (1999b). Orientación de las mezquitas en Toledo. *Tulaytula, 4*, 67–75. http://hdl.handle.net/2445/48387

Ríus Piniés, M. (2000). La alqibla en al-Andalus y al-Magrib al-Aqsà. *Anuari de Filologia. Secció B, Estudis Àrabs i Islàmics, 1998-1999, 3*, 17–358. http://hdl.handle.net/2445/22522

Rodríguez-Antón, A., González-García, A. C., & Belmonte, J. A. (2018a). Estimating the reliability of digital data acquisition in cultural astronomy: Its use in the case of Roman North Africa. *Journal of Skyscape Archaeology, 3*(3), 191–206. https://doi.org/10.1558/jsa.34685

Rodríguez-Antón, A., González-García, A. C., and Belmonte, J. A. (2018b). Astronomy in Roman urbanism: A statistical analysis of the orientation of Roman towns in the Iberian Peninsula. *Journal for the History of Astronomy, 49*(3), 363–387. DOI: https://doi.org/10.1177/0021828618785664

Romano, G. (1997). Deviazioni negli orientamenti del tipo «Sol Aequinoctialis». *Memorie della Società Astronomica Ital-iana, 68* (3), 723–729.

Sanabria Sierra, M. D. C. (2015). *La catedral de Coria (Cáceres): Estudio histórico-artístico* [Doctoral dissertation, Universidad Nacional de Educación a Distancia]. UNED repository. http://e-spacio.uned.es/fez/view/tesisuned:GeoHis-Mcsanabria

Samper, A., Moreno-García, D. & Herrera, B. (2024). Study of the effects created by the sunlight passing through the rose windows of Mallorca Cathedral. *Nexus Network Journal*. DOI: https://doi.org/10.1007/s00004-023-00760-x

Spinazze, E. (2015). *La luce nell'architettura sacra del X-XII secolo dalla 'Romandie' alla Toscana: Testimonianze sull'influsso dell'osservazione del cielo nell'orientazione degli edifici*. [Doctoral dissertation, Università Ca'Foscari Venezia] UCV Repository: http://dspace.unive.it/handle/10579/6515

Spinazzè, E. (2016). The alignment of medieval churches in northerncentral Italy and in the Alps and the path of light inside the church on the patron saint's day. *Mediterranean Archaeology and Archaeometry, 16* (4), 455–463. DOI: https://doi.org/10.5281/zenodo.220970

Urrutia-Aparicio, M., González-García, A. C., and Belmonte, J. A. (2021). East or Easter? Keys to the orientation of Romanesque churches along the way of Saint James. *Journal for the History of Astronomy, 52* (3), 289–310. DOI: http://doi.org/10.1177/00218286211026209

Urrutia-Aparicio, M., Belmonte, J. A., and González-García, A. C. (2022). Land-and skyscapes of the Camino de Santiago: An astronomy and world heritage sustainable approach. *Sustainability, 14* (5), 3047. DOI: https://doi.org/10.3390/su14053047

Vilas-Estévez, B., Varela, R., & González-García, A. C. (2018). Previous tradition? Coincidence? Design? How it was possible to create the illumination effects at the Cathedral of Saint James (Galicia, Spain)?. *Mediterranean Archaeology and Archaeometry, 18*(4), 251-251. DOI: https://doi.org/10.5281/zenodo.1478696

Vogel, C. (1962). Sol aequinoctialis. Problèmes et technique de l'orientation dans le culture chrétien. *Revue Sciences Religieuses, 36*(3-4), 175–211. DOI: https://doi.org/10.3406/rscir.1962.2332.

APPENDIX

Table 3. Data from the cathedrals in modern-days Spain and Portugal: The name of the place and the monument, latitude (φ), longitude (λ), azimuth (A), horizon altitude (H), declination (δ), and approximate construction date. The last two columns represent the group and type of cathedrals considered in the work. The group refers to the divisions made based on different cultural explanations for their orientation (T: after the last Council of Trent (1563), C: 'canonical' (i.e, equinoctial, paschal), M: over a mosque, PM: potentially over a mosque, CM: Christian temple prior to mosque and later reconverted, R: Roman city, --: does not fit into the above categories). The type is simply to distinguish current cathedrals (CA) from ancient of former cathedrals (ACA) and co-cathedrals (CO).

Place	Monument	φ(°)	λ(°)	A(°)	H(°)	δ(°)	Date	Group	Type
Idanha-a-Velha	Sta. Maria da Egitânia	40/00	−7/09	95.5	1.5	−3.2	585	CM	ACA
Roda de Isábena	S. Vicente Mártir	42/17	0/32	80.8	3.8	9.4	1025	C	CA
Jaca	S. Pedro	42/34	−0/33	95.4	1.9	−2.7	1075	C	CA
Santiago de Compo-stela	Santiago	42/53	−8/33	86.0	0.5	2.9	1075	C	CA
Braga	Sta. Maria	41/33	−8/26	77.1	2.7	11.4	1089	C	CA
Salamanca	Virgen María	40/58	−5/40	108.9	0.1	−14.1	1120	−−	CA
Tuy	Sta. María	42/03	−8/39	100.3	1.9	−6.4	1120	−−	CA
Oporto	Nossa Senhora da Assunção	41/09	−8/37	89.3	0.6	0.9	1120	C	CA
Lugo	Sta. María	43/01	−7/33	73.4	1.1	12.9	1129	R	CA
Zamora	Transfiguración del Salvador	41/30	−5/45	98.2	0.3	−5.9	1140	−−	CA
Leiria	Nossa Senhora da Pena	39/45	−8/49	88.6	0.8	1.6	1140	C	ACA
Lisboa	Sta. Maria Maior	38/43	−9/08	84.6	−0.1	4.2	1147	CM	CA
Solsona	Sta. María	42/0	1/31	64.6	1.6	19.7	1150	R?	CA
Santo Domingo de la Calzada	Santo Domingo	42/26	−2/57	97.4	0.4	−5.2	1158	−−	CA
Lamego	Nossa Senhora da Assunção	41/06	−7/48	78.0	1.8	10.2	1159	C	CA
Orense	S. Martín de Tours	42/20	−7/52	86.6	7.3	7.4	1160	C	CA
Sigüenza	Virgen María	41/4	−2/38	73.9	2.0	13.4	1160	C	CA
Tarazona	Virgen de la Huerta	41/54	−1/43	43.9	0.3	32.7	1162	PM	CA
Coimbra	Nossa Senhora da Assunção	40/13	−8/26	91.7	9.5	4.8	1162	C	ACA
Ávila	S. Salvador	40/39	−4/42	90.6	1.0	0.2	1170	C	CA
Urgell	Sta. María	42/21	1/28	89.8	1.8	1.3	1175	C	CA
Tudela	Sta. María	42/4	−1/36	68.8	0.7	16.1	1180	M	CA
Ciudad Rodrigo	Virgen María	40/36	−6/32	122.6	2.2	−22.5	1180	PM	CA
Évora	Nossa Senhora da Assunção	38/35	−7/54	60.6	0.3	22.8	1186	R	CA
Santander	Ntra. Sra. De La Asunción	43/28	−3/48	88.3	0.5	1.5	1195	C	CA
Plasencia	Virgen María	40/2	−6/5	67.8	2.3	18.4	1195	PM	CA
Monzón	Sta. María del Romeral	41/55	0/12	64.3	1.7	20.0	1195	−−	CA
Cuenca	Virgen María y S. Julián	40/5	−2/8	92.5	6.7	2.4	1196	M	CA

Place	Monument	φ(°)	λ(°)	A(°)	H(°)	δ(°)	Date	Group	Type
Vitoria	Sta. María	42/51	−2/40	69.4	1.6	16.1	1202	C	CA
Lleida	Virgen María	41/37	0/38	42.3	0.7	34.1	1203	CM	CA
León	Virgen María	42/36	−5/34	72.7	1.4	13.7	1205	R	CA
Mondoñedo	Virgen María	43/26	−7/22	90.9	9.4	5.8	1219	C	CA
Burgos	Sta. María	42/20	−3/42	41.4	0.4	34.0	1221	−−	CA
Toledo	Virgen María	39/51	−4/1	87.6	3.9	4.3	1226	CM	CA
Palma de Mallorca	Sta. María	39/34	2/39	122.3	0.3	−24.1	1229	M	CA
Tarragona	Virgen María	41/7	1/15	34.5	2.2	40.2	1230	R	CA
Burgo de Osma	Virgen de la Asunción	41/35	−3/4	91.7	3.2	0.8	1232	C	CA
Catedral Vieja de Cartagena	Sta. María	37/36	−0/59	61.1	6.5	26.7	1245	R	CA
Setúbal	Nossa Senhora da Assunção	38/31	−8/53	92.8	2.4	−0.7	1248	C	CA
Viseu	Nossa Senhora da Assunção	40/40	−7/55	119.8	1.1	−21.4	1250	PM	CA
Teruel	Sta. María	40/21	−1/6	67.7	3.9	19.5	1250	−−	CA
Badajoz	S. Juan Bautista	38/53	−6/58	51.1	1.5	30.3	1250	PM	CA
Segorbe	Sta. María de la Asunción	39/51	−0/29	46.5	4.2	35.1	1250	PM	CA
Ibiza	Virgen de las Nieves	38/54	1/26	65.2	0.5	19.4	1250	M	CA
Faro	Sta. María	37/01	−7/56	77.9	0.8	10.1	1251	CM	CA
Valencia	Virgen María	39/29	−0/22	41.0	1.7	36.9	1262	CM	CA
Huesca	Sta. María	42/8	−0/24	84.3	0.5	4.5	1273	M	CA
Silves	Nossa Senhora da Assunção	37/11	−8/26	83.3	0.8	5.8	1279	M	ACA
Orihuela	S. Salvador y Sta. María	38/5	−0/57	71.6	−0.1	14.4	1280	CM	CA
Barcelona	Sta. Eulalia y la Sta. Cruz	41/23	2/11	132.6	0.5	−30.2	1298	R	CA
Ciutadella de Menorca	Sta. María	40/0	3/50	58.7	0.6	23.9	1300	M	CA
Baeza	Asunción de la Virgen María	37/59	−3/28	80.6	0.7	7.8	1300	CM	CA
Guadalajara	Virgen María	40/38	−3/10	47.9	2.7	32.7	1300	M	CO
Palencia	S. Antolín	42/1	−4/32	58.9	1.5	23.7	1321	−−	CA
Tortosa	Sta. María	40/49	0/31	97.0	5.0	−2.0	1347	M	CA
Girona	Sta. María	41/59	2/50	90.9	5.2	2.8	1347	C	CA
Seo de Zaragoza	S. Salvador	41/39	−0/53	53.7	0.6	26.7	1350	M	CA
Oviedo	S. Salvador	43/22	−5/51	74.8	0.7	11.4	1385	C	CA
Guarda	Nossa Senhora da Consolação	40/32	−7/16	105.6	−0.0	−11.8	1390	−−	CA
Murcia	Sta. María	37/59	−1/8	69.5	0.3	16.2	1394	M	CA
Pamplona	Sta. María la Real	42/49	−1/38	64.3	2.5	20.3	1394	R?	CA
Bilbao	Santiago	43/15	−2/55	97.8	6.4	−1.2	1397	C	CA
Viana do Castelo	Sta. Maria Maior	41/42	−8/50	55.7	1.4	25.9	1400	−−	CA
Ciudad Real	Sta. María	38/59	−3/56	44.5	0.1	33.8	1400	−−	CA
Vila Real	São Domingos	41/18	−7/45	94.1	2.8	−1.3	1424	C	CA
Sevilla	Sta. María de la Sede	37/23	−6/0	84.6	0.3	4.4	1434	M	CA
Cáceres	Virgen María	39/28	−6/22	43.3	0.4	34.5	1450	PM	CO

Angra do Heroísmo	São Salvador	38/39	−27/13	353.7	6.1	57.0	1461	--	CA
Aveiro	Nossa Senhora da Miséricórdia	40/38	−8/39	62.4	1.1	21.4	1464	--	ACA
Astorga	Virgen María	42/27	−6/3	39.4	0.7	35.3	1471	R	CA

Place	**Monument**	**φ(°)**	**λ(°)**	**A(°)**	**H(°)**	**δ(°)**	**Date**	**Group**	**Type**
Mérida	Asunción de la Virgen María	38/55	−6/21	58.5	1.8	25.2	1479	--	CO
Calahorra	Sta. María de la Asunción	42/18	−1/57	57.8	0.7	23.7	1484	--	CA
Funchal	Nossa Senhora da Assunção	32/39	−16/54	70.5	7.2	20.3	1493	--	CA
Alcalá	Santos Justo y Pastor	40/29	−3/22	70.8	1.4	15.4	1497	R	CA
Las Palmas de Gran Canaria	Sta. Ana	28/6	−15/25	63.1	−0.2	23.5	1497	--	CA
Plasencia	Sta. María de la Asunción	40/2	−6/5	67.2	2.3	18.8	1498	PM	CA
Coria	Virgen de la Asunción	39/59	−6/32	62.9	6.5	24.9	1498	PM	CA
Salamanca	Virgen de la Asunción	40/58	−5/40	109.9	0.1	−14.7	1513	--	CA
Albacete	S. Juan Bautista	39/0	−1/51	116.2	0.7	−19.6	1515	PM	CA
Logroño	Sta. María de la Redonda	42/28	−2/27	88.6	0.0	1.1	1516	C	CO
Elvás	Nossa Senhora da Assunção	38/53	−7/10	337.1	0.6	4.4	1517	PM	ACA
Barbastro	Sta. María de la Asunción	42/2	0/7	65.3	2.3	19.7	1517	M	CA
Córdoba	Sta. María	37/53	−4/47	60.4	0.4	23.2	1523	M	CA
Almería	Virgen de la Encarnación	36/50	−2/28	110.6	0.5	−16.1	1524	--	CA
Segovia	Virgen María	40/57	−4/8	134.9	3.6	−29.4	1525	PM	CA
Granada	Sta. María de la Encarnación	37/11	−3/36	47.3	6.8	37.5	1526	M	CA
Málaga	Virgen de la Encarnación	36/43	−4/25	85.8	1.2	4.1	1528	M	CA
Jaén	Asunción de la Virgen María	37/46	−3/47	66.8	0.4	18.4	1540	M	CA
Bragança-Miranda	São João Baptista	41/48	−6/46	100.8	2.4	−6.4	1545	--	ACA
Getafe	Sta. María Magdalena	40/18	−3/44	80.2	0.5	7.7	1549	C	CA
Miranda do Douro	Sta. Maria Maior	41/30	−6/16	164.4	1.0	−45.2	1552	T	CA
Portalegre	Sta. Maria	39/17	−7/26	290.4	−0.4	15.4	1556	T	CA
Leiria	Nossa Senhora da Assunção	39/45	−8/48	72.8	4.2	15.9	1559	T	CA
Albarracín	S. Salvador	40/24.	−1/27	66.5	4.7	20.9	1572	PM	CA
Soria	S. Pedro	41/46	−2/28	65.5	2.7	20.0	1573	PM	CO
Tarrasa	Espíritu Santo	41/34	2/1	66.3	1.1	18.3	1574	T	CA
Valladolid	Virgen de la Asunción	41/39	−4/43	41.3	0.6	34.6	1589	--	CA
Beja	São Tiago Maior e São João Baptista	38/01	−7/52	55.6	−0.1	26.3	1590	PM	CA
Guarda	São Luís	40/32	−7/04	75.8	0.2	10.8	1596	T	ACA
Cádiz	Sta. Cruz	36/32	−6/18	124.8	1.7	−26.2	1597	CM	CA
Coimbra	Santíssimo Nome de Jesus	40/13	−8/26	347.9	0.2	48.5	1598	T	CA

Huelva	Nuestra Señora de la Merced	37/16	−6/57	9.7	0.3	52.0	1606	T	CA
Alicante	S. Nicolás de Bari	38/21	−0/29	67.9	3.6	19.5	1616	M	CO
Oporto	Sta. Casa da Misericórdia de Penafiel	41/12	−8/17	199.4	0.8	−44.5	1621	T	ACA
Santarém	Nossa Senhora da Conceição	39/14	−8/41	271.9	0.0	1.5	1672	T	CA
Place	**Monument**	**φ(°)**	**λ(°)**	**A(°)**	**H(°)**	**δ(°)**	**Date**	**Group**	**Type**
Zaragoza	Nuestra Señora del Pilar	41/39	−0/53	120.1	−0.1	−22.2	1681	R	CA
Castelo Branco	São Miguel	39/50	−7/29	87.9	−0.2	1.5	1682	C	CO
Ceuta	Virgen de la Asunción	35/53	−5/19	141.6	1.2	−38.5	1686	CM	CA
Jerez de la Frontera	S. Salvador	36/41	−6/8	136.6	2.1	−34.1	1695	M	CA
Cádiz	Sta. Cruz	36/32	−6/18	196.4	−0.2	−50.6	1722	T	CA
Lleida	Virgen María	41/37	0/37	328.1	1.3	40.5	1761	T	CA
Ferrol	S. Julián	43/29	−8/14	60.1	1.1	22.0	1764	C	CO
Vic	S. Pedro	41/56	2/15	92.6	1.9	−0.7	1781	C	CA
Vigo	Virgen María	42/14	−8/44	81.1	4.0	9.3	1816	C	CO
Madrid	Virgen de la Almudena	40/25	−3/43	184.8	0.2	−49.2	1883	T	CA
San Sebastián	Buen Pastor	43/19	−1/59	153.1	2.1	−38.7	1888	T	CA
Aveiro	Nossa Senhora da Glória	40/38	−8/39	45.5	1.1	33.0	1835	T	CA
San Cristóbal de La Laguna	Virgen de los Remedios	28/29	−16/19	110.2	3.9	−15.7	1904	T	CA
Vitoria	María Inmaculada	42/51	−2/41	255.9	0.7	−9.8	1907	T	CO
Castellón	Sta. María la Mayor	39/59	−0/2	84.0	−0.2	4.5	1939	C	CO
San Feliú de Llobre-gat	S. Lorenzo	41/23	2/3	75.0	3.4	13.5	1939	T	CA
Bragança-Miranda	Nossa Senhora Rainha	41/48	−6/46	288.3	3.7	16.1	2001	T	CA