www.maajournal.com

Mediterranean Archaeology and Archaeometry
Vol. 21, No 1, (2021), pp. 205-214
Open Access. Online & Print.

DOI: 10.5281/zenodo.4574637

GISEMUNDUS AND THE ORIENTATION OF THE ROMANESQUE CHURCHES IN THE SPANISH PYRENEES (11TH – 13TH CENTURIES)

J. Lluis i Ginovart, I. Ugalde-Blázquez* and C. Lluis-Teruel

Universitat Internacional de Catalunya, Barcelona School of Architecture
Carrer de la Immaculada, 22, 08017 Barcelona, Spain

Received: 02/11/2020
Accepted: 20/01/2021
**Corresponding author: I. Ugalde-Blázquez (iugalde@uic.es)*

ABSTRACT

This study examines an ensemble of thirty-two Romanesque churches in the region of Boí Valley and Aran Valley in the Spanish Pyrenees, built between the 11th and 13th centuries. The data obtained allowed for a geometric study of the orientation of these churches based on four Romanesque liturgies: Gemma animae (c.1120), by Honorius of Autun; Rationale divinorum officiorum (c.1150), by Jean Beleth; Mitralis de Officio (1190), by Sicard, Bishop of Cremona; and Prochiron, vulgo rationale divinorum officiorum (1291), by Guillaume Durand. A group of these churches have been equinoctially oriented. The mountainous topography does not allow a setting-out by observing the solar ortho, because the angular altitude of the skyline (AAS) is >0º. Therefore, we conclude that, due to their precision azimuth (Az) (91.41º, ± 1.91º), they have been traced using instrumental systems inherited from Vitruvius, Hyginus Gromaticus, Gisemundus, or Gerbertus Aureliacensis. It is concluded that the method of land surveying sources of Gisemundus (c.800), is the one that geometrically allows the sacral orientation from East to West to be plotted with less error.

KEYWORDS: Romanesque Architecture, Church Orientation, Christian Religion, Archaeoastronomy, Aran Valley, Boí Valley

1. CHURCH ORIENTED TO THE EAST, WHERE THE SUN RISES (ECCLESIAE AD ORIENTEM VERTUNTUR UBI SOL ORITUR)

In the mountainous regions of the Spanish Pyrenees, there are two valleys with important Romanesque constructions built between the 11th and 13th centuries. One is the Boí Valley on the southern slope of the Pyrenees, belonging to the diocese of Urgell, with a total of nine sacred buildings. The other is the Aran Valley on the northern slope of the Pyrenees, bordering the Department of Haute-Garonne (France) whose parishes belonged to the Diocese of Comenge (France) until 1084, with a total of 24 churches.

The historical-archaeological expedition of the l'Institut d'Estudis Catalans (1907) to these churches led by Josep Puig i Cadafalch (1867-1956), found important architectural differences in the constructions of both valleys. It determined that initially the churches of the Aran Valley were covered with wooden structures and that they were later transformed with the construction of barrel vaults, conserving as supports the initial pilasters of circular section and non-monolithic construction, unlike the churches of the Boí Valley (Puig i Cadaflach, 1908).

The objective is to determine the geometric practices and the degree of precision that both clerics and laymen might have known and that were used to build these churches in the Boí Valley and the Aran Valley (11th to 13th Century) with equinoctial direction. The orientation of these churches are based on four Romanesque liturgies: Gemma animae (c.1120), by Honorius of Autun; Rationale divinorum officiorum (c.1150), by Jean Beleth; Mitralis de Officio (1190), by Sicard, Bishop of Cremona; and Prochiron, vulgo rationale divinorum officiorum (1291), by Guillaume Durand; which recommended canonical orientation ad orientem. Therefore, another form of orientation based on the feast of the Patron of the church and its corresponding day of the year was not used in this case (Lluis i Gino-vart et al., 2017).

This research completes those carried out on the orientations of the churches of Aran Valley (Lluis i Gino-vart et al., 2017: e059) (Lluis i Ginovart and López Piquer, 2018: 23-33), (Lluis i Ginovart et al., 2019: 226-241.), by introducing geometric precision of the layout methods, especially those from Ars gromatica Gisemundi (scrip-ta c. 800) of the Codex Riuipullensis 106 (c. 850-900) of the monastery of Ripoll, due to its geographical proximity to the valleys of Boí and Aran.

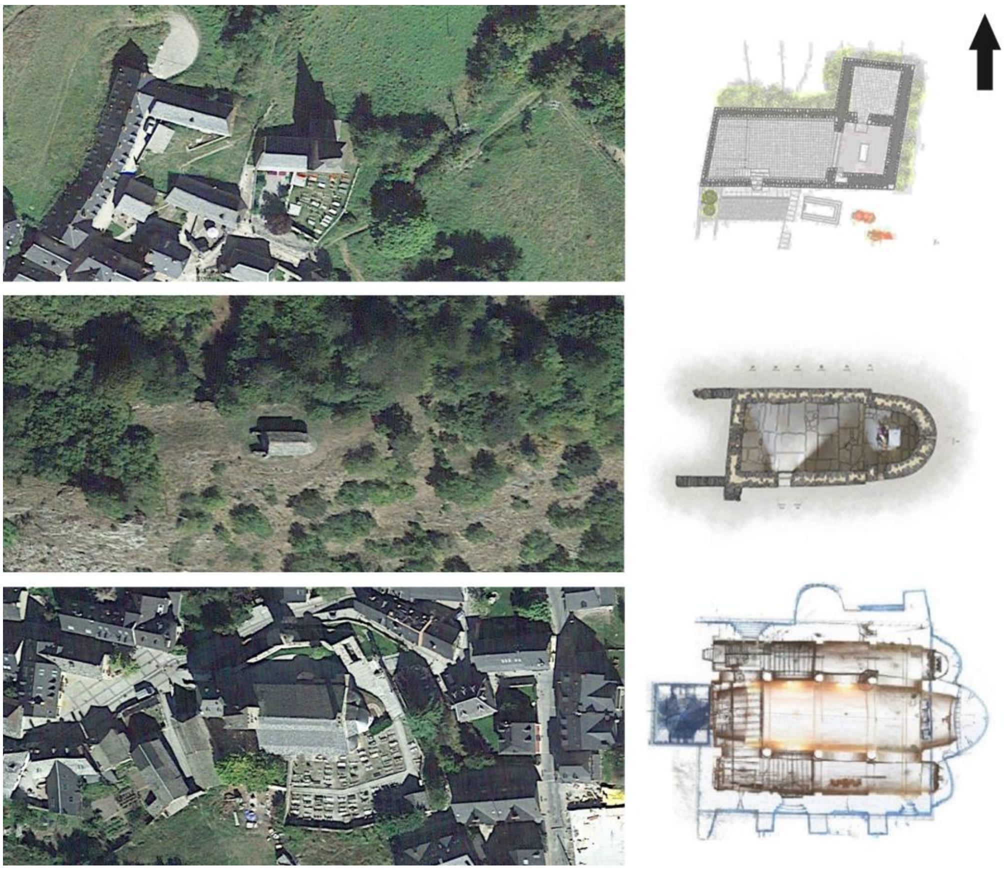
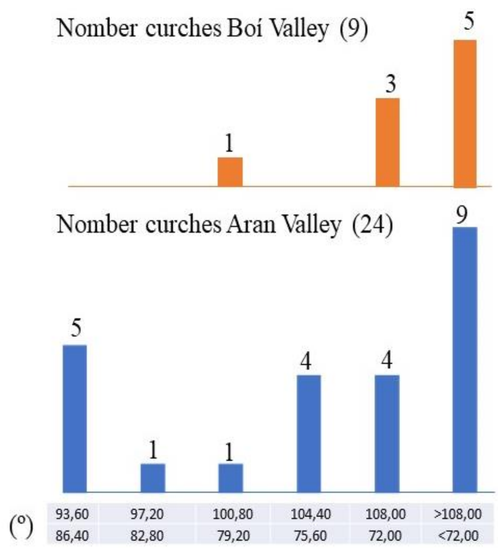


Figure 1. Orthophoto from Google Maps (2021) and plan of some churches equinoctially oriented: Sant Andrèu de Casau, Sant Miquèu de Vilamòs and Santa Maria d'Arties.

Table 1. Orientation of the churches during early Romanesque in Boí Valley & Aran Valley.

Aran Valley				Boí Valley			
Church name	Azimut (A (º)	Height h (º)	Declin. δ (º)	Church name	Azimut (A (º)	Height h (º)	Declin. δ (º)
Santa Maria de Cap d'Aran	109,57	32,40	-14,90	Santa Maria de Taüll	107,70	15,00	-2,40
Sant Estèue de Tredòs	102,14	38,00	-9,30	Sant Climent de Taüll	107,70	14,00	-3,10
Santa Eulària d'Unha	**92,87**	**45,00**	**-2,29**	Sant Joan de Bohí	143,70	14,00	-22,40
Sant Feliu de Bagergue	101,53	38,30	-8,98	Santa Eulalia de Erill la Vall	107,20	10,50	-5,30
Sant Andrèu de Salardú	94,11	43,40	-3,89	La Nativitat de Durro	109,20	19,00	-0,60
Santa Maria d'Arties	**92,12**	**45,80**	**-1,50**	Sant Feliu de Barruera	98,70	19,00	6,60
Sant Martín de Casarilh	75,99	57,30	10,00	Santa Maria de Cardet	105,75	14,50	-3,60
Sant Pèir d'Escunhau	50,90	0,00	-47,30	La Assumpció del Cóll	60,75	14,50	31,10
Sant Estèue de Betren	102,62	38,00	-9,30	Sant Joan de Caselle	75,50	7,00	15,30
Sant Miquèu de Vielha	120,02	25,60	-21,70				
Santa María de Mijaran	98,73	40,70	-6,59				
Sant Martín de Tours	104,99	35,80	-11,49				
Sant Andrèu de Casau	**90,30**	**47,00**	**-0,29**				
Sant Fèlix de Vilac	128,15	0,00	-47,28				
Sant Martín d'Aubèrt	119,63	25,70	-21,57				
Sant Pèir de Betlan	**92,80**	**45,00**	**-2,27**				
Sant Joan d'Arròs e Vila	40,70	0,00	-47,24				
Sant Estèue de Montcorbau	103,52	37,20	-10,07				
Santa Maria de Vilamòs	105,23	35,40	-11,85				
Sant Miquèu de Vilamòs	**88,99**	**46,90**	**-0,35**				
Sant Ròc de Begòs	107,08	34,40	-12,86				
Sant Fabian d'Arres de Jos	164,72	0,00	-47,25				
Era Mair de Diu dera Purifacion	117,55	26,90	-20,31				
Sant Blai de Les	126,96	0,00	-47,19				



A group of these churches have been equinoctially oriented, probably in autumn, since the spring equinox is when there is more snow around those higher than 1200 m. The mountainous topography does not allow a setting-out by observing the solar ortho, because angular altitude of the skyline (AAS) is >0º. The data from the orientations of the Boí Valley (González-García and Belmonte, 2019: 2240) and the Aran Valley (Lluis i Ginovart et al., 2019: 226-241) are analysed, represented in Table 1.

2. DETERMINATION OF PRECISION

The study of the sacred orientation is conducted through different hypotheses. They are arranged according to the Easter calendar according to the Easter date of the year of construction (McCluskey, 1998). Another criterion traces them according to the feast day of the patron saint, in the Christian churches (Spinazzè, 2016) and Byzantine churches (Liritzis and Vassiliou, 2006a; Liritzis and Vassiliou, 2006b), all reminiscent from classical times (Liritzis & Castro 2013).

A different criterion consists in supposing that the orientation of the church is influenced by the geographical environment or a characteristic landscape (Sassin, 2016), a method that determines a setting-out regarding its constructive needs, therefore it would not rely on liturgical aspects (Pérez and Pérez, 2018). Finally, there is the canonical criterion supposes locating the apses from East to West according to the liturgical treatises of the time (Delcor, 1987).

To quantify the range of precision of the canonical orientation of the Churches from East to West, the summary of the methodological process of data collection accuracy, the computer process of data processing, the value of appreciation of the measurement of the time and that of the replanting of the work are determined.

The precise determination and quantification of the azimuth (Az) in the Aran Valley was performed using Terrestrial Laser Scanning (TLS). The laser scanner used is the Leica P20, with a GPS positioning, referred to the cartography of the Institut Cartogràfic de Catalunya (ICC) (Esteban and Delgado, 2004). In the case of the Boí Valley, it was carried out using the archeometric methodology, whose process to determine the declination δ has an error of 1 ½º. (González-García and Belmonte, 2015). The information was computerized, with Cyclone and subsequently a three-dimensional mesh was generated, with the 3DReshaper program. The estimated precision of this process [0.025 m] determines an error of ¼º.

The appreciation value of the toolkit's layout for the simulation of the gnomon starts from the *alna* of the Boí Valley (0,780 m), the espan (0,195 m) and the finger (0,016 m), and the *cana* of the Aran Valley (1.896 m)], the span (0.237 m) and the finger (0.020 m), which is taken as a reference of the appreciation value for being the smallest of the units of length, and the measure of its error could be ±1.04% with respect to the *alna* & *cana*. Nowadays the evaluation of the uncertainties in constructions is set around ±0.025 m. Should we draw a circumference of a *cana* in diameter (1.896 m), the arc of circumference related to the measure of the Aranese finger, similar Boí Valley, shall have an angle of 1º. This value is very similar to the geometric precisions of Roman settlements' setting-out, establishing one grade.

The tolerance of the process is 3 ¾º, therefore it is established as a reference [± 3.60º- ± 1%] with an interval limit of [1% -3%] equivalent to the 10-day adjustment of Inter Gravissimas (1582) (Table 2). The results establish that only 11.00% (1/9) of the churches in the Boí Valley tend towards the E-W orientation, while in the Aran Valley they are 29.17% (7/24). From a statistical point of view, it is clear that, if it was desired that the churches of the Boí Valley be oriented towards the east, the relative error of the layout and its methods is high. On the contrary, one out of every five sacred constructions in the Aran Valley (20.83%) are oriented with absolute precision, taking into account that only 11.60% of the Romanesque churches of the Iberian Peninsula are established in this canonical orientation (Pérez and Pérez, 2019).

Table 2. Sample of the tolerances E-W of the churches in Boí Valley & Aran Valley (Centuries 11th to 13th).

Error (+,-) (º)	3,60	7,20	10,80
Tolerance Error (+) (º)	93,60	97,20	100,80
Tolerance Error (-) (º)	86,40	82,80	79,20
% Error	1%	2%	3%
Nomber churches Boí Valley (9)	0	0	1
% Total (9)	0%	0%	11%
Nomber churches Aran Valley (24)	5	1	1
% Total (24)	20,83%	4,17%	4,17%

3. OBSERVATION AND LAYOUT INSTRUMENTS

Among the instruments that are used to trace the orientation (Centuries 11th to 13th), we have references from the *groma*, the *metae*, the *signa* and the *perpendiculus*, referred to in Frontinus' (Thulin, 1913); *De arte mensoria* and *Limitis repositio* by Nypsius (Blume et al. 1848: 286). However, they do not appear in the *Etymologiarum* (c.630) by Isidorus Hispalensis, meaning that their survival over Centuries 11th to 13th is doubtful.

The setting-outs in *De limitibus constituendi* by Hyginus Gromaticus are performed *lineam autem per metas extendemus et per eam ad perpendiculum cultellabimus* (Blume et al. 1848: 192), an operation that is completed by extending a string between two stakes and throwing a plumb on it. A similar expression is found in *De limitibus* de Frontinus: *pertice aequlite ad perpendiculum cultellare debemus, tum ad permensum rigorem extendere linean* (Blume et al. 1848: 33-34; Guillaumin, 2015).

These elements do appear, nonetheless, in the *Etymologiarum* (Lindsay, 1911) the string, *linea* (XIX.XVIII.3), the *regula*, rule (XIX. XVIII.2) the *circinus*, compass (XIX. XIX.10) and the square, *norma*, (XIX. XVIII.1).

Another reference will be *La siensa de atermenar* (1401) by Berand Boysset (1355-1415), who will dedicate a part to the construction of the square through a ruler and a compass (Carpentras Bibliothèque Municipale, CBM: 327, fol. 216 r) and without any instruments (CBM: 327, fol. 218 r, fol 220 r). In the same treaty, there are plumb operations *perpendiculum* or alignment *extendere lineam* in the same terms than those expressed in the Roman surveying (Portet, 2004). Vitruvius will use Plato to define the square 10-sided and the Pythagorean triple (3, 4, 5) (Vitruvius, 1899: L.IX). Cetius Faventinus (f. 350) will get the square according to the principle of proportionality (2, 2, 2+ 10/12) (Faventivi, 1899: XXVIII).

4. LAYOUT TRACED OF THE CANONICAL ORIENTATION

From the methodological point of view specifically used for the orientation of the churches (11th to 13th Century), links can be found in the inheritance of the Vitruvius methods (M_1, M_2), the *gromatic* methods (1st to 3rd Centuries) (M_3, M_4, M_5, M_6), those of the Ripoll *scriptorio* (M_7, M_8) of Gisesmundus and those of the apocryphal work of Gerbertus (M_9, M_{10}). Finally, it is considered the use of the compass (M_{11}).

Method (M_1). Vitruvius (c.80 - 20 BC), in *De architectura* (Vitruvius 1899: LI.VI.6). This method determines a meridian orientation through two shadows and its execution requires six geometric operations (Cantor, 1875).

Method (M_2). Vitruvius (c.80 - 20 BC), in *De architectura* (Vitruvius 1899: LI.VI.12). This method determines an equinoctial orientation through three shadows and its execution requires fifteen geometric operations (Cantor, 1875).

Method (M_3). Hyginus Gromáticus (c.100), in *De limitibus constituendi* (Blume et al. 1848: 166-208). This method determines a meridian orientation using an observation procedure during the *hora prima*.

Method (M_4). Hyginus Gromaticus (c.100), in *De limitibus constituendi* (Blume et al. 1848: 188). This method determines a meridian orientation using an observation method during the sixth hour.

Method (M_5). Hyginus Gromaticus (c.100), *De limitibus constituendi* (Blume et al. 1848: 188-189). This method determines a meridian orientation through two shadows, and its execution requires six geometric operations.

Method (M_6). Hyginus Gromaticus (c.100), *De limitibus constituendi* (Blume et al. 1848: 189-191). This method determines an equinoctial orientation and its conduction requires fifteen geometric operations (Guillaumin, 2005: 240-241).

Method (M_7). Gisemundus (c. 800), in *Ars gromatica siue geometría Gisemundi* [28]. This method determines an equinoctial orientation through two shadows and its execution requires four geometric operations (Lluis i Ginovart et al., 2018).

Method (M_8). Gisemundus (c. 880), in *Ars gromatica siue geometría Gisemundi*. This method determines an equinoctial orientation through two shadows using an instrumental procedure, whose execution requires two geometric operations (Lluis i Ginovart and López-Piquer, 2018).

Method (M_9). Apocrypha of Gerbertus (c.1000), *Geometria Incerti Auctoris*. This is a method similar to the ones from Vitruvian (M_1), Hyginus Gromaticus (M_5) and Gisemundus (M_7).

Method (M_{10}). Apocrypha of Gerbertus (c.1000), *Geometria incerti auctoris*. The proposition referred to in *Alia ratio meridianum describendi* is similar to (M_2) (M_6), determining the equinoctial orientation through fifteen geometric operations.

Method (M_{11}). Use of the compass (c.1150). This method determines a meridian orientation through the alignment of a magnetized needle.

The eleven methods described above are based on both solar observation and on an operating system relying on instrumental layout. Therefore, we find inaccuracies in the geometric layout that can lead to *errors* those are classified as *accidental*, *systematic* and *mistakes*. Among the *accidental* ones, the so-called instrumental errors caused by factors such as the execution of the setting-out, the visibility and the refraction. *Systematic* errors would be those caused by construction failures and by misalignment of the layout instruments. Finally, some errors can occur due to *mistakes*, although experience and work methodology can almost completely eradicate them. The analysis starts from the determination of the error interval of the churches of the Aran Valley, while taking as a sample those five churches whose reference value of the azimuth (Az) has an error range of [± 1%], ± 3,60º and angular altitude of the skyline (AAS) [45.00º-47.00º], which represents (20.83%) of the churches studied. Thus, the most probable value is the resulting mean of the azimuths (e_a)= 91,41º. The mean quadratic error (e_c) of the average is obtained 1,91º.

Table 3. Tolerances of the layout methods of the orientation (September, 22, 2020).

Method	Author	Orientation type	Tracing	Characteristics	Geometric operations	Error (max) =0,92%
M1	Vitruvius	Meridian	Instrumental	2 umbra	6	0,12
M2	Vitruvius	Equinoctial	Instrumental	3 umbra	15	0,05
M3	Hyginus Gromaticus	Meridian	Observation	Hora pima	-	-
M4	Hyginius Gromaticus	Equinoctial	Observation	Hora sexta	-	-
M5	Hyginus Gromaticus	Meridiano	Instrumental	2 umbra	6	0,12
M6	Hyginus Gromaticus	Equinoctial	Instrumental	3 umbra	15	0,05
M7	Gisemundus	Equinoctial	Instrumental	2 umbra	4	0,15

M8	Gisemundus	Equinoctial	Instrumental	2 umbra	2	0,23
M9	Apocrypha of Gerbertus	Meridian	Instrumental	2 umbra	6	0,12
M10	Apocrypha of Gerbertus	Equinoctial	Instrumental	3 umbra	15	0,05
M11	-	Meridian	Observation	Compass	-	-

The azimuths of the five churches have a range of [89.50º - 93.32º]. Even though the tracing method that was used during the layout of the selected churches is unknown, tolerance can be determined [-0.50º, +3, 32º] with respect to the value of the canonical orientation [90º]. The maximum tolerance ($e_{m,max}$= 3.32º), established on a circumference the diameter of which measures a *cana* of the Aran Valley, an arc of circumference of (0.065 m) is obtained, which is 3.25 times the appreciation value of the Aranese finger. The maximum error established for the five selected churches is (0.92%), while in the Roman settlements it was (0.28%). (Table 3)

5. ANALYSIS OF THE RESULTS

The M3, M4, and M11 methods are assessment methods and therefore are not strictly geometric, for this reason they are not included in the error analysis as they are assessment values and thus difficult to calibrate. Layouts by observation, M_3 and M_4 methods, are the simplest and most direct, but they are the least accurate as well. The first is unreliable when determining the height of the sun with respect to the ortho or the observation date on which the phenomenon occurred, and this is because the height of the horizon is [45.00º-47.00º]. Moreover, the M_4 method can be somewhat imprecise in determining the exact moment in which the shortest shadow of the sixth hour occurs.

Observatory layout based on the compass, it would be necessary to determine the magnetic declination at a point in the interval of the extreme coordinates of the church of longitude (λ) [0.69º-0.92º] and latitude (ϕ) [42.70º-42, 81º]. Nowadays this value is established as [+0º, 51′ E; +0º, 55 ′E], margin of error [± 0º 21′], and annual transfer to the East of (0º10′). At the time of dating of these churches, the correction to be made to the real North would be in the interval [+16º; +22º]. This hypothesis (M_{11}) is very improbable, since the use of the compass during this time is quite uncertain and there are no sources that testify its use before the Renaissance. In addition, the magnetic declination of the 11th to 13th Centuries would be in an interval of [16º - 22º], which is outside the canonical range of the orientations with an azimuth equal to 90º.

Three hypotheses need to be assumed: (A) with the perfectly vertical *gnomon* and a completely horizontal ground, (B) another with the *gnomon* inclined (± 1º) on the horizontal ground, (C) and with a vertical *gnomon* on a slightly collapsed ground (± 1º) (Table 5). These systematic errors, whose average value for hypothesis C is (± 1.12º), unnoticed by the human eye, could constitute up to a third of the established maximum error ($e_{m,max}$= 3,32º) (Table 4).

Table 4. Systematic errors according to their modelling in SketchUp.

	Geometric methods							
Hypothesis	M1	M2	M5	M6	M7	M8	M9	M10
A	0,14º	0,23º	0,08º	0,23º	0,08º	0,19º	0,08º	0,23º
B	0,11º	0,89º	0,02º	0,89º	0,03º	0,12º	0,02º	0,89º
C	1,07º	1,52º	0,94º	1,52º	0,92º	0,96º	0,94º	1,52º

Instrumental layouts with two shadows: methods M_1, M_5, M_7 and M_9, which are determined from two shadows, one pre-meridian and the other post-meridian, and are projected on a circle in order to guarantee that their lengths are equal. They are distinguished in that Vitruvius takes the first shadow five hours before noon, in such a way that it determines the radius of the circumference, generating a circle of large diameter, meaning that the *gnomon* had to have a small magnitude. In the other methods, the circumference is first traced and then one shall wait for the moments when the shadow enters and leaves such circumference. Once the two points are found, other variations are presented. Vitruvius (M_1) makes a challenge that will join the centre of the circumference in order to determine the meridian. Hyginus (M_5) does it the same way, but from the midpoint of the line that results from joining both points, with a margin of error ($e_{M1,5,}$ = 0,12). The simplest method is that of Gisemundus (M_7), since it joins the two points determining the equinoctial axis, thus having a greater margin of error in its layout (e_{M7} = 0,15) greater than (M_1, M_5). Furthermore, M_8, which is based on two shadows very close to each other and temporally close to the sixth hour, is the simplest, since it is based only on joining the ends of two nearby shadows of equivalent lengths. However, it may be imprecise because it is the layout with the largest margin of error (e_{M7} = 0,15) among all methods.

Instrumental layouts based on three shadows: The M_2, M_6 and M_{10} methods use three shadows to determine the orientation, by means of geometric procedures that are much more complex than those analysed up to now. Due to their complexity, they would lead them to operate with a much lower tolerance ($e_{M2,6,10}$ = 0,05).

6. THE LAYOUT OF THE SACRED ORIENTATION

It is likely that the instruments referred to in the *Etymologiarum* (XIX.18) and transmitted to the *De Universo* by Rabanus Maurus (c. 776-856) (Rabanus Maurus, 1864: XXI.11) were used to map these methods. Therefore in the M_1, M_5 and M_9, after bisecting the angle, and leaning on the pole, the equinoctial axis would be marked through a *pertice aequlite ad perpendiculum* using lead and square (CBM: 327, fol. 142 r), and obtaining a tolerance percentage of up to ($e_{M1,5,7}$ = 0,12). *La siensa de atermenar* by Berand Boysset shows how this very axis would be traced with the pole and, by making an *extendere lineam* through the usage of the poles (CBM: 327 fol. 251 r), it could have been used in the methods M_7 (e_{M7} = 0,15) and M_8 (e_{M8} = 0,23).

Regarding the instrumental methods, it is observed that the simplest one from the geometric point of view in order to determine the equinoctial line are the Gisemundus' M_7 and M_8, although M_8 is operated with remarkably close shadows (Figure 1). The M_1, M_5 and M_9 methods require six operations with the compass but, should the tracing be undertaken in an interval before the third hour or after the ninth hour, the angle suggested by the solar projection allows an accurate bisector—the meridian can be thus plotted in a very precise way. Moreover, the M_2, M_6 and M_{10} methods are the ones with the greatest geometric complexity, requiring up to fifteen operations. This fact, added to the one that the shadows are very close, and that the angles are very similar, are the facts that would have produced a greater relative error. These methods are assigned the maximum calculation error ($e_{m,max}$ = 3.32º), and represents only one arc of circumference ($arc_{r0,50}$ = 0.034 m) of one meter in diameter.

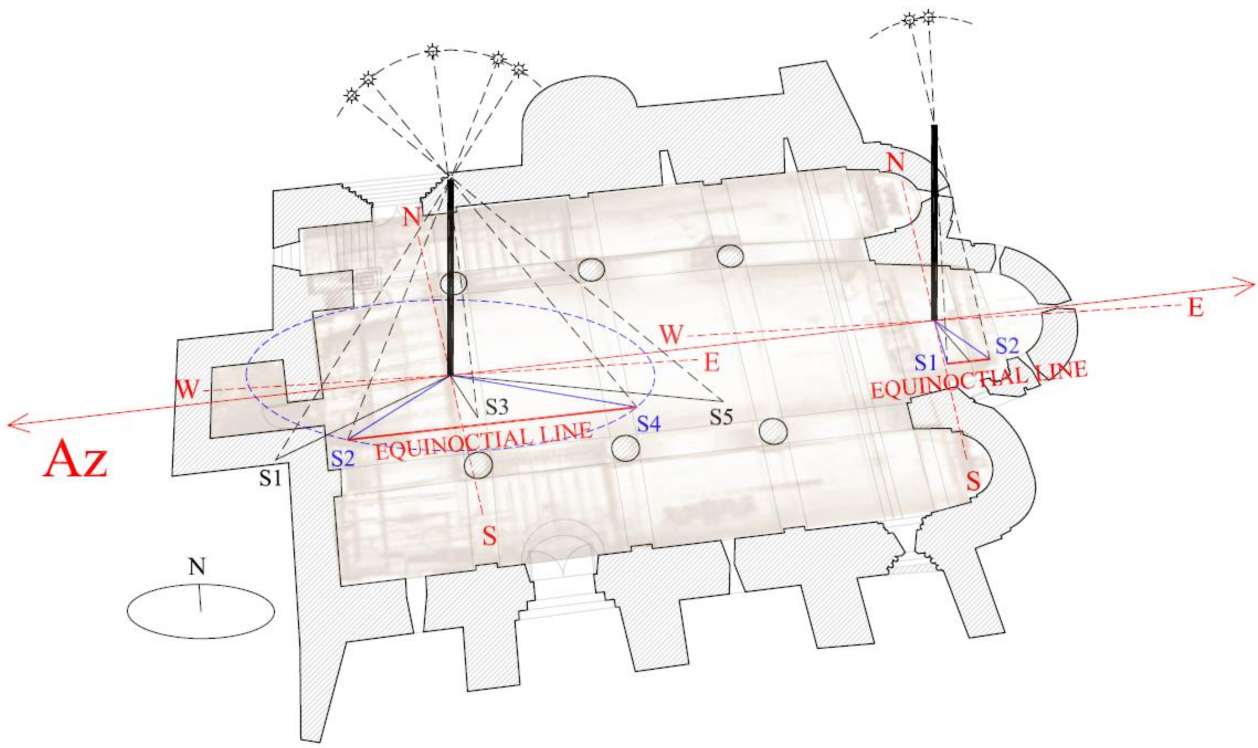


Figure 2. Ars gromatica Gisemundi, c.880: a) Method M_7; b) Method M_8.

7. ORIGINS PLOTTED FROM GISEMUNDUS

The methods with the greatest tolerance to absorb possible errors of the setting-out are the M_7 and M_8 of Gisemundus (Figure 2). These *ecclesiae ad orientem* had to be set out, or, by means of two shades, pre and post meridian, drawn only with an *extendere lineam*; or lined up, close to the sixth hour, through *extendere lineam* y *pertice aequlite ad perpendiculum*, using a plumb line and a square.

On the work of Gisemundus, Rudolf Beer (1863-1913) gave the first reference in his *Die Handschriften des Klosters Santa Maria de Ripoll, I* (1907), making known the uniqueness of this land surveying treaty (fol. 76-86) (Beer, 1907). This work was disseminated in Catalonia by the *Boletín de la Real Academia de Buenas Letras de Barcelona* (1910) (Beer and Barnils, 1910). It will be Carl Olof Thulin (1871-1921), who introduces it within the *Corpus agrimensorum Romanorum* (Thulin, 1911). This corpus was studied and edited in part from the history of science perspective by

Josep Maria Millàs Vallicrosa (1897-1970) (Millàs, 1931).

The codicological origins of the *Ars gromatica Gisemundi* (scripta c. 800) (AGG) are located in the *Pseudoboethii* (scriptum 8th century), of which two copies are preserved: the *Codex Parisinus* BN 8812 (c. 800-833) from southern France (110/097) and *Codex Riuipullensis* 106 (c. 850-900) of the Ripoll monastery (118/096) (Toneatto, 1995: 999-1112).

Discriptio Hispaniae fol. 81v 32-82r 24 is a passage from the Geometry of *Gisemundus* (AGG) a medieval treatise of agrimensura written by an unknown author, probably a monk known as *Gisemundus* who had some agrimensorial experience. The most likely origin of the *Discriptio Hispaniae* is that it was made during the Byzantine occupation of parts of southern Spain during the second half of the 6th century and the first quarter of the 7th. century. The most likely origin of the *Discriptio Hispaniae* is that it was made during the Byzantine occupation of parts of southern Spain during the second half of the 6th century and the first quarter of the 7th. Century (Olesti, 2018: 278-308).

The orientation methodology is developed in: fol.77r25-77v 10 (Andreu, 2012: 58). The sources of the introductory part refer to the *Demonstratio artis geometricae de Pseudoboecio* and to some *excerptas* from the *Corpus Agrimensorum Romanorum*, and especially to the *De limitibus* of Hyginus Maior (fl. 98-102) (Toneatto, 1982).

Gisemundus's Ripollensis codex contains traces of visigothic writing, and identified the work of a high-medieval surveyor from sources close to Hyginus Maior, who, far from being a mere copyist, knew the foundations of this discipline both at a theoretical and practical level (Olesti, 2017: 257-274).

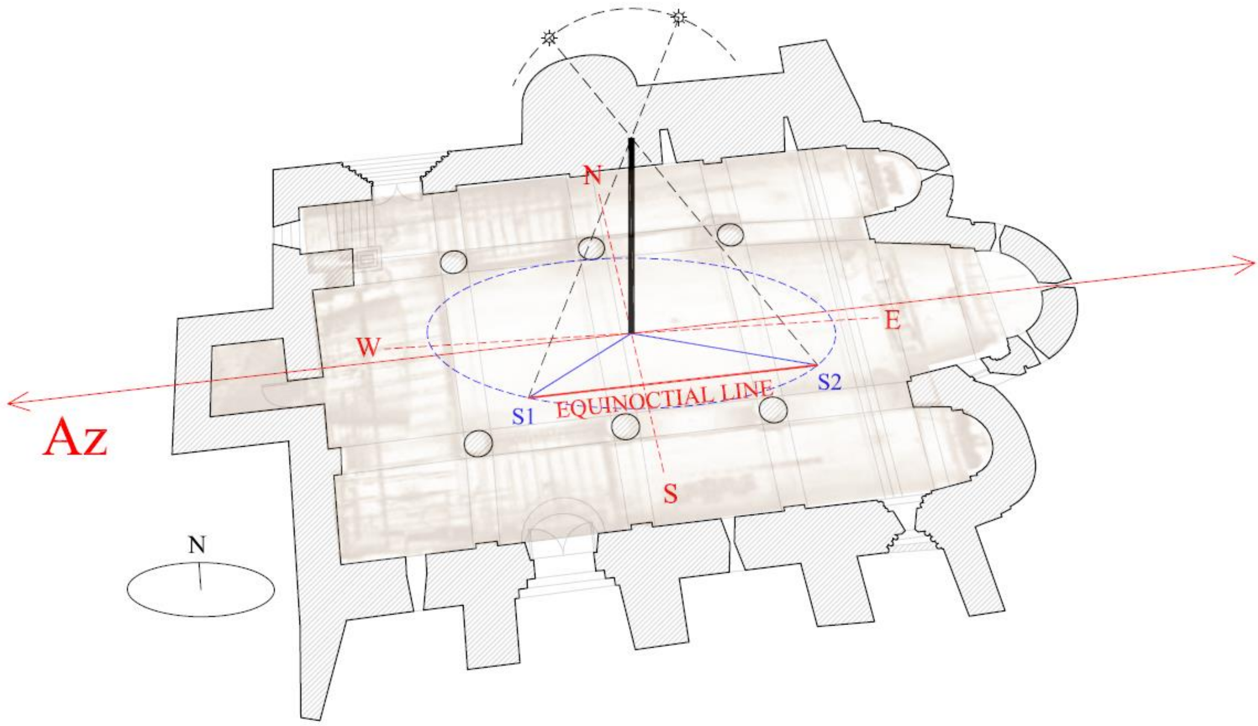


Figure 3. Method M_7 by Gisemundus, setting-out of a church ad orientem.

Within this context, the M_7 method is deeply practical, the five observed shadows figuratively trace the analema of the solar course. It starts from a geometric construction of only two basic principles: the tracing of a circumference and having a gnomon squared on the plane where the circumference has been located. The architect draws the circumference first thing in the morning, with a diameter smaller than the shadow cast at that time (shadow 1). This is the only geometric operation you have to perform. Then you just have to observe, mark the point where the shadow coincides with the circumference (shadow 2) and wait for the path of the sun to approach the base of the gnomon (shadow 3). Subsequently, the point where the end of the shadow coincides with the circumference (shadow 4) must be re-marked and thus, joining the points (2-4), the E-W orientation is already obtained, without the need to use the last longest shadow in the afternoon (shadow 5).

The M_7 construction of the *Ars gromatica Gisemundi* (c.800), is eminently practical derived from land survey experience. His theory is not described, part of the principles of Marcus Vitruvius Pollio (c.80-c.20 BC) that claim to know astronomy and know the use of *gnomon* in order to determine the equinoxes and solstices (Vitruvius, 1899: L.I). Vitruvius defined the construction of sundials (Vitruvius, 1899: L.IX, 7). The concept is based on the layout of the *analemma*, which is first depicted in the edition of Giocondo (1511) (L.IX, VIII) [fol. 92]. Marcus Cetius Faventinus picks up the tradition of the construction of sundials, defining the double ax or plecino and the semicircular or quadrant (Hevia 1979: XXIX).

The construction of the M_7 method is carried out directly in the place of the sacred settlement, but hypothetically it will allow a possible instrumentation, so that the gnomon arranged as a *norma* on a flat base could be transported or remade with a certain ease. There is a possible reference in the *Codex Riuipullensis* (225) from the middle of the eleventh century (fol94r-97v), *De horologio*, *Incipit:* "*In rotunda et plana equaliter"* which, according to the instrument made on a flat stone or slate support, can mark, with the circumferences drawn on it, the meridian line *ab eadem ipsa meridiana linea due orientur.*

8. CONCLUSION

Apart from the important constructive differences between the Boí Valley and the Aran Valley, there are also clear differences in the methods of tracing the orientation of their churches. In the Boí Valley they did not have the criteria to orient their buildings according to the liturgical treaties towards the east. In the Aran Valley, the churches Santa Eulària d'Unha, Santa Maria d'Arties, Sant Pèir de Betlan, Sant Andrèu de Casau and Sant Miquèu de Vilamòs, are oriented in the canonical direction of the liturgical treatises of the time with a statistical range of [89.50° - 93.32°] and therefore have a high plotting precision. The maximum error established on the East West axis in these churches is 0.92%, while in the Roman settlements the error in orientation was 1°, which would represent 0.28%. If we take the average error of these buildings (1.66 °), it is concluded that they have been made with scientifically based methods, close to those developed by the Roman technique.

It is not possible to determine which method was used for its orientation, but the degree of precision requires a highly developed practical knowledge at the time of staking out the building. The methods of the *Ars gromatica Gisemundi* (c.800) (AGG) are the simplest from a geometric point of view, directly tracing the E-W direction. These were already known to copyists in southern France (c.800-833) and from Ripoll (c. 850-900), being a readaptation that sanctioned the practical application of Vitruvius' meridian method.

REFERENCES

Andreu, R. (2012). *Edició critica, traducció i estudi de l'Ars gromatica siue geometría Gisemundi*.Ph. D. thesis. Departament de Ciències de l'Antiguitat i de l'Edai Mitjana. Barcelona, Universitat Autònoma de Barcelona.

Beer, R. (1907). *Die Handschriften des Klosters Santa Maria de Ripoll, I.* Viena, In Sitzungsberichte, Akademie der Wissenschaften in Wien, Philosophisch-Historische Klasse, Band155/3, pp. 65.

Beer, R. and Barnils, P. (1910) *Los manuscrits del monastir de Santa María de Ripoll*, Barcelona Estampa de la Casa Provincial de Caritat, pp. 49-50.

Blume, F., Lachman, K., Rudorff, A. (1848) *Die Schriften der Römischen Feldmesser Herausgegeben und erläutert*, 2 vols. Berlin, Bei Georg Reimer.

Cantor, M. (1875) *Die römischen Agrimensoren und ihre Stellung in der Geschichte der Feldmesskunst. Eine historisch-mathematische Untersuchung von Dr. Moritz Cantor*. Druk un verlag von B.G.Teubner, pp. 66-69, fig. 12-13-14.

Delcor, M. (1987) Les églises romanes et l'origine de leur orientation. *Les Cahiers de Saint-Michel de Cuxa* 18, pp. 39-53.

Esteban, C. and Delgado, M. (2004) Sobre el análisis arqueostronómicos de dos yacimientos tinerfeños y la importancia de los equinoccios en el ritual aborigen. *Tabona: Revista de Prehistoria y de Arqueología* 13, pp.187-214.

Faventivi, C. (1899). *N. Ceti Faventivi. Liber artis architectonae. En Valentinus Rose (ed). Vitruvii. De architectura Libri Decem*. Lipsiae, In aedibus B. G. Teubneri, pp. 283-309.

González-García, A. C. and Belmonte, J. A. (2015) The orientation of pre-Romanesque churches in the Iberian Peninsula. *Nexus Network Journal*, 17(2), pp. 353–77.

González-García, C. and Belmonte, J.A. (2019) Archaeoastronomy: A Sustainable Way to Grasp the Skylore of Past Societies. *Sustainability*, 11(8): 22401.

Guillaumin, J. Y. (2005) *Hyginus Gromaticus: Les arpenteurs romains. Tome I: Hygin le Gromatique. Frontin*. Paris, Les Belles Lettres.

Guillaumin, J.Y. (2015) Le discours des agrimensores latins:caractéristiques et sources, transmission et adaptation. *Studia Philologica Valentina* 17,14, pp. 9-34.

Hevia, A. (1979) *M. Cetio Faventino. Las diversas estructuras del arte arquitectónico o Compendio de Arquitectura* 1:129. Traducción del latín con una noticia introductoria. Oviedo, C.O.A.A.T. y Seminario Metropolitano, pp. 100-104.

Lindsay, W. M. (1911) *Isidori Hispalensis episcopi. Etymlogiarum sive Originvm Libri XX. Oxonii,* Oxford, Oxford University Press.

Liritzis, I. and Vassiliou, H. (2006a) Does sunrise day correlate with eastern orientation of Byzantine Churches during significant solar dates and Saint"s day name? A preliminary study. *Byzantinische Zeitscrift* 99, 2, pp. 523-534.

Liritzis, I. and Vassiliou, H. (2006b) Further solar alignments of Greek Byzantine churches. *Mediterannean Archaeology & Archaeometry*, Vol.6, No.3, 7-26.

Liritzis, I and Castro, B (2013) Delphi and Cosmovision: Apollo's absence at the land of the hyperboreans and the time for consulting the oracle. *Journal of Astronomical History and Heritage*, 16(2), 184-206.

Lluis i Ginovart, J. and López Piquer, M. (2018) The orientation of the romanesque churches of val d'aran in spain (11th-13th centuries). *In 7th Euro-American Congress on Construction Pathology, Rehabilitation Technology and Heritage Management, REHABEND 2018*. Cáceres, pp. 23-33.

Lluis i Ginovart, J. et al. (2017) Topología de la arqueología litúrgica del primer románico del Val d'Aran. *Arqueología de la Arquitectura*, 14: e059. doi: http://dx.doi.org/10.3989/arq.arqt.2017.013.

Lluis i Ginovart, J. et al. (2019) Orientation of the romanesque churches in the region of Val d'Aran, Spain (11th–13th centuries). *Archaeometry* 61(1), pp. 226-241.

McCluskey, S.C. (1998) *Astronomies and Cultures in Early Medieval Europe*. Cambridge, Cambridge University Press, pp. 165-207.

Millàs, J.M. (1931) *Assaig d'història de les idees físiques i matemàtiques a la Catalunya medieval*, Vol. I, Barcelona, Institució Patxot, pp. 238-243.

Olesti Vila, O. (2017) Héritage et tradition des pratiques agrimensoriques: l'Ars Gromatica de Gisemundus. *Dialogues d'histoire ancienne*, 43-1, pp. 257-274.

Olesti Vila, O. et al. (2018) New perspectives on Byzantine Spain: the Discriptio Hispaniae, *Journal of Ancient History*, Vol. 6, Issue 2, pp. 278-308.

Orfila, M., Chávez-Álvarez, E. and Sánchez, E. (2017) Urbanizar en época romana: ritualidad y practicidad. Propuesta de un procedimiento homologado de ejecución, *SPAL* (26), pp. 113–34.

Pérez, J. and Pérez, V. (2018) La orientación de las iglesias mozárabes. *España Medieval*, 41, pp. 171-197.

Pérez, J. and Pérez, V. (2019) La orientación de las iglesias románicas en la península ibérica. *Anuario Estudios Medavales* 49(2), julio-diciembre, pp. 761-791.

Portet, P. (2004) *Bertrand Boysset, la vie et les oeuvres techniques d'un arpenteur médiéval* (v. 1355- v. 1416). Paris, Éditions Le Manuscrit, pp. 221-231.

Puig i Cadaflach, J. (1908) Les iglesies romàniques ab cobertes de fusta de les Valls De Bohí y d'Aran. *Anuari de l'Institut d'Estudis Catalans.* MCMVII, pp. 119-136.

Rabanus Maurus (1864) *De Universo Libri Viginti Duo. Documenta Catholica Omnia. De Scriptoribus Ecclesiae Relatis*. JP Migne. Patrologia Latina, MPL111.

Sassin, A. (2016) Church Orientation in the Landscape: a Perspective from Medieval Wales. *Archaeological Journal* 173(1), pp. 154-187.

Spinazzè, E. (2016) The alignment of medieval churches in northern-central Italy and in the Alps and the path of light inside the church on the patron saint's day. *Mediterranean Archaeology and Archaeometry* 1(4), pp. 455-463.

Thulin, C.O. (1911) *Die Handschriften des Corpus agrimensorum Romanorum*. Berlin, Akademie der Wissenschaften, pp. 87.

Toneatto, L. 1982. Note sulla tradizione del Corpus Agrimensorum Romanorum. I Contenuti e struttura dell'Ars Gromatica de Gisemundus (IX sec.) *Mélanges de l'école française de Rome Année* 94-1, pp.191-313.

Toneatto, L. (1995) *Codices artis mensoriae. I manoscritti degli ancichi opuscoli latini d'agrimesura (V-XIX sec.).* Spoleto: Centro Italiano di studi sullu'alto medievo.

Thulin, C. (1913) *Corpus Agrimensorum Romanorum*. Leipzig: Tevbner, pp. 15-19.

Vitruvius, M. (1511. *M*) *Vitruvius per Iocundum solito castigatior factus, cum figuris et tabula, ut iam legi et intelligi potest*. Tacuino, Venecia.

Vitruvius, M. (1899) *Vitruvii. De architectura Libri Decem. Iterum edidit Valentinus Rose*. Leipzig: Teubner.