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Research

Astronomical Knowledge in the Sacred Architecture of the Middle Ages in Italy

Abstract. The present work reports the results of the archaeoastronomical examination of sacred buildings in Italy dating from the medieval period. This leads to the problem of understanding the training of the architects in the middle ages, and, in particular, their knowledge of astronomy, a theme which is dealt with on the basis of the analysis. The first section of this paper takes into consideration the astronomical knowledge present in documents of architectural/constructive nature, including astronomical and gnomonic knowledge, geometry, design, the use of both the civil and the liturgical calendar, as well as knowledge of both technical and practical nature, such as measuring techniques and site techniques. The analysis concludes with a database aimed at defining a series of objectives and work methodologies which are scientifically shared and correct.

Introduction

The present work reports the results of the archaeoastronomical examination of sacred buildings in Italy dating from the medieval period. It refers mainly to buildings of a monumental nature. These buildings were mainly constructed by workmen who were clearly expert and cultured. This leads to the problem of understanding the training of the architects in the middle ages, and, in particular, their knowledge of astronomy, a theme which is dealt with on the basis of the analysis.

Before attributing an astronomical intentionality to the alignments established by the ancient architects, it is important to assess carefully the structure of knowledge possessed by said architects. For this reason, the first section of this paper takes into consideration the astronomical knowledge present in documents of architectural/constructive nature. 'There is constant reference to the *Man-architect* who projects (consciously or unconsciously) onto his planned and finished artifact all the *theoretical and applicative processes* available in the period in which he operated' [Mandelli 1997: 8]. Among said processes we cannot fail to consider astronomical and gnomonic knowledge, geometry, design, the use of both the civil and the liturgical calendar, as well as knowledge of both technical and practical nature, such as measuring techniques and site techniques.[1]

Astronomical knowledge of ancient architects[2]

De architectura by Vitruvius [1997; 2009] is the most significant evidence to document the attention with which Western ancient builders considered the heavens. Vitruvius includes astronomy among the disciplines which, together with practical knowledge, is necessary in the training of the architect. It is appropriate that the architect

> … have a literary education, be skilful in drawing, knowledgeable about geometry and familiar with a great number of historical works, and should have followed lectures in philosophy attentively; he should have a knowledge of music, should

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not be ignorant of medicine, should know the judgments of jurists and have a command of astronomy and of the celestial system (Vitruvius I,1,3 [2009: 5]).

The fields of these new disciplines are, immediately afterwards, outlined briefly (I,1,4-10) through the description of characters, objectives and interrelations.

Knowledge of the heavens, together with that of optics (which is part of geometry), is necessary in order that the lighting inside buildings is correctly planned.[3] Medical science cannot disregard the notion of the inclination of the earth's axis which determines the different climatic zones. Astral concordances and musical accords, squares and triangles represent on the theme of accords a common subject of debate between musicians and astronomers:

> Through a study of astronomy, the architect recognizes east, west, south and north as well as the principles governing the sky, the equinoxes, the solstices and the courses of the stars. If someone is ignorant of these subjects it will be impossible for him to understand the principles behind sundials (I,1,10 [Vitruvius 2009: 10].

Vitruvius outlines an educational project of an encyclopedic nature having fields of knowledge which are inter-connecting and communicating; admitting nonetheless that the competences requested from the architect, necessarily, cannot be of a high level but rather of a medium level: '… in order that he will not fail, if need should arise, to judge and test decisions and evaluate these various areas and techniques' (I, 1, 17).

The relevance given to astronomy in professional training is confirmed by an important passage which is easily recognized from the second division of architectural activities.[4] According to Vitruvius (I, 3, 1), gnomonics represents, together with the construction of buildings (Books I-VIII) and mechanics (Book X), one of the three components of architecture, and therefore, of the structure of the volume itself.[5] In fact the entire Book IX is dedicated to astronomy and, in particular, to the art of constructing instruments for measuring time. The astronomical arguments however are amply dealt with throughout the entire volume, particularly with regard to two planning problems: the choice of orientation and the quality of lighting within rooms.

The theme of city walls is intended to show how the environmental conditions (natural and artificial) are decisive for the health of the inhabitants (I, 4, 1). For this reason Vitruvius recommends not to orient coastal cities toward the South or the West, mentioning also certain arguments concerning the orientation of buildings (I, 4, 2) which are picked up again in Book VI. The indications regarding city walls are followed by reflections on the fabric of the city:

> When the walls have been built around the city, the lots for housing inside them must be allocated and the main avenues and narrow cross-streets orientated so that they take account of climatic conditions. The streets will be laid out correctly if care is taken to keep the winds out of the cross-streets … (I, 6, 1) [Vitruvius 2009: 27].

In this case the astronomical notions are used to identify the wind directions (fig. 1). Vitruvius describes the method, referred to today as the 'Indian circle',[6] through which the meridian and equinoctial lines are drawn as starting points for defining the directions of the sixteen winds he refers to (I, 6, 6-7 and 12-13). The definition of an orientation is based on the analysis of the movement of the shade of a gnomon and not on the direct observation of the position of the sun on the horizon. Embedded in the earth a gnomon, a circumference is traced with its centre in the foot of the gnomon. Following the movement of the shade, it is necessary to mark the two intersection points of the line of shade with the circumference. Pointing the compass at these two points, two arches having equally ample circumferences are traced, the intersections of which identify the north-south line.

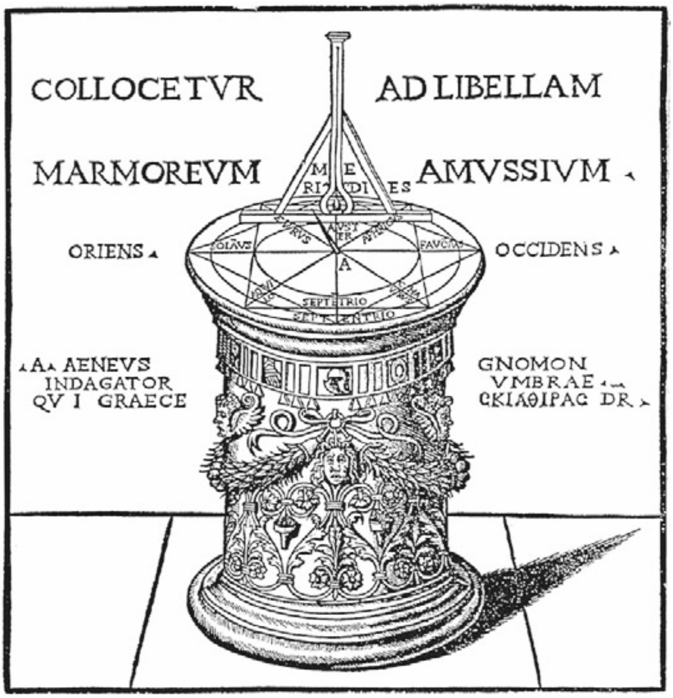


Fig. 1. The wind directions according to Vitruvius, from the 1521 edition of *De architec*tura by Caesare Caesariano

On the basis of the description of the winds, it is then possible to name the equinoctial and the solstitial directions (I, 6, 5): *ab oriente aequinoctiali, ab occidente aequinoctiali, ab occidente hiberno* (from the direction facing the sunrise during winter solstice), *ab oriente hiberno* (from the direction facing the sunset during winter solstice).[7]

The construction of sacred buildings is dealt with in book IV. According to the tradition to which Vitruvius refers,[8] the front of temples must face the west (IV, 5, 1-2) while the altars must face the east (IV, 9, 1). In the passage, the theme of orientation id faced from the point of view of the religious rite, without providing any details on the accuracy of measure or eventual symbolic meanings. The person officiating, while going up onto the altar to make the sacrifice, will, look toward the east having in front of him the façade of the temple, the statue of the divinity and the eastern part of the sky. This position in space reinforces the symbolic overlapping between the rising of the sun and the simulacrum of the divinity. The suggested planning indication does not envisage diversifications with regard to the type, the latitude or the climate.

Alongside the 'horizontal dimension' Vitruvius does not avoid mentioning the 'vertical' dimension obtained through the direct relationship with the heavens. In Book I the 'hypaethral form of the temple' is referred to in the context of the theoretical enunciation of the sixth principle of the art of construction: décor (I, 2, 5).[9] The positive appearance of a finished piece of work free of any defects is based on a precise calculation and on the respecting of a *statio* intended as 'concordance between the architectural structure and the significance of the divinity and the place' [Ferri 1960: 59; 1966: 475]. In relation to this, open top or hypaethral temples reserved to divinities such as Jupiter the Thunderer, Heaven or the Moon are erected 'as open-air shrines, beneath their patron deity, because we see the appearance and effect of these divinities in the light of the outdoor world' (I, 2, 5). This is an architectural model[10] which transforms a ritual need testified to also by Varro (*De Lingua Latina,* V, 66) and by Ovid (*Fasti,* II, v. 667-672). It recalls the Capitoline temple of Jupiter Optimus Maximus in which lived, according to tradition, the God of 'boundaries' Terminus*,* whose refusal to give up his place at the altar of Jupiter (with whom he resided) underlined to the Roman world the sacredness and the fixed nature of boundaries. Terminus lived in the open air because an opening made in the roof of the temple allowed the God to have nothing other than the starry sky above him.[11]

The planimetry of the hypaethral temple (III,2,8) presents, compared to the other types described, a more complex composition of the spaces and, above all, a different layout of the cell. The central part is open-roofed, defined by a double sequence of columns whose distance from the walls is equivalent to that of the portico of a peristyle. It has folding doors and unlike other types, it is accessible from both the *pronàon* and the *pòsticus.* The precise description of the possible proportions of space and of the dual opening system (horizontal and vertical) is based on precise luminous characteristics of the internal space, and therefore, on its natural relationship with the daily course of the sun: sunrise, sunset and passage into the meridian.

The symbolic relationship between celestial geometries and planned geometries is quoted (Book V) with regard to the planimetrical figure of the theatre with regard to the dodecagon used by astrologists to carry out calculations 'on the twelve heavenly signs on the basis of the musical harmony of the stars' (V, 6, 1).

The opening to Book VI dwells on the necessity to plan private dwellings paying great attention to the characteristics of the terrestrial regions and to their relationship with the zodiac and the course of the sun (VI, 1, 1).[12] The exposure to sunlight, obtained through an in-depth typological analysis of the rooms generally present in private dwellings, underlines the climatic and environmental qualities (temperature, humidity, mould, heat, healthiness, light…) obtained thanks to a correct orientation. Also for the rooms in countryside dwellings it is necessary to reflect carefully on the possible orientations (VI, 6, 1-5), just as farmers do.[13] On this occasion, Vitruvius, in order to assess the quantity of light which will enter a room, indicates as a practical method the operation of glancing at the visual obstacle with a cord (VI, 6, 6-7).[14]

The specific notions with regard to astronomy are contained in book IX which opens with a long preface characterized by extensive literary and scientific references. The art of calculating a horoscope and the astronomical calendars are the two possible practical applications of the discipline illustrated by Vitruvius in the first six chapters of this book. The treatment of *universe, axis of the world, poles, zodiac, planets, moon and sun, the globe* finds its conclusion in a brief excursus on the history of astronomy.

Chapters 7 and 8 are dedicated to the problems of measuring time, in the seventh chapter themes linked to gnomonics are dealt with, in other words the art of constructing solar clocks.

The translators of the Latin text have always concluded, as far as the meaning of the term 'analemma' is concerned, that it refers to a projection from above of the movement of the sun, on the level of the meridian (from Greek *ana* in the sense 'from the top to the bottom'), that is, an orthographical projection.[15] Vitruvius illustrates his geometrical method (fig. 2) by choosing as a location Rome, stating at the outset, before any other consideration, that in order to outline the analemma, it is necessary to be familiar with the latitude of the location. In the Roman world, the measurement of latitude was substituted by the relationship between the height of the gnomon and the length of its shadow projected on a horizontal surface at the sixth hour (noon) of the day of the equinox.[16]

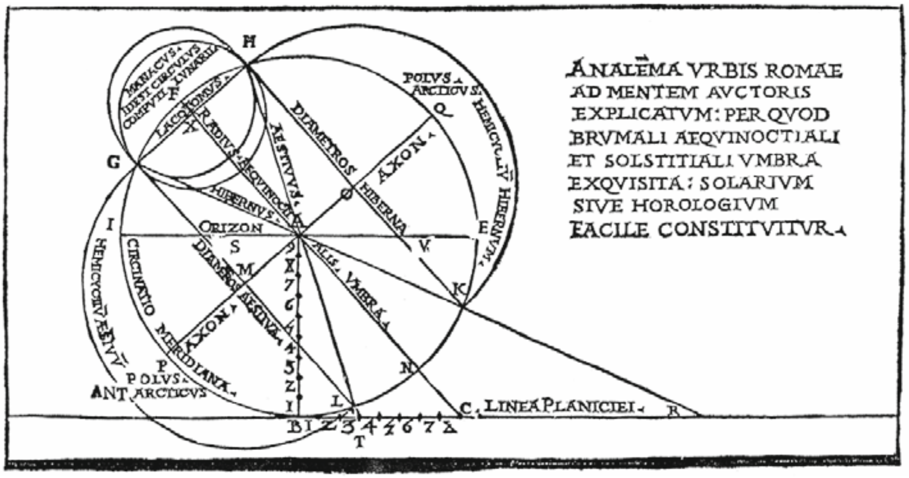


Fig. 2. The analemma of Vitruvius to the latitude of Rome, from the 1521 edition of *De architectura* by Caesare Caesariano

The exposition of the graphic procedure is not complete. Vitruvius, in fact, does not entirely resolve the issue underlining nevertheless that, in order to complete the drawing, it is necessary to trace the lines of the hours both during solstice as well as equinox, for each month. With the analemma it will thus be possible to create any type of watch which, in any case, will be characterized by the division of the day into twelve equal parts for whichever month of the year. Overall, it is possible to believe that the astronomical arguments cited by Vitruvius in the volume, even if not always faced in a rigorous and complete manner, are sufficient to indicate the existence in architectural planning of reflections on the relationship with the sky: the orientation with respect to the astronomical solstitial and equinoctial directions, the control of the internal lighting and basic geometries for the construction of solar clocks, together with their relative symbolic contents.

Similar notions of astronomical nature, elementary but fundamental for good planning, are contained also in *Liber artis architectonicae* by Marcus Cetio Faventinus (third century A.D.). From Vitruvius, who is specifically quoted, the following are very briefly taken: the theory of winds, the Tower of the Winds of Athens (chap. 2), orientation in rural houses (chap. 13) and urban houses (chap. 14), the design of solar clocks (chap. 29) through the description of a flat face (*pelecinum),* of a hemisphere (*hemiciclyon*) and of a double (*horologio duplex*). The arguments, nevertheless, do not face the problem of the practical technique through which it is possible to identify the astronomical directions and present numerous imprecise elements in the part dedicated to gnomonics [Toneatto 1995; Cam 2001, 2002; Plommer 1973].

The *Constitutio limitum* by Hyginus Gromaticus[17] is a further primary source in relation to the measurement and breakdown operations in the Roman period. Similar to other ancient populations, the Romans worried about positioning correctly, with respect to the course of the sun in the sky, not only cities and buildings but also the territory. Written documents testify how, for the land surveyor it was of vital importance to succeed in finding the correct orientation with respect to the cardinal points. Among the instruments available there were probably also portable meridians as confirmed by the recovery of an ivory sample in the workshop of Verus, Pompeian land surveyor.

According to Hyginus, the 'definition of the *limites*' is the most important operation in gromatic art. It deals with the aligning of the foundation cross according to the two axes east-west and north-south (course of the sun and world axis).[18]

The origin of the system is to be found in the Etruscan science of haruspicy [Aveni-Romano 1994] which divided the sky into four parts according to the course of the sun. The ancient ceremony is described already by Titus Livius[19] with regard to the coronation of Numa Pompilio: the intersection between the two axes traced in the sky, and for extension, the stationary point of the haruspex is the *templum.* The terms *time* and *temple* find therefore the root of their meaning in the discipline of the most ancient gromaticians.

On the cardinal orientation of the *limites Hyginus* this can be linked to the archaic tradition of sacred buildings: ancient architects, such as Vitruvius, wrote in fact that temples usually look toward the west; subsequently they nevertheless decided to rotate religious monuments (see [Dilke 1967: fig. 2a])[20] toward the part of the sky from which the earth takes its light (east) (I, 21).

Immediately afterwards though we discover that a frequent error was that of following the direction given by the rising or the setting of the sun on the horizon:

> Many surveyors, being ignorant of the principles of the universe, have followed the sun, that is its rising and setting, although this cannot be sighted once and for all by the *ferramentum*. What takes place then? When the groma had been positioned after the taking of the auspices, perhaps in the presence of the very founder himself, they sighted the next sunrise, and established *limites* in both directions; but in this system the cardo did not tally with the sixth hour [i.e., did not face due south].[21]

The orientation toward the rising of the sun, the intention not to conserve parallelism with the nearest century, the choice to follow the direction lengthwise of the territory together with the rotation by 90° between cardo and decumanus, are the possible exceptions to the correct planning theory listed by Hyginus.

Examining the possible 'errors' for the system of tracing of the *limites* , we learn that some have used the direction provided by the points of sunrise and sunset, for ignorance regarding the relationship between the course of the stars and the geographical nature of the location (latitude). In other cases, conscious of this error, they decided to overlook it, limiting themselves to valid directions, therefore, exclusively for that location. Within the scope of the centurial operations, Hyginus recalls that this local condition can change rapidly due to the prospective relations between the stationary point and eventual obstacles on the horizon such as, for example, the mountains. In a significant miniature contained in one of the most ancient manuscripts of the *Corpus Agrimensorum* we find illustrated the following error:

If the cardo or decimanus starts not far from a mountain, how can proper bearings be taken on the sun's course, seeing that the sun has set on the groma but is still shining on the other side of the mountain? [Dilke 1967: fig. 2c, pl. 4].

The first method used by Hyginus to determine the meridian line, in a similar approach to that of Vitruvius, is based on elementary concepts of gnomonics 'art, sublime and divine' and therefore on the observation of shade in movement (VIII,1). After the definition of the five celestial circles (northern, solstitial, equinoctial, brumal, austral), the length of the day is mentioned (twenty-four temporary hours). The starting point of the *limites* is the meridian line (shade at the sixth hour) with respect to which the perpendicular line for the east-west direction is placed.

First we shall draw a circle on a flat area on the ground, and at the centre of the circle set up a vertical rod (sciotherum), whose shadow should at times fall inside the circle [i.e., as well as outside]; this is a more reliable procedure than an attempt to work out the east-west line. We shall observe how, from the first rising of the sun, the shadow is reduced. Then when the shadow reaches the line of the circle, we shall mark that spot on the circumference. Similarly, we shall observe the shadow leaving the circle and mark (that spot on) the circumference. When we have marked the two points on the circle where the shadow entered and left, we shall draw a straight line through these two points on the circumference and mark the middle of it. We should draw a straight line from, the centre of the circle to pass through this point. Along this line we shall plot the cardo, and from it at right angles we shall establish the decumani in a straight line. Indeed, at whatever point on this line (from the centre of the circle) we project at the right angle, we shall correctly establish a decumanus (IX, 1-5) [Dilke 1967: figs. 2d, 2e, plate 6].

The second method outlined by Hyginus for the definition of a cardinal orientation was analysed by Neugebauer [1975].[22] The geometrical procedure which is particularly complex examines three extreme points of shade of a vertical gnomon.

Among the other gromatic volumes, also *De limitibus* [Guillaumin 2005: 157-161] by Sextus Iulius Frontinus (about 30-104 d.C.) faces the theme of the orientation of the main axes. In a much more concise manner there is mention of historical references (III, 1), tracing errors (III, 5 and 12), but there is no description of the direct procedure for identification of the meridian line.

The quadrivium and Vitruvius in the training of the medieval architect

The interest in astronomy on the part of ancient builders is evident also from other sources.[23] In book VIII of the *Synagoge,* Pappus of Alexandria (fourth century A.D.) attributes the name of *Mechanicus* to the architect, and following the route of *De architectura* by Vitruvius states in the prologue the necessity to consider practical studies (carpentry, building,…) rather than solely theoretical studies of architecture. Alongside geometry, arithmetic and physics, the training of the architect includes also the use of astronomy in the definition of orientation [Downey 1946-48, 1948; Meek 1952].

From a few sporadic pieces of news contained in studies of historical nature, we know that, with all probability, the apprentice architect in the field of Byzantine culture had to face the study of the quadrivium, i.e., arithmetic, astronomy, geometry and music.[24] Even if it is not possible to know the degree of depth of knowledge of the various disciplines involved in the training, it is likely that notions of general knowledge were given, useful for dealing with the basic needs already identified by Vitruvius in his study.

Between the ninth and the tenth centuries Calcidius Macrobius, Martianus Mineus Felix Capella, Boethius, Cassiodorus, Isidorus Hispalensis, the Venerable Bede, Iohannes Scotus Eriugena and other authors produced an important series of Latin studies. The merit of this phase of scientific culture is that of having given a certain structure to the various disciplines by condensing in the quadrivium the surviving nucleus of ancient scientific culture.

The teaching of these four disciplines is already present in the Carolingian school of thought coordinated by Alcuin (735-804) [CISAM 1972; Leonardi 1981; Frova 1974] which directed its attention towards music, astronomy, and astrology.[25] Thanks to the extraordinary interest of Charlemagne in art, architecture too finds significance and major developments linked to the cultural reform based on the study of the seven liberal arts [Frothingham 1909: 67].

The gromatic codes are part of the vast patrimony of ancient literature handed down during Carolingian and Ottonian periods. To this regard, the studies carried out by Toneatto [1994-1995] give account of the vast manuscript tradition of the texts, classified in three classes starting from the Arcerian code (A and B) dated the fifth-sixth century.

A quotation from the two directions traced by the surveyors is contained in *Etimologie* by Isidorus Hispalensis (ca. 560-636) which, in Book XV (Of buildings and of fields) notes the mutually perpendicular direction in relation to the orientation of the sky.[26] The author, despite not being an architect, recalls also the necessity to correctly orient sacred buildings on the basis of the ritual functions which must take place in syntony with the sky and its celestial bodies (XV, 4,7).

The study by Hyginus was also known by Gerbertus (Pope Sylvester, ca. 950-1003), as can be understood from the book on Geometry. In chap. 43 the logic of tracing the main cardo-decumanus cross is described, whereas chap. 44 is the description of the geometrical method for identifying the meridian line through the shade of a gnomon.[27]

The systematic analysis of Carol Krinsky [1967] on both direct and indirect documentary testimonies, in relation to the manuscripts of Vitruvius underlined how these were available to some of the most important Carolingian scholars. On this point, it is possible to list Eginhard, biography of Charlemagne (as can be deduced from his letter of 14 March 940 to the disciple Vussin, pupil of the Carolingian school of Fulda),[28] Alcuin, Hrabanus Maurus (ca. 780-856). Copies of the *De architectura* were present, moreover, in the medieval libraries of Reichenau, Murbach, Gorze (South Tyrol), Bamberga, Regensburg, Fulda, Melk. Among the most ancient indirect testimonies of the Vitruvian study, there is also a letter of Cassiodorus dating back to 511.

Only few integral buildings were handed down to us in the decades leading up to the eleventh century, and the documentary testimonies which survived are often difficult to attribute a date to. In any case, in the eleventh century, manuscripts by Vitruvius existed in Toul and in the Netherlands. In the twelfth century, the text was known in Rouen, Cluny, Montecassino. Within the first half of the fifteenth century, the study was available not only in Italy but also in many English cities, and the same can be said for both Spain and Poland.

Among the scholars of the Middle Ages who became acquainted with Vitruvius, either through reading all ten books or only some sections of them, Carol Krinsky [1967] lists: Hermann the Paralytic of Reichenau (Reichenau 1013-1054), Hugo of St. Victor (1096-1141), Gervase of Melkley (beginning of the thirteenth century), Vincent of Beauvais (1190 approx-1264), William of Malmesbury (1180 approx-1243 approx), Theodorich of St. Trond, Petrus Diaconus (1107 approx-1159), Albertus Magnus (1206-1280), maybe Filippo Villani (1280-1348), Jean de Montreuil (1354-1418), canon of Rouen and secretary to Charles VI of France, Petrarch (1304-1374), Boccaccio (1313-1375), Giovanni Dondi (1330-1388), Domenico di Bandino, Nicola Acciaioli, who, in one piece of writing dating back to 1359, leaves to the library of San Lorenzo his books as evidence. In general, among the medieval scholars who could have been acquainted with Vitruvius or his teachings, we can also consider those who, in Florence, had at their disposal the *Mappae clavicola*, Bernward of Hildesheim (960-1020), St. Thomas Aquinas, the circle of men who studied at the court of Frederick II, the fourteen architects of the Cathedral of Milan.

Of the seventy-eight registered hand written copies of *De architectura* a remarkable thirty-nine are conserved in Italy. Of these only one sample bears a date previous to the tenth century, three manuscripts in the eleventh century, three manuscripts in the twelfth century, four manuscripts in the thirteenth century , four manuscripts in the fourteenth century. The existence of a still consistent number of manuscripts and of indirect sources, authorizes us, in conclusion, to hypothesize the diffusion of the study and of its teachings also within the processes of professional training of the architect during the entire Middle Ages [Brown 1963; CISAM 1975, MacDonald 1977; McCluskey 1998; Radding and Clark 1997; Romano 1995; Shelby 1972; Zaitsev 1999].

The fields of research for architecture

In the relationship between architecture and the sky it is possible to identify three different design issues.

The first regards the alignment of buildings with visible points on the horizon which coincide with the rising or setting of a celestial body (sun, planets, stars or moon) on particular dates during the astronomical or liturgical year for sacred buildings.

The second is the relationship between planimetric design and the design of the elevations. We are all familiar today with several 'light effects' which sometimes have almost hierophanic characteristics which, on certain days of the year, were used to engross, captivate and amaze the spectator.

Contrary to the first two issues, the third comes after the design and building stages and concerns the question of decorative elements. It is reasonable to believe that many years after the works were terminated, certain wall finishes were chosen rather than others to paint frescoes or palace statues. Whoever did this was fully aware – thanks to direct observation – that such finishing would be struck by a single ray of light on a specific day.

Orientation

Identifying the orientation of a building by tracing the axis on the ground using poles and cords is, most probably, the first material act at the origin of the construction of any building. In order to determine the alignments with the rising of a celestial body on the key dates during the year, presumably very simple procedures were followed, already known in the pre-historic period, based upon direct observation and the use of sights [Incerti 1999: 142-143]. For the determination of the equinoctial direction (recto of rising-setting of the sun on the days of equinox) it was instead possible to use the shade of a gnomon to trace the local midday or to apply the 'Indian circle method'. In both cases, according to the degree of accuracy sought by the operator, the error made on the orientation could be in the region of 2°.

To determine today the value of the azimuth compared to the north, it is sufficient to proceed with a comparison with the azimuth of the sun. This is a very delicate procedure: it is necessary to carry out a large number of measurements at brief intervals, recording each time the instants of the clock t^i and the G^i position of the sun compared to the main axis. The definitive value is obtained from the average of the values deriving from the completion of the well-known equations of spherical geometry [Incerti 1999: 143-146]. The result, relating to the Gregorian calendar, must still be corrected to take account of the quantity by which the Julian calendars were anticipated in past centuries.

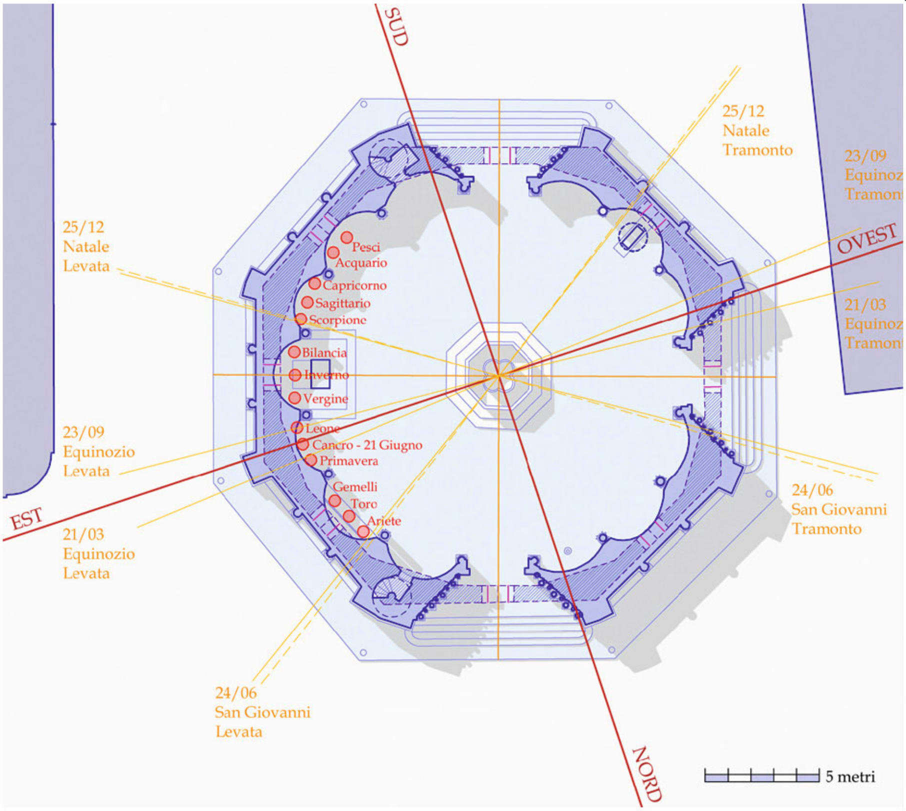


Fig. 3. The Baptistery of Parma

A more detailed explanation of orientation can be given for the Baptistery of Parma, constructed in 1196, under the direction of Benedetto Antelami (fig. 3). The main axis from the altar to the baptismal font points to the rising sun on the feast of the Purification of the Blessed Virgin Mary (2 February). The patron saints of the Baptistery are the Virgin Mary and St. John the Baptist, and the episode of the Purification is also displayed in of the inner lunettes. The solstitial direction (very near the feast of St. John Baptist, 24 June) is indicated by numerous elements found in the fifteenth sector: the bas relief of John the Baptist, the beginning of the cycle of the months, the unexpected appearance of St. John the Evangelist in the sector reserved for the prophets, the singular cross with leafs in the last starred sky. As highlighted by the lines that indicate the sunrise and sunset on the equinoxes and solstices, it is likely that the placement of the statues of the months and that of Antelami's zodiac were influenced by astronomical considerations. The cycle starts with the summer solstice sunrise. The statue of spring is aligned with the equinoctial axis, but is not positioned between the appropriate statues of the month. The strange position of spring (between Gemini and Cancer) can be explained on archaeoastronomical principles.

The table below provides some data regarding the orientation of a series of sacred buildings:

Abbey of Chiaravalle della Colomba (Parma, 1135)	Sunrise Assumption of Mary (15 August)
Abbey of Fontevivo (Parma, 1142):	Direction equinoctial
Abbey of St Maria in Strada (Bologna, 1250):	Direction equinoctial
Abbey of Pomposa (Ferrara, 1026)	Direction equinoctial
Baptistery of Parma (Parma, 1196)	Purification of Mary (2 February)
Scrovegni Chapel (Padova, 1303)	Festivity of the Perdon d'Assisi (2 August)
Chapel of St Salvatore (Terni VII-XII)	Direction solstitial, sunrise winter solstice, sunset summer solstice
Cathedral of Pienza (Siena, 1459)	Summit of the mountain Amiata
Chartreuse of Ferrara (Ferrara, 1452)	Direction equinoctial
San Miniato al Monte (Florence, 1018)	Lunistice

Lights and openings

Several buildings belonging to very different historical periods are testimonies of the accurate alignments created between a precise point in space and a gap in a wall where an observer was obliged to stay still in order to properly observe the transit of heavenly bodies (the moon, the planets or the stars). Confirmation of these events has often reinforced the theory that the form and position of these openings, from the smallest to the biggest and most impressive, was connected possibly to precise astronomical objectives.

One of the most amazing episodes confirming the existence of the aforementioned intentional design are the unique light effects which appear to characterize the central nave in Vézelay at a particular time during the year. On the day on which the church celebrates the ancient feast of St. John the Baptist (24 June), very close to the summer solstice, the light penetrating through the southern windows produces a series of solar 'notches' on the floor of the central nave and said notches are perfectly aligned with the axis of the church. There derive clearly symbolic and spiritual implications: the almost round patches connect two paradigmatic areas of the sacred space: the atrium and the apse, irresistibly inducing the believer to look toward the gothic choir. We ought to emphasize also the designer's remarkable expertise and elegance in the way in which he sought to align the 'patches of light' (from the windows placed in axis on the keystone) and the main pillars of the central nave: not only is the pattern created on the floor by the sun rays pleasant to look at, it also enhances the rhythm of the architectural score.

The horizontal axis created by the patches of light together with the vertical axis, created by the central column of the portal which is dominated by the Majestic Christ[29] suggests the theme of the cross as a cosmic symbol.

The survey a aimed at analyzing the relationship between designs in which the plan and the elevations have astronomical implications, must dedicate particular attention to the identification of both morphological and dimensional aspects of windows and rose window (open or plugged) as well as the characteristics of horizontal and vertical surfaces. Over time traditional survey methods have been backed up by the use of 3D scanners integrated with the use of topographic data. In the case of the Abbey of Pomposa (fig. 4), for example, a total of 37 million points were recorded.[30] The interior and exterior of the Abbey were surveyed with a series of 25 station points and a total of 42 scans.[31]

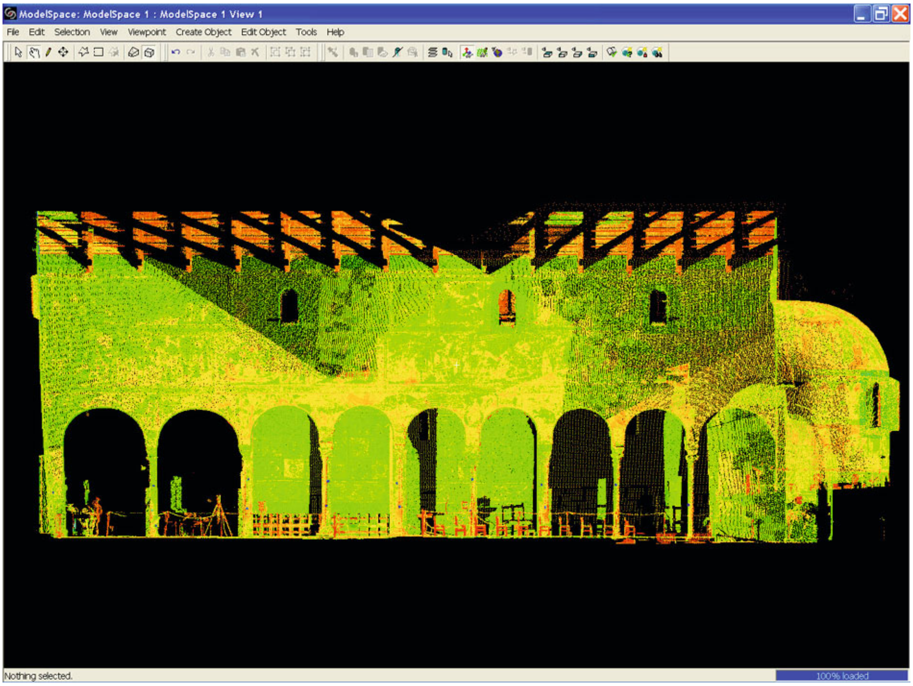


Fig. 4. Abbey of Pomposa, 1026 A.D. The point cloud that resulted from the survey with 25 station points and a total of 42 scans. Image: author

In order to identify the presence of particular luminous events which coincide with important dates in the liturgical and astronomical calendar, today there are useful programs for calculating the calendars and ephemeris as well as specific software for the tracing of sundials.[32]

For the ancient architects, it was possible to determine the azimuth at sunrise on any date, and also the astral co-ordinates upon the passing of the canonical hours thanks to the astrolabe, the analemma of Vitruvius or that of Ptolomaeus [Incerti 1999: 80-97; Sinisgalli and Vistola 1992] (analogical calculators capable of resolving problems linked to spherical astronomy). By using these, and with the assistance of models in scale or, much more simply, of very basic and simplified graphs, a good architect was able to choose the exact position of those openings which, placed at topologically significant points, would guarantee surprising luminous effects [Incerti 1999 : 146-147].

There is evidence of many similar episodes in the Cistercian Abbey of Chiaravalle della Colomba (Alseno, Parma, 1135) [Incerti 1999 : 146-160]. On the feast day of St. John the Baptist (24 June of the Julian calendar),[33] very close to the summer solstice, the light coming from the two small oculi placed on the vertical wall which joins the transept and the apse reach the entrance door of the church.[34] These are two north-east windows located at an ortive amplitude very close to the limit established by the summer solstice. The azimuth at sunrise on 21 June. (Julian calendar) is in fact 56.1 degrees; this kind of opening can capture the sun's rays for only a few days a year and, plainly, only in the very early morning when the sun is very low on the horizon. Given the size and angular values of the triangle that is created,[35] if the oculi had been moved by a mere 20 cm, this would have horizontally shifted the patch of light by approximately 80 cm. Therefore, it is clear that the unknown architect of the Chiaravalle Abbey was obliged to calculate the position of the small windows on the vertical wall to create this unique light effect (figs. 5 and 6).

Figs. 5-6. Abbey of Chiaravalle della Colomba, 1135 A.D. The ray of light that strikes the door of the Abbey of Chiaravalle della Colomba on the feast day of St. John the Baptist (Prime). Photos: author

These phenomena were useful for both calendar-related functions as well as for marking the advent of a particular date during the year or the accounting of time: in other words, for indicating a precise moment during the day

Three other episodes are significant here:

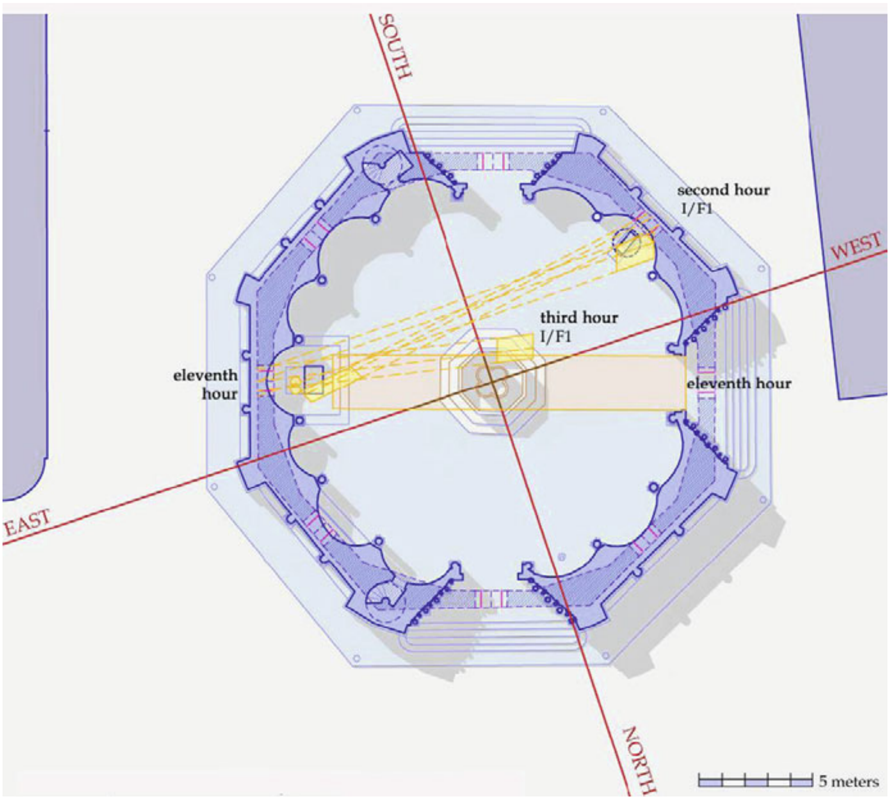
The capital of the Abbey of Chiaravalle and the gnomonic *oculo* which indicates the beginning of summits

The Baptistery of Parma (1196 A.D.): feast day of St. John the Baptist. The main baptismal font is struck by a ray of sunlight (figs. 7-8).

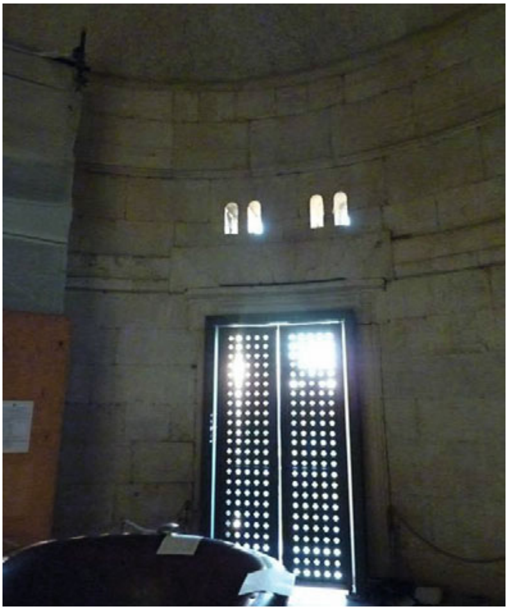
Mausoleum of Teodorico (ca. 520 A.D.) (figs. 9-10).

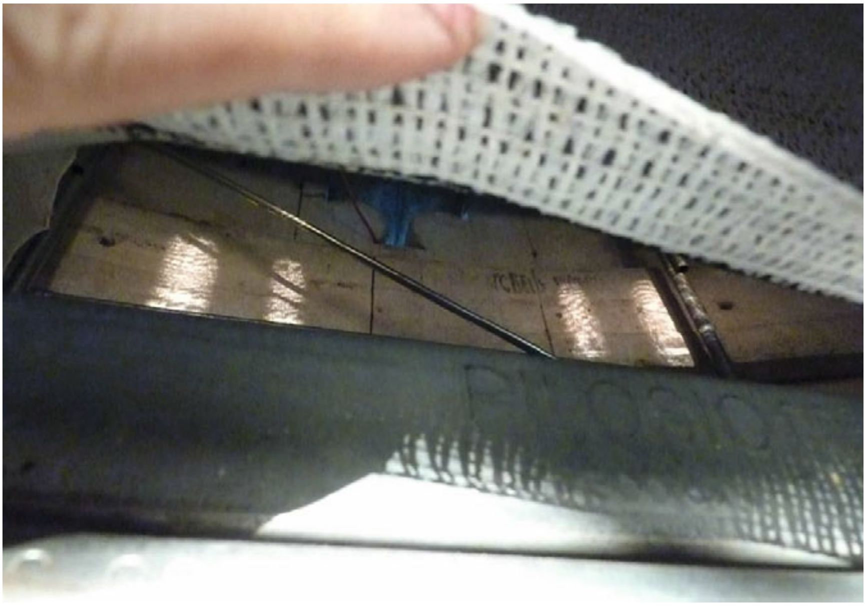
Light, pictures and sculptures

Numerous episodes testify the attempts to find symbolic implications in the design and position of these images and sculptural elements [Incerti 2014a]. In the Abbey at Chiaravalle della Colomba, the fresco of the Virgin Mary on one of the main pillars of the Abbey is illuminated at the *sexta hora* on 8 September (birthday of the Virgin). Several episodes occurring in the Baptistery of Parma involve the main protagonists of the decorative elements.



Figs. 7-8. The Baptistery of Parma: feast day of St. John the Baptist. The main baptismal font is struck by a ray of sunlight. Other events involve the smaller baptismal font and the altar. Photo and drawing: author





Figs. 9-10. Mausoleum of Theodoric the Great, ca. 520 A.D. Azimuth 84.5°, G. Romano (1995), window analysis M. Incerti (2012). A protruding band highlights the impost of the superior band of the structure which continues in a circular course. Slightly above this, in correspondence with the door giving access to a room located on the floor above, there are four small, non-parallel loopholes. At sunrise on the day of equinox the sun enters through these loopholes, illuminating the aforementioned band opposite. Photos: author

The most important, for its accuracy and incredible scenic effect, is the fresco of the Baptism of Jesus, an excerpt from the cycle of St. John the Baptist (the fifth register of the cupola); a ray of light coming from the window of the third order, in the ninth sector, encounters perfectly the figure of the Messiah. This phenomenon used to begin on 25 March and ended around 10 April; it lasted therefore roughly two weeks and took place in the middle of the Easter period [Incerti 2011] (fig. 11).

Fig. 11. Baptistery of Parma. On the fifth level of the cupola a ray of light strikes the painting of the Baptism of Jesus in the Jordan during the Easter period, beginning on 25 March and ending around 10 April. Photo: Mons. Giorgio Schianchi, reproduced by permission

The presence of astronomical and astrological iconography

It is impossible to speak about archaeoastronomical analyses without covering the subject of astronomical and astrological iconography which was very common in the Medieval period. These representations were mostly symbolic and provide evidence that at that time people were aware of cosmology and themes related to the calendar.

The database

From the edition of the volume by Giuliano Romano, *Archeoastronomia italiana* [1992], several archaeoastronomical studies on Italian architecture were published, particularly those regarding sacred buildings. It can therefore be significant to record the know-how acquired, verifying the methodologies, the procedures adopted, and the conclusions declared through the use of a data-base.[36] The data on each single building were put together in a file consisting of fifty entries, organized into seven macro-categories. Table 1 shows an example for one of the monuments studied, San Miniato in Monte in Florence, Italy.

current denomination	San Miniato in Monte		
previous denominations.	San Giovanni	architectural surveys	Mandelli (1993, 2013)
type of building	monastery	archaeoastronomical survey	theodolite
limit *ex-ante*, limit *ex quo*	1018-1207	orientation data	30/05/2001
monastic order/party requesting the work	Benedictines	geometrical element of reference for orientation	longitudinal axis
patron saint celebration	October 25	author of the archaeoastronomical survey	Incerti M., Incerti S.
region	Tuscany	azimuth *abside* from the north	129,93°
diocese	Florence	azimuth façade from the north	**309,93°**
latitude	43°45'35"_43,7596°	Google Earth reading of azimuth abside	131,6°
longitude	11°15'54"_11,2648°	coherence with the urban or territorial fabric	no
height above sea level (meters)	135	analysis of the horizon	digital model: D. Sampietro, Laboratorio di Geomatica, Polit. di Milano Polo Regionale di Como
azimuth sunrise 21 March (time of the founding)	85,3°	lunistitia superior,-maximum amplitude rising full moon	**Asunset =311° Hmax=73° 15/12/1019_ d=28,30°**
azimuth 21 June (time of the founding)	sunrise = 54,7° sunset = 305,3°	lunistitia inferior, minimum amplitude rising full moon	**Asunrise =132° Hmin=17° 20/06/1019_d= -29,36°**
azimuth 23 September (time of the founding)	268°	declination sun/moon in degrees	-
azimuth 21 December (time of the founding)	sunrise =123 ° sunset =237,1°	deviation declination sun/moon in degrees	-
deviation azimuth façade in degrees	1,07° H=1,19°	methods and instruments of calculation/visualization	ephemeris sun: G. Ferrari lunistitia: Solex11.0 visualization: Stellarium
deviation azimuth abside in degrees	2,07° H=2,29°		
significance of astronomical orientation	**lunistitia (?)**	liturgical significance of orientation	uncertain
luminous effects in architecture	Yes	list of luminous effects in architecture	list of effects
luminous effects of the decorative paintings and sculptures	Yes	list of luminous effects of the decorative paintings and sculptures	Mosaic zodiac (Bartolini S.), Mosaic apse, Christ in Majesty the foot (Getting)
calendar dates luminous effects	Summer Solstice, the end of September (Getting)	presence of astronomical/astrological symbols	Zodiac mosaic floor Sign gemini on the façade (?)
BIBLIOGRAPHY	Getting (1987); Shrimplin (2009); Mandelli (1993); Gurrieri (1988); Bartolini (2013).		

Table 1. The database for San Miniato in Monte, Florence

The database includes:

1) **General identification data:** progressive number, current denomination, previous denominations.
2) **Historical data:** type of building, century, limit *ex-ante,* limit *ex quo,* monastic order/party requesting the work, patron saint celebration/dedication, turnover of the building following its foundation.
3) **Geographical data:** region, diocese, latitude, longitude, height above sea level.
4) **Survey data:** architectural surveys, orientation data, geometrical element of reference for orientation, author of the archaeoastronomical survey, azimuth *abside* from the north, azimuth from north side, Google Earth reading of azimuth abside, azimuth of urban and territorial fabric, coherence with the urban or territorial fabric, analysis of the horizon.
5) **Astronomical and calendar data:** ASL _azimuth sunrise 21 March, ASL_21 June, ASL_23 September, ASL_21 December, ASL_other days, AST_azimuth

sunset other days, lunistitia superior-maximum amplitude rising full moon, declination sun/moon in degrees, corresponding date, hypothetical date of orientation, deviation declination sun in degrees, anticipation or delay on the nearest date, deviation azimuth abside in degrees, deviation azimuth façade in degrees, methods and instruments of calculation/visualization.

6) **Astronomical intentionality:** significance of astronomical orientation, liturgical significance of orientation, luminous effects in architecture, list of effects, luminous effects of the decorative paintings and sculptures, list of luminous effects of the decorative paintings and sculptures, calendar dates luminous effects, presence of astronomical/astrological symbols.
7) **Bibliography.**

TYPE	N.
Benedictine Abbey	3
Cistercian Abbey	5
Basilica	3
Baptistery	4
Chapel	1
Archiepiscopal chapel	1
Cathedral	10
Carthusian monastery	1
Church	10
Mausoleum	2
Olivetan monastery	1
Rotunda	1
TOTAL	42

Table. 2.

	V	V_VI	VI	VII_XII	XI	XI_XII	XII	XIII	XIV	XV	Total
Significance astronomical orientation	3	1	1	1	4	1	7	4		3	25
Lighting effects architecture			1	1			6			1	9
Lighting effects on the decorative apparatus				1	1	4			1		7

Table 3.

The architectural structures considered belong to the period between the fifth and sixth centuries.[37]

In organizing data, particular attention must be paid to differentiating not only by chronology but by type. The data must, in fact, be questionable, following a variety of interpretation logics which consent the reader to perceive the statistical frequency of astronomical intentionality on the basis of historical period, geographical area, cultural context etc. etc.

The presence in the data-base of buildings which are not oriented astronomically testifies the fact that the choice of a precise azimuth value could also have been avoided, when it was not important for the party requesting the construction work, or when the necessary exploration instruments were unavailable. If the figure of the architect, responsible for the project and for the setting up of the relevant building site, was undoubtedly present in the case of important monumental buildings, the building of smaller structures could be supervised by personnel not necessarily trained in the disciplines of the *quadrivium* and therefore understandably less rigorous in applying astrological rules during the orientation phase. Lastly, we must not forget that very often the urban context was already crammed and this was capable of having a strong impact on the planimetric form of the architectural product to be built.

In the data-base, only nine studies present research on the internal luminous effects inherent to architecture and only seven present analyses of the luminous effects on the decorative paintings and sculptures. On the latter two aspects, studies are scarce, most probably due to both the lack of adequate architectural surveys as well as to the fact that the persons involved did not have either the competence or the necessary instruments for the management of graphic reports.

Conclusions

The data-base for the moment is not intended to be used for the application of a statistical type analysis, in consideration also of the number of examples therein. Its realization is first and foremost aimed at the definition of a series of objectives and work methodologies which are scientifically shared and correct. It is in fact clear that the data cannot be grouped (as often happens) into a few macro categories (divided into vary wide chronological brackets), but rather should be very attentively extracted on the basis of the numerous and variable characteristics of the topic being analyzed, not least the monumental dimensions in comparison to those of minor rural architecture.

Lastly, we ought to emphasize the necessity that the *archaeoastronomical qualities* of the building are deciphered exclusively through a severe and rigorous metrical observation of its orientation, forms and geometrical aspects. The 'primary nature' of architecture is that of being a three-dimensional space which cannot be reduced to the simple horizontal level. For this reason, the archaeoastronomical survey cannot be considered complete and thorough if it is limited to the mere measurement of planimetric orientation. The contribution of the Science of Representation is, to this regard, essential, both due to the multitude of competences contained therein, ranging from procedure and methodological survey issues to the notions, in a number of specialized contexts, of the history of design and of geometry, to the potential offered by modeling in the study and validation of research hypotheses, to the use of integrated IT systems for the knowledge, the protection and the management of the patrimony having astronomical value. The objectives and the cognitive processes to be deployed are those typical of the *building survey* discipline. The survey is not a simple reading and translation of metrical data but rather must tend towards the representation of the *global knowledge of the artifact* in question through a graphical transcription, to be obtained through precise and rational studies of the building reality which are capable of detecting the formal, spatial, dimensional, technological and constructional values. In other words it is an operation of *critical reading,* to be carried out rationally, aimed at the obtaining the *total knowledge* of the organism to be studied, of its *visible parts* and its *invisible parts* [Docci and Maestri 1992: 3-5].

Notes

1. The latter have been widely discussed by the author of the present in a series of publications [Incerti 1999; 2001a; 2001b; 2001c; 2002a; 2002b; 2002c; 2010a; 2010b]. On measurement and relief techniques in the medieval period, see [Docci and Maestri 1992].
2. This is discussed in greater depth in [Incerti 2010].
3. '… a knowledge of optics enables light to be drawn correctly from well-defined areas of the sky' (Vitruvius I,1,4 [2009: 5]).
4. The first, more renowned division, is in I,2,1.
5. Because of the lack of ancient architectural manuals, apart from that of Vitruvius, it is impossible to verify the diffusion of this definition. Elisa Romano, in the introduction to Book IX *De architectura* [Vitruvius 1997: 1193] includes the quotation from Galen, according to which the *katagraphai* of clocks and clepsydras are part of architecture.
6. This is the most ancient and simplest method for marking out the direction east-west. See [Romano 1992: 37-38].
7. The astronomical directions are referred to in I,1,10; I,6,4; I,6,9; IV, 2; VII,13,2 and in numerous sections of Book IX. In I,6,9 Vitruvius outlines how the calculation of the circumference of the earth was carried out by Eratosthenes through the course of the sun, by measuring the shadows of each gnomon at equinox (solstice in reality).
8. With a few specific exceptions; see [Vitruvius 1997: 484-485, notes 188-191].
9. *Decor autem est emendatus operis aspectus probatis rebus compositi cum auctoritate. Is perficitur statione, quod graece θεματισμωι (thematismó) dicitur, seu consuetudine aut natura. Statione, cum Joui Fulguri et Caelo et Soli et Lunae aedificia sub divo hypaethraque constituerunt; horurm enim deorum et species et effectus in aperto mundo atque lucenti praesentes videmus*; see [Tosi 1991].
10. On the theme of light in Vitruvius and in particular on this type of temple see [Bettini 2010].
11. *Quid, nova cum fierent Capitolia? Nempe deorum cuncta Iovi cessit turba locumque dedit; Terminus, ut veteres memorant, inventus in aede restitit et magno cum Iove templa tenet, nunc quoque, se supra ne quid nisi sidera cernat, exiguum templi tecta foramen habent* (Ovid, *Fasti*, II, v. 667-672).
12. 'Therefore, since the position of the heavens relative to the mass of the earth is naturally governed by the inclination of the circle of the zodiac and the course of the sun, producing very different results, it is obvious that the siting of houses must be organized similarly with reference to the characteristics of the regions and variations of climate' (Vitruvius VI,1,1 [2009: 166]). On the problems associated with orientation in agricultural constructions, see Varro *De re rustica,* Cato *De Agricultura,* Columella *De re rustica*; see also [Vitruvius 1997: Bk. VI, notes 192-208].
13. On the problems associated with orientation in agricultural constructions, see: Varrone, *De re rustica*; Cato, *De Agricultura*; Colummella, *De re rustica*; see also [Vitruvius 1997: Bk. VI, notes 192-208].
14. The operation is very similar to that recorded by Villard de Honnecourt in his notebook (fol. 40) with regard to survey operations.
15. *L'Analemme est la description de la sphère sur un plan. On y trace les sections des différents cercles, tells que les parallèles diurnes et tout ce qui peut faciliter la science des ombres et de cadrans. Cette description se fait par des perpendiculaires abaissées sur le plan; ce qui lui a fait donner par le modernes le nom de projection orthographique. Le mot analemme signifie à peu près la même chose que lemme; l'analemme est pour les constructions graphiques, ce que le lemme est pour les démonstrations géométriques; c'est une figure subsidiaire où l'on prend ce qui peut abréger et faciliter la construction de la figure principale* [Delambre 1817: 458].
16. When the sun is in the constellation of Aries and Libra. On the description of the procedure see [Incerti 1999: 80-89].

17. On the hypothesis of dates (first-second century) and the handwritten tradition see [Guillaumin 2005: 65-72] and [Campbell 2000]. The texts that follow are taken from [Campbell 2000: 134-163].
18. According to Hyginus the north is on the right, the south is on the left, the west in front, the east behind.
19. *Augur ad laevam eius capite velato sedem cepit, dextra manubaculum sine nodo aduncum tenens quem lituum appellarunt. Inde ubi prospectu in urbem agrumquecapto deos precatus regiones ab oriente ad occasum determinavit, dextras ad meridiem partes, laevasad septentrionem esse dixit* (*Ad Urbe condita*, I, IV, 18). On the Etruscan tradition in the volumes on the Roman land surveyors see [Martines 1976; Frothingham 1917: II].
20. See on this the miniature in [Dilke 1967: fig. 2a, plate 2].
21. *Multi ignorantes mundi rationem solem sunt secuti, hoc est ortum et occasum, quod is semel conprehendi ferramento non potest. Quid ergo? Posita auspicaliter groma, ipso forte conditore praesente, proximum vero ortum conprehenderunt, et in utramque partem limites emiserunt, quibus kardo in horam sextam non convenerit* (Hyginus Gromaticus, *Constitutio limitum*, I, 22 [Guillaumin 2005: 82]). The quotation is in [Dilke 1979: 25; Dilke 1971: 57]; miniature [Dilke 1967: fig. 2b].
22. The procedure, described by Neugebauer, was elaborated on the basis of the writings of Al-Birūni, which are more comprehensible compared to the text written by Hyginus. The primary source is, however, in any case, Diodoro of Alessandria, an astronomer of the first B.C. [Neugebauer 1975: pt. 2, 841-842; pt. 3, 1376-1377]. The graph and the explanation are present also in [Guillaumin 2005: 240-241]; a miniature is found in [Dilke 1967: 17-19, fig. 2f, plate 6].
23. This is discussed in greater depth in [Incerti 2014b].
24. On the training of architects during the 1000 years of the Medieval period see [Frothingham 1909; Meek 1952; Briggs 1927; Venditti 1967; Vagnetti 1980; Kostof 2000].
25. See [Hägermann 2004: 198], [Berlinski 2003: 116] and [Eastwood 2002, 2007]. In the cathedral school of Laon, the teaching manual of Martin of Laon (Laon BM 468, f.9r, s.IX 3/4): *Phisica autem in quattuor divisions partitur, id est arithmeticam, astronomiam, quibus adhaerent astrologia, et medicin a, et etiam minors artes [mechanicas] quas aratores, et fullones, et cimentarii exercent.* Further on, f. 9v: *Astronomia id est astrorum lex. Astrologia, astrorum verbum. Inter astronomiam et astrologiam hoc differ quod astronomia ad certam rern pertinent, astrologia ad certam et incertam. Ad incertam enim pertinent dum in stellis auguriatur* [Eastwood 2007: 15]. On the theme of astrology see [Eastwood 2007: 16-17].
26. *Limites maximi in agris duo sunt: cardo et decumanus. Cardo, qui a septentrione directus a cardine caeli est; nam sine dubio caelum vertitur in septentrionali orbe. Decumanus est qui ab oriente in occidentem per transversum dirigitur, qui pro eo quod formam X faciat decumanus est appellatus* (Isidorus Hispalensis, *Etimologie o Origini* XV 4).
27. The method, similar to that of Hyginus, is in [Migne 1844-1855: vol. 139, coll. 151-152, ch. 93-94].
28. On these and following references, see also [Heitz 1975: 726-727].
29. Images of the phenomenon are present to be found also in [Oursel 1993].
30. For a description of the research and the credits see [Incerti 2006].
31. Each scan was carried out with a 5 cm grid to organize and recognize targets, a 2 cm grid for the survey itself, becoming 1 cm frequent on all the openings, for a total of approx 37 million points. For a description of the study and the credits, see [Incerti 2006].
32. Perpetual Calendar by G. Tavernini; G. Effem (Version 4/2001) by G. Ferrari; Archisole by C. Frison; Merid98P (Version 6/01) by G. Ferrari.
33. It is well known how the figure of St. John the Baptist is traditionally associated with the symbol of the 'door', in other words the opening through which the catechumens enter for the first time into the Christian congregation thanks to the sacrament of Baptism. The Benedictine rule, adopted faithfully by the Cistercians documents for us the presence in the church of monks at this moment of the day for the celebration of the First hour.

34. On the feast day of St. John the Baptist the patch of light touches the left door post. Most likely three days before , i.e., on the day of summer solstice, the band of light reaches the centre of the threshold.
35. The base of the rectangular triangle is equivalent to approximately 52 m.
36. Work conducted both by the author of the present as well as by other authors. In the second case, the research results published were submitted to assessment by *Google Earth*, historical data was checked and the ephemeris calculated.
37. The authors and the bibliographical references are included in the individual files.

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