

The Layout of a Gothic Dome Base. Geometry and Construction of the Octagon in the Guarç's Gothic Layout (c. 1345–1380)

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Abstract The study of the Gothic layout of Guarç (c.1345–1380) through its imprints allows the determination of the methodology of its outline. The outline of the octagon dome is determined by the geometric method of design. At the same time, the proportional theory that exists behind the parchment allows the transport of the project to the site using simple metrological arithmetic operations.

Keywords Gothic · Medieval geometry · Octagon

1 Introduction

In the Capitular Archive of Tortosa's cathedral (ACTo), a Gothic layout was released by Matamoros (1932). The parchment represents the projection of a plant with the notation "En Antony Guarç". Guarç's parchment is one of the small numbers of orthogonal representations of a cathedral project preserved from medieval Europe. The study of the Gothic layout of Guarç (c.1345–1380) through its imprints allows the determination of the methodology of its outline. The outline of the octagon dome is determined by the geometric method of design. At the same

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time, the proportional theory that exists behind the parchment allows the transport of the project to the site using simple metrological arithmetic operations.

There are not many representations of Gothic *ichonographia*. However, some of the representations from existing buildings are conceived as typological notes, such as Villard de Honnecourt (c.1175–1240), (BNP ms.fr.190093), Notre-Dame de Cambrai plans (fol.14v.), the Saint-Etienne de Meaux cathedral (fol.15r) and Vaucelles abbey (fol.17r) (Lassus 1858, 112–124, 130–131).

Other representations are considered examples of models, such as those attributed to Michel de Fribourg, which are the Paris and San Croix de Orleans (1388) cathedrals and the Musée de l'Oeuvre Notre-Dame de Strasbourg (Inv.29, Inv. 21) (Bucher 1968, 59, Fig. 15, Vandekerchove 1989, 317–318).

Other plans are considered a global project from a part or the totality of the buildings. Therefore, these plans have a mission to advance the future of the buildings, and they relate to Guarç's parchment. The global projects are as follows: the Steyr plan (Vienna Akademie ABK no 17052), Zagreb (ABK no 16926), Augsburg (ABK no 16846), Kuttemberg (ABK no 16841) (Bucher 1968: 59), the Nürnberg plan, (German-isches National-Museum) (Bucher 1972), the Milan cathedral project that is attributed to Henri Parler (c.1392), (Musée de l'Oeuvre Notre-Dame de Strasbourg, Inv. no 29), the plan from Antonio de Vincenzo (1390–1392) (Museo de San Petronio de Bologna, cart. 389, no 1), and the (S2–S3) Siena Duomo and Museo dell'Opera della Metropolitana plans (Carli 1979, 22–24; Ascani 1989; 268–270; Ascani 1997, 89–94).

Finally, partial Gothic masonry projects can be found. This is the case of A Project of Colonia (c.1280–1308) (ABK no 16873) and the E attributed to the Master Johannes (c.1310–1320), (Dombarchiv des Metropolitantkapitels Cologne). The project of the presbytery of the cathedral of Strasbourg, (Musée de l'Oeuvre Notre-Dame de Strasbourg, Inv. no 6 v.), the deformation (Inv. no 06/10/11) and façades (Inv. no 15/16) and the draft counter (c.1350) (Hauptstaatsarchiv of Stuttgart Inv No. N201) also include partial Gothic masonry projects. Other examples are the tower plans of Vienna's cathedral (Museen der Stad Wien, Inv. no 105067), (Vrijs 1989: 412), the stair plans of Vienna (ABK no 16.855) (Vrijs 1989: 372), the (ABK no 16953) (Bucher 1979: 72), and the examples from Strasbourg's stairs (ABK no 16.832) and (Victoria and Albert Museum no 3550) (Recht y otros 1989, 405).

In Spain, the late Gothic drawings with complete floor plans are dated after Guarç's plan. This is the case of the Seville cathedral, the Convent of Bidaurreta (1433?, 1490?) (Alonso y Jiménez 2012, 57–77; Alonso y Jiménez 2009a, 63–74) and the parchment by Bartolomé de Pelayos for the cathedral in Coria (1502) (Sánchez 1982, 63–76). In addition, there are the floor plan of the Church of San Bartomé in Javea (1513) (Zaragoza 2003, 175–176), the Church of Segovia (1524) by Juan Gil de Hontañón (Casaseca 1978, 2951), the plans of Juan de Alava in the convent of San Esteban in Salamanca (1524) and the Salamanca cathedral (c.1537) (Alonso y Jiménez 2009b, 116–117).

The aim of the investigation is to complement an initial work about the layout of Guarç (c.1345–1380) where it is assessed the layout of the heptagon (Lluís i Ginovart et al. 2013). Thus, present work completes the initial study with the layout

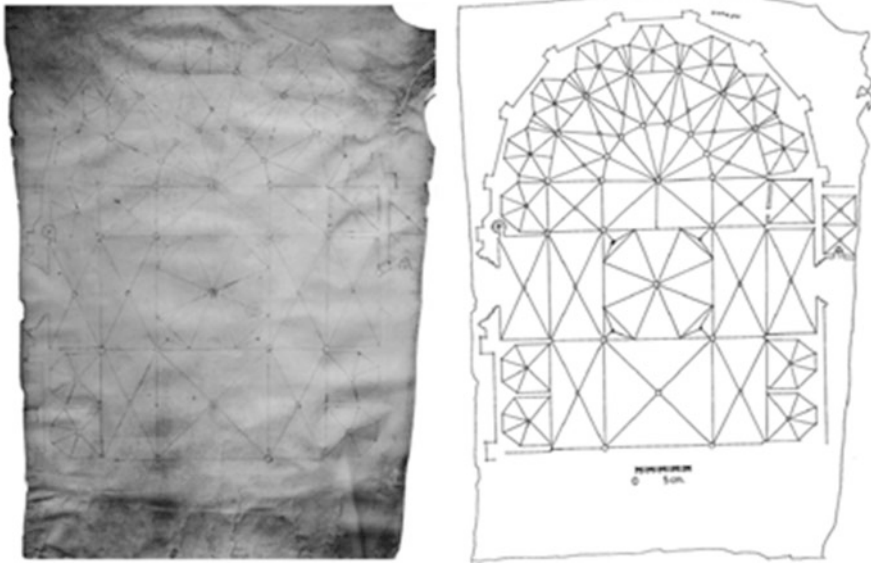


Fig. 1 Guarç's parchment. ACTo. Fábrica no 49 (c.1345–1380)

of the dome through the figure of the octagon. The methodology used for the study of the document is based on the analysis of its auxiliary layout and the lines and compass points on which the final plan is drawn. The studies ms. 1092 Stiftsbibliothek from Sant Gall (c.820) are a model to explore Guarç's layout (Horn y Born 1966, 285–308; Fernie 1978, 583–589; Horn y Born 1979; Nees 1986, 1–8; Sanderson 1985, 651–632). The analysis of the imprints allows to establish an interpretative methodology of the graphical construction of the octagon (Fig. 1).

2 The Traça of Guarç

Guarç represents the plan of a design for the chancel and part of the body of the nave of a cathedral. The system for representing the entire building is an orthogonal projection, *ichonographia*, except for the detail of the door of the adjoining chapel, which is shown as a vertical projection. Matamoros believes that the plan of Guarç was part of the preparations for the Gothic building before Bernat Dalguaire and Benet Basques de Montblanc (1345). Almuni dates it to the resumption of the stonework in approximately (1375) with the onomastic appearance of Guarç in the work accounts from (1379–1382). Thus, the chronology of the layout must be from the periods (1345–1380) (Matamoros 1932, 52; Almuni 1991, 362–364).

The basilica floor plan with three naves, a dome, and a polygonal apse was never built. The chancel consists of eight interconnected hexagonal chapels with

heptapartite vaults and a square floor plan with a simple vaulted ceiling, which is laid out as a double ambulatory. The ambulatory has a regular layout, with two rectangular sections and seven trapezoidal sections with a displaced keystone. The presbytery has a central keystone and eleven ribs. The body of the three naves contain two complete structural sections. The first section is roofed with a dome, an octagonal plan, and an *octopartite* vault with intermediate ribs; the second is a simple vaulted ceiling. The lateral naves are half the size of the central module and have a rectangular floor plan with an extended vaulted ceiling. The side module has two chapels with a hexagonal floor plan and is roofed by *sexpartite* vaults.

3 The Imprints by Guarç

An analysis of the preceding imprints to the final plans allows us to establish an interpretive methodology of the possible graphical construction. Several points on the support penetrate the parchment. There are marks that break the surface of the parchment: some points are located on the perimeter to fasten the parchment to its support, other points are from compass marks that could be used to transport measurements or for tracing circumferences, which penetrate and break the surface of the parchment. An analysis of the auxiliary lines and points gives us the drawing sequence and determines the number of graphical operations. Some points are used only once, others are used twice, and others (such as PO.1) are used up to five times, which comprise most of the base of the auxiliary drawing.

The lines modify the surface of the parchment, and are drawn using a punch (straight sections) or through a two-pointed compass (for circular layouts), while others are similar to graphite strokes. The technique that uses sharp tools frames the drawing and establishes the proportions, whereas the graphite strokes were placed as auxiliary strokes and then fixed with final ink strokes (Fig. 2).

The sequence of auxiliary lines should have been:

- T0. Fixing points on the edge of the parchment, the incisions pierce the surface.
- T1. Fitting lines of the drawing. The border lines T1.1 and T1.2. A point in T1.1 is used to lay out T.1.3; the measure between lines T1.1 and T1.3 is the module used for the lay out of the plan.
- T2. Fitting lines of the plan. T2.1 is located at the mouth of the apse. It is the starting point for determining the ratio of the width of the naves. A line outside the main drawing is drawn, T2.2, which is divided into six equal parts.
- T3. Vertical composition lines of the plan. T2.1 contains points with a dual function. Some are used for the lay out of the dome, and others to set the proportions of the central nave related to the lateral naves. The first point is located at $1/3$ of the total length, and the second at $1/6$. The sequence of the lines is drawn as follows: the total width of the plan with T3.1 and T3.2, the width of the central nave through T3.3 and T3.4, and finally the widths of the side naves, with T3.5 and T3.6.

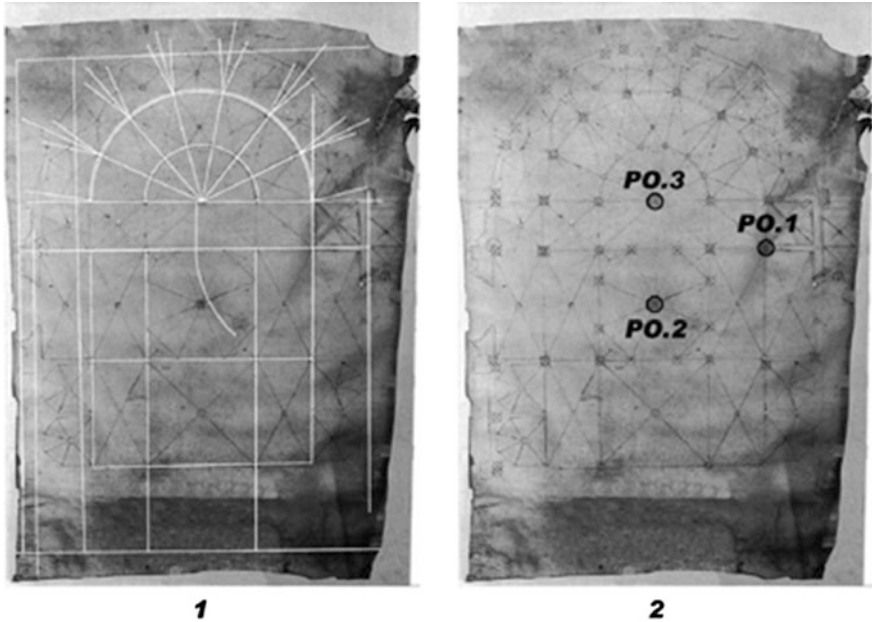


Fig. 2 Types of auxiliary imprints. 1 lines, 2 points

- T4. Horizontal composition lines of the plan. The horizontal lines T4.1 and T4.2 cross the vertical drawn before, shaping the structure of the nave. At this point it was possible to draw the dome or also the apse.
- T5. Composition lines of the apse. It is drawn an arch from T4.1 to T2.1 and centre in PO.1, named T5.1. Following is drawn the vertical line T5.2, which end determines the location of the semi-circular apse. This process can be interpreted as the method for laying out the heptagon.
- T6. Layout lines of the apse. The line T5.2 has the same length as the distance between the points (T2.1–T3.3) and (T2.1–T5.1). It determines the location of the straight section of the presbytery, marked by the line T6-1. The point PO.3 is the centre of the presbytery and the arches T6.2, and its correction T6.3 according to lines (T3.5–T6.1). After, the arch T6.4 completes the presbytery.
- Lines T7 and T8 are the main lines in the auxiliary operations to determine the construction of the apse (Fig. 3).

About layout points PO, there are:

- PO.1, origin of a lot of both layout operations and measure translation.
- PO.2 centre of the dome.
- PO.3 Keystone of the choir and centre of apse layout.

The layout of the dome drawn on the parchment takes the main line, T2.1, at the foot of the presbytery as the base and constructs the structural square, which

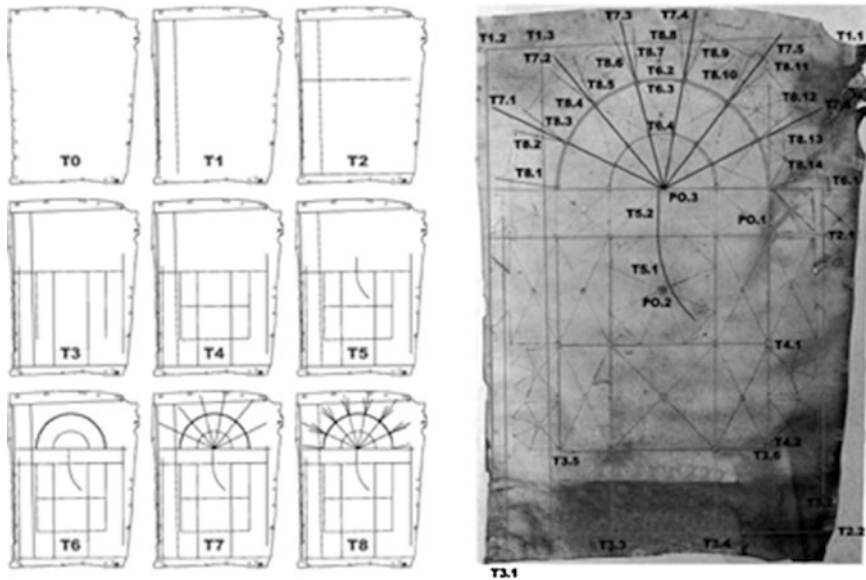


Fig. 3 Layout sequence, auxiliary points and lines

contains the dome. A compass point is observed at P1, P2, P3 and P4. The centre of the square, PO.2, was laid out. This point is determined by the intersection of the diagonals (P1–P3) and (P2–P4) where the auxiliary layouts of graphite are still visible. The opposite vertices of the square (P1, P3), have two compass marks unlike the rest. The points P5 and P6 are obtained by rotating the segment (P1–PO.2) on the side (P1–P2) and the side (P1–P4). The same sequence is conducted on point (P3) with the distance (P3–P5), translating over the sides (P2–P3) and (P3–P4) of the square (P1P2–P3–P4) and obtains points P7 and P8. The distance (P5–P7) and (P6–P8) is the measurement of the side of the octagon. Points P9, P10, P11, and P12 are obtained by the reiteration of this measurement with a compass, whose marks can be observed on each point (Fig. 4).

4 The Geometry of the Layout of the Octagon

The layout of the dome of the parchment needs a method to draw the octagon (Fig. 5). Euclid's *Elements* (c.325–c.265 BC) (Heath 1908, 91–95) do not address the layout of the octagon based on the inscription of the octagon in the square, only appear some relation between the square and the circle in Books (IV.6), (IV.7), (IV.8) (IV.9). Ptolemy (c.85–165) in his *Almagest* (Toomer 1984, 35–74) also do not address the layout of the octagon. It appear in the Gromatic text *Fragmentum de hexagono et octogono*, which is attributed to Marcus Terentius Varro (116–27 BC)

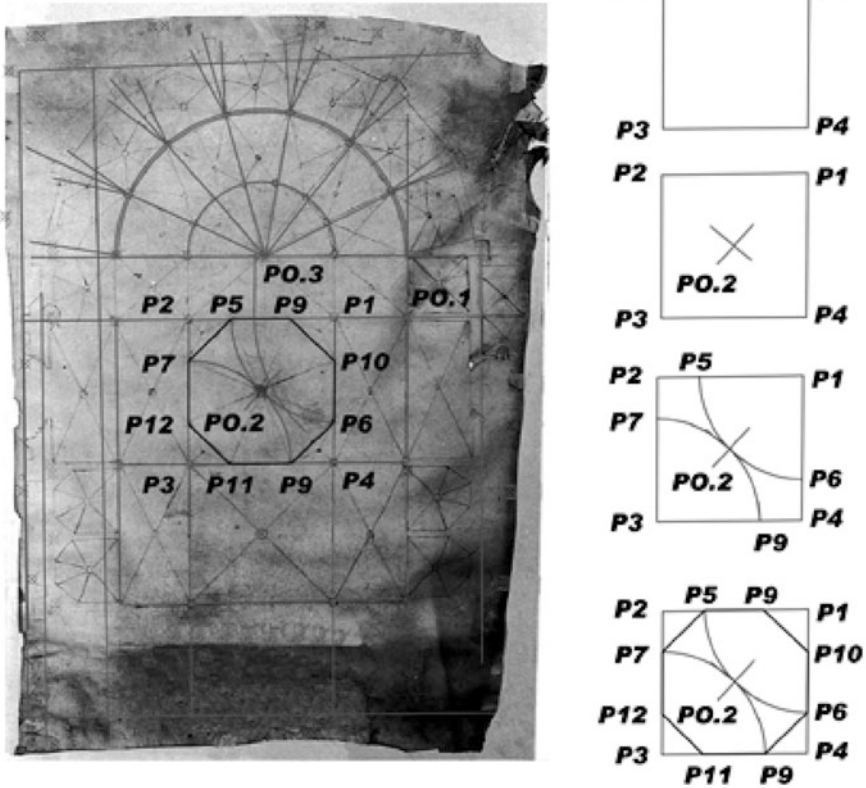


Fig. 4 Layout sequence of the octagon

(Bubnov 1899, 552). This text contains the drawing of the octagon through the iterative layout of eight perpendicular lines over the diameter of the circumference. This squaring method was widely used in Roman flooring (Watts 1996, 165–182). The problem was also considered by Hero of Alexandria (c.20–62) in his *Metrica* (LI.XVIII) (Schoene 1903, 57–59; Bruins 1964, 3). His method is considered a reference for the layout of some octagonal apses from the eighth part of the circumference using the triangle (13, 10, 13, $h = 12$) (Cantor 1907, 377–379; Özdural 2002, 217–242).

The method from Mohammad Abu'l-Wafa Al-Buzjani, (940–998) *en El libro de construcciones geométricas que son necesarios para los artesanos* (c.990) starts from the side with the same measure of compass (Chap. II.8). (Woepcke 1855, 330). The figure *mediatrix* of the *De triangulis* (c.1250) by Jordanus Nemonarius (1225–1260) (P.IV.15), *Octogonus circulo inscriptus inter quadratum eidem inscriptum et quadratum circumscriptum proportionali* (Beaujouan 1975, 453–454).

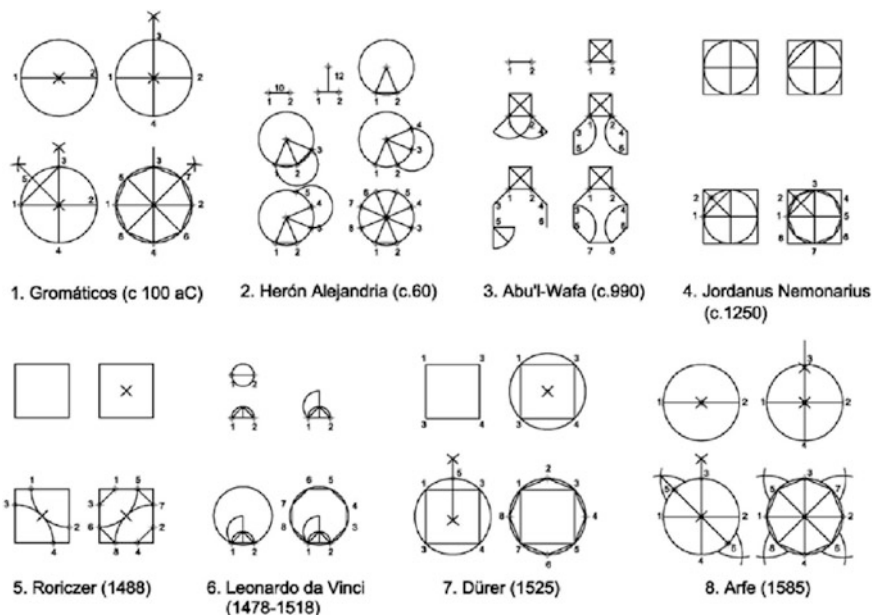


Fig. 5 Layout of the octagon 1 Gromaticos (c.100 aC), 2 Hero of Alexandria (c.60), 3 Abu'l-Wafa (c.990), 4 Jordanus Nemonarius (c.1250), 5 Roriczer (1488), 6 Leonardo da Vinci (1478–1518), 7 Dürer (1525), 8 Arfe (1585)

The Gothic design of the octagon appeared in the *Geometrie Deutsch* (1488) (fol 3r.) by Matthaüs Roriczer (+c.1495). There it is drawn using the inscribed square and abates its semi-diagonal (Roriczer 1999, 56–60; Hoffstadt 1847, 20; Shelby 1977, 119–120; Recht 1980, 25), which is similar to the method WG 18 appearing in the Frankfurt album (1560–72) (Bucher 1979, 219). Luca Pacioli (1445–1517) uses a method of squaring the circle (Dist. 4. Cap2) in the *Summa de Aritmética, Geometría, Proportioni et Proporcionalità* (1494), which is similar to Nemonarius (Pacioli 1523, fol31v) and dedicates (Part.III.TI.C.39-40-41-42) of the *Divina proportione* (1497) to the octagon, where applies integer arithmetic ratios between the diameter and the side of the octagon (Pacioli 1509, III, 7r–7v).

Leonardo da Vinci (1452–1519) in the Windsor codex 12542 (1478–1518) constructs the circle that is inscribed on the side of the square of the isoptic of the side of the octagon (Reynolds 2008, 51–76). Albrecht Dürer (1471–1528) in the *Underweysung der Messung* (1525) uses the reiterated process for the partition of the side of the square with the compass. Otherwise, in the *Il Primo libro d'architettura* (1545) by Sebastiano Serlio (1475–c.1554) it is used the Roriczer method (Serlio 1545, 19). In the architectural manuscript (c.1545–1562) by Hernán Ruiz el

joven (c.1514–1569) it is used also Serlio method (Navascués 1974, Lam. XXIII). Juan de Arfe (1535–1603) wrote *De varia commensvracion para la escvltvra y arquitectura* (1585), where he layouts the figure by using the circumference and its average arcs (LI.T1.C2.13) and octagon the inscribed in the square (LI.T1.C2.14) (Arfe 1585, 7v–8r).

5 The Gothic Modular Structure: Traça Verus Fabrica

An initial module makes the lace parchment. Guarç divided the width of the cathedral in six parts (91 mm), a measurement that is considered a unit pattern. The rectangle, next to the primary key of the presbytery, has a ratio of (91/82 mm). The proportion between the side chapel's width and the separation wall is 8/1 and makes the modulus of the side nave 9 units and the central one 18 units. In conclusion, Guarç uses the 18/8 numerical relationships between the nave and the side chapel or, what is the same, the tonal relationship 9/8 between the ambulatory and radial chapel.

The pattern of *Llibres d'Obra* (ACTo) is the *cana* of 8 spans, and the span of 12 fingers. The Tortosa's *cana* is defined in the (IX Book, Rubric 15.5) of the *Consuetudines Dertosaes* (1272) (AHCTE, Arxiu Històric Comarcal Terres Ebre, cod.53, fol.256r) and the text *Costums Generals feutes de la insigne ciutat de Tortosa* (1346) (FBMPM, Fundació Bertomeu March Palma Mallorca, fol.100r). The unification of the Tortosa's *cana* to Barcelona's (24-VII-1593) was determined to be 1858 m (Fig. 6).

The Tortosa cathedral's apse has the metrological proportions of 150 spans wide, 100 spans deep and height, radial chapels with square floor plan of 21×21 spans, and the stake out of the axis of the pillars separated by 3 *cana* (24 palms).

The (9/8) ratio is the same between the Guarç's geometric layout and the general stake out of the radiating chapels of 24 spans wide and is drawn to 54 spans. The modular structure of Guarç's plan, from a geometric perspective, is the same executed work, and there is a need to apply a proportional factor for placing it. If Guarç's project had been executed, the scale value would be 3 (Fig. 7).

Because of the parchment's modular structure, it can be speculated as an arithmetic relationship that can carry, with certain comfort, the parchment's measurements to the work. The relation that Hero spread, which was based on the isosceles triangle angle (360/8) (13, 10, 13), actually (13.9, 9.50, 13), was known among the Gothic masters. In Guarç's case, the radial chapel floor plan is (8×7.5) , and the dome is layout on the square (18×18) . The octagon side is similar to the depth of the radial chapel (7.5), which is obviously an arithmetic approximation (7.456). Hero measurement errors, similar to Guarç's, are completely negligible in Gothic building measurements (Fig. 8).

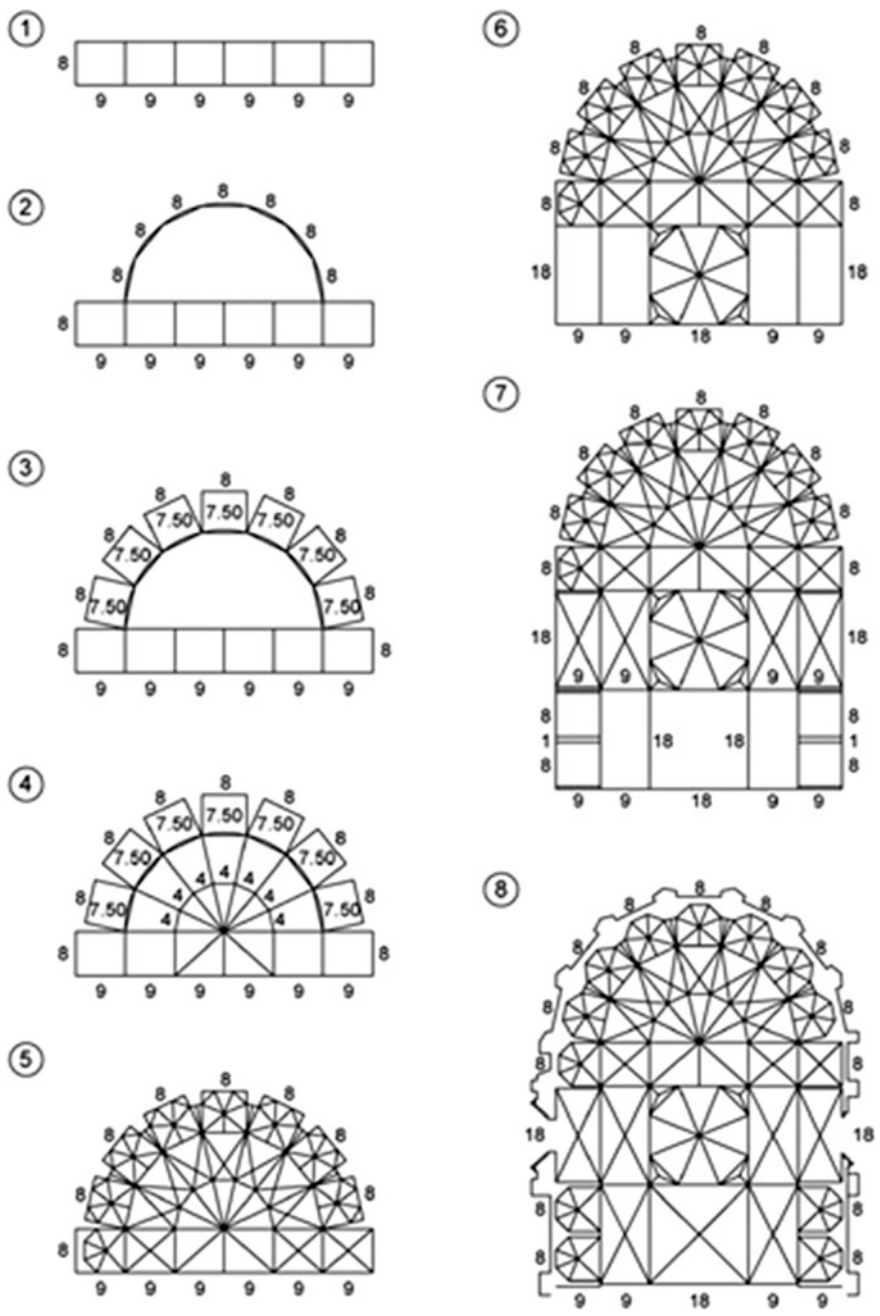


Fig. 6 Modular structure of Guarç's parchment (c.1345–1380)

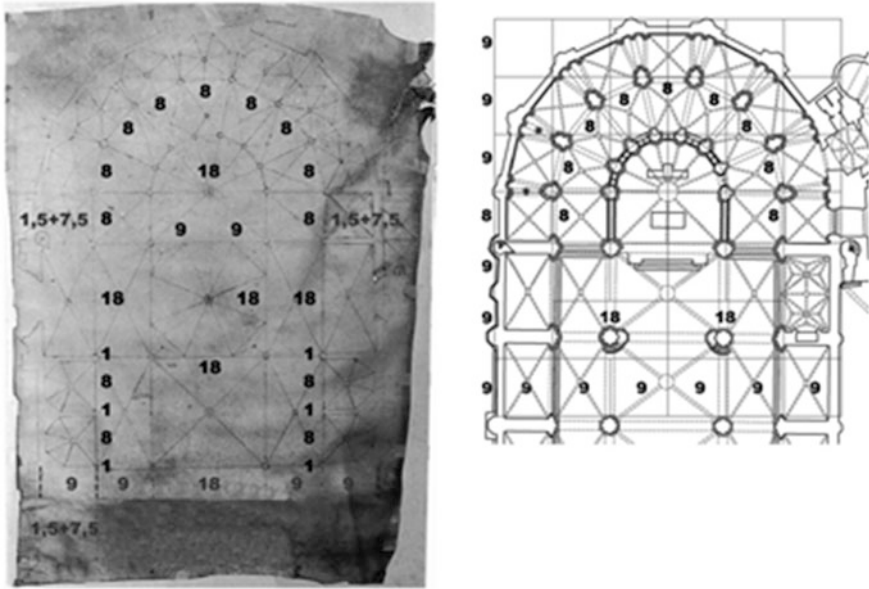


Fig. 7 Modular structure of Guarç's parchment and the Cathedral built (c.1345–1380)

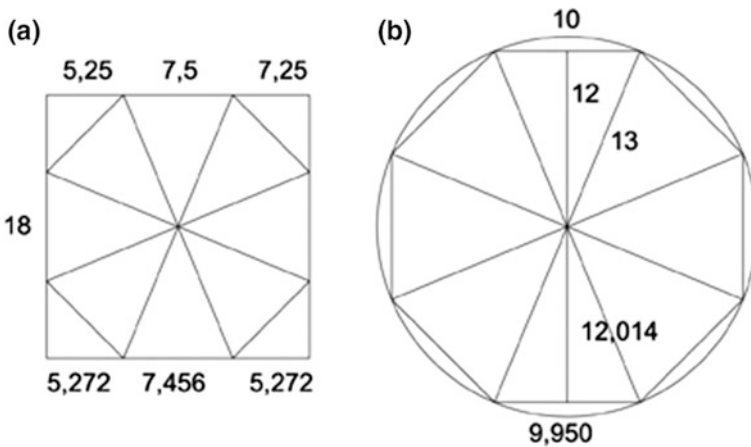


Fig. 8 Approaches to the figure of the octagon. **a** Guarç and **b** Hero of Alexandria

6 Conclusion

The geometric layout of the octagon used by Guarç (c.1345–1380) is similar to the layout published in *Geometrie Deutsch* (1486) by Matthäus Roriczer (c.1435–1495). The *geometria fabrorum* in Guarç's layout will raise two basic issues.

On the one hand, the design layout is drawn geometrically with a compass. On the other hand, the masonry transposition will have a metrological and arithmetical nature. The parchment structural plan has an arithmetic base of nine and allows us to solve as an algorithm by integer numbers the design layout and its later use in the masonry.

Geometrical operations of the octagon drawing, posed with *circino* (Etym.XIX.XIX.19.10), allude to instrumentally immeasurable metrics. With a changed scale, the design must be moved to the masonry with a different instrument, such as the *linea* (Etym.XIX.18.3) and the *norma* (Etym.XIX.18.1) that must have a metrological base. The arithmetic transposition of Guarç's octagon over a square of base 18 and which side is 7.5 (the same as the depth of the radial chapel), has a *Metric* base in Hero of Alexandria.

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