Kenza Boussora
Said Mazouz

The Use of the Golden Section in the Great Mosque at Kairouan

The geometrical analysis conducted reveals very clearly a consistent application of the golden section. The geometric technique of construction of the golden section seems to have determined the major decisions of the spatial organisation. The golden section appears repeatedly in some part of the building measurements. It is found in the overall proportion of the plan and in the dimensioning of the prayer space, the court and the minaret. The existence of the golden section in some parts of Kairouan mosque indicates that the elements designed and generated with this principle may have been realised at the same period. This suggests and opens the possibility for further inquiry into the dating of the transformations that took place in this mosque. Authors Kenza Boussora and Said Mazouz examine earlier archaeological theories about the mosque, demonstrate the geometric constructions for the golden section, and apply these constructions to the plan of the mosque to test their hypothesis.

Introduction

This paper undertakes a geometrical and a numerical analysis of some architectural drawings of the Great Mosque of Kairouan, in Tunisia. This mosque was founded around the year 670 A.D.; it is the first mosque in North Africa and the most famous one. However, it has a scattered building history. Archaeological research provides detailed evidence that this mosque went through many transformations and additions before it acquired its present form [Ettinghausen and Grabar 1987], but discussion about the dating of the different periods of evolution of this mosque seems to end in a confrontation between the different historians and archaeologists. No shared agreement exists about the periods of transformation and the work that took place in each of them. The aim of this study is to try to find whether a common shared way of design that links some elements together exists, despite the many phases that this mosque went through.

The geometrical analysis conducted reveals very clearly a consistent application of the golden section. This principle governs the mosque's spatial organisation, as well as that of some of the architectural elements, such as the minaret.

The geometric technique of construction of the golden section seems to have determined the major decisions of the spatial organisation. The golden section appears repeatedly in some part of the building measurements. It is found in the overall proportion of the plan and in the dimensioning of the prayer space, the court, and the minaret.

The existence of the golden section in some parts of Kairouan mosque indicates that the elements designed and generated with this principle may have been realised at the same period. This suggests and opens the possibility for further inquiry into the dating of the transformations that took place in this mosque.

Review of the Archaeological Researches

In considering the archaeological research conducted to date, it appears that no information exists about the mosque of 670, founded by Uqba Ibn Nafi. Only suppositions are present among

historians. Their data shows that at this period the mosque was very simple, similar to the prophet's mosque in Medina. While basing her argument on historical references, Mohamedi describes this mosque as having a square shape, with surrounding walls [Mohamed 1976].

To foster a better understanding of the historical evolution of this mosque, we undertook an analysis of earlier archaeological researches conducted by Marçais, Creswell, Lézine, Sebag, Golvin and Mohamedi. Although our analysis did not intend to go into great detail, it has shown that many divergent arguments exist among these authors in the identification of both the periods of evolution and the transformations that took place. The hypotheses put forward by Marçais [1954] and Creswell [1932-40, II; 1958] concerning the work of restoration and addition were questioned later by Lézine and Sebag [1962]. Golvin [1968] put forward another evolution scheme, which was echoed few years later by Mohamedi [1976]. This scheme was different from that presented by Lézine and Sebag.

These divergent arguments are summarized here. Creswell writing in 1958 considers that the prayer space had seventeen naves perpendicular to the *qibla* wall, and one aisle along this wall. He recognizes the existence of seven bays. Closely related to his argument was that of Marçais, who observes that this mosque had seventeen naves, with one parallel to the *qibla* wall. Their point of divergence was in the determination of the number of bays. Marçais suggests that this mosque had initially only three bays. In his view, the four other bays were added in the Abou Ibrahim Ahmed period. This argument has been strongly challenged. In fact, if this mosque had only three bays, the prayer space would have been greatly disproportioned compared with the court's dimensions.

Later, in 1962, Lézine and Sebag proposed a new evolution scheme. They had identified three stages of transformation. The first period was 817-838, during the reign of Ziyadat Allah; the second was 856-863, during the reign of Ibn Ibrahim Ahmed; and the last one was 875-902, during Ibrahim II's reign. Lézine considers that the minaret was realised during the first period, that is, between 817 and 838.

In acknowledging the difficulties that lie behind the establishment of the periods of transformation, Mohamedi proposes another evolution scheme for this mosque. This was closely related to that earlier elaborated by Golvin. She also proposes three stages, but these are different from those proposed by Lézine and Sebag. According to Mohamedi, the first period began in 703, the second in 725 and the third in 772. These periods were respectively initiated by Hassan Ibn Numan, Bishr Ibn Safwan, and finally by Yazid Ibn Hatim.

Mohamedi demonstrates that during the first period, the mosque was constructed in the same place as that of the initial one. At the second stage, the mosque was enlarged on the north side, with the construction of the minaret on this side. In the last stage, the mosque was completely destroyed and reconstructed; only the *mihrab* was preserved.

This last consideration is important; it will serve later in this paper to explain that, with the complete destruction of this mosque, it became possible, during its reconstruction, to introduce a principle or a common way of design that might have linked some of this mosque's elements together.

The Description of the Kairouan Mosque

The mosque had an irregular plan. Its form was nearly a rectangle, with its four sides not perfectly parallel. Only the eastern side had a good alignment. Mohamedi explains that this deformation is due to the site conditions. In fact, a commercial axis bordered the western side.

This axis linked the two opposite gates that existed in the traditional town [Mohamedi 1976]. Lézine observes that, along this mosque, a covered road had existed. This had two rows of boutiques. He also affirms that all the transformations that took place in this mosque respected this urban constraint [Lézine and Sebag 1962].

This mosque is composed of two parts: the court and the prayer space. The dimensions of this space are less than that of the court. It has seventeen naves perpendicular to the *qibla* wall. The axial aisle and the one parallel to the *qibla* wall are larger than the others, forming a T-shaped plan. This form was characteristic of the North African mosques [Lézine 1966]. Two domes punctuate this central aisle, one at the crossing of the T, and the other at the opening to the court. This latter is surrounded by porticos. Archaeological evidence demonstrates that these porticos did not exist initially, but were added during the Hafside era [Mohamedi 1976].

The minaret is the dominating feature in this composition. Its elevation is divided into three levels. However, many differences exist about the chronological dating of these levels. The first and the second level of the tower are considered to be realized in the same period [Lézine 1966]. The dating of the third level raised some questions as to whether this level was constructed at the same time as the previous ones, or later. The reason for this challenge is related to its architecture, which shows similarities to the architectural characteristics of the Hafside period. These characteristics are found in both the cornice with its double brick line in saw-toothed brick on the row of small niches below and in the folded dome.

The explanation put forwards by Lézine supposes that the minaret had already all its three levels when first constructed. However, this third level may have been rebuilt in the Hafside era. Lézine carries on the argument for the presence of this third level initially by instancing the width of the minaret's walls, which are enormous, measuring between 3.30 to 3.40 m. It appears here that such a thickness would have supposed a consequent height. Another aspect about this minaret that is intriguing is its position. The minaret is neither at the corner of the mosque nor at its axis. The minaret's axis is positioned at 5 m. away from the mosque's axis.

It appears from this rapid overview of the mosque that many questions concerning the dating of some of its elements remain open. However, prior to answering these questions, it may be interesting to see whether there exists within this mosque a generating concept that lies behind the realisation of some of its elements. The existence of such a concept may help to answer some of the intriguing questions.

It appears from intuitive observation of this mosque that it is well proportioned. Taking into account the fact that many traditional buildings have used the golden section, a hypothesis was formulated that the golden section may have been used in this mosque. The following analysis will try to assess the extent to which the golden section is used as proportioning system in the mosque.

The Golden Section

Throughout history, proportion has been a significant concept in architectural design. The Greek transcribed the ancient knowledge of proportional techniques. This knowledge was traced back centuries earlier at the times of Moses and Solomon [March 1998]. The concept of proportion is based on ratio defined by Euclid as "a relation in respect of size between two magnitudes of the same kind" [March 1998]. Ratio is expressed as $a:b$ or represented by a function a/b ; a and b can be any number. A proportion involves equality of two or more ratios, and potentially between four magnitudes $a:b::c:d$ [March 1998].

The general principle of the system of proportion is to resolve the problem of how to punctuate the interval between 1 and 2, by a series of measures that are not only additive and multiplicative, but also, productive of both order and complexity [Padovan 1999]. In architecture, the role of the proportioning system is to create a set of visual relationships between all the different parts of a building, and between the parts and their whole. The aim is to provide a sense of order in the overall structure. The visual order created is sensed and recognized through different experiences [Ching 1943].

The golden section is considered to be among the most used principles of the architectural proportion [Padovan 1999]. The chronology of its exploration has raised many debates among historians of mathematics. Although the golden section was used by the Greek in their designs, it was already understood a millennium earlier [Heath 1921]. Van der Waerden [1983] has traced it back to the ancient civilizations of India, China, and Babylon, and even further back to the Neolithic period between 3000 and 2500 B.C. Other researches demonstrated that the golden section has also been used in the construction of the Pyramid [El-Said and Parman 1976]. The application of the golden section in architecture enables the overall structure of the building to be integrated, from the site to the smallest detail. Euclid describes the golden section as “division in extreme and mean ratio”. During the Renaissance, it was known as the “Divine proportion”, and later, in the nineteenth century it was called the “Golden section” [El-Said and Parman 1976].

The Geometrical Construction of the Golden Section

The golden section is occasionally represented by the letter ϕ , phi, equal to $(1+\sqrt{5})/2$, or 1.618... The golden section ratio can be defined geometrically as a division of a segment into what Euclid termed “the mean and extreme ratio”, that is, a division of a line in such a way that the lesser portion is to the greater as the greater is to the total length [Ching 1943]. It can be expressed algebraically by the following equation, where a represents the lesser portion and b the greater:

$$a/b = b/a+b.$$

The golden section can be derived from simple geometric constructions and can be constructed in several ways.

Fig. 1. Construction of the golden section by division

In this paper we will present two techniques using geometric construction as a tool to obtain the golden ratio. The first method consists of the division of a line into a golden section (Fig. 1). This starts by drawing a segment AB; then a rectangle with length AB and width AB/2 is drawn. Next, a diagonal is drawn from A to the opposite corner D. Then the width BD is subtracted from the diagonal by drawing an arc, which has this width as its radius. The diagonal is then divided into two segments resulting from the intersection of this arc with the diagonal.

The last step is to rotate the longer segment of this diagonal onto the adjacent long side, AB. The intersection point C subdivides this side so that the ratio:

$$AC : CB :: AB : AC = 1 : \phi : 1 : \phi^2 :: 1 : 1 : \phi$$

The second method consists of generating a golden rectangle from a square [March 2001], Fig. 2. The specific steps are:

- Draw a square having AB as a side;
- Divide AB in half;
- Draw a diagonal from the middle of the side AB to the opposite corner;
- Swing this diagonal till it cuts the line AB at C.

The golden rectangle generated will have AC as its length; its width will be equal to AB. Following the same method, a golden section progression will be obtained across the entire line AB. We will then have:

$$AC : AB :: AB : BC :: BC : CD :: BD : BC :: \phi$$

Fig. 2. Construction of the golden section by extension

The Geometrical and Numerical Analysis of Kairouan Mosque

The overlay of the drawing of this mosque plan with regulating lines shows very clearly that a proportioning system is used (Fig. 3). From this a hypothesis was formulated, postulating that the golden mean proportion may have been employed. In order to justify the validity of this hypothesis, an analysis of the drawings of this mosque was carried out.

At its beginning this analysis started with the overall dimensioning of the mosque. It made use of the geometric technique of construction of a golden section presented earlier. This was applied as a tool to verify the existence of the golden section and its effect on the plan dimensions. The different steps of this analysis are presented here.

Step one begins by trying to fit the plan of this mosque into a golden rectangle. However, it should be remembered that the plan of this mosque is not a perfect rectangle, but one that is slightly deformed due to urban constraints (as was mentioned, a commercial axis linking the two opposite doors of the traditional town bordered the western side). This axis is not perpendicular to the two other sides. Because of this deformation, the following construction of the golden section will not begin by a true square, but will try to follow the initial direction of the plan.

Fig. 3. Existence of regulating lines

Fig.4. Dimensions of the plan. The use of the geometrical construction of the golden section

The length of the western side AB is taken here as the initial measure. A square is drawn, having AB as its side. Then, a circle is struck from the middle of AB to the opposite corner of the square. This diagonal will be rotated on the line AB. The point C, resulting from the intersection of the square diagonal and the line AB, will be rotated on the adjacent side of AB; C' results from this intersection. A golden rectangle having AB as its length and BC as its width is obtained. It can be noticed that this rectangle corresponds exactly to that determining the plan of the mosque (figure 4).

This analysis was not restricted to the geometric construction only. We now proceed with the numerical analysis of some major dimensions:

- The external eastern side measures about 127.60 m.
- The external western side measures about 125.20 m.
- The external southern side measures about 78 m.
- The external northern side measures about 72.70 m.

This numerical analysis shows that the ratio of the length AB (125.20 m.) to the width BC (78 m.) is equal to 1.605... This falls short of the golden section value of 1.618, due to the fact that the construction of the golden section did not begin with a true square.

The second step of the analysis tries to find the proportioning relations that exist between the dimensions of the court and those of the prayer space. The geometrical method employed here is that of the division of a line into golden section (see Fig. 1). The division of the interior of the western side AB into the golden section gives the point D (Fig. 5).

Fig. 5. The geometric division of the plan: court and prayer space

This point is obtained as follows:

- Erect a perpendicular to AB at B. Its length BC is equal to AB/2;
- With C as center and BC as the radius describe an arc cutting AC at X;
- With A as a center and AX as the radius describe an arc cutting AB at D.

We have then,

$$AB : AD :: AD : DB :: \phi .$$

The position of this point in the plan corresponds exactly to the limit that divides the plan of this mosque into covered space and exterior space.

It is also interesting to look for the results the numerical analysis gives. This demonstrates that the ratio of the internal side AB (121.93 m.), to the length of the court (75.48 m.), is equal to 1.615. It can be noticed that this value is nearly equal to the golden ratio, 1.618.

The third step of this analysis tries to find the reasons that lie behind the intriguing position of the minaret. Following the same method, the northern side AE was divided into a golden section (Fig. 6). A perpendicular EG is drawn from E, having $AE/2$ as length. The radius GE is rotated, cutting AG at X. Similarly, the radius AX is rotated, cutting AE at F. The point F resulting from this division corresponds exactly to the edge of the minaret. The other edge is defined by the mosque's axis. The interval between this point and the mosque's axis gives the dimension of the side of the minaret.

This geometrical analysis was supported by a numerical one. This latter takes into account the following measures: the internal side of the northern wall measures 65.5 m. and the position of the point F to the interior north east corner is 25.16 m., whereas its distance to the opposite corner is 40.33 m. The ratio of the northern side AE to AF (65.5:40.33), is equal to 1.624. It can be noticed that this is very near the value of the golden ratio, 1.618.

Fig. 6: The geometric construction of the minaret, using golden section proportion

It has already been mentioned that the position of the minaret, which is neither at the corner nor on the mosque's axis, has raised many questions. This analysis demonstrates that both the position and the dimension of the minaret are not arbitrary, but are governed by golden mean considerations.

The last step of this analysis is concerned with the minaret's elevation. It tries to verify whether this elevation follows the same rules as those of the plan. The geometrical construction of the golden section, presented in Fig. 7, shows that the proportioning relations between the dimensions of the first floor, its height, and its width are those of the golden section. This is obtained by drawing a square having the width of the minaret's base as side. A diagonal is drawn from the middle of the left side to the opposite corner. This diagonal is then rotated, cutting the minaret at B. This point corresponds to the height of the first level, excluding the cornices. The same geometric technique is followed by drawing a square having the height AB of the first level as side. This construction gives the point C, corresponding on the drawing to the height of the third level without the dome. It should be noted that neither the height of the dome nor that of the cornice appear in this geometric construction.

Fig. 7: The height of the minaret is determined by the geometric construction of the golden section

Nevertheless, it is worth noting here that there is no evidence to prove that the height of the dome or that of the boundary between the second and the third levels and the cornice derive from golden mean considerations. This last observation may sustain Lézine's argument, presented earlier, that the third level was reconstructed later, during the Hafside era, with the addition of the cornice and the dome.

Conclusions

The analysis presented here suggests the presence of the golden section in the Great Mosque of Kairouan within a limited and well-defined space. It is found in the proportioning of the plan dimensions. In fact, the golden section is employed in setting up the length and the width of the mosque. It has been demonstrated that the plan of this mosque is inscribed into a golden rectangle, slightly deformed to accommodate the front gallery situated on the western side. Moreover, the division of this rectangle into covered space, prayer space and exterior space or court, is governed by a rule that corresponds to the golden section. This principle or concept is also used in fixing the position of the minaret and its dimensions, both in plan and in the elevation.

Considering the impact of the introduction of these generating rules into the composition of the plan, two hypotheses are suggested. The former suggests that these principles existed already within the initial plan of the mosque. However, the confrontation of this hypothesis with the archaeological evidence presented earlier in this paper reveals that these rules could not have existed from the beginning of the mosque's construction, because both the initial size and the dimensions of the mosque were different from the later ones.

The second hypothesis seems to be more realistic. It suggests that this principle of the golden section were added later and that the elements that have been generated by this principle may have been realized at the same time. It should be noted that the introduction of such rules into the composition of the mosque supposes that a big project of destruction and reconstruction was

undertaken. This hypothesis appears to be supported by Mohamedi's argument, which demonstrates that the mosque was completely destroyed and reconstructed, with the exception of only the *mihrab*. It can be observed that at this stage possibilities were opened for the introduction of such rules into the composition of the mosque.

While it should be noted here that the aim of this study is not to give answers to all the questions that remain open about the dating of this mosque, nonetheless its findings might be useful in providing more information for those trying to set up the chronological dating of the work of transformation that took place in this mosque.

References

- CHING, FRANCIS D.K. 1943. *Architecture: form, space and order*. New York: Van Nostrand Reinhold.
- CRESWELL, K.A.C. 1932-40. *Early Muslim Architecture*. 2 vols. Oxford.
- _____. 1958. *A short account of early Muslim Architecture*. Suffolk: Richard Clay and Company.
- EL-SAID, ISSAM and AYSE PARMAN. 1976. *Geometric concepts in Islamic art*. London: World of Islam Festival Publishing Company.
- ETTINGHAUSEN, RICHARD and OLEG GRABAR. 1987. *The Art and Architecture of Islam: 650-1250*. Middlesex: Penguin Books.
- GOLVIN, LUCIEN. 1968. Quelques réflexions sur la grande Mosquée de Kairouan à la Période des Aghlabides. *Revue de l'Occident Musulman et de la Méditerranée* 5: 69-77.
- _____. 1974. L'architecture religieuse des "Grands abbasides", la mosquée d'Ibn Tulun, l'architecture des Aghlabides. Vol. 3 of *Essai sur l'architecture Religieuse Musulmane*. Paris: Coll. Archéologie Méditerranée, CNRS.
- HEATH, T.L. 1921. *A History of Greek Mathematics*. Oxford: Oxford University Press.
- LÉZINE, ALEXANDER and PAUL SEBAG. 1962. Remarques sur l'Histoire de la Grande Mosquée de Kairouan. *IBLA* 99 (3rd trimester): 245-256.
- LEZINE, ALEXANDER. 1966. *Architecture de l'Ifriqiya, recherches sur les monuments Aghlabides*. Paris: Librairie C. Klincksieck.
- MARÇAIS, GEORGES. 1954. *Architecture Musulmane d'Occident*. Alger : Art et Metiers Graphiques.
- MARCH, LIONEL. 1998. *Architectonics of Humanism: Essays on Number in Architecture*. Sussex: Academy Editions.
- _____. 2001. Palladio's Villa Emo: The Golden Proportion Hypothesis Rebutted. *Nexus Network Journal* 3, 2: 85-104. <http://www.nexusjournal.com/March.html>
- MOHAMEDI, ANISSA. 1976. *Naissance d'une architecture musulmane au Maghreb*. Alger: Université d'Alger, Faculté des Letters et Sciences Humaines.
- PADOVAN, RICHARD. 1999. *Proportion. Science, Philosophy, Architecture*. London: E & FN Spon.
- VAN DER WAERDEN, B.L. 1983. *Geometry and algebra in ancient civilization*. Springer-Verlag.

About the Authors

Kenza Boussora is an architect and senior lecturer at Biskra University, Algérie. She did her M.phil degree at Oxford Brooks University and is now preparing her Ph.d degree on the formal aspects of Islamic architecture in North Africa. She is also the author of a book entitled *Histoire de l'architecture en pays islamiques, cas du Maghreb*, edited by Casbah éditions Algiers.

Said Mazouz studied in Algeria, where he graduated as an architect in 1985. He then undertook post-graduate studies in Britain (Oxford Polytechnic, now Oxford Brookes University) and took his M.phil in 1988. He completed his doctoral studies, once again in Algeria, at Constantine University. Although particularly interested in the process of architectural design and environmental issues in architecture, he is also working on the application of scientific approaches to architecture. He has published a number of papers dealing with these issues in well-known research journals. After fifteen years of teaching and research work, he is now a senior lecturer and Head of the department of architecture at Mohamed Khider University in Algeria.