Proportional Systems in the Design of the Cathedral of St. George of the Greeks, Cyprus

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Abstract. The cathedral of St. George of the Greeks was built in the 14th–15th c. in Famagusta, Cyprus to accommodate the religious needs of the Greek orthodox community living under a Frankish aristocracy. Its design is a hybrid of western European and Greek orthodox architectural traditions which reflect the political and social circumstances of its creation. This paper examines the degree to which the underlying design methods employed can be extrapolated from the physical remains of the building, the historical sources bearing upon its interpretation and comparisons with related structures. Results are presented of a recent (2016) photogrammetric survey of the building and a new digital reconstruction of the church derived from it. These are used to quantify, assess and illustrate a three dimensional armature of regulatory proportions which it is proposed for reasons of ecclesiastical philosophy and practical execution, were employed to shape the building's physical form.

Keywords: Proportions · Medieval · Architecture · Photogrammetry · Geometry · Masons · Pell Numbers · Root two · Armature

1 Introduction

The Cathedral of St. George of the Greeks is the largest Orthodox Church from the Lusignan period (circa 1191–1489) in Cyprus and is of an architectural style that might best be described as Franco-Byzantine. Now ruinous it was begun probably in the mid to late fourteenth century as an addition to the much older and smaller Hagios Epiphanios which adjoins it on the south side. St George's can be viewed as an orthodox alternative and some might say a competitor to the Latin cathedral of St. Nicholas, which is situated a mere 150 m away. St George's combination of a Latin basilica and sculptural detailing with Byzantine centralized planning and byzantine religious art raises a number of questions about its provenance and the motivations and preoccupations of its architects. In this regard the circumstances of its invention are germane. Until the Crusades in the twelfth century AD medieval Cyprus was culturally and religiously Byzantine albeit with a substantial Arab influence. This changed in the 1190's when the English King Richard I gave the island as a fiefdom to Guy de Lusignan a long time vassal who had been ousted from his position as king of Jerusalem after the death of his wife Sybilla [1]. Although described by his peers as "simple and unsophisticated" ("simplex et minus

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astutus") [2] Guy de Lusignan succeeded in holding Cyprus by means of a series of military and political stratagems (Fig. 1).

Fig. 1. Left - the West end of the Cathedral of St George of the Greeks showing the rose window/ oculus. Right - the East end of the Cathedral showing the three apses, lancet windows and flying buttresses supporting the clerestory.

In doing so he founded a dynasty of Frankish rulers and fundamentally recast Cypriot society in a European feudal mold. Guy de Lusignan died in 1194 and was succeeded by his brother Amaury who obtained a crown from the Holy Roman Emperor, Henry VI becoming in 1197 the first Lusignan king of Cyprus. Of importance here is that Amaury took steps to displace the Orthodox Church by introducing the Roman communion, a process that was continued by his successors with papal assistance. Cyprus became the center of European trade with Africa and Asia after the fall of Acre in 1291 and this brought the kings of Cyprus into conflict with Italian merchants who dominated trade in the eastern Mediterranean. This led to a Genoese occupation of Famagusta in 1372. The kingdom was then made a tributary to the Mameluke state in 1426 and the succeeding monarchs gradually lost almost all independence until the last Queen, Catherine Cornaro, was forced to sell the island to Venice in 1472. The Genoese occupation of Famagusta from 1372 and later the Venetian Republic from 1472 allowed the Orthodox Church to regain a position it did not have during the feudal kingdom of the Lusignans, thus despite the absence of evidence regarding its foundation and commissioning, it has generally been assumed that the building of St George of the Greeks was started during or shortly after this recrudescence of Eastern Orthodoxy in the mid-fourteenth century under the influence of the Genoese [3]. However, as Jeffery noted of this period in Famagusta's history in 1918 "*not a single monument of importance can be identified with any certainty as belonging to the period of the Genoese Occupation of the city*" [4, p. 103]. It is within this prolonged condition of uncertainty that we approached research into the intentions of the architects of the cathedral of St George of the Greeks.

2 The Surviving Fabric of St George of the Greeks

The Cathedral of St George of the Greeks is in a ruinous, roofless condition and lies in the south eastern quarter of the old walled city of Famagusta, close to the Latin Cathedral

of St. Nicholas. Unlike St. Nicholas's which is still in use, now as a mosque, St George's retains some of its original internal wall decoration and is largely unmodified, since it was severely damaged by an earthquake in 1735 and has been a recorded as ruin for at least the past one hundred and fifty years. Over this period it has received intermittent academic attention. It was noted by the Marquis de Vogüé and Baron Emmanuel Guillaume Rey in 1860, and was visited by the British architects Edward I'Anson and Sydney Vacher in 1882–1883 though it was drawings of the West and South elevations of the Cathedral of St Nicholas in Famagusta that Vacher exhibited at the Royal Academy in 1882. It was not until 1900 that the physical remains of the Cathedral of St George of the Greeks was first reported to scholarly audiences by the French architectural historian Camille Enlart who visited Cyprus in 1896 under the auspices of the Ministère de l'Instruction Publique et des Beaux-Arts. He drew several medieval structures dating from the period of the Crusades (including St George of the Greeks) from which were produced engravings which were published in his *L'art gothique et la renaissance en Chypre* [5]. In 1919 George Everett Jeffery published an account of the building noting that both St Nicholas and St George were "*were undoubtedly erected between the years 1373 and 1571*" [4] therefore between the start of the Genoese occupation and the end of Venetian rule, a view which still persists in many quarters. It should be noted that both Enlart and Jeffery were not able to record the cathedral's lower details fully, as it was still covered with debris from the collapsed vaults [6, p. 169]. The basic plan layout of St. George comprises a nave divided from two side aisles of equal length by two rows of four columns unequally spaced such that a square is defined by four columns at the midpoint of the nave. At the eastern end of the nave and each aisle there is a semicircular apse covered by semi domes that formed the raised sanctuary or bema. Flying buttresses supported the upper clerestory walls of the main aisle and it is believed a hemispherical dome on a short cylindrical tower existed above the central crossing, which was observed and drawn by Cornelis De Bruyn in 1683 [7, pp. 185–186, Fig. 25]. The austere, unarticulated external wall surfaces at the east end are pierced only by two-centered arch windows. The western end of the church, with the three doorways still retains a rose window above the central one. The building is made entirely from high quality ashlar limestone masonry. Stylistically it has been argued that St George's presents closer parallels with churches in the Crusader mainland states than with Frankish or German counterparts in mainland Europe, which if true may reflect the origins of the citizens its served [8, pp. 309–310].

3 The Photogrammetric Survey

Several methods exist for the accurate capture of the 3D form of buildings [9]. Unlike laser scanning which was considered as an alternative means of data capture for this project [10, pp. 1–25] stereo photogrammetry requires little specialist equipment and so does not require special customs security clearance or transportation and tends to take less time. It does require careful planning and execution on the ground but for the purposes of this study its advantages of simplicity were overriding factors in its selection as the preferred technique. Stereo photogrammetry uses a series of photographs of the

building taken from different angles and positions that are then processed through specialized software to produce a detailed 3D surface model and photographic textures overlaid upon it. It is not the purpose of the discussion here to rehearse photogrammetric methodology, this can be found well described comprehensively elsewhere [11–13]. However the capture of textures in particular for this project is of some consequence. One of the major advantages of stereo photogrammetry over laser scanning is the ability to generate photorealistic continuous colour textures precisely mapped onto the 3D point-cloud geometric data (Fig. 2).

Fig. 2. Left – the 3D digital model of the Cathedral as it exists from the North West showing the photo-textures overlaid upon the surface of the geometric model. Right – the 3D digital model without photo-textures, viewed from the south east.

This means that images of internal surface decoration like wall paintings are premapped to their respective points and are as complete as the original photographs. This potentially allows the religious frescoes and other iconography and their state of preservation to be considered simultaneously along with the 3D form of the building, thus providing a contextually more complete, richer and more integrated data set for examination. It also gives the data set a potential use beyond this study firstly for preservation and conservation of the building and secondly for developing more effective heritage interpretation material. St. George's interior surfaces would originally have been substantially covered with frescoes of ecclesiastical scenes, only some of which still survive in a faded and damaged state in some of the tombs' arches and between the registers of the three apses with pointed semi-domes in the eastern end. Discussion of the narrative arc of the interior decorative schema is beyond the scope of this study but photogrammetric recording of its current state carried out for this study may assist in doing so in the future. For this study the photogrammetric and texture data has been used to generate orthographic 2D scale drawings of the building which have been the principal vehicle for examining the dimensional and proportional relationships of the design (Fig. 3.).

As noted above previous plans of the building were known to have significant inconsistencies so the 3D point cloud model was horizontally sectioned at 1 m above nave floor level to give an accurate floor plan that conformed exactly to the elevations and sections. From these a reconstruction was developed based on the photogrammetric survey, careful on-site measurement and recording of molding profiles and previous

Fig. 3. A longitudinal section of the existing remains of the interior wall of the south aisle with a reconstruction based on proportional analysis of the arcuation of the nave, clerestory and cupola superimposed upon it.

interpretation. In this regard we looked to Theophilus A.H. Mogabgab's extensive study and restorations of the historic buildings in Famagusta between 1937 and 1939 [14]. He photographically recorded much of the fabric of St George of the Greeks at this time but he also made a reconstruction of the windows which we have used here in reconstructing the elevations. It is notable that the remains of a surviving clerestory window on the south nave wall, instead of being smaller as one might expect, in fact has exactly the same height as those on the side aisles' walls. In addition, both groups have the same distance between their sills and the decorative string-course separating the registers. All have hood moldings which in wetter climates serve to direct rainwater away from the window opening, but in Cyprus are functionally anachronistic.

4 Dimensions, Geometry and Proportions

The practical or operative craft of masonry has always relied upon geometry for its effective execution. It was inevitable that this became imbued with meanings and symbolism, particularly in temples and churches and so by implication the importance of an internally coherent geometrical schema for religious buildings was often an essential part of their perceived spiritual efficacy as well as an aesthetic goal of elegance, repose and unity in design. The most ancient, and in the fifteenth and sixteen centuries most revered western authority on architectural design was the first century BC Roman author Vitruvius who states: "*The architect's greatest care must be that his buildings*

should have their design determined by the proportions of a fixed unit. When therefore account has been taken of the symmetries of the design and the dimensions have been worked out by calculation, it is then the business of his skill … to produce a proper balance by adjustment, adding or subtracting from the symmetry of the design …" [15, p. III. 1. 1.16]. Here symmetry is used not in the modern axial sense but instead to mean a balance of proportion by use of geometry. Metaphysically this preoccupation with proportional design became attached to the Christian doctrine of the affinity of souls. This was a philosophical concept that led firstly to the idea that an inborn sense makes us aware of harmony, in other words that the perception of harmony through the senses is possible by virtue of the affinity of our souls. Secondly as articulated by Leon Battista Alberti (1404–1472) it led to the idea that that a harmonic balance of proportions through geometry in a building would more effectively convey the communion of ones soul through prayer to heaven and allow the soul to partake of the vital force which lay behind all matter and which bound the universe together [16]. This was an old and much venerated Aristotelian idea and Fra Luca Bartolomeo de Pacioli (c. 1447–1517) in the second half of the Quattrocento went so far as to say in his book De Divina Proportione (On the Divine Proportion) published in Venice in 1509 but written between 1496–1498 that divine functions are of little value if the church (temple) has not been built 'with correct proportions' ('con debita proportione'). He goes on to say that perfect proportions must be applied to churches, whether or not the exact relationships are manifest to the 'outward' eye [17]. Beyond this the fabric of the well-proportioned late medieval/early modern church was not only seen as an amplifier of ones prayers it was also a palimpsest of metaphor and symbolism which was open to those who understood through spiritual and moral guidance how to interpret and learn from it. For instance at an elementary level the geometry of the circle representing heaven and the square representing earth and the geometric union of these two figures in their correct relative vertical positions in the central crossing and dome of the church was a symbol of heavenly perfection on earth. From this background the starting point for proportional analysis of this, or indeed any late medieval or early modern ecclesiastical building is normally detection of the module, the fundamental unit (mentioned by Vitruvius) used to regulate the dimensions of the building. Usually this is a divisor of the wall thickness of the nave which itself is often a multiple of the local unit of measure. At St George of the Greeks the wall thickness ranges between 1375 mm and 1400 mm. A Lombardic/Venetian foot = 347.73 mm, therefore four Lombardic/Venetian feet = 1390.92 mm, which is within a 1.1 % error of the lower range of 1375 mm and 0.5 % of the upper range of 1400 for the main east-west wall of the nave. The byzantine foot was 312.3 mm (but could be between 308 mm and 320 mm) which does not give a good multiple fit to the known wall thickness. We have no data on a Genoese foot but the Genoese palmo = 248 mm again does not yield plausible whole multiples to fit the wall dimension. However the French ell [aune] (1372 mm) lies dimensionally very close to the lower limit of the wall thickness. The French ell was mainly used as a cloth measure and it would be unusual to find it deliberately applied within an architectural context and so for the purposes of this study we discount it. The columns of the nave originally had the same thickness as the walls (1400 mm) but were later reinforced with an additional shell of masonry in 1491 after an earthquake [6, p. 190]. This increased the diameter to ~2300 mm. The triplet

colonettes on the nave wall oppose each column are 680–690 mm (~2 Venetian feet). Given the above it is recognized here that the closeness of fit of the wall and column dimensions to Lombardic/Venetian feet may not necessarily indicate a post 1372 date (i.e. after the Genoese occupation of Famagusta) but could do and could also indicate a design created by a northern Italian master mason some time before this. In an attempt to reconcile or "harmonise" the available historical evidence for the building of the new Cathedral of St George of the Greeks Kaffenberger places its erection between 1350 and 1374 and states that it was "probably begun in around the 1360 s at the very latest" [6, p. 179] and suggests citizens' piety following a plague of 1349 as a possible motivating factor in the Cathedral's inception. He also notes both that there were substantial donations towards the building of the Orthodox cathedral documented in the year 1363 [6, p. 180] and that, "…in the 1360s, the city was already suffering from a commercial decline, which would have slowly decreased the availability of financial resources necessary to start large scale building projects" [6, p. 181]. He also notes that if the cathedral were finished before the Genoese takeover of Famagusta in 1374 this would mean a construction duration of 25 years, 10 of which in the (1360's) may have been in a period of economic hardship, but during which donations were received. Twenty five years is a short period of time to complete a building of this size and Kaffenberger suggests between 50–100 years as realistic for the Latin cathedrals of Famagusta and Nicosia [18]. One might therefore reasonably assume a similar construction period for St George of the Greeks, in which case a completion date somewhere in the 1390's or 1400's at the earliest might be realistic. This would place its completion squarely within the Genoese occupation of Famagusta which began in 1372. Paschali gives a date range of between the late 1360's and ca. 1400 for the completion of the late Byzantine wall paintings which covered the two lowest registers of the central apse and the three lowest registers of the south apse [19, p. 282] (Fig. 4).

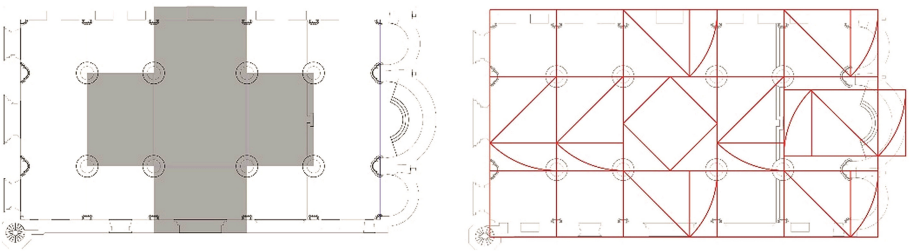

Fig. 4. Plans of St George of the Greeks: Left - showing the symmetrical central crossing. Right – the proportional arrangement of root two ($\sqrt{2}$) rectangles in process of quadrature which define the plan and the intercolumniation of the church.

Irrespective of the provenance of the unit of measure the plan conforms to medieval architectural practice insofar as it appears to be extrapolated from the wall width. The width across the cathedral between inner wall surfaces is 21.0 m or 15 × the wall module. The interior length of the nave from the west door to the iconostasis is 22 modules, the bema has a length of 5 modules from west to east, (excluding the apses). The square at

the central crossing is 7 modules on each side from the column centers, and 6 modules wide from the inner faces of the original columns (before they were thickened). The bays in the nave are 5 modules long (west to east) by 7 modules wide between column centers and those in the aisles are 5 modules long by 4 modules wide from the column center to the internal surface of the wall (Fig. 5).

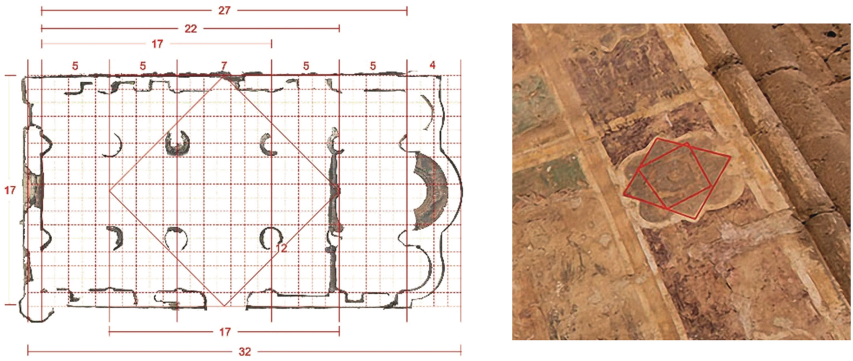

Fig. 5. Left - plan of the Cathedral derived from the photogrammetry survey overlaid with the module grid and Pell Numbers. Right - the quadrature motif, one of a number of representations of this very specific geometric figure which appear on the internal walls of the church (authors' emphasis in red lines). (Color figure online)

The use of whole number units in the plan is philosophically attractive in an Aristotelian sense, and would have had a number of practical advantages for the builders during the cathedral's construction. However the choice of numbers of units is not arbitrary because they have been selected to give close approximations to the irrational dimensions that naturally arise from the use of root two, the diagonal of the square. Many are in fact Pell Numbers which asymptotically approximate root two ratios as their values tend towards infinity. An example here is the body of the cathedral before the iconostasis an area which is 15 units wide by 22 units long. A true root two rectangle of the same width of 15 units would have a length of 21.21 units… 3.7 % shorter. This is small enough to be undetectable to the human eye but not an insignificant deviation from the geometric ideal. On the one hand the approximation of irrational dimensions with whole number ratios in this way has a long history in architectural theory and historical practice and their use at St George of the Greeks may have been a purely practical one in a perfectly normal inherited technical tradition which accepted this degree of approximation. On the other hand it is clear from the extant fabric that the geometric ideal was well understood. The plan form has at its heart the square as the generative geometric figure but the arms of the cross-in-square plan it produces are clearly not squares but are root two ($\sqrt{2}$) rectangles, whose long sides are equal to the diagonal of the central square. This ancient form of geometric rather than arithmetic extrapolation from one figure to another has a number of well-known properties of self-similarity (it is the basis of the widely used A paper size system), and traditionally is produced using compass and squares in a method known as quadrature, involving the rotation of a square about its

center. Intriguingly in the south apse of the sanctuary of St George's there exist some of the better-preserved frescoes in the first and second register representing the Deposition and Entombment on the left side of the window and the Anastasis and Holy Women at the Empty Tomb on the right. A close inspection of the geometric motif that runs around the window and at the edges shows a repeating image of the quadrature or rotating squares. The use of a motif (in this case the quadrature) as a semiotic clue to the underlying geometry of the design of the fabric of the building as whole is a common architectural trope intended to assist a viewer who had been suitably instructed to better appreciate or "read" the building as a message of overall coherence, integration and unity of design intended by the church architects as a reflection of divine creation. Symbols and signs were central to Christian thought and so a late medieval Christian would be alert to their presence and receptive to the messages like this one that they were intended to convey. But of principal interest here is the coherent way in which a bilaterally symmetrical Orthodox centralized plan form has been extended through the consistent use of repeating root two geometry to create a three aisled (one nave and two aisles) Franco-Byzantine basilica plan form. We suggest here that it indicates that the intention to unify these two traditions of Christian architectural design was not an afterthought or whim but was encoded from the outset in the "genes" of the design when the architect first started drawing its basic plan form. The mechanics of the process of extending that initial centralized square to create the basilica plan and maintain the high degree of proportional unity and coherence in it is only possible because of the unique properties of self-similarity of the root two rectangle, properties with which medieval master masons and later architects were entirely familiar both in the Christian west and the Orthodox east. It is suggested here that it is the use of *ad quadratum* root two proportional geometry, which was common to both traditions, that is the real unifying factor in this building's design (Fig. 6).

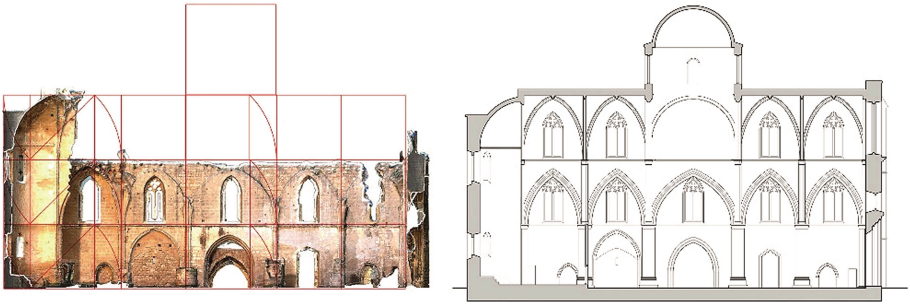

Fig. 6. Left – the internal south wall of the nave taken at the mid line longitudinal section of the church showing the root ($\sqrt{2}$) rectangles extrapolated upwards to form a three dimensional armature. Right – the same section reconstructed based on the root two proportions on the left.

This coherence also extend upwards in the third dimension to the elevational and sectional arrangement of the design through a relatively straightforward repetition of identical root two rectangles. The degree of fit between photogrammetry data and armature is very good, the height of the registers defined by the decorative string course that

separates the wall into three vertical registers or stories very closely align with multiples of a five module square giving a good alignment with the top to the springing of the vaulting. Each of the bays of the vault are of course one × five module squares wide. The height of the side aisle fits exactly within two × five module squares and the middle bay within three × $\sqrt{2}$ rectangular modules. The total height of the nave fits within three 5 × 5 module squares which is equal to the total interior width of the church which is three by five module squares wide. In order to clarify the overall composition of these proportional arrangements we recreated them as a three dimensional armature to overlay upon the 3D data from the photogrammetry as an aid in the digital reconstruction of the cathedral. It is highly probable that the architects responsible for the design of St George of Greeks conceived their initial ideas for the building in this way too, as an armature, a simplified mental model if you like, aided in memory by remembering a few of the whole number dimensions (lengths, breadth heights and so on) of the armature. From these key dimensions and the visual picture of their relationships between one another the architect could extrapolate detail as required, though the property of self similarly of the root two geometry and the *ad quadratum* method (Fig. 7).

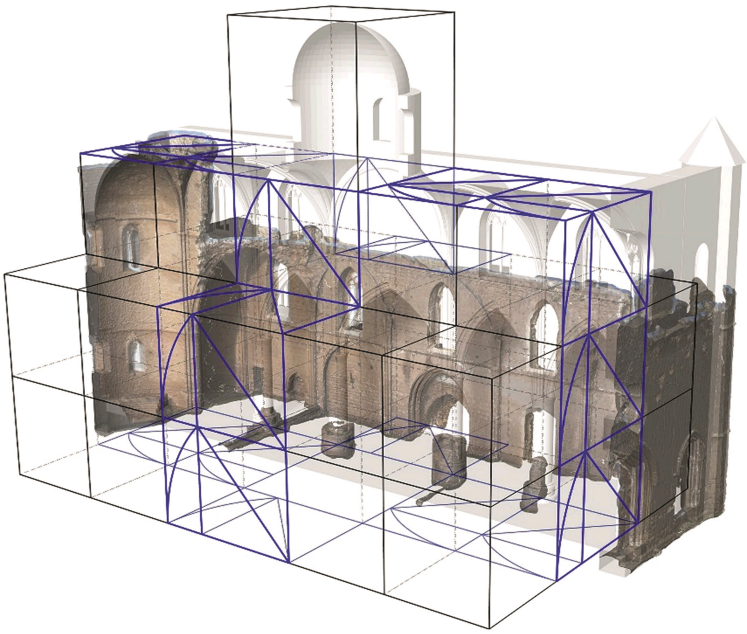

Fig. 7. The 3D armature of root two ($\sqrt{2}$) proportions superimposed upon the photogrammetry data and the reconstruction of the cathedral.

5 Conclusions

The use of root two ($\sqrt{2}$) geometry and its arithmetical approximation in church architecture is by no means unique to St George of the Greeks in Famagusta. Derived from

antecedents in Roman building practice these properties may be found both in western European church architecture and in churches in the Byzantine world. It was a method of design shared by medieval and early modern master masons and architects of both the Orthodox and Latin architectural traditions. It is suggested here that the use of *ad quadratum* (the utilization of root two geometry for developing internally coherent architectural designs) was the key underlying unifying factor in the design of the Cathedral of St George of the Greeks and that it was recognized as such by the architects. It shaped the overall form and provided a unifying framework of proportionally related regulatory lines of control to allow firstly a mathematically and architecturally meaningful union of orthodox cross-in-square plan with a Latin basilica plan and secondly an armature on which to place the architectural elements. The method of *ad quadratum* was philosophically attractive because through the concept of idealized architectural proportions it supported the Platonic concept of the affinity of souls and therefore the efficacy of prayer. There is evidence that a modular system of measurement was used and that this was applied as arithmetic whole number multiples (Pell Numbers) of the module to approximate the irrational numbers that naturally arise from the use of root two geometry. This may have been practically useful during construction but would also have been philosophically attractive in terms of the Christian interpretation of Aristotelian atomism and the indivisibility of the fundamental unit. There is also evidence from the surviving wall paintings that this program of design was meant to be understood by audiences other than the architects, in this case the clerics who served in the sanctuary beyond the iconostasis. There remains much to discover in the Franco-Byzantine churches of the Eastern Mediterranean surrounding the role of proportional systems in religious belief. We would suggest that the approach described briefly here can be usefully and more fully extended to other buildings of this type to do so.

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