Keywords: architect's cubit,
ottoman architecture, design
analysis, northern Greece,
structural systems, symbolism,
diagonals, geometry, geometric
systems, measuring systems,
module, morphology, number,
proportion, proportional
systems, symmetry

The Use of the Module, Metric Models and Triangular Tracing in the Traditional Architecture of Northern Greece

Abstract. This paper presents the analysis of the design and construction of the traditional houses in northern Greece and the correlation with the use of the metric system of the architect's cubit and the existence of architectural tracing and proportions. Of particular significance is the detection of certain metric models widely applied in the urban centres of northern Greece during the nineteenth century, and the general application of the Pythagorean theorem on the triangular tracing. The analysis was based on the application of the functional and constructional module on plans and façades of houses in order to investigate its influence on the standardisation of the design of the spaces and their elements, as well as of the construction. This makes it possible to reconstruct the design principles that characterise the traditional houses in the Ottoman Empire and the proportions of their parts, as well as to identify similarities and differences between the various urban centres of northern Greece. Another finding of the research involves the way in which the structural grid is applied to the design of the façades and to the placement of the structural elements and the openings of the timber-frame construction. As a result, conclusions are drawn concerning the role and the effect of the measuring system and the various metric models on the constructional rationale and on the development of the form of the traditional house.

1 Previous studies of tracing and proportion

The tracing and proportions that define the structure and the form of buildings from early on until the present day, have been the object of many previous studies. For the architecture of the Ottoman period, and specifically in the area of the Balkan Peninsula, the studies that are related to this paper are summarised below.

N.K. Moutsopoulos analysed the existence of geometrical harmonic tracing in the façades and the interior spaces of large mansions in Kastoria with the use of circles and diagonals. The façades are subdivided into smaller zones and parts, from which smaller sizes and proportions are derived (see [Moutsopoulos 1988: 126-128]). In his earlier studies, Moutsopoulos [1956] applied geometrical tracing in sections of Byzantine inscribed cross-shaped churches and showed that there exist constructional tracings that define the proportions of their parts (see [Moutsopoulos 2010: 100-136] and [Konstantinidis 1961: 51-52]). Similar studies concerning medieval churches in Bulgaria were presented by I. Popov [1955] and G. Kozukharov [1974]. Popov investigated the proportions using diagonal tracing and squares (quadratura or ad quadratum), while Kozuharov used equilateral and right-angled triangles in order to explore circular and arched tracing.

For Bulgaria, R. Anguelova [1993] and M. Cerasi [1988] cite the studies of P. Berbenliev, who investigated harmonic tracing following the principles of the golden section in the façades of eighteenth- and nineteenth-century houses. It is also mentioned that “the masters of Bratzigovo ... traced their plans directly on the site, which would sometimes result in harmonic relation and even in golden rule proportions” [Cerasi 1988: 93].¹ Furthermore, Cerasi mentions that “the analysis of plans and elevations of buildings by Balkan masters has shown the existence of proportions and tracing inscribed in circles”,² but stresses that “these are called up by the fundamentally empirical modular measurement systems as well as by the general rationality of Ottoman architectural practice” [Cerasi 1988: 95]. Moreover, concerning constructional tracing and proportions, Stoichkov draws the plan of a nineteenth-century mansion in Koprivchititsa, Bulgaria, overlaying a modular grid of 90 cm along with axes of symmetry and tracing [Stoichkov 1977: 58]. Cerasi redraws the above-mentioned plan on an *arşin* grid (75.8 cm), which is based on the actual module used by master-masons during that period [Cerasi 1988: 99]. All in all, Cerasi analyses the metric system of the period of the Turkish domination and its use by the builder guilds. He also presents plans of public baths and private houses of the seventeenth and eighteenth centuries from Topkapı, which are laid out on a grid, and thus proves that the basic module in use is the architect’s cubit (*mimar arşin*) [Cerasi 1988: 93]. Similar plans of public baths and religious buildings drawn in scale on an *arşin* grid are also presented by G. Necipoğlu-Kafadar [1986].

Apart from the above, B. Sisa analysed plans and sections of Protestant wooden bell towers in the Carpathian basin using as a starting point the medieval theory of the constructional principles of the circle-square-triangle,³ which provides evidence that carpenters did not use drawings but applied these principles directly during the construction stage [Sisa 1990: 327]. Sisa’s drawing analysis shows that these timber structures are based on a constructional grid with specified proportions [Sisa 1990: 338, 347].

Based on this bibliographical review, it can be seen that apart from the studies by Stoichkov and Cerasi, who apply a uniform constructional grid to house plans, and Necipoğlu-Kafadar, who presents original drawings, the rest of the studies do not use or present a given module but apply tracing of circles and diagonals that subdivide the façades or sections into smaller parts, without mentioning the use of the module.

In relation to the above, the contribution of the present study lies mainly in the investigation of metric proportions and the use of the module in the design of traditional houses and the identification of specific metric models and building types in combination with architectural tracing, which are largely applied in the urban centres of Northern Greece during the eighteenth and nineteenth centuries. It is shown that constructional tracings exist, but only concerning the plan and its tracing on the ground, whereas the proportions of façades and heights derive from the consequent subdivisions and not from diagonal tracing.

2 Methodology

The starting point of this study is the author’s Ph.D. thesis [Oikonomou 2007] which involved the analysis of the typological, morphological, constructional and environmental characteristics of forty traditional houses in Florina, in northwestern Greece. An important part of this work was dedicated to the investigation of the application of the module in houses of the nineteenth century.⁴ The research led to a

scientific paper presented in Greece [Oikonomou and Dimitsantou-Kremezi 2009]. More recent work [Oikonomou et al. 2009] extended the research in order to include eight houses from different towns and settlements in north-western Greece. Four of them were situated in Florina and were included because of their unique characteristics, whereas the rest of the examples were from Ano Kranionas in the Korestia area, Trikala, Oxia on Mount Vitsi, and Kastoria. The selection was based on the fact that their plan design is derived from the same building type design, that of the house with the central (cross-shaped) *sofa*.

The current work is a further extension of this approach to selected traditional houses in the wider area of Northern Greece. This investigation is based on the application of the functional and constructional module (a modular grid) on original or redrawn plans and façades of selected typical houses. To compile the present study, a total of one hundred houses from different towns and settlements in Northern Greece were selected and analysed, twenty of which are presented here. Most of them are situated in Florina, Kastoria, Siatista, Eratryra, Kozani, Veria, Serres, Xanthi, Ioannina, Arta, Trikala and Ampelakia. Apart from these, two remaining Ottoman monuments of Florina are also included in the study. The aim of this analysis is to investigate the influence of the module on the standardisation of the design of the spaces and their elements, as well as on the construction.

Before beginning, it will be helpful for the reader to define the main elements that characterise the houses here. These are *oda*, room; *sofa*, central hall; *eyvan*, covered patio or alcove; *hayat*, a living space.

3. Investigation of the application of the module in the traditional architecture of northern Greece

3.1 The metric system of the *mimar arşin*, or architect's cubit

The measuring of plots and the construction of buildings in the Ottoman Empire was based on the *mimar arşin*, or architect's cubit. The arşin is divided into 24 *parmak*, or fingers; the finger is divided into 12 *hatt*, or lines; and the line is divided into 12 *nokta*, or points [Cerasi, 1988: 92]. The arşin is also divided into two equal parts called *kadem* [Özdural, 1988: 113].

The Ottomans used the arşin from the beginning of the sixteenth century, though its precise measurement varied. Alpay Özdural mentions that the imperial measuring unit was equal to 72.1 cm in 1520; 73.4 cm during the last quarter of the sixteenth century [Özdural 1988: 103]; and 76.4 cm during the third quarter of the eighteenth century. The arşin of 75.8 cm was the fourth and final version, assigned as the imperial measuring unit by Selim III, during the years 1794-95, and remained in use until 1934, when it was replaced by the metre [Özdural 1988: 106].

The arşin, similar to the old English yard, was both an instrument and a measuring unit [Cerasi 1988: 92]. As an instrument, it was usually made of ebony, wood, bronze, copper or bone and could be folded into two parts (*kadem*) or four parts. As mentioned, it was subdivided into parts of 12 or 24 [Özdural 1988: 113].

3.2 The module and the grid

From earlier studies [Oikonomou 2007, 2009], it was seen that the *oda* usually have a square plan with dimensions 5x5 or 6x6 arşin. The *sofa* has a rectangular plan with its small dimension (width) equal to 3, 4, or 5 arşin. When the hall results from symmetrical

repetition, its width is equal to 7 or 8 arşin (2×3.5 or 2×4). The sizes of the oda and sofa are usually combined, resulting in many different possible variations. It should be noted that in houses with large odas with dimensions 6×6 arşin, the sofa's width is never smaller than 4 arşin. The same applies to four-room houses with an inner sofa, even when the odas are 5×5 arşin. In general, from the research presented in this paper, it can be seen that there is a tendency to use whole multiples of the arşin.

Concerning the placement of windows, it should be noted that the module is equal to the width of the openings. As a result, in an oda with dimensions 5×5 arşin, the windows are placed either at intervals of 1 arşin or at intervals of 1 kadem. In the first case, two windows are placed on each façade, whereas in the second one, each façade has three windows (fig. 1).

Fig. 1. The placement of windows according to the constructional and functional module

3.3 The basic metric models

The metric models, which can be found in the architecture of northern Greece, as well as in the urban centres of the wider Balkan area, are possibly based on plans that existed in Istanbul.⁵ These plans were drawn on rid paper with a module based on the architect's cubit and at a scale of 1:48 [Cerasi 1988: 93]. The module is related to the dimensions of the spaces and to the spacing of the structural elements. In the earlier designs, the walls are depicted in great detail, while in the more recent ones, the walls are depicted with one single line and the decorative elements in great detail [Cerasi 1988: 93, pictures 1 and 2].

In the architecture of northern Greece, the two most common metric models that are observed are:

- a) The house with odas of 5×5 arşin and sofa with a width of 3 arşin (figs. 2, 14);
- b) The house with odas of 6×6 arşin and sofa with a width of 5 arşin (figs. 9, 20-21).

The first model is usually used in houses with two odas and a sofa, whereas the second one in houses with four odas and an inner sofa.

The following models are also commonly found:

- c) Houses with odas of 5×5 arşin and sofa with a width of 4 arşin (figs. 5, 15);
- d) Houses with odas of 6×6 arşin and sofa with a width of 4 arşin (fig. 16).

The house model a-5/3/5 can be adjusted on the plot and the needs of the owner. The subtraction of an oda results in a non-symmetrical house with one oda of 5 x 5 arşin and a sofa of 3 x 5 arşin (model a1-5/3) with a total length of 9 arşin. Respectively, the doubling of the sofa, leads to a house with two odas of 5 x 5 arşin and a twin sofa of 3 x 5 arşin (model a2-5/3/3/5). The total length in this case is 17 or 18 arşin, depending on the thickness of the external walls [Oikonomou and Dimitsantou-Kremezi 2009: 311, fig. 2].

In the house model c-5/4/5, the doubling of the sofa can lead to a house with four 5 x 5 arşin odas and a twin sofa of 4 x 11 arşin (model c1-5/4/4/5). The total length in this case is 19 arşin and the width 12 arşin [Oikonomou et al. 2009: 555, fig. 13-14].

At this point, a standardisation concerning the total length of the building façades should be noted. Usually, the length of the house is 14 arşin (model a-5/3/5 and c-5/4/5) or 17 arşin (model b-6/5/6). Furthermore, there are many houses with a length of 16 arşin (model c-5/4/5 and d-6/4/6). Finally, there are large mansions with a total length of 21 or 23 arşin (model f-6/8/6 or model g-7/7/7).

This standardisation is closely related to the standard thickness of the walls. For instance, a house with two odas of 5 x 5 arşin, a sofa 3 arşin wide and light-weight timber-frame walls of 19 cm (1/4 a.) has a total length of 14 arşin (5+3+5+1), whereas a house with two odas of 5 x 5 arşin, a 7 arşin wide hayat, thick exterior walls (57cm – 3/4 a.) and light-weight interior walls has a total length of 19 arşin (5+7+5+2). In conclusion, the choice between thick or thin walls defines the final dimensions (length and width) of the house (fig. 2).

Fig. 2. Plan of a building (Mavroudis house) with rooms of 5 x 5 arşin and a sofa of 3 x 5 arşin

Fig. 3. Plan of a building (Anagnostopoulou house) with rooms of 5 x 5 arşin and a hayat of 7 x 5 arşin

Fig. 4. Façade of Ioannou Mansion in Florina.
The upper floor height is 4 arşin and the ground floor height is 3.5 arşin

Fig. 5. Façade of Chatzitzotzas Mansion in Florina.
Redrawn from plans by A. Stoios and M. Papagiannakis

Finally, it should be noted that the metric system of the architect's cubit is also applied to the building façades, where, similar to the building plans, a standardisation of sizes is also observed. The total height of the houses, without the roof, is usually 7 arşin. Nevertheless, there are many houses with a height of 8 or 9 arşin, which have a raised ground floor. The upper storey height is 3.5 or 4 arşin, while the ground floor height is 3 or 3.5 arşin. These dimensions correspond to the exterior dimensions of the spaces, the dimensions of the structural elements and, consequently, to the dimensions of the façades. Finally, the upper storey windows have a sill height of 1 arşin and a clear height of 2 arşin, whereas in the ground floor, they have the same sill height, but a total height of 2 arşin including the cornice. In this way, the placement of the openings on the façades is characterised by a relationship of a - $2a$ - a , where a is equal to the window's width and the sill height, and $2a$ to its height (figs. 4-5).

3.4 The use of triangular tracing

The metric models that are analysed contribute to the standardisation of the construction of the traditional house. Most of the buildings presented have a fully rectangular plan. At the same time, the constructional and functional module is applied accurately, not only in the placement of the basic structural elements and the openings, but also in the dimensions of the spaces. All the above lead to the conclusion that before the construction of the house, certain basic architectural tracing, which assumes basic knowledge of geometry, took place.

For the tracing of the rectangular perimeter of the house and its basic walls, the Pythagorean theorem with the basic right-angle 3-4-5, 5-12-13 and 8-15-17 triangles⁶ is applied with the use of *knotted ropes*. Stoichkov has proven that master builders in Bulgaria used the 3-4-5 and 5-12-13 triangles during the nineteenth century [Stoichkov 1977: 126, 145]. The same methods certainly apply in Northern Greece during this period.

Fig. 6. Use of the module and triangles 3-4-5, 6-8-10, 9-12-15 and 5-12-13 in the tracing of the metric models

The 3-4-5 triangle can be multiplied by various factors (2, 3, 3.5, 4, 5, 5.5, 6, etc.) to produce triangles of the necessary dimension; thus multiplication by a factor of 2 produce the 6-8-10 triangle; by a factor of 3, 9-12-15; and so forth. The 5-12-13 triangle can be divided by a factor of 2 to produce a triangle 2.5-6-6.5, whereas the 8-15-17 triangle can also be divided by the same factor to produce a triangle 4-7.5-8.5.

Furthermore, the use of circular auxiliary tracing can not be ruled out, especially for houses with odas of 5 arşın and a sofa of 3 arşın. The numbers 5-3-5 are related to the subdivision of a line with a length of 13 into two parts with lengths of 8 and 5 (extreme and mean ratio) and the Fibonacci series (see [Konstantinidis 1961: 190-191]).

The following diagrams include observations concerning the various metric models and their way of tracing (fig. 6). In this way, the relationship with the above-mentioned characteristic right-angled triangles is investigated and conclusions concerning the possible tracing of the spaces of the houses and their design can be drawn. Finally, the possible influence of the characteristic 3-4-5 triangle in the placement of the diagonal structural parts of the timber frame and in the form of the small pediment on the main façade is also investigated. Noting that $\tan 53^\circ$ is approximately equal to $4/3$ and that $\tan 37^\circ$ is approximately equal to $3/4$, the fact that the diagonal elements are in many cases placed at an angle of 53° and that the pediment often has a slope of 37° suggest that this triangle might have also been used in the construction of the façades, independent of the tracing of the plan (fig. 7).

Fig. 7. Use of the module and basic triangle 3-4-5 in the construction of the timber-frame structure

At this point it is useful to site the definition given by Jouven concerning the (harmonic) tracing:

A harmonic trace is a geometric figure whose design coincides with the main lines of a building (or what amounts to the same, its graphic representation in geometrical projection). The choice of this geometric figure, conceived at the same time as the building by the architect, is based on the remarkable properties that are included in it [Jouven 1951: 7].

Jouven also explains:

We mean by main lines those whose knowledge is sufficient to determine the elements of construction (perimeter, axes, lines of change, etc.). We can say in a quick way that they are the main lines of a first rough drawing of the building [Jouven 1951: 7].

In well-known *academic* plans of important buildings of the Renaissance period or the neoclassical and eclectic buildings of the eighteenth and nineteenth centuries, designed by engineers using the metric system and constructed with dressed stone and fired-clay bricks, the construction is accurate and we do not generally observe discrepancies between the tracing and the actual building. Nevertheless, when investigating the application of the tracing to actual *traditional* buildings, we must expect discrepancies in terms of the reference lines; namely, the starting point for the tracing of the building is found either on the outer edge of the wall, or in its middle. This is due to the fact that traditional buildings have no specific plan (only rough drawings) (see [Cerasi 1988: 93]) and certainly no façade drawings, are constructed by master masons based on principles of timber-framed construction, and are built with local, natural materials, such as field stone and adobe bricks. Consequently, when the builders construct a thick adobe wall, they may trace the centre line of the wall, or they may start from its exterior corner. It seems that the basic tracing and the basic models and rough drawings involve only light-weight structure. These model drafts are adjusted on site according to the need to create thick exterior walls due to climatic (northern orientation), or for reasons related to function (location of fireplace) and safety (proximity to the street).

Apart from the above, we must bear in mind that the tracing of the upper stories is also made on the ground, and the construction is based on the specific grid and module of the architect's cubit [Kizis 1994: 131, 153-154]. This can result in a rather complex triangular tracing, without necessarily meaning that the diagonals are in fact traced on the ground: only the (exterior or interior) corners of the rooms are pin-pointed by wooden marks (see also [Kizis 1994: 154]). In this way it is impossible to find any sign or mark of the presented tracings as they were made on the ground before the buildings were actually built.

3.5 Building typology

The house types that are found in urban centres differ significantly from those in rural settlements, not only in their development through time, but also in their basic structure. The development of building types in urban centres is parallel or later than that of the types in the villages, but it is not always linear and can be more intricate. We could talk about a synthetic design process, which is dictated by economic or spatial factors. The transition from simple to more complex types is achieved with the addition (multiplication) of spaces during the eighteenth and early nineteenth centuries (see [Kuban 1995: 105]). Nevertheless, during the second half of the nineteenth century,

there are house plans that derive from the reduction of the number of spaces – namely the subtraction of one oda – from a closed, complete type, such as that of the house with the central sofa.

The master-builder proposes the application of the building type that is appropriate not only for the owner's economic situation and needs, but also to the size of the plot, which, in the urban centres, usually has a limited street front. These parameters lead to the adjustment of the basic model type with the subtraction of living spaces, and as a result variant types, which can be considered, for example, as the two thirds ($2/3$) of a complete and established type, occur. In other instances, the repetition of an element, such as the sofa, leads to larger, twin-type houses (fig. 8).

Fig. 8. Typological considerations for the traditional houses of the nineteenth century

3.6 Building construction

The light-weight walls of the upper storey (*çatma*) are thin (19 cm) and formed by a complex timber frame, which is filled with adobe bricks and, in some cases, small stones or fired-clay bricks. The basic, vertical structural elements (*direk*) are positioned in the corners of the spaces and between the openings, at regular intervals of about 150 cm (2 arşin). In between, horizontal elements are placed at heights of 75 and 225 cm (1 and 3 arşin). This leads to the creation of large and small frames. In the former, openings with a width of 75 cm (1 arşin) are placed at regular intervals relative to the dimensions of the

interior space. In the latter, smaller vertical elements are placed over and under the window. Finally, diagonal elements of triangulation are placed in all the frames in order to increase the rigidity of the structure.

The constructional grid of the main façade is directly related to the plan and is very interesting. The basic structural elements are always placed at regular intervals, while the windows are placed symmetrically with respect to the interior space. In this way, in the upper storey of a typical house with *odas* with an interior dimension of 5 arşin (379 cm) and an exterior of 5.5 arşin (417 cm), the four basic *direk* are placed at 1.75 arşin (133 cm) intervals, whereas the three openings are placed at 0.5 arşin (38 cm) intervals. Similarly, in a typical house with upper-storey *odas* of 6 arşin (455 cm) interior and 6.5 arşin (492 cm) exterior dimensions, the four basic *direk* are placed at 2 arşin (152 cm) intervals and the three openings at 0.75 arşin (57 cm) intervals (fig. 9).

Fig. 9. Typical construction of a house in Florina, Northern Greece

The structural elements of the ground floor are usually thick walls made of local stone or adobe bricks. These walls are 0.75 to 1 arşin (57 to 75 cm) thick and have an average height of 3.5 to 4 arşin (265 to 300 cm) and comprise horizontal structural wooden elements (ties) at intervals of 1 arşin (75 cm). This construction is typical in most towns and rural settlements. Finally, it should be noted that in Florina, where a local structural system exists, the ground floor walls of increased thickness include *direk* at regular intervals (4, 5 or 6 arşin) that follow the structural module and correspond to the interior partition walls. On the upper storey, the *direk* are placed in the corners and the middle of every space (at 2, 2.5 or 3 arşin intervals). The main reason for the development of this system is the fact that the construction material (local river stone) is relatively weak and the subsoil is unstable because of the river bed.

4 Presentation of the study

4.1 The Ottoman monuments of Florina

The Ottoman bath in the town of Florina has three easily discernable building phases, spanning a period of three centuries. The core of the bath can be dated according to typology (bath with small dimensions, see also [Kanetaki 2004]) and the measuring system of its construction (9 by 6.75 arşin, with an arşin equal to 73.4 cm, mentioned by Ibn Ma'ruf for the period 1569-74), to the end of the sixteenth or the beginning of the seventeenth century [Özdural 1988]. This is in agreement with the mention of the bath by Evliya Çelembi (1661) [Dimitriadis 1973] with the interior morphological elements (arches, squinches and dome), and the careful construction of the external stonework (dressed stones and cornerstones). The tracing of this core is based on the use of a triangle 3-4-5 multiplied by a factor of $2\frac{3}{4}$ to produce a triangle measuring $6\frac{3}{4}$ - 9 - $11\frac{1}{4}$ arşin (fig. 10).

Fig. 10. The Ottoman bath of Florina. Plan

At the same time, the octagonal tracing of the central space and squinches is based on the use of a circle with a diameter of $6\frac{3}{4}$ arşin, and in this way the interior diagonal is equal to the exterior dimension. The transversal timber frame-work (*klapes*) are also placed at approximately 1 arşin (73.4 cm) intervals, whereas the fired-clay bricks used in the interior side of the walls and the dome are based on $\frac{1}{3}$ arşin (dimensions of 23x11.5x4 cm). The individual bath and the antechamber were added to this core during the eighteenth century, according to the 76.4 cm arşin then in use (see also [Özdural 1988]). The south-eastern part may have also included an individual bath, with an orthogonal plan and domed cover, which was later destroyed.

The Ottoman *kule*, or defensive tower, in the town of Florina initially had a second storey, of which only part of the eastern façade, comprising a closed opening, the end of the staircase and a second smaller opening, are preserved. The morphology of the tower (pointed Islamic arches with four tracing centres) resemble earlier Ottoman monuments of the sixteenth and seventeenth centuries (see also [Brouskari 2008]). Nevertheless, its construction (stonework with river stones and use of timber ties) suggest a more recent, eighteenth-century construction. Apart from the above, the tracing and the construction

of the kule (external dimensions equal to 9 arşin and distance between the timber ties equal to 4 arşin) is based on a 75.8 cm arşin, which was declared as the imperial measuring unit during the years 1794-5 by Selim III (see also [Özdural 1988]). Consequently, its construction can be dated with a fair degree of certainty to the end of the eighteenth or the beginning of the nineteenth century. The octagonal tracing of the walls, arches and squinches is based on the use of a circle with a diameter of 9 arşin, and thus the internal diagonal is equal to the external dimension (fig. 11).

Fig. 11. The Ottoman tower of Florina, plan

At the same time, the internal height is equal to the internal dimensions ($9/\sqrt{2}$ arşin) and as a result, an imaginary sphere can be inscribed in the interior (fig. 12-13). All the above elements – octagon, double square and sphere – constitute elements of symbolism in Islamic architecture.

Fig. 12. The Ottoman tower of Florina, section

Fig. 13. The Ottoman tower of Florina, section

4.2 The traditional houses of Florina

In small buildings like the Mavroudis house (model 5/3/5; see also fig. 2), the dimensions of the odas are 5x5 arşin and of the sofa 3x5 arşin. The tracing of the ground floor is based on 6-8-10 triangles (3-4-5 multiplied by a factor of 2) (fig. 14). Other buildings (model 5-3), have a plan that is equal to the 2/3 of the model, whereas the duplication of the sofa (model 5-3-3-5), leads to different plans [Oikonomou and Dimitasantou-Kremezi 2009: 311, picture 2].

Fig. 14. Ground floor plan of Mavroudis house

Fig. 15. Ground floor plan of Chatzitzotzas Mansion. Redrawn from [Stoios, Papagiannakis]

Fig. 16. Ground floor plan of Temelkos house

Fig. 17. Ground floor plan of Ioannou Mansion

Chatzitzotzas Mansion (model 5/4/5 - see also fig. 5) is a two-storey house with an inner sofa built around 1875. On the ground floor, the dimensions of the odas are 5 x 5 arşin and of the secondary rooms are 5 x 4 arşin. The sofa measures 4 x 10 arşin. Note that the width of the secondary rooms is equal to that of the sofa. The tracing of the ground floor, including the thick stone wall on the back, is based on a 10.5-14-17.5 triangle (3-4-5 multiplied by a factor of 3.5) (fig. 15).

In Temelkos house (model 6/4/6) the simple tracing uses two 6-8-10 triangles (fig. 16). The odas have a square plan with dimensions 6 x 6 arşin and the inner sofa measures 4 x 6 arşin.

In a different house plan deriving from the model 6/5/6, that of Ioannou Mansion, one can see the extension of the inner sofa in the front, a special space known as *divan-hane* with dimensions 5 x 5 arşin. The tracing is based on the 6-8-10 (3-4-5 multiplied by a factor of 2) and 5-12-13 triangles (fig. 17).

4.3 The Mansions of Kastoria

In Kastoria, during the eighteenth century, the building type with a hayat and eyvan, and the same plan (two odas with a hayat and an eyvan) is found in more than one case: the mansions Tsiatsapa (1754, fig. 18) and Sapountzi (fig. 19).⁷ The arşin in use is that of the eighteenth century (76.4 cm). The internal dimensions of the odas are 6 x 6 and the eyvans are 5 arşin wide, whereas the hayat is 8 arşin deep and has an area equal to that of the main spaces. The tracing of the perimeter is made with the use of two 12-16-20 triangles, while two 8-15-17 triangles are used in the tracing of the interior eyvan walls. A very interesting finding is the fact that a circle with a radius of 17 arşin can be used for the tracing of the two kiosks on the façade of the Tsiatsapa Mansion.

Fig. 18. Upper storey plan of Tsiatsapas Mansion. Plan redrawn from [Mazarakis 2005:a]

Fig. 19. Upper storey plan of Sapountzis Mansion. Plan redrawn from [Mazarakis 2005:a]

Fig. 20. Upper storey plan of Papaterpos Mansion. Plan redrawn from [Mazarakis 2005:a]

Fig. 21. Upper storey plan of Mitousis Mansion. Plan redrawn from [Papaioannou 2003]

During the nineteenth century, in Kastoria, the house type with the central (cross-shaped) sofa (Papaterpos, Mitoussis and Vergoulas Mansions) follows the model 6/5/6.

Papaterpos Mansion (fig. 20) and Mitousis Mansion (fig. 21) are very similar. Both are three-storied houses built in the nineteenth century. The building type of both is that of the house with a central sofa. On the upper storey, the main odas in Papaterpos Mansion have a size of 5 x 6 arşin, while those of Mitousis Mansion have a size of 5 x 7 arşin, while the dimensions of the other two odas in both cases are 6 x 6 arşin. In both mansions, the sofa has a width of 5 arşin and the eyvans that form the cross, are 5 arşin wide in Papaterpos Mansion and 4 arşin wide in Mitousis Mansion. In both cases, the perimeter of the mansion (without the rear wall) is basically a square with dimensions 17 x 17 arşin (model 6/5/6). The tracing of the basic walls is based on the 5-12-13 and 12-16-20 (3-4-5 multiplied by a factor of 2) triangles (fig. 20).

4.4 The Mansions of Siatista

In Siatista, there are many large mansions of the second half of the eighteenth century with an inner sofa (Poulkidis, Nerantzopoulos, Kanatsoulis and Manousis Mansions), which follow a completely different metric model (7/7/7 or 7/8/7). In most cases, the tracing of the perimeter is made with the use of 10.5-14-17.5 (3-4-5 multiplied by a factor of 3.5) and 15-20-25 (3-4-5 multiplied by a factor of 5) triangles, whereas in the tracing of the interior sofa walls, the 8-15-17 triangle is used. The arşin in use is that of the eighteenth century (76.4 cm).

Fig. 22. Upper storey plan of Poulkidis Mansion. Plan redrawn from [Moutsopoulos 1964]

Poulkidis Mansion (1752) and Nerantzopoulos Mansion (1754), probably built by the same master-builders, show an identical tracing of the perimeter based on the triangle 16.5-22-27.5 (3-4-5 multiplied by a factor of 5.5) (fig. 22). The tracing of the interior hall walls is made with the use of the 8-15-17 triangle. A very interesting finding is the fact that these interior walls can be traced with two circles with a radius of 15 arşin (fig. 22) and in that way two squares 15x15 are inscribed in the building perimeter. Also, a circle with a radius of 17 arşin can be used for the tracing of characteristic points of wall intersections.

Kanatsoulis Mansion (1757) and Manousis Mansion (1763) show an identical tracing of the perimeter based on the triangle 16.5-22-27.5 (3-4-5 multiplied by a factor of 5.5) (fig. 23). The tracing of the rooms and the interior hall is made with the use of the 8-15-17 triangle. The right interior wall of the hall can be traced with a circle with a radius of 15 arşin (fig. 23) and a second circle with a radius of 17 arşin can be used for the tracing of the main oda projection on the left. The plans of the two Mansions are identical, suggesting that they were built by the same master builders (probably the ones that built Poulkidis and Nerantzopoulos Mansions).

Fig. 23. Upper storey plan of Kanatsoulis Mansion. Plan redrawn from [Mazarakis 2005:b]

Fig. 24. Middle floor plan of Alexiou Mansion. Plan redrawn from [Moutsopoulos 1964]

Alexiou Mansion (1760) is a very large building and has a simple tracing of the perimeter that uses the triangles 12-16-20 (3-4-5 multiplied by a factor of 4) and 18-24-30 (3-4-5 multiplied by a factor of 6) (fig. 24). The hall has a width of 8 aršin. The dimensions of the plan, the construction of the walls, and the overall morphology of the mansion indicate that there must have been a second floor with timber-frame walls and projections that was destroyed at an unknown time.

In the nineteenth century, a different aršin (75,8 cm) is used, and the tracing of smaller buildings, like Lioukas Mansion, uses the 9-12-15 (3-4-5 multiplied by a factor of 3) and 12-16-20 (3-4-5 multiplied by a factor of 4) triangles (fig. 25). Nevertheless, the model applied (7-7-7) is similar to that of some eighteenth-century buildings in Siatista.

Fig. 25. Upper storey plan of Lioukas Mansion. Plan redrawn from [Moutsopoulos 1964]

4.5 The Mansions of Kozani

In Kozani, there are a few eighteenth-century mansions, such as the G. Vourkas Mansion (1748) and the N. Vourkas-Katsikas Mansion, with plans similar to the ones of Siatista. In fact the same plan is applied 'in mirror'. In N. Vourkas-Katsikas Mansion (1762), the tracing of the perimeter is based on the 15-20-25 triangle, while the 8-15-17 triangle is used in the tracing of the interior sofa walls and the rooms (fig. 26).

Fig. 26. Upper storey of N. Vourkas Mansion. Plan redrawn from [Haritidou-Mavroudi 1986]

Fig. 27. Upper storey plan of Paloukas Mansion. Plan redrawn from [Mazarakis 2005:b]

In the plan of Paloukas Mansion (fig. 27), the tracing of the perimeter, the hayat and all the interior walls is based entirely on the transformations of the 3-4-5 triangle: 6-8-10, (3-4-5 multiplied by a factor of 2); 9-12-15 (3-4-5 multiplied by a factor of 3); and 12-16-20 (3-4-5 multiplied by a factor of 4).

4.6 The Mansions of Eratyra

The Eratyra Mansions have many characteristics in common with these of Siatista and Kozani. In Chatzigiannis Mansion, the tracing of the inner sofa is based on the triangle 8-15-17, and the tracing of the perimeter is made with the use of a circle of a 15 arşin radius (fig. 28). On the ground floor, a combination of a 9-12-15 and a 5-12-13 triangle is used. The applied model is in fact similar to the 2/3 of the completed building type with four rooms and an interior hall-sofa.

Fig. 28. Upper storey plan of Chatzigiannis Mansion. Plan redrawn from [Aivazoglou-Dova 1998]

Fig. 29. Upper storey plan of Bairaktarous Mansion. Plan redrawn from [Aivazoglou-Dova 1998]

Lazaridis Mansion (1798) and Bairaktarous Mansion show a similar tracing of the perimeter based on the triangle 15-20-25 (3-4-5 multiplied by a factor of 5) (fig. 29). The tracing of the rooms and the interior hall is made with the use of the 8-15-17 triangle. The plans of the two mansions present many similarities, suggesting that they were built by the same master builders.

4.7 The Mansions of Ampelakia

In Ampelakia there existed small houses with an open hayat and with a typology of rural origin, like Tsokanos house. In this building, the simple tracing uses a combination of 9-12-15 and 5-12-13 triangles, and the perimeter is based on a circle with a radius of 13 arşin (fig. 30).

On the other hand, in larger buildings like Krasoulis Mansion (1797), which has an open hayat with an eyvan, the tracing of the perimeter is based on the 13.5-18-22.5 (3-4-5 multiplied by a factor of 4.5) and 9-12-15 triangles. The tracing of the eyvan uses a 5-12-13 triangle (fig. 31) The plan shows similarities with nineteenth-century cross-shaped plans.

Similar tracing can be found in the G. Schwartz Mansion, built in 1798. The L-shaped stone perimeter wall is designed and constructed with the use of an 18-24-30 (3-4-5 multiplied by a factor of 6) triangle, while the tracing of the interior walls is based on the 5-12-13 and 9-12-15 (3-4-5 multiplied by a factor of 3) triangles (fig. 32). All the eyvans are 5 arşins wide.

Fig. 30. Upper storey plan of Tsokanos house. Plan redrawn from [Megas 1946]

Fig. 31. Upper storey plan of Krasoulis Mansion. Plan redrawn from [Moutsopoulos 1966]

Fig. 32. Upper storey plan of G. Schwartz Mansion. Plan redrawn from [Moutsopoulos 1966]

5 Conclusions

In this paper, the application of metric proportions and tracing has been investigated in selected examples of eighteenth- and nineteenth-century mansions and traditional houses in Northern Greece. This has made it possible to identify certain metric models and housing types that were commonly applied, together with the triangles used in their tracing. The basic house types with a central sofa or an inner sofa are, in some cases, adjusted to the size of the plot and the demands of the owner, resulting in smaller houses with two or four odas and an inner sofa with or without eyvan. The three basic metric models are the 5/4/5, the 6/5/6 and 7/7/7.

In Kastoria, during the eighteenth century, the building type with a hayat and eyvan, and the same plan (model 6/5/6 with a hayat 8 arşin deep) is applied to more than one case (Sapountzi and Tsiatsapa Mansions). During the nineteenth century, in Kastoria, the house type with the central sofa (Papaterpos, Mitoussis and Vergoulas Mansions) follows the model 6/5/6.

The same model and the model 5/4/5 are also found in Florina, Trikala, Eratryra, Veria, Xanthi during the nineteenth century, while in towns such as Siatista and Kozani in the second half of the eighteenth century there are mansions with an inner sofa (Nerantzopoulos, Manousis, Poulikidis and Vourkas Mansions) that follow a completely different metric model (7/7/7 or 7/8/7). Another important finding is that the tracing of the Siatista and Kozani Mansions (1740 – 1765), as well as of two Kastoria Mansions (Sapountzi and Tsiatsapa), is based on the arşin of 76.4 cm, whereas in the majority of the other presented examples (1795 and after), the 75.8 cm arşin is used.

Concerning the use of triangular tracing, it should be noted that during the period of the eighteenth and nineteenth centuries, the basic triangle 3-4-5 and its transformations (multiplied by factors of 2, 2.25, 3, 3.5, 4, 4.5, 5, 5.5 and 6) is used for the tracing of the perimeter. Nevertheless, the change in the building types and the space dimensions resulted in a significant change in the use of orthogonal triangles. Consequently, apart from the above-mentioned triangle, during the eighteenth century, the triangle 8-15-17 is widely used in the tracing of hayats and sofas. On the contrary, during the nineteenth century, in the compact house forms, the 5-12-13 triangle is used in the tracing of sofas and eyvans.

From the above, it can be seen that the choice of certain basic models – prototypes and triangles is directly linked to the application of the predominant building types during the different periods and in the different areas (type with hayat and eyvan, type with an inner sofa and type with a central sofa) and largely affects the form and the proportions of the houses.

Further research should include a larger number of mansions from the wider Balkan area, including houses of Albania, countries of the Former Yugoslavia, Bulgaria and Turkey, pertaining to different building types. In that way, the principles and the proportions of the traditional house of the Ottoman Period can be derived and similarities and differences between the different urban centres of the different countries can be noticed.

Acknowledgments

Aineias Oikonomou would like to thank the Greek State Scholarships Foundation (I.K.Y.) for supporting the post-doctoral research of which this study forms part. The research was supervised by Professor Aikaterini Dimitsantou-Kremezi, and was conducted in the Laboratory of Architectural Form and Orders, N.T.U.A. School of Architecture. The author would also like to thank Arch. Eng. Achilleas Stoios and Arch. Eng., M.Sc., Michalis Papagiannakis for providing the original drawings of the Chatzitzotzas Mansion in Florina.

Notes

1. Cerasi [1988] cites [Berbenliev and Partasev 1963], as well as his personal communications with P. Berbenliev.
2. Cerasi [1988: 95] also notes that the use of long leather strips for the measuring and tracing on the site encourages circular and diagonal tracing.
3. See also Jouven [1961: 23, 24], for the council concerning the construction of the Milan Cathedral *ad quadratum* or *ad triangulum* (1391), as well as Jouven [1951: 25], for the principle “circle-square-triangle” by the Bauhütten building guild in Germany, according to Ghyka [1931]).
4. This investigation departs from the approach described by Cerasi [1988] and Stoichkov [1977].
5. See also Eldem [1955: 223], who mentions that it is very likely that the initial designs on which the basic building types were based were designed by capable Turkish architects.
6. See also Choisy [1976: 49-50] and Konstantinidis [1961: 112] concerning the construction of right angles with the application of the Pythagorean theorem in Egyptian and Indian architecture, respectively. The 3-4-5 triangle is sometimes called the Egyptian Triangle.
7. These two mansions are based on a similar plan, which is applied in a symmetrically opposite way.

References

- AIVAZOGLU-DOVA, D. 1998. Eratryra. Pp. 275-308 in *Greek Traditional Architecture. Greece. vol. 7. Macedonia A'*, G. Lavas, ed. Athens: Melissa Publications (in Greek).
- ANGUELOVA, R. 1993. Bulgaria. Pp. 83-148 in *Balkan Traditional Architecture*, L. Vagena-Papaioannou and D. Kamini-Dialetti, eds. Athens: Melissa Publications (in Greek).
- BERBENLIEV, P. and V. H. PARTASEV. 1963. *Bratigovskite Maistori Stroiteli prez XVIII i XIX vek i tahnoto arhitekturno tvorcestvo*. Sofia: Tehnika (in Bulgarian).
- BROUSKARI, E. 2008. *Ottoman Architecture in Greece*. Athens: Ministry of Culture, Directorate of Byzantine and Post-Byzantine Antiquities (in Greek).
- CERASI, M. 1988. Late-Ottoman Architects and Master Builders. Pp. 87-102 in *Muqarnas V: An Annual on Islamic Art and Architecture*, O. Grabar, ed. Leiden: E.J. Brill.
- CHOISY, A. 1976. *Histoire de l'Architecture. vol. 1&2*. France: Editions SERG.
- DIMITRIADIS, V. 1973. *Central and Western Macedonia according to Evliya Celembi*. Thessaloniki: Society for Macedonian Studies (in Greek).
- ELDEM, S. H. 1955. *Türk Evi Plan Tipleri*. Istanbul: Istanbul Teknik Üniversitesi – Mimarlık Fakültesi, Pulhan Matbaası.
- GHYKA, Matila C. 1931. *Le Nombre d'or*. Paris: NRF.
- HARITIDOU-MAVROUDI, E. 1986. To arhontiko tou Nikolaou Vourka (i Elia Katsika) stin Kozani (The mansion of Nikolaos Vourkas (or Nikolaos Katsikas) in Kozani). Pp. 43-56 in *Eponyma Arhontika ton Hronon tis Tourkokratias (Eponymous Mansions of the Period of the Turkish Domination)*. Athens: National Technical University of Athens.

- JOUVEN, G. 1951. *Rythme et Architecture. Les Traces Harmoniques*. Paris: Editions Vincent, Freal et Cie.
- KANETAKI, E. I. 2004. *Ottoman Baths in Greece*. Athens: Technical Chamber of Greece Publications (in Greek).
- KIZIS, J. 1994. *Pilioritiki Oikodomia (Domestic Architecture in Pelion 17th – 19th c.)*. Athens: Cultural Technological Foundation ETBA (in Greek).
- KONSTANTINIDIS, D. 1961. *Peri armonikon haraxeon eis tin arhitektonikin kai tas eikastikas tehnas. Historia kai Aesthitiki (On Harmonic Tracing in Architecture and Visual Arts. History and Aesthetics)*. Athens, Greece (in Greek).
- KOZUKHAROV, G. 1974. *Svodut v Anticnostta u Srednite Vekove*. Sofia, Bulgaria: Anticnostta (in Bulgarian).
- KUBAN, D. 1995. *The Turkish Hayat House*. Istanbul: T.C. Ziraat Bankasi, MTR.
- LABORATORY OF THEORY OF FORMS. *Archive*. Xanthi: Section of Architectural Design and Construction, Department of Architecture, Democritus University of Thrace.
- LOUKAKIS, P. 1977. *To giannotiko spiti (The house of Giannena)*. Pp. 194-228 in *To Elliniko Laiko Spiti (The Greek Popular House)*, P. Mihelis, ed. Athens: N.T.U.A (in Greek).
- MAZARAKIS-AENIAN, F., ed. 2005. *Arhontika tis Kastorias (Mansions of Kastoria)*. Athens: Historical and Ethnological Society of Greece (in Greek).
- , ed. 2005. *Arhontika tis Kozanis kai tis Siatistas (Mansions of Kozani and Siatista)*. Athens, Greece: Historical and Ethnological Society of Greece (in Greek).
- MEGAS, G. 1946. *Thessalikai oikiseis (Houses in Thessaly)*. Athens, Greece: Ministry of Reconstruction Publications (in Greek).
- MOUTSOPOULOS, N.K. 1964. *Ta arhontika tis Siatistas (The mansions of Siatista)*. In *Scientific Year-Book of the Polytechnic School, vol. A. 1961-1964*. Thessaloniki: Aristotle University of Thessaloniki (in Greek).
- . 1966. *Ta Thessalika Ampelakia. Isagogi stin istoria, tin koinopraxia kai ta arhontika tis komopoleos (The Thessalian Ampelakia. An introduction to the history, the joint-venture and the mansions of the town)*. Athens: Ios Review, “Thessaly” (in Greek).
- . 1967. *I laiki arhitektoniki tis Verias (The popular architecture of Veria)*. Athens, Greece: Technical Chamber of Greece Publications (in Greek).
- . 2010. *Naodomia (Construction d'Églises)*. Thessaloniki: University Studio Press (in Greek).
- NECIPOĞLU-KAFADAR, G. 1986. Plans and Models in 15th- and 16th-Century Ottoman Architectural Practice. *Journal of the Society of Architectural Historians* 45, 3: 224-243.
- OIKONOMOU, A. 2006. Lessons from traditional architecture on sustainable planning and building design. Pp. 87-94 in *ECOPOLIS: Sustainable Planning and Design Principles. Revealing and Enhancing Sustainable Design*, D. Babalis, ed. Florence: Alinea.
- . 2007. *Comparative Investigation of the Architectural Structure and the Environmental Performance of 19th Century Traditional Houses in Florina*. Ph.D. dissertation. Athens, Greece: National Technical University of Athens, School of Architecture (in Greek).
- OIKONOMOU, A. and A. DIMITSANTOU-KREMEZI. 2009. Investigation of the Application of the Module in the Traditional Architecture of Florina. Pp. 309-318 in *Appropriate Interventions for the Safeguarding of Monuments and Historical Buildings. New Design Tendencies. Proceedings of the 3rd National Congress*, M. Dousi and P. Nikiforidis, eds. Thessaloniki: Ianos Publications (in Greek).
- OIKONOMOU, A., et al. 2009. Application of the Module and Construction Principles in the Traditional Architecture of Northern Greece. Pp. 543-562 in *LIVENARCH IV (RE/DE) Constructions in Architecture. 4th International Congress Liveable Environments and Architecture*. vol. 2. Ş.Ö. Gür, ed. Trabzon, Turkey: Karadeniz Technical University, Faculty of Architecture, Department of Architecture.
- OUSTERHOUT, R. 2008. *Master Builders of Byzantium*. Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology.
- ÖZDURAL, A. 1988. Sinan's Arşin: A Survey of Ottoman Architectural Metrology. Pp. 101-115 in *Muqarnas XV: An Annual on the Visual Culture of the Islamic World*, G. Necipoğlu, ed. Leiden: E.J. Brill.

- PAPAIOANNOU, K. 2003. *The Traditional Greek House*. Athens: National Technical University of Athens Publications (in Greek).
- POPOV, I. 1955. *Proporcii v Bulgarskata Arhitektura (Proportions in Bulgarian Architecture)*. Sofia, Bulgaria: Hayka y Yekystvo (in Bulgarian).
- SISA, B. 1990. Hungarian Wooden Belltowers of the Carpathian Basin. Pp. 305-352 in *Armos, vol. A*. Thessaloniki, Greece: Aristotle University of Thessaloniki, Polytechnic School, Department of Architecture.
- STOICHKOV, J. 1977. *Za Arhitekturata na Koprivchitza (The Architecture of Koprivchitza)*. Sofia, Bulgaria: Tehnika (in Bulgarian).

About the author

Aineias Oikonomou is an architect and for two years was an adjunct lecturer at the Departments of Architecture of University of Patras and Democritus University of Thrace. He earned a Ph.D. and M.Sc. degree in Architecture from the National Technical University of Athens, Greece, and he completed a one-year post-doctoral research in the Laboratory of Architectural Form and Orders, N.T.U.A. School of Architecture. His research interests include architectural morphology, restoration, study of pre-industrial building techniques, history of construction technology and Islamic architecture.