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ESTUDIOS / *STUDIES*

Stratigraphic analysis of elevations and "inductive metrology": an integrated approach in the study of the archaeological complex of St. Mary's church in the Veliki Brijun island - Croatia (from 5th to 11th centuries)*

Lectura estratigráfica de los alzados y "metrología inductiva": un enfoque integrado en el estudio del complejo arqueológico de la iglesia de Santa María en la isla Veliki Brijun - Croacia (siglos V-XI)

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ABSTRACT
This paper aims to demonstrate the potentiality of an integrated approach in the study of architecture, which combines archaeological analysis of elevations and calculation of the units of measurement employed to trace the plans. The complex of St. Mary's Church, on the Veliki Brijun Island, represents a particularly interesting case study to which one can apply to this approach, because it is an architectural palimpsest characterized by a long stratigraphic sequence dated from the 4th to the 16th centuries. Most importantly, this method has confirmed the stratigraphic sequence and has contributed to better know the architectural phases, even though the architectural palimpsest is very complicated. Also, on the other hand, it has shed light on several aspects linked to the building sites and to the workforces.

Key words: measuring systems; analysis of elevations; Veliki Brijun; Late Antiquity; Early Middle Ages.

RESUMEN
El objetivo de este artículo es mostrar la potencialidad de un enfoque integrado en el estudio de arquitectura, que combina la lectura estratigráfica de los alzados con el cálculo de las unidades de medida utilizadas para trazar los planos. El complejo de Santa María, en la isla de Brioni Mayor, es un caso de estudio particularmente interesante para la aplicación de este enfoque, ya que es un palimpsesto arquitectónico caracterizado por una amplia secuencia estratigráfica comprendida entre el siglo IV y el siglo XVI. Por un lado, este método confirma la secuencia estratigráfica y ayuda a comprender mejor las fases de construcción; por otro, arroja luz sobre aspectos relacionados con el sitio de construcción y los trabajadores.

Palabras clave: sistemas de medida; análisis de los alzados; Veliki Brijun; Antigüedad tardía; Alta Edad Media.

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The graphic plates and photographs, if not differently indicated, are by the author.

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"Inductive metrology" is the title of a book published in 1877 by Sir William Matthew Flinders Petrie, in which the author outlined a method to derive ancient metrological systems from the architecture, by applying it to a wide sample of buildings distributed in a large chronological and geographical context.

Many studies in the past have been devoted to the ancient metrological systems, and different sources have been employed, both written and archaeological, by enabling the knowledge of the main units of measurement in Antiquity and Early Middle Ages[2].

In recent years, interesting metrological studies have been besides carried out in the Iberian Peninsula, where Early Medieval constructions of different cultural traditions have been analysed both in plan and elevation[3].

We will focus on the Veliki Brijun Island (Brijun archipelago - Istria), a site that in the Early Middle Ages became a byzantine stronghold in the Adriatic Sea, particularly important during the Gothic War (535-554 A. D.).

By means of a case study —the complex of St. Mary's Church, that is a palimpsest characterized by a stratigraphic sequence dated from the 4th to the 16th centuries— this paper aims to demonstrate the potentiality of an integrated approach in the study of an architecture that combines, on the one hand, archaeological analysis of the elevations and, on the other, a metrological analysis applied to the plans of preserved buildings.

There are two main aspects to analyse: which ones are the geometries used to trace the plans and which ones are the basic units of measurement behind the principal "module".

STRATIGRAPHIC ANALYSIS OF THE ELEVATIONS

The complex of St. Mary's Church is located near the west coast of the Veliki Brijun Island, 100 meters away from the sea, on the inlet of *Dobrika*, one of the most protected areas of the archipelago (Fig. 1).

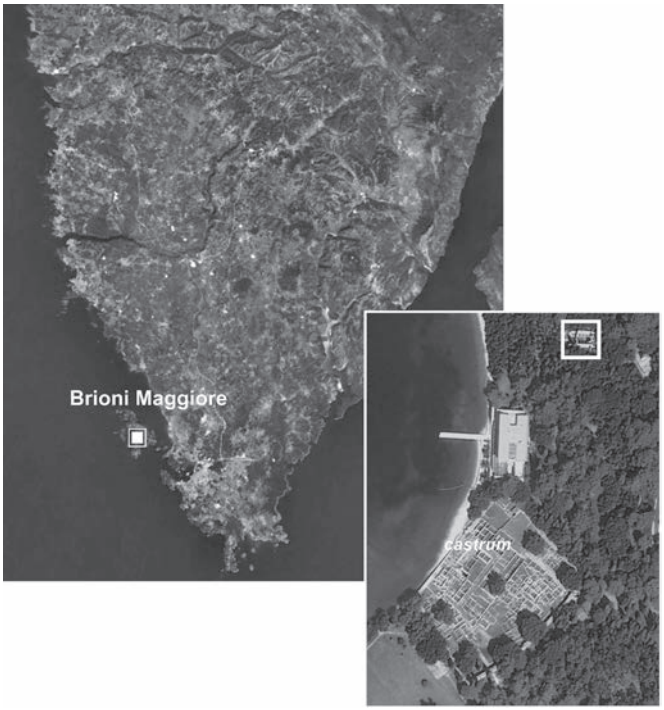

Figure 1. Veliki Brijun Island, complex of St. Mary's and Byzantine *castrum*. Geografic localisation.

According to some researchers, written sources mention the presence of a bishop on the island in the 5th and 6th centuries[4], the so-called *«Episcopus Cessensis»,* but his residence and the baptistery have never been located.

The first nucleus of the complex could date to from the 5th century onwards, or to the beginning of the next. The religious complex isn't coeval with the roman villa, but with a settlement that developed over it (after the abandoned of this roman villa). This villa is 200 meters south-west away and its material culture, brought to light by means of archaeological excavations in the last century, and particularly the presence of goods arrived with shipments from north

2 About the Roman and Greek measures of length, Smith (1859: 750-756); about the Byzantine foot, particularly Restle (1979); about the Ravenna foot, De Angelis D'Ossat (1962: 50-51); about the Carolingian one, Curini (1976) and Fernie (1978: 389-391).

3 For the Visigothic and Umayyad architecture, Caballero and Utrero (2005); Arias (2001, 2008), for the Asturian region; Jiménez Hernández (2015) and Gonzalez Gutierrez (2017), for the Islamic architecture.

4 A bishop named *Videmius* is mentioned in the acts of the Synod of Grado (579 A. D.) and of Marano (591 A. D.); Paolo Diacono, in the *Historia Langobardorum*, records the episode of his arrest in 588 A. D., during the Three-Chapter Controversy disorder. Another bishop, *Ursinus*, is mentioned in the acts of the Lateran Council of the 679 (Begović Dvoržak and Dvoržak Shrunk 2012: 96-97; Simsig 2002: 160-161; Zanella 2004: III, 26).

Africa, demonstrate the presence of elites[5]. During the Gothic War, the island became an important Byzantine naval and military base, well connected with Ravenna, and the settlement was fortified, but it didn't include St. Mary's Church. The necropolis developed around the Church, after the fortification of the settlement.

It is almost nothing known about the destiny of this religious complex in the following centuries. Sources mentioning its transformation into a Benedictine Monastery (in an uncertain age[6]) are too late to be considered.

Originally composed of several buildings, this complex is currently in state of ruin and its function, in relation to the *castrum*, is actually unclear[7].

The stratigraphic analysis of the elevations made it possible to recognise at least five building phases from the Late Antiquity to the High or Late Middle Ages, permitting also to follow changes in masonry techniques. During each constructive phase, the same limestone extracted on the island from a quarry about a half kilometre away from the complex was used.

1st Period

The church is the oldest building, maybe originated in relation to the development of the nearby settlement, and it is the result of two different and independent building sites (Figs. 2 and 3).

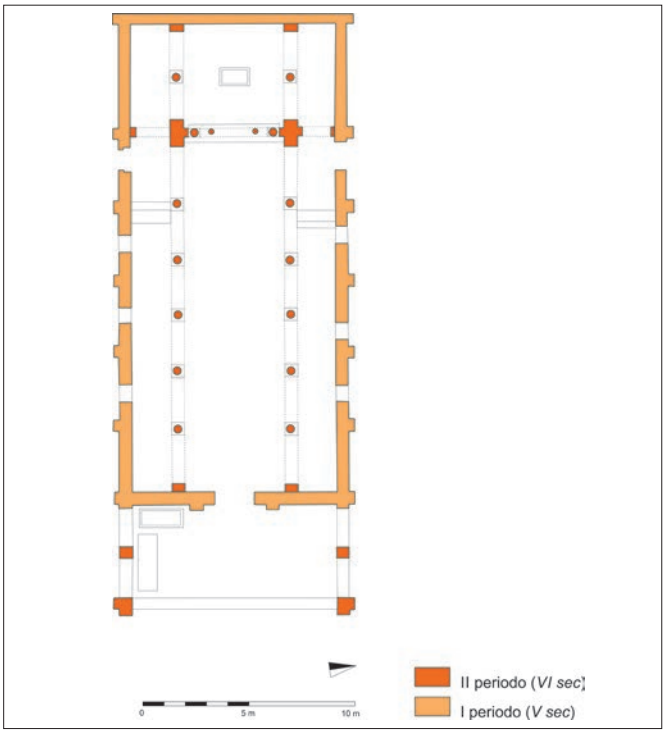

Figure 2. Veliki Brijun Island, complex of St. Mary's. 1st and 2nd periods in plan.

Figure 3. Veliki Brijun Island, complex of St. Mary's. Central nave from east.

[5] The first investigation in the fortified settlement dates back to 1908, when Anton Gnirs brought to light the southern entrance of the walls. At the beginning of 1930s, Mario Mirabella Roberti undertook an excavation on the south-east of the settlement, discovering a defensive structure characterized by the same masonry technique of the St Mary's basilica (Brusin and Roberti 1935). In 1952, the excavations carry out by Stefan Mlaker, curator of the Archaeological Museum of Istria, enabled to understand the main civil character of the settlement and its continuity until the 15th-16th centuries (Mlkar 1975-1976; Simsig 2002: 162-186). Between 1976 and 1983, Branko Marušić also dug in the settlement, discovering a series of sculptural elements reused in the buildings, maybe originally belonging to the church, and bronze rings decorated with simple engraved crosses (Begović Dvoržak and Dvoržak ShrunK 2012: 92-94).

[6] In *De'Commentarj storici-geografici della Provincia dell'Istria*, written between 1641 and 1654 by the bishop of Cittanova (*Novigrad*), Filippo Tommasini, the St. Mary's Church of Brioni is called «basilica-*monastero*», without any other indication; in 1847, Pietro Kandler suggested a Benedictine attribution of this complex, but the source is unclear.

[7] According to a recent interpretation, a first episcopal complex would have been located to the north-west of the settlement, where Vasta Begović and Ivana Schrunk have recognized a church in some structures, previous the byzantine fortifications; anyway, the baptistery hasn't been identified. During the byzantine domination, the episcopal seat would have been transferred outside the settlement because of a lack of space, by converting the pre-existing St. Mary's Church outside the walls (Begović Dvoržak and Dvoržak Shrunk 2012: 94-98).

The perimeter walls are the only remains of this first period. The only chronological clues are a series of sculptural elements attributed to its liturgical furnishing, dated back to the 5th century or to the beginning of the next one, brought to light during the research in the *castrum*, where they had been re-used in the later restorations (Begović Dvoržak and Dvoržak Shrunk 2012: 92-94).

2nd Period

The basilica was then remodelled, probably along with the conclusion of the fortifications and the restoration of some buildings in the settlement which reuse sculptural elements of the first church. The nave was divided by two rows of columns, not coinciding with the external pilasters of the perimeter walls, and by pillars leaning against the walls and delimiting the presbytery. This last space was raised and equipped with a new enclosure. In the end, an atrium was leant against the facade to host burials, some of these with sarcophagus (Fig. 2). In the atrium and around the basilica, an extended necropolis developed in relation to a burial conversion of the site. The oldest funerary objects, discovered at the beginning of the 1930s by Mirabella Roberti's research, are Goths fibulae of the Weimer type dated to the first half of the 6th century (Brusin and Roberti 1935).

Therefore, this renewal operation of the basilica could be contextual to the Gothic War, when the island became a military base for the byzantine navy and the settlement had to be fortified.

3rd Period

The internal path was changed by partially closing the arches on the side of the altar and building an archway in the southern aisle, near the lateral entrance.

The masonry technique is the same as that one of the wall leaning on the south-east corner of the basilica, which prolongs the eastern wall southwards. This shows the existence of a lateral building, previous to the actual, maybe only used by the clergy and thought to be a first sacristy (Figs. 4 and 5).

There is no chronological data for this period, except that one coming from the relative architectural sequence.

Figure 4. Veliki Brijun Island, complex of St. Mary's. 3rd and 4th periods in plan.

Figure 5. Veliki Brijun Island, complex of St. Mary's. Arches and archway closing of the 3rd Period.

4th Period

While in the previous periods, walls are built in small blocks of rough limestone, arranged in courses slightly regular, and with several regularising flakes, the fourth period is characterized by irregular masonries of broken or rough stones, maybe of reuse origin.

The building site consists of a series of activities that renew and transform the previous structures. In particular, it is worthy to mention (Fig. 4):

- A cistern is built behind the basilica, leaning against the eastern wall, of 1.77×2.95 meters and about 2 meters deep (Fig. 6).

Figure 6. Veliki Brijun Island, complex of St. Mary's. Cistern of the 4th period

- The southern building is completely remade, only maintaining a small part of the previous construction. This new building has a rectangular plan of 6.10×11 meters and two small apses of 2 meters diameter in the eastern wall. It is directly connected with the presbytery, of which southern wall is transformed to host an entrance, and another access is guaranteed by a western entrance[8]. There is no evidence of internal subdivisions, or burials, and its function over time is only hypothetical: *xenodochia*, *hospitium*, *domus presbyterorum*, *salutatorium*, or monastic rooms (Fig. 7).
- Another building is added to the opposite side of the basilica, with a rectangular plan of 5.30×13.4 meters. Only part of the northern and eastern walls survives, with two arrow slits to the north and an entrance at least in the west side, where the wall of the 4th period ends (Figs. 8 and 9).

[8] The southernmost entrance seems the result of a later intervention.

Figure 7. Veliki Brijun Island, complex of St. Mary's. Apses of the southern building (4th Period).

Figure 8. Veliki Brijun Island, complex of St. Mary's. North wall of the northern building, internal side (4th and 5th periods).

Figure 9. Veliki Brijun Island, complex of St. Mary's. Eastern wall of the northern building, internal side (4th and 5th periods).

- The entrance from the southern aisle of the basilica is closed with the construction of the lateral building, as well as the perpendicular archway (Fig. 5).
- Maybe a new pavement is laid by employing the ancient sculptural decorations. The liturgical furniture is renewed, as it is shown by some fragments with weave pattern that could be ascribed to this period of architectural renovation.

The only chronological evidences derive from these fragments, dated to the Carolingian age (8th-9th centuries) by means of stylistic analysis. It is particularly interesting the reuse of a slab of the previous presbytery enclosure, that is turned and redecorated on the other side with triviminee bands, small eight-tipped roses and pinwheels (Simsig 2002: 183-184, 208; Begović Dvoržak and Dvoržak Shrunk 2012: 92).

5th Period

Later on, the complex was restored and others buildings were added to it. Its masonry technique uses small blocks of rough limestone, arranged in regular and parallel courses. In particular, it is to be mentioned (Fig. 10):

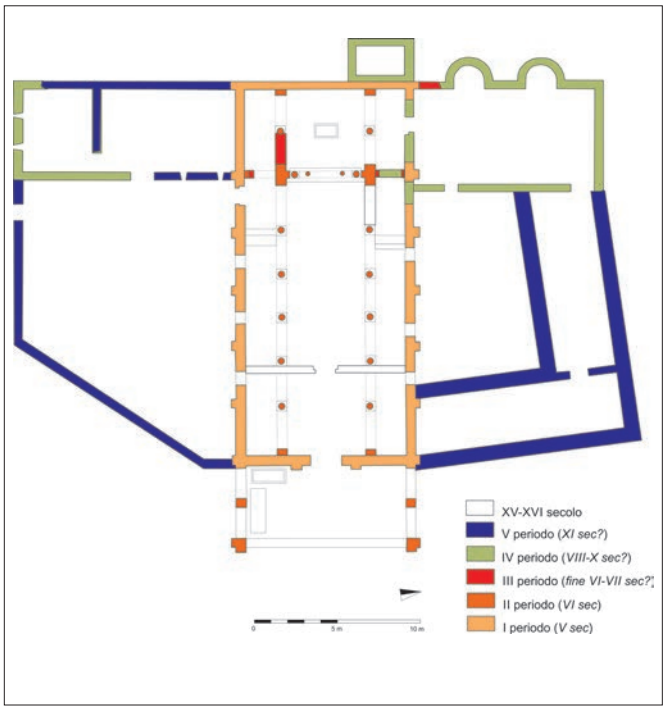

Figure 10. Veliki Brijun Island, complex of St. Mary's. 4th and 5th periods in plan.

- The upper walls of the central nave were restored or partially rebuilt.
- The northern building of the fourth period was reconstructed (Fig. 11), preserving only some parts of the previous perimeter wall. Two rooms, directly connected, were created inside by maintaining the previous foundations. The presence of stone shelves and holes for the wooden beams of the ceiling evidences the original existence of at least two floors. In fact, the ancient north wall was raised and completed with a small arrow-slit. Similar openings can be seen in the room near the basilica, in the west wall, but related here to the ground floor. The previous western entrance was kept instead.
- The free space in front of the northern building was surrounded by an extended enclosure wall, closing in the north-west corner of the basilica. Only one later entrance allowed the connection with the outside.

Figure 11. Veliki Brijun Island, complex of St. Mary's. Western wall of the northern building, external (5th period).

- Also the free space in the opposite side of the basilica was closed, but with two imposing parallel walls filled with rubble and mortar. They delimit a gallery. Some few courses of the walls survive in elevation, but their dimensions suggest that they had to support an upper level and maybe some vaults. No entrance is recorded.

These last interventions seem to coincide with a functional transformation of the complex that remains closed and protected from the outside. They could be thus connected with a monastic conversion of the structures, of which chronology is only hypothesized.

As *ante quem* limit for the fifth period, we know that in 1312 the archipelago was depopulated because of a wave of plague that contaminated the Istrian peninsula and its islands. In addition, the masonry technique is comparable with numerous examples of churches in Dalmatia and Istria, dated to the 11th and 12th centuries (Zanetto 2017: 249-263).

6th Period

During the wave of plague of 1312, it seems that the religious complex was transferred to the Templars and, after their condemnation in 1314, it became a Commandery of the Order of Saint John (Schiavuzzi 1908: 121). On the basis of the toponymy study of Camillo De Franceschi, in 1374 the St. Mary's Church in the Veliki Brijun Island is not mentioned anymore, proably because it was totally abandoned by that time (De Franceschi 1939-1940; Simsig 2002: 159).

Only between the 15th and 16th centuries, new interventions are documented in the basilica. The length of the aisles was in fact reduced of two bays by building a transversal wall. The chronology for this building site is based on two sepulchral epigraphs discovered in the external bays (or in the new narthex). These monuments are related to a new settlement born in the north-eastern coast of the island (Simsig 2002: 160).

The same masonry technique, including some brick fragments, is recognizable also in the bay near the presbytery, where the arch that divides the central and the southern aisle is walled (Figs. 3 and 10).

GEOMETRICAL INSTRUMENTS: PRACTICE AND THEORY

An inductive metrological analysis requires the knowledge of some elementary principals followed on a building site namely during the drawing of the plan on the ground.

After the design stage and the preparation of the site, the first operation of the building site consisted of tracing the perimeter walls, as the Bishop Agnello (5th century) explains in the *Liber Pontificalis*[9], by reproducing elementary geometric shapes.

Buchwald (1992: 293) identifies three types of geometrical applications in architecture, in the following order:

- The geometry that outlines the first shape of the building, or its perimeter.
- The geometry that defines the articulation of the internal spaces.
- The geometry that defines the secondary shapes and the decorative details.

Therefore, it was firstly important to trace the perimeter of the building in plan, following certain geometric schemes, which for the Middle Ages consist essentially of the modular grid and the *quadratura* (Buchwald 1992: 300-302, 1995).

The modular grid (Fig. 12.2) is typical of churches with basilical plan and the scheme is based on the concept of "module", which represents the elementary unit of measurement used in the field to facilitate the operations. It is generally equivalent to more than 1 meter and is multiple of a basic unit of measurement deriving from a specific metric system. In this way, it was possible to express great lengths with small numbers and to guarantee mathematical proportions, order, harmony, balance and symmetry, without difficult arithmetic calculations (Arias 2008: 26-27; Dufaÿ 1985: 309-311).

This method might have been more conceptual than practical and it has been recognized in several Late Antique basilicas in Asia Minor, Greece, Ravenna and Upper Adriatic coast[10].

Some proportional relationships are always observed in these basilicas, particularly between width/length of the internal space, between width/length of the central aisle or between width of the central aisle/width of the lateral aisles. Until the age of Justinian, they correspond to the classical proportions (√2, √3, 5/3, 4/3), generally taking into account also the width of the walls. Later on, new proportions spread, such as the type 1:2:3:4 (it is frequent the relationship 1:3 or 1:2 between width/length of the rectangular plan; another one is 1:2 between length of the central aisle/length of the lateral aisle). The distance between the colonnades, according to Underwood (1948: 64), would be the "module" (Buchwald 1995: 22-24; De Angelis D'Ossat 1962: 36-37).

While in Asia Minor, the modular grid is progressively replaced by a new geometric scheme, named *quadratura* (Fig. 12.1), better suited for the cross-in-square churches that largely spread in the Byzantine regions from the 7th-8th centuries[11], in the West, central-plan buildings are extremely rare and the modular grid continues to be the principal scheme until the highest expressions of the Late Romanesque and Gothic architecture (Lyman 1987)[12].

As we can assume by the Byzantine treaties, the rope and the stick, or the reed, were the main instruments employed for the measurement of the ground (Ousterhout 1999: 60) and therefore also the main instruments to trace a plan.

[9] «*Fundator ecclesiae Petrianae, muros per circuitum aedificans, sed nondum omnia complens*» (Gritti 2012: 20-21).

[10] Buchwald (1995), about Asia Minor; Dufaÿ (1985), about Greece; De Angelis D'Ossat 1962; Tavano 1982; Vidulli Torli 1985.

[11] This scheme is based on the square of the central dome that generates the module (Buchwald 1984: 223-229).

[12] Studies carried out in the abbey churches of Fruttuaria and Cluny II (10th-11th centuries), as well as in the crypts of St. Bénigne in Dijon and St. Peter in Geneva (11th century) show that, behind the project, there are still modular grids (Guerreau 1996; Pejrani Baricco 1996).

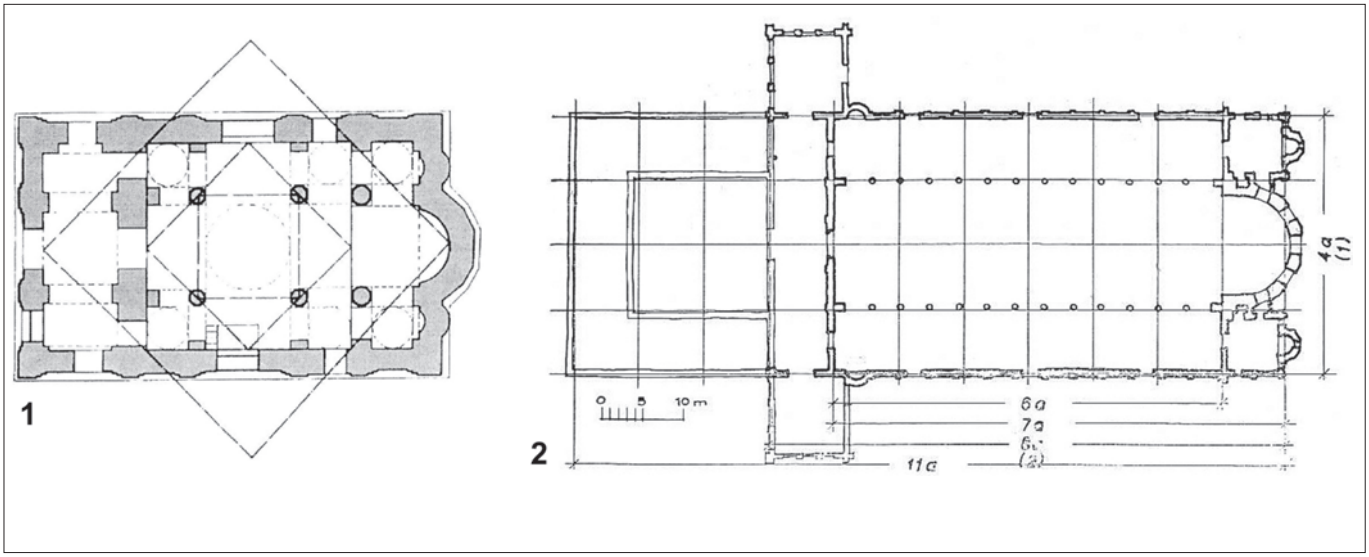

Figure 12. 12.1. East church of Sardi in Turkey (half of the 13th century). Plan with the square for the *quadratura* method (from BUCHWALD 1979). 12.2. Sant'Apollinare in Classe (Ravenna). Modular grid method (from PETROVIĆ 1962).

With a rope, it was possible to trace a circle and, by applying the Pythagorean Theorem, to obtain right angles. Simple geometric methods allowed to calculate most of the classical proportions (Zanetto 2017: 151-152), but couples of whole numbers, of which relationship gives the irrational numbers of the classical tradition, were certain already known. Therefore, the use of big modules was extremely important.

The basic procedure consisted of the subdivision of the rope in twelve modules by means of knots, each one corresponding to a precise measure that was a multiple of a standard and smaller unit of length, generally the foot. In this way, it was possible to draw squares, or rectangles, simply on the base of the Pythagorean rule 3+4+5 (Arias 2008: 44-46, Brogiolo and Cagnana 2012: 129)[13].

But beyond the Pythagorean rectangle, of which proportions are equivalent to 4/3 = 1'3333, also the √2 and √3 were derivable from a couple of whole numbers, of which relationship give a result very close to the classical proportions 1'414 = √2 and 1'73 = √3[14].

A proportion very close to the golden ratio 1:1.61 is equally obtainable by the relationship between two whole numbers, basically 5/3 = 1'666[15], and will be the most widespread proportion in the Early Middle Ages, between the 8th-11th centuries. It is the basis, for instance, of the building sites in the episcopal complex of Aquileia. The same proportion is easily recognisable in other churches in the Venetian Lagoon, such as St. Nicolò al Lido and the cathedral of Torcello. In Istria, it was used to outline the plan of the Benedictine monastery of Kloštar (Zanetto 2017: 152-159).

A frequent use of this proportion is documented also in the Carolingian architecture, as it was seen in the design of the *Torhalle* of Lorsch (8th century), both in plan and elevation, and excluding the perimeter walls, as well as in the decorative elements (Curini 1976).

The Longobard Temple of Cividale (half 8th century) is characterized by the same proportion: its plan is within a rectangle of 10.4 × 6.30 meters, excluding the thickness of the walls, and the maximum height of the nave, coinciding with the centre of the groin vault, is 10.25 meters high from the original floor level. Consequently, the facade in elevation can be also inscribed in a rectangle equivalent to 5/3 (Fig. 13).

Completely different, and singular, is another Lombard building, namely the Temple of Clitumnus, which dates to between the beginning of the 7th and the second half of the 8th centuries. The classical proportion √2, that

[13] In order to work with bigger measurements and with longer ropes, it was possible to use 24 modules (6+8+10) or even 60 modules (15+20+25), as it has been demonstrated for some early medieval churches in the Iberian peninsula (Caballero and Utrero 2005: 171-174).

[14] The proportion √2 is the measure of the diagonal of a square of side 1 which is equivalent to √2 = 1'414, while the proportion 1.75 is the result of the relationship 7:4.

[15] The concept is the same expressed by the Fibonacci number, in which every number is connected with the previous one by a golden ratio.

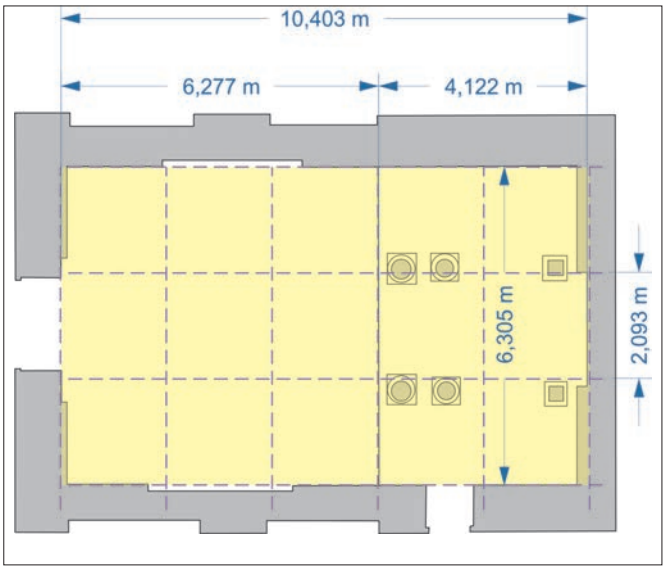

Figure 13. Longobard Temple of Cividale. Plan with modular grid and measures.

gives 1.41, is predominant in the plan. It is recognisable in the rectangle that inscribes the nave and in the relationship between the nave and the western porch. The same proportion is also used to define the elevations (Fig. 14). However, some inaccuracies, feature the general project with proportions that vary between 1.40 and 1.46, maybe due to the presence of more constructive phases.

The Pythagorean proportion 4/3 = 1'333 has been instead frequently used in the churches of the Asturias region, ascribed to the period between the end of the 8th and the beginning of the 10th centuries (Arias 2001, 2008).

5/3: a constant rule in the complex of St. Mary's church in the Veliki Brijun Island

Our object of study, the St. Mary's complex in the Veliki Brijun Island, survives only partially in elevation, therefore the analysis will consider essentially its plan.

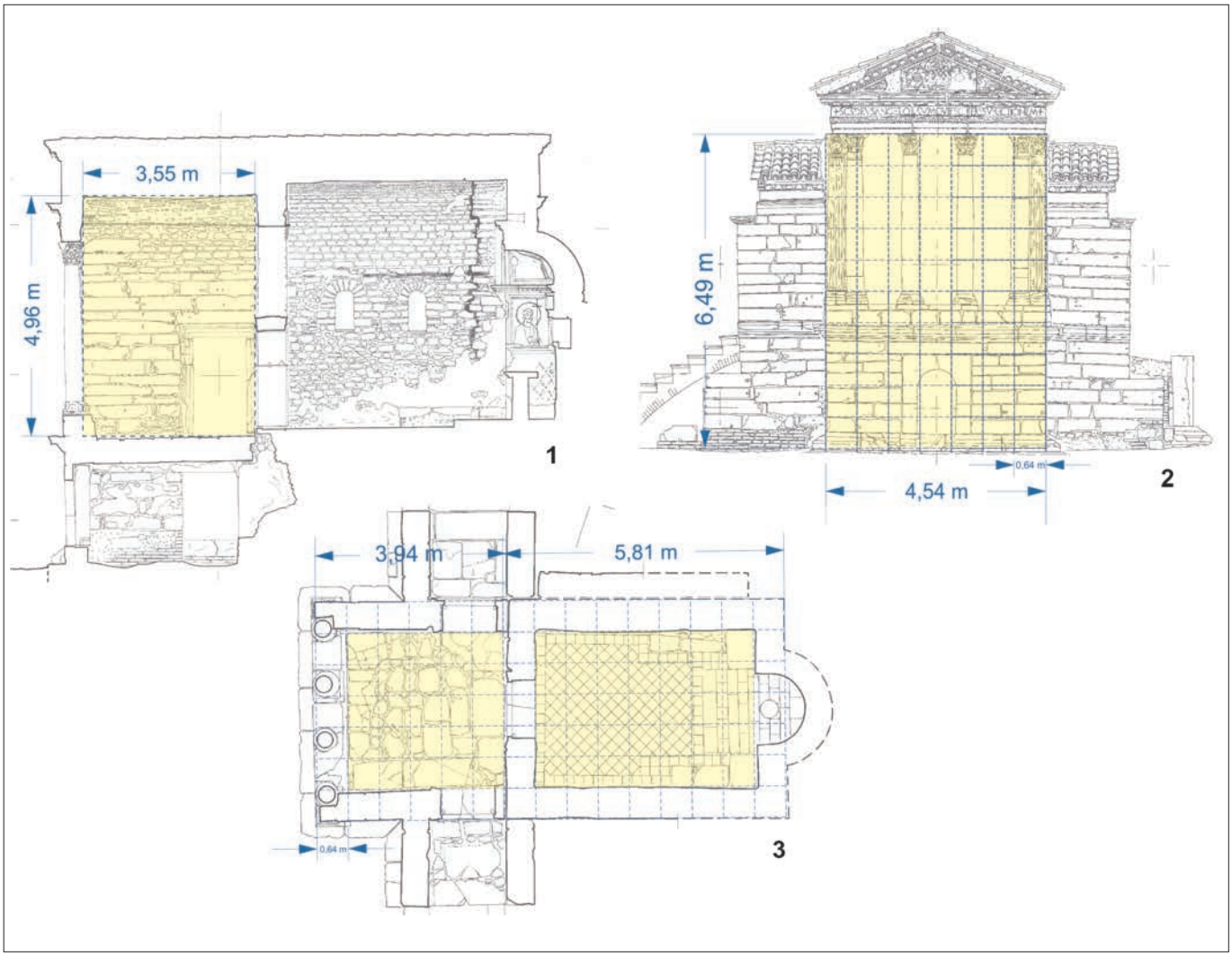

Figure 14. Temple of Clitumnus. Plan, longitudinal section and western view, with modular grid and measures (reworking from Judson Emerik 1998).

The goal is to guess the drawing behind the architectural realization, the rules and the geometrical proportions, as well as to define the order of the tracked lines, because these are keys to understand its planning and to derive the measuring systems.

Starting from an edit plan[16], vectorised and scaled by means of a series of measures directly taken in the field, it was possible to work with the modules and to recognize a constant proportion very close to the golden ratio, almost certainly obtained by applying the elementary relationship between the numbers 5 and 3.

What it is interesting is the constant use of this proportion in every building site that played a significant rule for a definition of the complex.

1st Period

The perimeter walls of the church belong to the first building site and set the limits of a rectangle of 23.1×10.8 meters (Fig. 15). The proportion 1:2.14 between width and length, including the walls' thickness, is the same of the northern Theodorian basilica of Aquileia and of the southern Post-Theodorian one (4th century). By excess (1:2.3), it is also very close to the northern Post-Theodorian basilica (Zanetto 2017: 15-26) and to the first Cathedral of Pula (4th-5th centuries).

According to Tavano (1982) and Vidulli Torli (1985: 54-55, 1988), this proportion tends to decrease over time in the northern Adriatic, while the apses spread. In the 6th century, relationships were very close to the golden ratio, but those obtained with the help of the Pythagorean rule, will be predominant[17].

In the basilica of St. Mary, the rectangle 5/3 is the basis for a definition of the laymen space, covering an area of about 17.15×10.30 meters (1:1.66), including the perimeter walls' thickness. The same proportion is repeated also in elevation (Fig. 16).

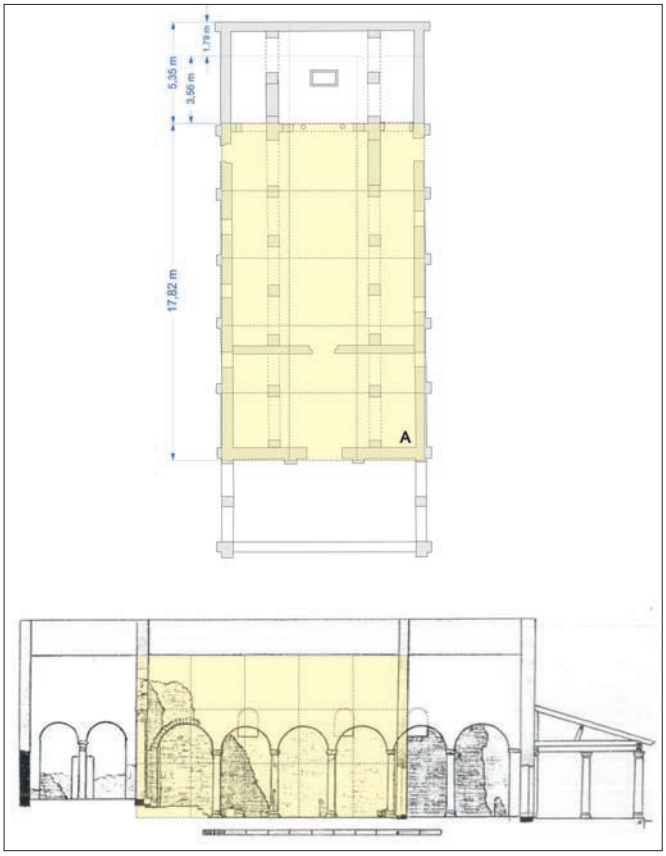

Figure 15. Veliki Brijun Island, complex of St. Mary's. Rectangle 5/3, modular grid and measures in the 1st period (reworking form SIMSIG 2002).

Therefore, during these constructive interventions dated to the 5th century or the beginning of the next, the rules to obtain a rectangle very close to the golden one aimed to delimit the laymen space, are well known and similar comparisons can be found in the Euphrasian basilica of Poreč and St. Maria Formosa of Pula (6th century), although these both examples have independent apses.

2nd Period

In the 6th century, the internal spaces of the basilica of Brijun was notably transformed, by defining the aisles and adding a porch to the western facade (Fig. 17). Although the perimeter did not change, apart from the addition of the porch, the interior was renewed in a second moment, as it is equally documented in the Post-Theodorian basilicas of Aquileia[18].

[16] Two edited planimetries were overlapped and controlled through a series of measures taken directly in the field. They were published by Begović Dvoržac and Pavletić (1998: 49) and Begović Dvoržac, Dvoržac Schrunk and Tutek (2007: 236).

[17] Tavano (1982) observes that during the 5th century the proportion vary between 1:1.83/1.88 in the St. Giusto basilica of Trieste, in the Pre-Euphrasian basilica of Poreč, in the St. Giovanni Evangelista of Ravenna and in the St. Eufemia of Grado (this last rebuilt in the 6th century on the top of 5th-century foundations). During the 6th century, the proportion decreases again (St. Agata of Ravenna and St. Apollinare Nuovo, 1:1.70/1.72), reaching a relationship very close to the golden rectangle (Euphrasian basilica of Poreč, St. Maria Formosa of Pola, 1: 1.65/1.66). Anyway, a 5/3 proportion is already used in St. Maria delle Grazie of Grado (5th century), a basilica with apse and lateral *pastophoria*, and it much depends on the diffusion of independent apses.

[18] The so called 'Post-Theodorian' basilicas seem to be the result of two different building sites: the first one (perimeter walls) dates to the half of the 4th century; the second one consisting on the raising of the floor level (it became higher), on the erection of columns and on a new organization of the internal spaces, dates to the 5th century (Zanetto 2017: 15-17).

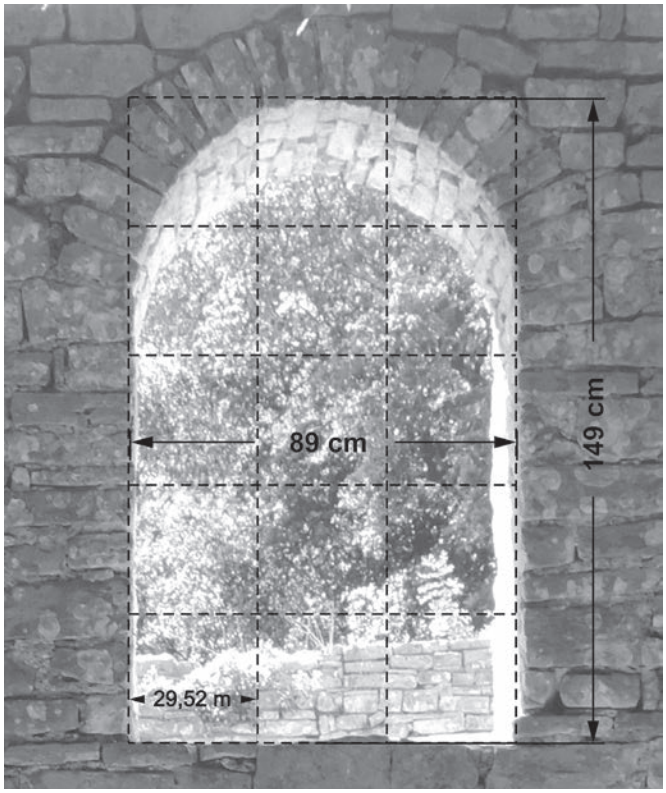

Figure 16. Veliki Brijun Island, complex of St. Mary's. Window inscribed inside a rectangle 5/3, in the basilica (1st period).

4th Period

The use of the proportion 5/3 to draw a plan on the ground will remain constant during the following centuries in the northern Adriatic, particularly to define the naves and the distance between the rows of columns in the basilicas. In the Early Middle Ages, similar proportions are documented in the cathedral of Torcello (on the project of 8th or 9th century) and in St. Maria e St. Donato of Murano (9th century). In the hinterland, they are observable in the Pagans' Church of Aquileia and in the near and coeval porch (the end of 9th century or beginning of the next). The relationship 5/3 is also documented in the Longobard Temple of Cividale to define its plan and elevation (half 8th century), as well as in some Carolingian buildings such as the *Torhalle* of Lorsch (8th century), to define both the architectural shape and the decorative elements. In Istria, another example is the first church of the Kloštar monastery (7th-9th) (*Ibid.* 2017: 94-98), with a single nave inscribed in a rectangle 5/3 = 1'666.

In the Veliki Brijun complex, this proportion was at least used to trace the foundations of the southern building (B) and the cistern behind the basilica (C) in the 8th or 9th century (Fig. 17).

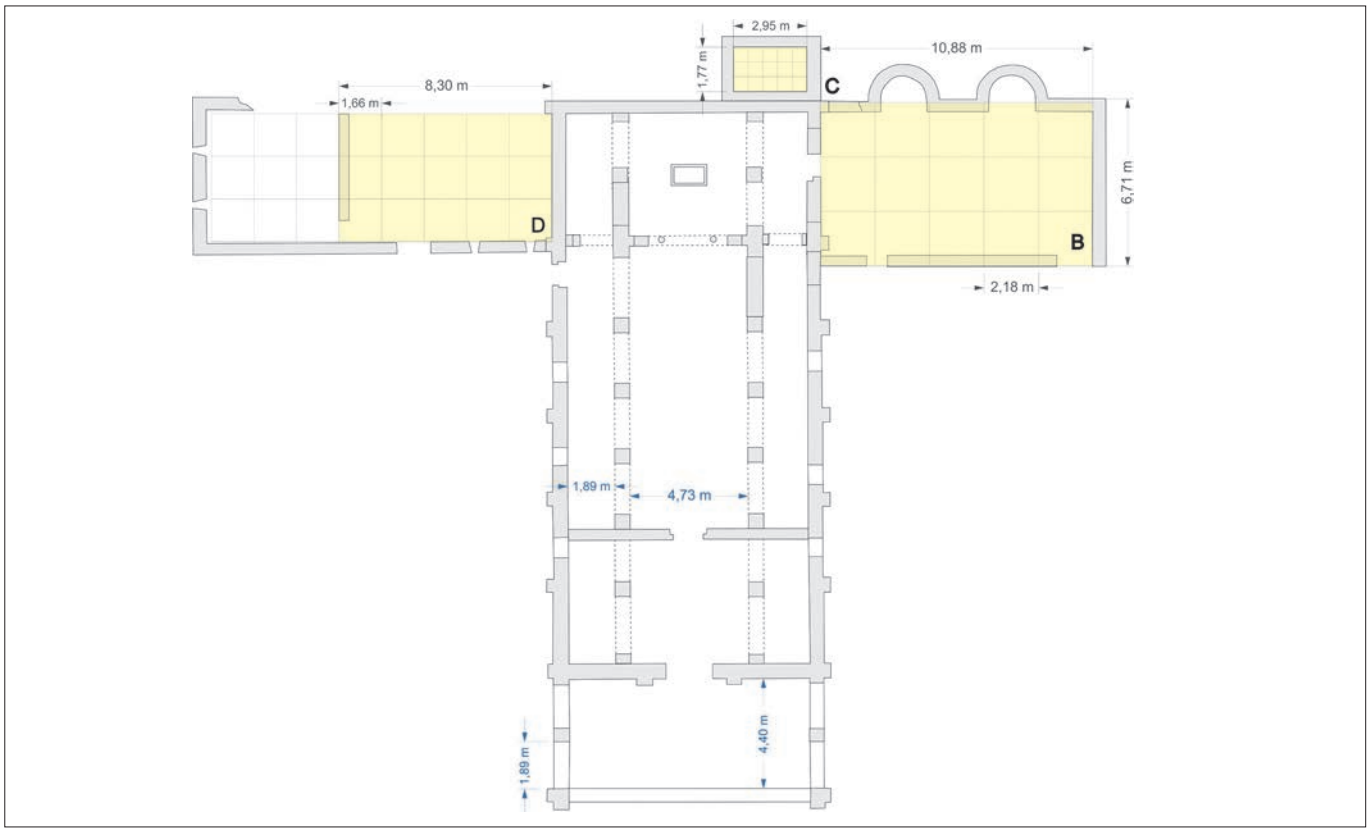

Figure 17. Veliki Brijun Island, complex of St. Mary's. Rectangle 5/3, modular grid and measures in the 2nd (blue) and 4th (grey) periods.

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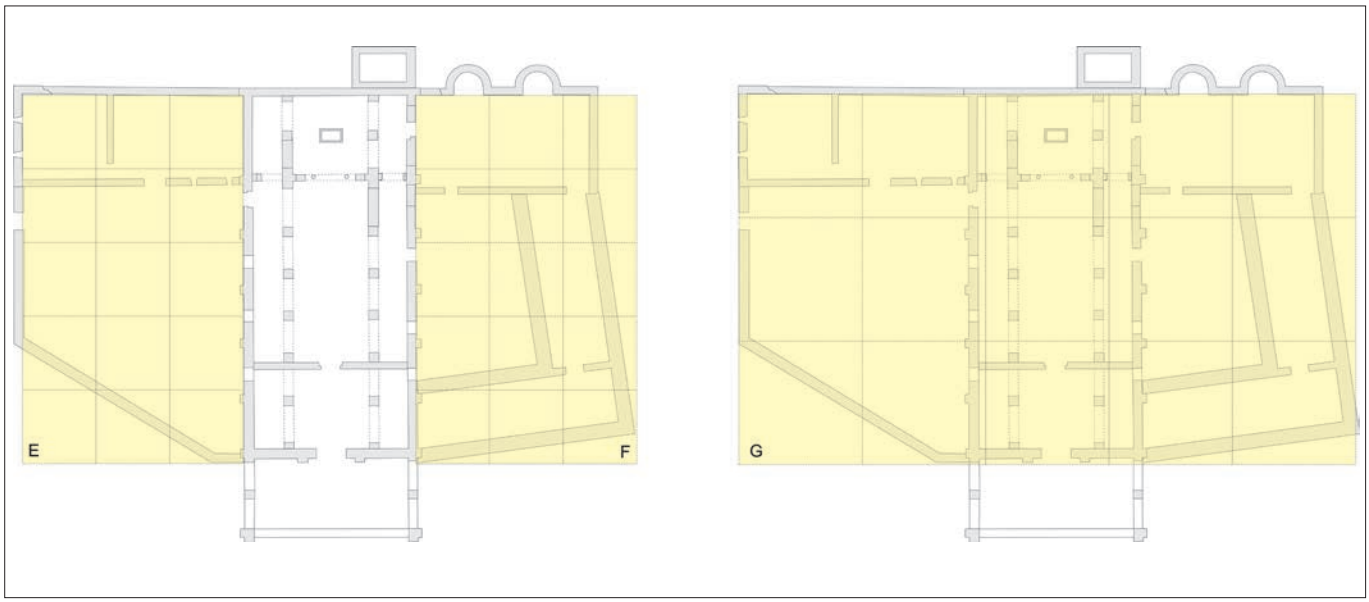

Figure 18. Veliki Brijun Island, complex of St. Mary's. Rectangles 5/3 in the project of 5th period.

5th Period

In the 11th or 12th century, the religious complex was renewed and partially rebuilt. The use of the proportion 5/3 is not limited to the drawing of single parts, such as the room obtained by the division of the northern building (D), but it is the basis to entirely plan the complex on the ground (Fig. 18).

Very close proportions to 1:1.666 can be identified in the identical rectangles that inscribe the northern and southern buildings (E, F), which are clearly the result of a same project.

From a wider point of view, the rectangle 5/3 seems to have delimited the entire space occupied by the complex, except the apses of the southern building and the western porch (G).

It is almost impossible to determine exactly which parts could correspond to previous projects and to the last one, because every building could rest on more ancient foundations. Anyway, in the 11th or 12th century the rectangle 5/3 was consistently used by architects and masons, particularly to define the laymen space of churches. What it changes, are instead the eastern terminations, where three independent and semicircular apses become quite common. Significant examples are the basilica of St. Nicolò al Lido, in the Lagoon, or the second monastic church of Kloštar and the Sveti Lovreč parish church in the Istrian peninsula.

THE MEASUREMENT SYSTEMS IN THE EARLY MIDDLE AGES: A SUMMARY

In the Roman Age, there was a unified measuring system of lengths, based on human body and common all across the Empire, particularly in the Mediterranean regions. Its basic unit of measurement was the Roman foot, which was equivalent to 29.6 cm. Another foot less widespread, but known by written sources and by archaeological record, was the Drusian one, equivalent to 33.26 cm (Fernie 1978: 384)[19].

After the fall of the Roman Empire, the unified measurement system was also progressively lost and new units of measurement became common in the new kingdoms and under local authorities. The Italian peninsula had more systems than any other European region, because of its political fragmentation, and these varieties were reflected also in the names of the units (Brogiolo and Cagnana 2012: 126-127).

Three main systems of lengths were well known in Europe during the Early Middle Ages, other than the Roman one: the Byzantine system, the Carolingian system and the Islamic system.

The first one was well studied by Restle in the churches of Cappadocia, but it has been recognized also

[19] About the ancient Roman and Greek measuring and geometrical systems, the bibliography is ample enough (for instance, Adam 2002, Rootländer 1979, Taylor 2006,; Walthew 1978, 2002), dating the first studies at least back to the 17th century.

in the Late Antiquity and Early Medieval basilicas of the Upper Adriatic region, from Aquileia to Grado, from Torcello to Poreč (Restle 1979; Vidulli Torli 1985: 52; Zanetto 2017: 162-168).

Its basic unit of measurement, equivalent to 31.5 cm, was widespread in all the Byzantine Empire, including coastal regions submitted to the authority of Constantinople, such as Venice and the Dalmatian islands. The situation is different in the Exarchate of Ravenna, where a foot of 32 cm was used since the 6th century and it was the unit of length for a specific type of bricks called "*giulianei*" (De Angelis D'Ossat 1962: 50-51).

Another system used in the Italian Peninsula, known from written sources, is the Longobard one, initiated by the King Liutprand and corresponding to a foot of 44 cm (43.8 precisely), very close to the Roman cubit[20]. Anyway, a preliminary analysis of two Longobard buildings revealed the use of different measures: in the Longobard Temple of Cividale, the elementary module of the grid is about 206/210 cm and no basic units of measurement clearly results (Fig. 13); in the Temple of Clitumnus, the basic module is 64 cm instead, which could be the result of two feet of 32 cm, corresponding to the units used in the city of Ravenna and in the Exarchate (Fig. 14).

However, the ancient Roman foot of 29.6 cm remained in use over time and can be easily calculated in the Pagans' Church and in the porch of the basilica of Aquileia, as well as in Istria, for instance in the monastery of Kloštar (Zanetto 2017: 162, 165).

The Carolingian system was based instead on a foot of 33.3 cm, probably derived from the Drusian one, and it was widespread in the continental Europe among the Germanic and Carolingian people (Fernie 1978: 384). It has been recognised in the *Torhalle* of Lorsch as well as in the Palatine Chapel in Aachen (Curini 1976, Fernie 1978: 389-391)[21], but also in the Asturias region an identical foot has been documented in constructions dated to 8th-10th centuries, along with the using of a foot of 30 cm (Arias 2001; Caballero and Utrero 2005: 172).

Finally, the last main measurement system has been identified in Islamic constructions of southern Spain, particularly in Seville and Cordoba, and it seems to be based on a foot of 31.4 or 32 cm (Jiménez Hernández 2015, Gonzalez Gutierrez 2017). In this case, a Byzantine origin can be easily imagined.

Methodology and practical example

The "*Inductive Metrology"* is often the only possible way to study the ancient measurement systems and their application in architecture. The process experimented in the Veliki Brijun complex consists of four principal steps:

1. The first part of the work was carried out directly in the field and consisted of measuring a series of lengths by means of a laser distance meter of high precision. Major lengths, such as the width of the basilica, and other secondary measurements, such as the size of the entrances, were taken for testing and they were also fundamental to scale the plan to work on[22].
2. Then, it was important to understand which technique had been used to trace the plan: geometrical or "arithmetic". The first one is the result of the application of geometrical rules, which make it possible to obtain irrational proportions by tracing circumferences and rectangles (Zanetto 2017: 152). In the second one, as it is demonstrated in the complex of Veliki Brijun, similar proportions are obtained by means of elementary modular relationships, starting from the application of the Pythagorean rule. A basic element to distinguish the two processes is the less accurate results of the modular method that gives, for example, 1:1.66 rather than 1:1.61. The reconstruction of the drawing sequence was also fundamental to identify the first lengths traced on the ground, which are the most reliable measures to be tested, since they are independent from the errors generated by the sum of the tracks. After this step, the modules controlling the entire plan of the complex (multiples of the basic unit of measurement used) had been defined.
3. The "dividends", chosen from the most reliable and useful measurements of the buildings, were then tested with the main units of measurement, the "divisors", used in the Late Antiquity and Early Middle Ages in architecture. The size of the modules, the

[20] The «*Historia Langobardorum*», by Paolo Diacono, is the first written source that mentions this foot. Until the Italian Unification, a 'Liutprand foot' was still used in many cities in northern Italy, but to indicate different measures (Arslan and Pertot 2009: 65).

[21] In the Aachen Chapel, it is uncertain the use of the Carolingian foot, rather than the Roman one.

[22] The planimetry used as basis was taken from Begović Dvorža and Dvorža Shrunk (2012: 236) and from Simsig (2002: 188). By means of the measures taken in the field, these plans were controlled and corrected.

lengths of the perimeter walls and the measurements of the architectural elements can be considered the most useful. It is much less reliable the distances of pillars and columns, generally defined at a later stage.

4. Finally, after the test, only the results that gave whole numbers were maintained. Anyway, the divisions never give perfectly whole numbers, thus it was necessary to round up or down the values (1.998... will be 2; 3.07... will be 3 and so on).

This method was particularly applied in the Byzantine churches, while it had less fortune for the western Early Medieval architecture, maybe because the projects were less accurate. Inaccuracies and imprecision however are recognized in every church, from the Byzantine ones to the Late Romanesque or Gothic cathedrals too, within a 2% margin of error, equivalent to ± 50 cm in 25 m (Guerreau 1992: 99)[23].

In the complex here analysed, errors are also present and easily identifiable in some irregularities of the plan, particularly on the right angles, in which results are not very clear. Anyway, this type of analysis reveals unexpected potential in the study of architecture.

1st Period

The modular grid used to trace the rectangle 5/3 of the aisles, including the wall thickness, can be extended also in the presbytery and the side of every module is 356/360 cm, which is equivalent to 12 feet of 29.6 or 30 cm (Fig. 15).

Therefore, the size of the plan is 78 (18 in the presbytery, 60 in the aisles) × 36 Roman feet, and the same units of measurement is clearly identifiable in the thickness of the walls (59.2 or 59.9 cm), of 2 feet, in the windows (about 149×89 cm; Fig. 16), of 5×3 feet, and in the centering used in the lateral entrances (diameter of 180 cm), of 6 feet.

It is interesting to observe the coincidence between the presbytery and the external pilasters.

2nd Period

The modular grid used in the basilica changes in the porch (Fig. 17), of which width is about 440 cm (inside) and 490 cm (outside). The basic unit of measurement could be 31.5 (14 feet inside) or 32.5 (15 feet outside), but the first result is also given by the distance between the lateral pillars (6 feet of 31.5), and by the width of the aisles, which are 189 cm (6 feet for the lateral ones) and 473 (15 feet for the central one). Therefore, the use of a Byzantine measurement system is the most probable.

It is interesting to observe that the columns and the external pilasters are not in line, because they belong to different phases and different projects.

4th Period

In the 4th period the tests didn't give a unique and certain system of measurement (Fig. 17). The cistern inscribes a rectangle of 296×177 (proportion 5/3), obtained by means of modules of about 59 cm that are equivalent to 2 Roman feet. The external side, instead, gave different units (12 feet of 33 cm the length, 8 feet of 32 cm the width), but the result based on the modular grid, that is also perfectly consistent in the length as in the width, seems more reliable.

Similar problem arose in the northern building: starting from the modular grid used to obtain a rectangle 5/3, the horizontal measurements gave a foot of 32 cm as well as a foot of 33 cm. In this case, it is the width, coinciding to 21 feet of 32 cm, that clarifies the basic unit of measurement. Therefore, a foot of 32 cm, calculated in a grid of 1088×671 cm (34×21 feet), is the most probable and it is the same used in Ravenna and in the Exarchate. The module, instead, vary between 218/224 cm per side.

Anyway, the lack of precision is characteristic of this scheme, and no clear unit of measurement was obtained in the smaller lengths, such as the width of the apses or the entrances.

The northern building is even more complicated, because it is the result of two different building sites and the plan is very irregular. The latter was corrected with the real measurements, bringing to light some errors in the published drawing[24], and resolved the doubts created by the dividing wall, dated to the 11th-12th centuries, but with previous foundations (Fig. 19).

[23] According to Underwood, in the Byzantine churches of Justinian Age the error would be ca. half a foot, but Buchwald is less optimistic regarding this (Buchwald 1995: 22, Underwood 1948: 65).

[24] In the plan used as basis, the tests gave clearly a foot of 30 cm for the internal subdivision of the space in length, and 33 cm for the walls of 4th period. A control in the field made it possible to correct the measures: the vertical width vary between 498 and 535 cm, while the room on the left have a squared plan.

The use of a rectangle 5/3 is conceivable for the room on the right, that defines a modular grid of modules of 166 cm per side. Then the grid was extended on the left, to trace the plan of another room, but with less precision. The only whole result obtained by the tests corresponds with a foot of 33 cm that is very close to the Carolingian one. Therefore, every module would correspond with 5 feet of 33 cm per side.

Less precision of the drawing, and maybe different building phases (generally ascribed to the 4th period), would explain the use of different measuring systems and modules of different sizes.

5th Period

A foot of 30 cm is clearly recognizable in the plan of buildings and structures added during the 5th period. All of them certainly belong to the same project. The proportion 5/3 may have been also the base for the entire new project, with grids of very big modules (of more than 400 cm per side; Figs. 18 and 20).

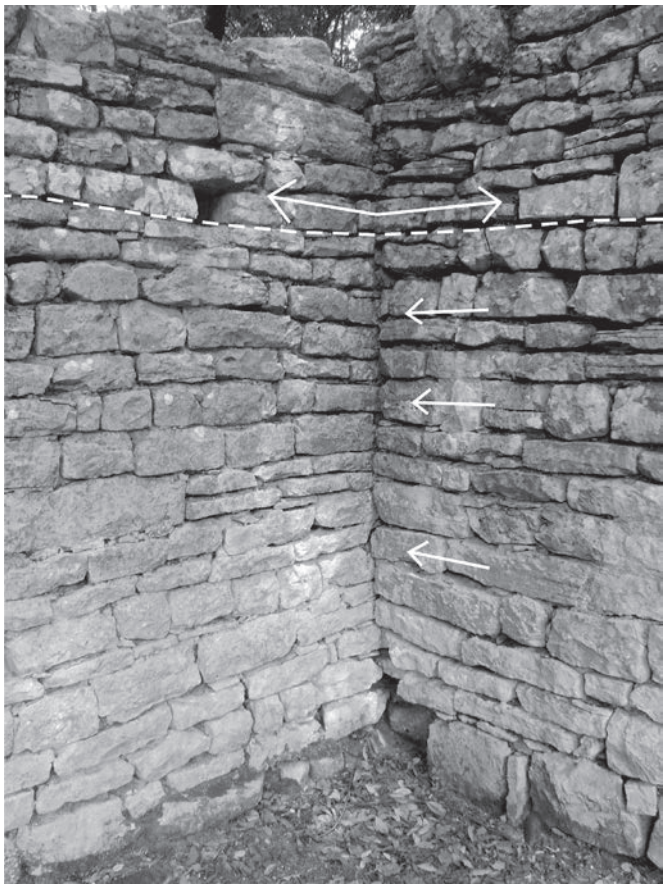

Figure 19. Veliki Brijun Island, complex of St. Mary's. Dividing wall in the northern building, with parts of 4th and 5th period.

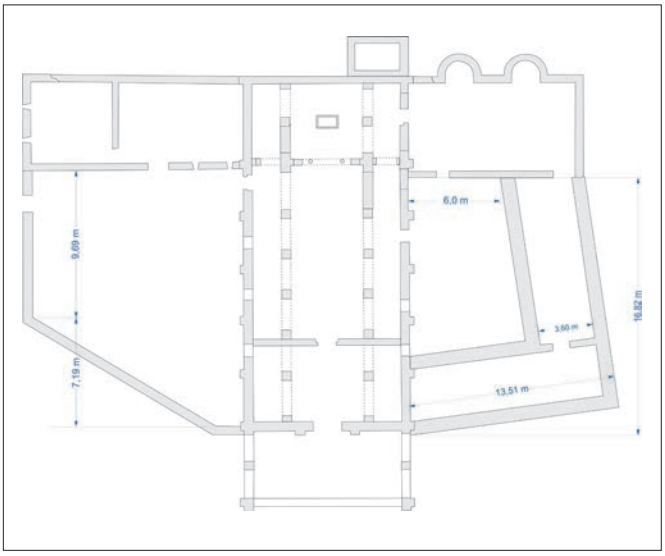

Figure 20. Veliki Brijun Island, complex of St. Mary's. Measure of 5th period.

CONCLUSIONS

The stratigraphic analysis of the elevations and the metrological calculation were carried out at different times and the results were crossed only at the end, resulting in a surprising consistency regarding the architectural phases and the changing of the measurement systems.

This integrated approach made it also possible to clarify some doubts of the stratigraphic sequence, particularly about the dividing wall of the northern building, of which lower parts seems to be dated to the 4th period, rather than to the 5th one.

The presence of different workforces in the building site, of different provenances and specialisations, is clear from the use of more units of measurement and from the reconstruction of the drawing steps.

About their provenance, the use of a Byzantine foot of 31.5 cm in the building site of 6th century could be explained by the presence in the island of the Byzantine people engaged in the Gothic War, while the use of a foot of 33 cm in the 4th period could be connected with the Carolingian domination in Istria later on in the 7th and 8th centuries.

Before and after these long periods, by contrast, the basic unit of measurement is the Roman foot, probably belonging to the local tradition diffused since the Roman age.

It is therefore that such a methodological approach represents an useful instrument to improve the stratigraphic sequence. It owns as well a high potentiality

to obtain statistic data when applied to many buildings distributed across a wide region.

The information obtained affects the comprehension of the techniques and instruments employed to trace originally the plan, the technological background of the workers and their provenance, the level of complexity of a building and the professionals employed in the site building.

A large amount of case studies could then allow us to trace a space-time map of the measurements employed in several contexts, from Late Antiquity to the Late Middle Ages, and compare so different constructive traditions. This could shed light on people mobility over time and on changes in the geographies of power.

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The idea to realize a metrological analysis of an architecture was suggested to me by my PhD supervisor, prof. Gian Pietro Brogiolo.

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