THE TIMBER ROOF OF HAGIA PARASKEVI BASILICA
IN CHALKIDA, GREECE: MULTI-DISCIPLINARY
METHODOLOGICAL APPROACHES FOR THE
UNDERSTANDING OF THE STRUCTURAL
BEHAVIOUR. ANALYSIS AND DIAGNOSIS.

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ABSTRACT:
The paper illustrates a multidisciplinary activity involving architects, civil engineers, architecture historians, wood technologists, dendrochronologists to determine the structural behaviour of an extraordinary timber roof structure: the roof of the church of Hagia Paraskevi in Chalkida (Greece).
The activity that has been carried out at international level for the specific characteristics of the structure recalls in its forms, materials, decorations, the Venetian typology.
The work carried out is focused mainly on the diagnosis and assessment of the components and connections of the timber structures.
In particular, the paper describes: the history of the building; the typology and the constructional analysis of the timber structure; the visual inspection
on the wooden components and joints for the estimation of the class of resistance; the punctual instrumental diagnosis; the definition of thematic mapping of the decays. The paper concludes with an overall assessment and estimation of the structural efficiency of the elements and connections of the roof timber structure.

KEY-WORDS: timber roof, cultural heritage, structural behaviour, diagnosis, multidisciplinary approach

1. Methodological introduction
The outstanding aspect of the study derives from the involvement on one side of two European Universities (National Technical University of Athens and Politecnico di Torino) and on the other side of two National Board of Antiquities – Ministries of Culture (of Greece and of Venice), on the problem of conservation of cultural heritage. This has brought to the definition of a working methodology that integrates and sometimes opposes two different cultures, offering an international dialogue between specialists in the field of timber structure conservation in the Mediterranean Basin.

All this finds justification in the case study of the extraordinary timber roof of the church of Hagia Paraskevi. And it couldn’t be in a different way: the church was realised in Greece in 13th century, the constructive typology - and maybe also the materials – derive from the Venetian school. Undoubtedly the influence of the late gothic Venetian style on the Greek construction develops in this roof structure with rare efficacy: for the truss typology at three elements, for the “barbacani” corbels, for the stone corbels, for the decorations with the winged lion, etc.

For the comprehension of mechanical behaviour have been used the recent Italian standards (UNI).

The basic themes of restoration, reinforcing and maintenance of built heritage, with particular attention to wood in cultural heritage, require new criteria based on multidisciplinary integrated competences, to support decisional and social complex processes:
- multi-disciplinary, for the study of complex problems;
- multi-scale, to take in account the single elements and the whole structure;
- multi-state, tailored to the different requirements of countries;
- multi-objective, customised to the different aims identified by a survey (diagnostics, conservation, restoration, maintenance, use, management);
2. The Hagia Paraskevi Church and its timber roof structure

2.1 Historical summary
In the period of Frankish rule, Chalkida was called Negroponte (Fig. 1).

![Map of Greece with the location of Chalkida](image)

Fig. 1 - Map of Greece with the location of Chalkida

Its strategic position for the conduct of trade in the Aegean and the wider area of the Eastern Mediterranean meant that often in its history it became a site of strife between many conquerors. Contact between the town and the Westerners date back to the Byzantine period, when emperors of the Komnenian dynasty, granted commercial privileges to the Venetians. In 1205 Boniface of Montferrat captured Euboea. Relations between the Byzantines and the Venetians were regulated by treaties in 1302 and 1310, according to which Chalkida remained a Venetian possession. After 1390 the Venetians were the sole rulers of the whole island. The Ottoman Turks finally captured Chalkida in 1470 under Mohamed II.

2.2 Description of the church
The church is a three-aisled basilica. The central isle ends in a flat sanctuary, and the side isles in square chapels that have no apses. The site on which the modern church stands was occupied by a Byzantine church of the late 5th or early 6th century. In the period between its initial erection and its modification in the 13th century, there were probably other changes. The first basilica was probably destroyed during the course of the Frankish occupation in the 13th century. It was reconstructed involving modifications and additions to the ground plan and the superstructure. Some
of the columns of the basilica were retained in situ and their basis were incorporated into the modern floor. The west facade and the south wall were reconstructed in the 14th-15th c. The west façade was reconstructed again after 1853’s earthquake (Fig. 2).

2.3 Comparison between roof structures of Venice and Hagia Paraskevi Church

The timber roof structures of Venice (in particular of the Venice Arsenal) and the one of Hagia Paraskevi church do have a common aspect: the marine environment with thermo-hygrometric conditions often of high risk. In the case of Hagia Paraskevi church we have to add the great seismic risk. The research intends to define a methodology that faces the restoration of roof structures of historical interest paying attention to the aspects of structural behaviour. The crucial scientific starting point keeps in consideration the coherence of data of mechanical behaviour of the timber
on-site, in relation to the thermo-hygrometric and chemical characteristics.

2.4 Roof construction
The pitched timber roof probably belongs to the 13th century phase and has many parallels in Western Europe, and also many similarities with some Italian roofs (Fig. 3). The trusses of the central roof with their corbel are excellent examples of Venetian art and were probably brought to Chalkida from Venice. The wooden corbels ("barbacani") of the roof are decorated with geometric and floral motifs, and enlivened with winged dragons and escutcheons and the winged lion of St. Mark.

The roof of the central nave was initially composed by a system of 21 trusses, 17 of which exist until today, in of about 8.50 m of span with an inter-axis of about 1.70 m. On the trusses there are timber joists (many of them seem substituted) and on them there are wooden boards on which lays the roof covering. Over the boarding lays the roof covering of Byzantine type tiles. The trusses are supported on the North and South stone masonry walls of the central nave of the church.

Fig. 4 - Roof system of the central nave, three-elements truss and detail
Each truss is made of only three elements, a tie beam and two rafters. The elements are jointed together with the mortise and tenon connection system. Each truss lays on two brackets. The span covered by the tie beams is 8.50 m and the section of the timber elements is around 20x30 cm (Fig. 4).

3. Architectural survey
In general, survey is the first real inspection aimed to identify quality and characteristics of each element. The conducted survey concerned all the joints tie-beam/rafter of the trusses. The geometric characteristics of the whole structure and the joints are reported on accurate drawings. A part of the diagnostic survey was the systematic constructional analysis of every joint that could be reached. Mainly axonometric sketches and drawings were used, for the recording of the original constructional details, the pathology and in many cases the previous interventions (Fig. 5).

*Fig. 5 - Constructive survey, detail of the connection between tie-beam and rafter.*
This survey was supported by a punctual inspection with an instrumented drill, that has allowed not only to verify the conservation state of the material, but also and mainly, the characteristics of the joint, this permitting to give dimensions of the tenons and mortises, where present. With the combination of observations and the performed tests, it was possible to determine the alterations of the connections, the previous interventions, with the aim of determining the real efficiency (or not) of the connections. In all the trusses, the connections among the rafters on the top of the roof have been visually examined and, in some cases, with instrumental tests. From such survey it was possible to verify that all the original joints of the structure where tenon and mortise, both for tie-beam/rafter, and for rafter/rafter at the top of the truss (the dimensions of the parts respect the values around of 1/3, 1/3, 1/3).

4. Diagnosis survey and results
On the timber roof of Hagia Paraskevi Church, both inspection and grading methodologies were carried out following the Italian standard UNI 11119/2004 Load-bearing structures – On site inspections for the diagnosis of timber members.

The identification of the wood was carried out by means of both macroscopic and anatomical inspection methods. The interest on the wood species knowledge is related to the analogies of the wood material used in some churches in Venice and in the ancient structures of the Arsenal. In order to establish the hazard classes of biological attack, the UNI EN 335 was followed. The structure as a whole is in a good conservation state, taking into account the directly visible elements, disregarding some minor insect attacks in the small sapwood portions. The wood was identified as Larix decidua Mill.

The most common defects are angled grain, knots and ring shakes. For those members with angled grain, reduction coefficients of bearing resistance will be recommended. In particular for “barbacani” it is suggested, as a precaution, to do not consider their action in relation to the truss, in correspondence of the joint (Fig. 6).

Regarding pathologies the following situations have been observed during inspection is that, in general, the wood is protected from rain and water so its moisture content is commonly less than 20% (class 1 of UNI EN 335:1993). Locally wood is not completely protected and its moisture content could be greater than 20% (Fig. 7-8).
It is suggested, for the heads of the tie-beams and rafters, as well as of "barbacani", to make a proper ventilation of the heads so to protect the material from fungi’s attack. All the insect attacks are at present concluded.
by a long time and limited to edge areas (remains of sapwood). The wooden parts into the walls are on the contrary generally attacked by brown rot fungi, in the best situation the attack is only on the external portions of the section. This is important in the evaluation of possible conservation interventions. In some cases ring shakes are relevant, it suggest the replacement of the part of the beam interested by this defect.

5. Numerical analysis verification
The European standards (Eurocode 5), the National Codes for the loads and the above described grading of the existing timbers have been used for the numerical analysis. The calculations concerning the load bearing capacity of the timber members and the connections verified the static efficiency of the authentic system.

6. Conclusions
Who has the assignment to evaluate the characteristics of elasticity and resistance of the structural elements and the efficiency of the connections of ancient wooden structures, with the purpose to evaluate the load-bearing capacity of the structures of which they belong to, has to pick up all the information on the material wood, on its principal characteristics physical-mechanics, of its defects and of the agents that could have caused the deterioration. Furthermore the expert has to analyse with attention the systems of mutual connection among the structures, in relationship to the geometric characteristics of the structural system which they belong and to their possible decay. Finally it is important to recognize the interventions of consolidation made in the time and to know how to evaluate its real effectiveness (i.e. prosthesis, additions of wooden parts, metallic parts etc.).
Considering the great number of variables present and the difficulty to carefully explore the whole volume of every wooden element (i.e. a rafter or a tie-beam), it would be illusory to pretend to evaluate all the factors above mentioned, or to foresee the breaking load of every element.
On the opposite, through an accurate examination and maintaining a certain safety degree, it is possible to reasonably esteem the elements current state (resistant section, admissible tensions, elastic module, etc.) and to give realistic data to the planner of the intervention on the existing structure.
The methodology applied for the investigation of the Hagia Paraskevi timber roof has proven once again the great role of preventive diagnosis. In fact generally an accurate diagnosis gives the possibility to avoid unnecessary and expensive interventions. In cases of structures belonging to
our cultural heritage preventive, diagnosis is even more important and absolutely necessary in order to ensure an optimum intervention that takes into account both safety requirements and all the other values of each specific historic structure. This is the only way to avoid the loss of ancient timber structures that are part of our cultural heritage.

The peculiarity of this international experience is evident also from the presented results that have found a common “language” both in the diagnosis phase, both in the intervention proposal.

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Bibliographic references

Figure 3 - Hagia Paraskevi Church: bottom-up view of the timber roof structures

Figure 6 - Drawing and images of some decays and pathologies