ANALYSIS OF JOINTS AND ORNAMENTS OF THE WOODEN CHURCHES STRUCTURES IN MARAMUREȘ COUNTY

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Abstract
The paper presents an analysis of wooden joints and ornaments used in construction of wooden churches built in XVIII-XIX centuries in Maramureș County, Romania. In the structure of wooden churches, Romanian masters revealed the wood - natural material and representative of Romanian culture and civilization of the Carpathian, faith-Christian monotheistic, Dacian population subsequently the only Roman people of the Carpathian basin which has cultivated such a faith, unlike existing polytheistic beliefs of the ancient peoples, woodworking skills that manifested from the creation of wood joints to ornaments and floral and geomorphic with sacred meaning to human existence. Wood joints, besides proving refinement and craftsmanship, good knowledge of proportions, showed the inclination to achieve balance of form - material - requests and tension accumulated in the structure of the wooden churches. This paper aims to present the triad: material - form - resistance (mechanical and over time) the most important joints in wood used in the structure of the churches of Maramureș.

Key words: wooden churches; joints; strength; ornaments; stress and strain state.

INTRODUCTION
The villages from Maramureș placed in north of Transylvania, mentioned for the first time in 13th and 14th centuries, combine in very harmonious way two different factors: historical and geographical in archaic structures for housework with spiritual one (Baboș 2004). The central point of Romanian communities is the church, which represents an expression of Christianity, spirit protection and pure soul of people. Churches have been constructed at one time with dwelling houses and other constructions, from the same materials – wood. The wood churches from the north of Transylvania by its architectural shape, structures and construction is a result of long creation process and selection if some previous models (Bănățeanu 1969; Bârlea 1909). The origin of these models is from the beginning of Christian life through-out the country. These constructions, mainly wood churches are built by horizontal oak or fir frames laid on a low rock. Specific of churches from Maramureș is the 50-60 meters height tower of gothic inspiration. The shape, dimensions, structure and the art of wood processing which are characteristic of these high towers from XV-XVII centuries represent “the high science” of peasant builder. They succeed in their doing using a very ingenious system of counter-wind which assures a very good stability of wood tower (Botiț et al. 2011; Breyer 1998).

OBJECTIVE
The aim of this study is to analyze the structural and aesthetic characteristics of the churches of Maramureș through the modern methods of investigation. The particulars of wooden churches, from the architectural plan, materials used, methods of joining wood, ornaments, tower and roof. Also finite
element analyzes a specific combination of column and beam scale 1:1. Tensions and calculated displacements revealed that connections made two to three centuries ago show the allowable values below, which shows the skill and sense of proportion of the Romanian craftsmen.

CHARACTERISTICS OF ROMANIAN WOODEN CHURCHES

The very spectacular elements of the timber churches are the porch and the tower. The porch guard the main entrance, it is around the nave and can be built with one floor as Șurdești Church (1721). The tower is slim, with a balcony where bells are mounted. This is positioned as height as possible to provide a very good acoustic of the bells and good point of view for the region. For example, the balcony position of Șurdești church (built in 1721) is at 18 meters, the height is about 12 meters and the width is about 8 meters and the belfry is about 54 meters, the Plopiș church (1798) and the one in Bârsana (newly built church, from 1995 to 2005, 71 meters high) (Fig. 1) (Cristea 1989, Curtu et al. 2011).

![Fig. 1. Wooden churches from Maramureș: a) Săpânța; b) Oncești; c) Șurdești; d) Budești; e) Basic plans of different wooden churches](image)

The roofs, covered with shingles have a very great escarpment. The base of roof is very close to the earth level. The shingles are tiled in a different pattern: straight, round, honeycomb, herringbone or fish - scale (Cristea 1989). In Fig. 2 can be seen different types of cutting the shingles.

It can be noticed that these are dismountable joints. These constructions can be strip down and strip up without destroying any component element. Due to some fungal attack, earthquake or fire, some of these buildings were destroyed among the years. The main elements of the timber churches are the solid wood beams processed by hand craft or in saw mills. The specific joints used are: dovetail joint, tongue and groove joint, lap joint, carpenter’s joint, mortice and tenon joint, gap joint.
The main strength structure built from solid wood beams (fir or oak) is covered by resinous timber (Dinescu 2006; Eliade 1975). The strength elements are made from solid wood. The constructive details of timber joining are presented in Fig 3. On the timber length the joining are made through the tongue and groove joint which can be at 90° or tilt under a certain angle. Walls are made of beams thinner than the base frame and merged into the "dovetail" or "dog" technique (Fig. 3). In the upper part of the structure, for uniting the walls and beams are used joints in steps, whose extension, by joining, form a pair of "wings" at each corner (Irimie 1983; Patterson 2001). The wings are artistically carved and allow supporting the gutter and protecting the load-bearing walls against the rain and snow; the wings cut in a decreasing manner allow a further slash or the forming of right angle or of spirals called" horse heads" (Fig. 3) (Lăzărescu 2004).

Fig. 2.

*Patterns of shingles used for roofs of wooden churches*

Fig. 3.

*Types of dismountable wooden joints*

The Romanian wooden churches strictly relate some of the specific construction aspects. The extension of the whole construction basis on the exteriors (the shape of the construction is similar with ship one, polygonal with the apse in the front called nave) goes to the strength improvement, the existence of the beams cantilever under the overhang with length between 0.2 and 0.6 meters are specific for these churches (Fig. 4).

The central nave of the church is separated in two parts: naos and pro-naos and the altar is always oriented to East. The wall that separates the nave from the altar, access between the two areas being done through the deacon’s doors, symmetrically placed in front of the center of the veil and through the imperial doors located centrally. In Fig. 4, the classical division of a Greek-Catholic church, made according to canons, with west-east orientation. Timber churches took over from ancient time specific constructional systems, type of church plan, decorative motifs and other specific elements (Madsen 1992; Natterer 1998; Eggertsson 2002).
Fig. 4.
Types of nave construction: a) simple; b) with principal apse; c) with principal and lateral apses

A great variety of wood carving from the door frame can be observed: spiral, hearts, ivy leaves, geometrical motifs, Catherine wheels, volutes, floral motifs. The door frames are ornamented with vegetable motifs (Fig. 5). The portals are vaulted semicircular. The terrace - limited or extended - is bounded by pillars disposed rhythmically and is meant to represent the memory of the ancient. At the same time, the terrace is fitted with a large table surrounded by benches. The doors and windows are of small dimensions, being fitted with forged iron grilles (Popa 1932; Sunley 1987; Ștefănescu 1968).

Fig. 5.
Ornaments of the pillars gate

The columns are processed from solid wood (fir or oak) and are carved manually (Fig. 5). The joint between them and the other constructive elements are made very simple and in a very efficient way.

Fig. 6.
Details of ornaments

FINITE ELEMENT MODELING OF WOODEN CHURCH STRUCTURE

There has been made a Finite Element Modeling of stresses and strains state of the connection between the column and girder bonded with bracing, as can be seen in Fig. 7. From the structure of the geometric model have been neglected the ornaments used by craftsmen.
Fig. 7. The geometry of the structure analyzed: a) Dimensions; b) the application of force and establishing the conditions for contour

Although most churches of Maramureș are made of oak wood material, but in FEM-modeling was used resinous wood, with elastic characteristics presented in Table 1. The properties of materials were introduced in preprocessing part taking into account the orientation (longitudinal, radial and tangential direction) of each part of analysed structure.

Table 1. Elastic properties of material used in FEM

<table>
<thead>
<tr>
<th>Materials</th>
<th>Density $[\text{g/cm}^3]$</th>
<th>Young's Modulus $E_1$ [MPa]</th>
<th>$E_2$ [MPa]</th>
<th>$E_3$ [MPa]</th>
<th>$G_{12}$ [MPa]</th>
<th>$G_{23}$ [MPa]</th>
<th>$G_{13}$ = $G_{23}$ [MPa]</th>
<th>Poisson Coefficient $\nu_{12}$</th>
<th>$\nu_{21}$</th>
<th>$\nu_{13} = \nu_{23}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fir</td>
<td>0.59</td>
<td>13000</td>
<td>940</td>
<td>490</td>
<td>950</td>
<td>760</td>
<td>150</td>
<td>0.35</td>
<td>0.6</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The structure has been loaded with a uniformly distributed force over the entire girder, the intensity of 0.07 $N/mm^2$ and as boundary conditions, the pillar has been embedded at the bottom, in the foundation as can be seen in Fig. 7, b. So, al degree of freedom (DOF) were restrained. For the mesh structure, we used solid finite elements type hexaedral with three degree of freedom per node. The analysis were performed in Abaqus program.

RESULTS AND DISCUSSION

Finite-element modeling showed that von Mises equivalent stresses of the most popular sections of the girder and pillar does not exceed 4 MPa, based on allowable stress of about 10 MPa for wood, which proves that the masters of Maramureș know from experience the ideal range of dimensions for the structure of the wooden churches (Fig. 8). The most stressed area of the analyzed structure is the joint between the column and the beam, and the beam surface at mid-length of the beam (Fig. 9). As can be noticed from geometry, the shutters are not arranged symmetrical symmetrically to the longitudinal axis of the girder. This leads to combined loading, the maximum stresses being recorded in area without shutters. In the contact area between pillar and girder and shutters with girder is noticed a contact pressure which is in fact a local compression of wood. To avoid the disconnection wood nails or keyed joint were used by craftsmen.
Maximum displacement size is relatively small with linear displacements ranging from 6 ... 7 mm, less than the allowable and 12 ... 15 mm for a beam length of 4000 mm (Fig. 10, a). Note that the asymmetry due to the direction \( x \) where support beams are joined housed only on one side of the column, crooked bending occurs, which leads to displacements and rotations of the girder both in the YOZ plane and in the XOY plane (Fig. 10, b). Also, the pillar tend to rotate in the same plane as girder (Fig. 10,c).

In the dynamic loads solicitations (earthquakes, high winds etc.), frequency of the beam is 4.283 Hz for the first mode of vibration. Starting mode 4, the pole and bracings start to enter the vibration, at frequencies close to the column frequency.
CONCLUSIONS

Timber churches took over from immemorial and brought over to ours some constructional system, type of church plan, decorative motifs and other specific elements which prove the creative spirit of the Romanian people. Timber churches are a reality that defines the spiritual geography of the Romanian people everywhere. Therefore these are an open regarding the art of wood casting and timber construction from Romania. The timber churches are made a message of Romanians peasants Middle Age doweling art and represent a veritable sources of historical information regarding the culture, wood casting technique and handcraft of the civilizations from geographical Charpatians space.

These constructions, due to their specific joints used in it, can be easily dismounted and mounted elsewhere. Their wooden structure assures a good insulation in both directions: thermal and phonic. The specific elements of the timber churches from Maramureș are: joints have cantilever beams, all joints are made in the demountable system, the richness of doors from naos and pro-naos architecture, the main elements (such as crosses, doors) are dated precisely, the overhang details are various and with suggestive ending. Their structure is characterized by symetry and antisymetry, good balanced proportions, shapes, equilibrium, interiors design, majestically and graceful roof, and compositional and ornamental abundance of decorations.

The FEM provides a simplified solution. Analyzing the stress-state on typical joints used in wooden church structure, the first conclusion is that the craftsmanship of peasant builder from previous centuries offered the possibility of obtaining wood structures near best. Not only the stress-strain state in the studied joints goes to this affirmation, but the whole structure is almost equally solicited and the external loads such wind, snow or earth quakes do not affect the behaviour of the strength structure.

Due to their complex construction of the tower, if some of the main counter wind elements are destroyed by fungal attack or by decay, the structure take over the supplementary solicitations gives and the new structure becomes a new equilibrate structure. Over 30% of counter wind failure, the alll structure becomes unstable.

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