BULETINUL INSTITUTULUI POLITEHNIC DIN IAȘI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iași
Volumul 62 (66), Numărul 2, 2016
Secția
CONSTRUCȚII. ARHITECTURĂ

A COMPARATIVE STUDY OF TIMBER STRUCTURES FOR PITCHED ROOFS

BY

IOANA-SORINA ENȚUC*, ALEXANDRU SECU, NICOLAE ȚĂRANU, ION FLORENȚA, SEBASTIAN-GEORGE MAXINEASA and GABRIEL OPRIŞAN

"Gheorghe Asachi" Technical University of Iaşi,
Faculty of Civil Engineering and Building Services,

Received: Juny 06, 2016
Accepted for publication: June 27, 2016

Abstract. Wood as building material has been used since ancient times due to its performance and generous applicability in implementation of various structural elements and building systems. The need to reduce losses in the process of implementing operational structures in construction, from excessive consumption of material has led to the development of new structural systems for wood construction and roofing structures. Frequently, modern structures of pitched roofs have in their composition systems made of prefabricated structural components and wood products. This paper examines several embodiments of wooden roofing structures, taking into account the structural system, materials and dimensions of lumber assortments and material consumption for various types of pitched roofs.

Keywords: timber structures; pitched roofs; material consumption; rational design.

1. Introduction

Wood has been used in construction since ancient times due to the performances of the material and its closeness to the natural environment. Wood

---

*Corresponding author: *e-mail:* ioana.entuc@tuiasi.ro

is easily processed, it has low weight, shows favourable mechanical properties and it is available in a large variety of assortments and construction products. An appropriate design may lead to rational use of wood material assortments to achieve efficient systems for sloping roof structures and reducing the material losses resulting from the use of assortments of timber. In addition, a good design may avoid labour intensive materials and construction elements, also enabling to find an optimal solution between weight and performance of structures.

The evolution of wooden structures, depending on the development of technologies for construction, the assembly possibilities and the use of raw or processed wood, has guided the design and implementation of specific structures for roofs. Technology development processing wood waste, the possibility of using laminates (OSB boards) and placing of metal pieces in the connection of timber products conducted to structural systems with high economic efficiency.

Three representative structural systems, namely the traditional trestle frame system, the roof framing with rafters and collars and the roof on timber trusses are analysed in this paper. Structural performance evaluation of roof structure was made using the software package WoodExpress, highlighting the advantages of each in terms of load capacity. The analysis is completed by a comparative study of the variants studied according to the material consumption in order to improve the economic criteria of sustainable development.

The comparative study for all of three systems was made taking into account the entire roof structure with the sheathing layer for covering.

2. Framing Systems for Timber Roofs

2.1. Trestle Frame Roof Structure

The trestle frame roof structure and its composition, Fig. 1, is determined by the size of the openings and their position in the plane of the vertical structural elements, frames or walls. The frameworks of traditional seats are arranged along the building at intervals of 3.5 to 4.5 m, depending on the position of frames or structural walls that support the roof structure, (Darie *et al.*, 2013; Marusciac, 1997; Rodriguez & Avellaneda, 2012).

Along of the roof slope structure there are rafters made of beam types or plank boards, arranged at distances of about 70 to 90 cm and supported by purlins. The wooden rafters are elements with a minimum width of 58 mm and arranged by line of the greatest slope with a distance between their bearings equal to 2.00 to 3.50 m.

The purlins are timber elements oriented along the longitudinal direction; they are made of wooden beams with cross sections from 100 ×

× 120 mm to 200 × 250 mm and supported by posts. The wall purlins are those elements that sustain the rafters and are supported on the exterior wall of the building. The fixing of wall purlins on the structural walls of the building is performed by steel anchors included in a reinforced concrete ring.

The posts are vertical or inclined wooden elements situated along the building; they rest on longitudinal or transverse structural walls through the base plates. These elements are made of sawn timber with rectangular cross-sections between 150 × 150 mm to 200 × 200 mm or roundwood cross sections with diameters between 120 mm and 170 mm.

Collars or transverse ties are horizontal elements placed under the purlins, to strengthen the posts and rafters and to make undeformable transverse structures. The usual cross-section dimension of the collars is 28 × 150 mm.

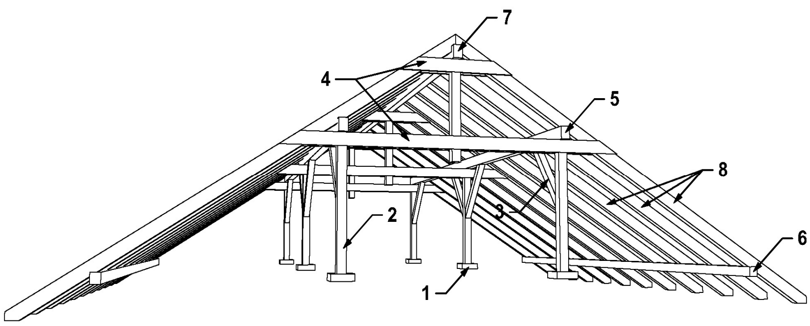

Fig. 1 –Trestle frame roof structure:
1 – base plate; 2 – post; 3 – braces; 4 – collars; 5 – current purlin;
6 – wall purlin; 7 – top purlin (ridge beam); 8 - rafters.

Braces are timber elements with square or round cross-sectional dimensions between 100 × 100 mm to 120 × 120 mm providing the longitudinal bracing of the building.

All structural elements of this type of roof, namely rafters, purlins, posts and wall purlins, have big cross-section and are made of solid sawn lumber. These solid wood elements are delivered generally on site, where they are individually cut to size and required shape and then assembled. Hence, it results in the loss of materials, waste from cutting the wood elements, a longer period of execution, and greater cost regarding handling of the timber members and management of waste.

The transverse assembly made by posts and collars in line with posts is named the trestle system or chair. The optimum distance between these assemblies is 3 to 5 m.

Joints between elements of wood, in the case of this structural system, are traditional, like a notched joint reinforced with staples or bolts (for bearing rafters on purlins or braces with struts or purlins). The joints between collars and rafters or struts are realised by nails or staples. The purlin wall and the distribution plate is anchored in reinforced concrete elements using anchor bolts or steel bars.

At the roof level this roof can preserve useful spaces depending on the arrangement of the frames or the posts along the roof structure.

The roof deck made of plank is not a structural element of roof, and it does not contribute to increasing the rigidity of the roof structure.

2.2. Collars Roof Structure

A rafter and collar roof structure, Fig. 2, consists of an unstructural ridge roof purlin, rafter ties, rafters, and blockings; all of these are obtained from board, and structural roof decking from OSB wood panel. This system is widely used in lightweight wooden structures. The advantage of this system of framing is that the space under the roof may beecome living or storage space (Ching, 2008).

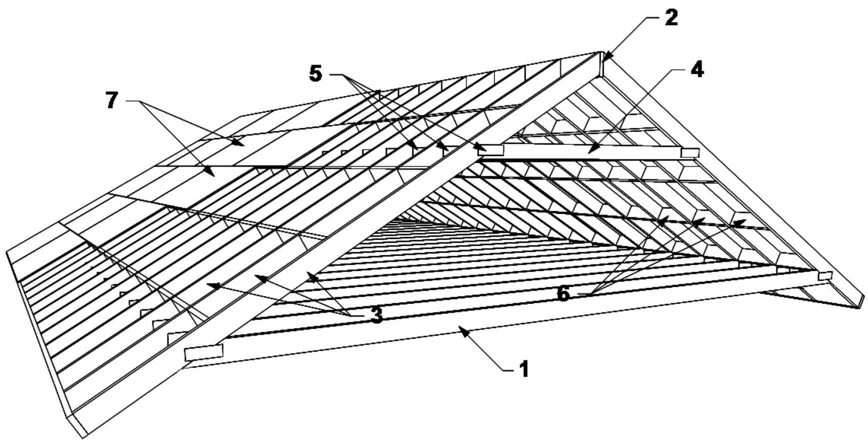

Fig. 2 – Roof structure with collars: 1 – rafter tie; 2 – ridge;
3 – rafters; 4 – collars; 5 – steel plates; 6 – blocking; 7 – OSB sheathing.

The roof consists of rafters fixed at the ridge and the collars and rafter ties which are the horizontal roof members, blocking and structural roof deck.

The rafters made of boards, positioned to 400 mm or 600 mm, are fixed at the ridge while in the transverse direction they are connected by collars and rafter ties. The maximum length of the rafter board is usually between 4 m and 6 m.

The collars and the rafter ties, (horizontal roof members), keep the rafters against the ridge board and prevent the spreading of the rafters when they are subjected to various types of loading, (Branco & Descamps, 2015). The purlin height should exceed the rafter height by at least 50 mm to enable the joining with rafters at the ridge.

The solid blockings, generally made from short pieces of lumber, run between rafters at 1.2 m distance. Their role is to prevent rotation or lateral displacement of the rafters. The OSB panels or other wood structural panels, working as structural roof sheathing, should be installed perpendicular to the rafter to provide a diaphragm in the roof plane. The structural wood panel is fixed on the rafters and blockings by nails. The contact between collars and rafters and rafters as well as the ridge board respectively, can be realised by nails and steel plates. (Thallon, 2008). The useful space obtained at the roof level is not imposed by the intermediate structural elements as posts. The roof structure can be delivered on site as a prefabricated system formed by rafters and collars; the set of pieces is then lifted, assembled and stiffened with blockings and OSB panels.

Using the board lumber for the entire roof system and a suitable prefabrication system leads to a decreased on-site or fabric waste and a reduced cost of its handling and transportation. The height of rafter cross-section, about 200 mm, enables embedding an efficient insulation system in the space between rafters to save useful space. The collar ties placed on the bottom part of rafters can serve as a rest on the joists if the ceiling joists are parallel to the rafters and individually designed.

2.3. Trussed Rafter Roof

The trussed rafter roof, Fig. 3, represents a structural system for a modern solution of a residential building. The timber roof trusses are generally made from small lumber members fixed in nodes by steel plates and screws or punched steel plates.

Blockings between top chords, wood structural panel for sheathing are provided and, if necessary, horizontal braces placed on the longitudinal direction of the roof are utilised. This roof system can cover larger spans than the types described before; the loads applied on roof are transferred only to the exterior walls. One disadvantage of this roof structure is that the web members block the space that could be used for storage or habitable, (Ching, 2008; Thallon, 2008).

The truss girder or trussed rafter represents a triangular wooden structure usually made from smaller elements, timber board or plank, joined by nails, screws and steel plates. This truss system can be manufactured on the construction site or in specialized workshops and shipped to the construction site for mounting. The internal elements of truss, namely the web members, are subjected to axial forces, tension or compression while the top and bottom chords are subjected to axial forces combined with bending. In the case of the arrangement of the trusses at 400 mm or 600 mm, to provide a good rigidity of the roof structure, blockings and wood structural panels should be used. If the distance between truss girders are bigger, it is recommended to use vertical and horizontal braces in roof plane (Aghayere & Vigil, 2008; Secu *et al.* 2015).

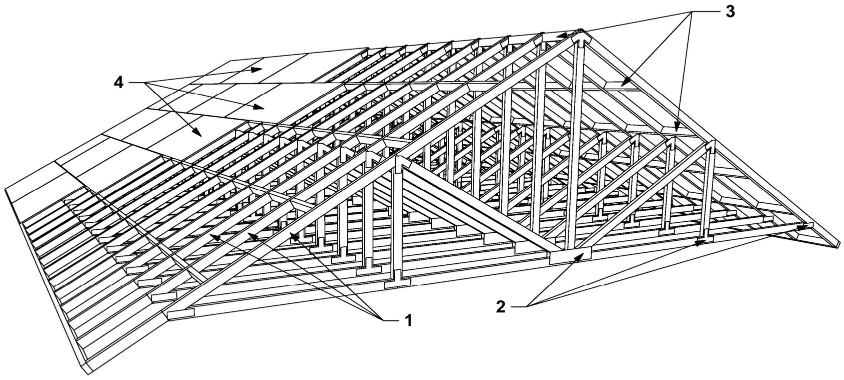

Fig. 3 – Trussed rafter roof:
1 – truss girders; 2 – steel plates; 3 - blockings; 4 – structural sheathing (OSB panel).

The solid blockings, generally made from short pieces of lumber, run between top chords at 1.2 m distance. The blockings cross section can be equal to the cross section of the rafters. Their role is to prevent rotation or lateral displacement of the rafters. As a structural roof sheathing the OSB panels or other wood structural panels installed perpendicular to the rafter can be used to provide a rigid diaphragm in the roof plane. The structural wood panel is fixed on the rafters and blockings by nails. The contact between collars and rafters respectively rafters and ridge board, can be realised by nails and steel plates, (Thallon, 2008).

3. The Comparative Analysis of the Roof Types

A structural analysis was carried out for the three types of roof structure described above. The analysis was performed according to the provisions of (SR EN 1995 - 2004), on a residential building having 9 × 12 m in the horizontal plane and the same geometry and architecture. The structural elements for each case were analysed and checked. The wood used in the manufacturing of different types of timber roofs had to be stress graded (SR EN 338 - 2010). For the current study, the investigated loads applied to each roof structure included the self-weight (as dead load) the environmental loads (snow and wind) corresponding to Iasi, Romania, and live loads for maintenance. The dead loads were evaluated using the volumes of elements for sawn lumber, OSB panels, steel fasteners and plates, and their corresponding densities. The structural schemes of the three analysed framing systems corresponding to the types of roofs described before are illustrated in Fig. 4.

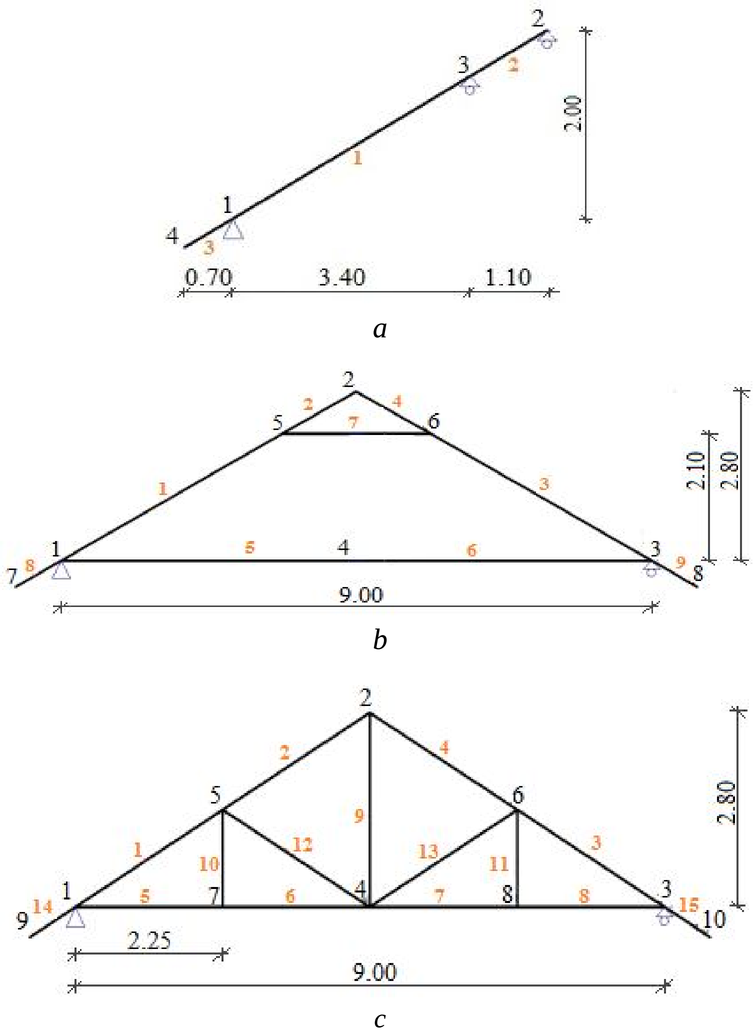

Fig. 4 – The structural schemes of the analysed roofs: *a* – trestle frame roof structure; *b* – roof structure with collars; *c* – trussed rafter roof.

The selection of the cross sections for all individual timber members and the joints detailing appropriate to the three framing systems of the pitched roofs have been carried out according to the provisions of Eurocode 5. Table 1 presents the wood products and the steel pieces utilised to conceive the three roof framing systems analysed in this paper.

Table 1
The Application of Steel and Wood Products in the Analysed Roof Structures

	Trestle frame system	Collar roof structure	Trussed rafter roof
Solid timber beams	x	–	–
Timber board	x	–	–
Timber board	–	x	x
OSB panel	–	x	x
Nails, screws	x	x	x
Staples	x	–	–
Steel plates	–	x	x

The study of the materials consumption, Table 2, corresponding to the 9×12 horizontal surface of the building has given the following results: the volume of wood required to construct the roof structure with collars is 6.632 m^3, the trussed rafter roof structure needs 6.547 m^3, while volume of wood for the traditional trestle frame roof structure is 5.389 m^3.

Table 2
Material Consumption, Corresponding to the 9×12 m^2 Building Surface

Components of the roof structure	SI	Trestle frame system	Collar roof structure	Trussed rafter roof
Wood products (total volume)	m^3	5.389	6.632	6.547
Wood products (consumption/m^2)	m^3/m^2	0.047	0.058	0.064
Solid timber beams	m^3	4.628	–	–
Timber board	m^3	0.750	–	–
Timber plank	m^3	0.011	6.632	6.547
OSB panel	m^3	–	0.281	0.281
Steel connectors (total volume)	m^3	0.004	0.043	0.104
Steel connectors (consumption/m^2)	m^3/m^2	0.046×10^{-3}	0.398×10^{-3}	0.962×10^{-3}
Nails, screws	m^3	0.0003	0.003	0.003
Staples	m^3	0.0036	–	–
Steel plates	m^3	–	0.040	0.101

Fig. 5 illustrates the volumes of the materials utilised to construct the three types of the roof structures. It should be mentioned, however, that in case of the traditional roof structure, the material consumption for the deck needed to support the roof has not been taken into account.

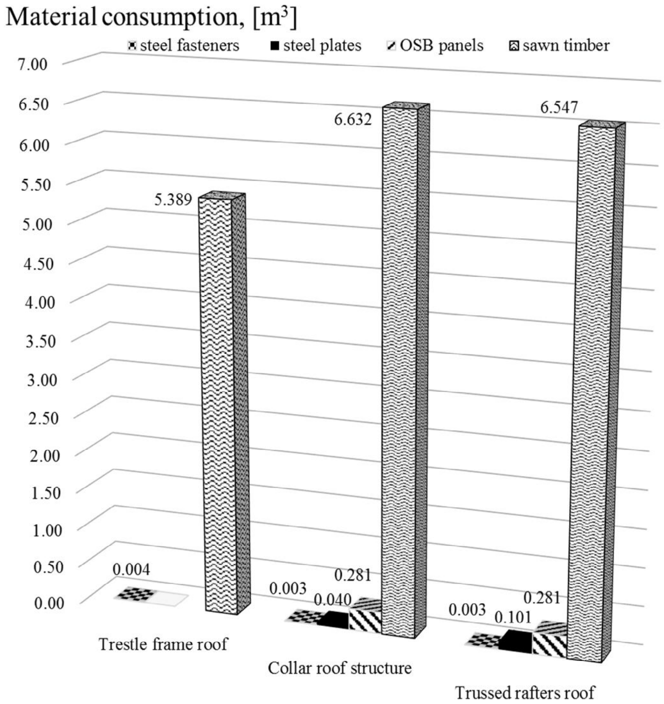

Fig. 5 – Material volumes for the analysed roof structures.

Table 3 presents all the data corresponding to the timber members and the steel components required to establish the permanent loading of the roof structures for the structural analysis. A representative illustration regarding the weight of each material utilised in the roof structures is given in Fig. 6.

Table 3

The Weight Corresponding to the 9 × 12 m² Building Surface

Unit weight for the roof components	SI	Trestle frame structure	Collar roof structure	Trussed rafter roof
Self-weight of the roof	kN	21.864	31.837	36.273
Weight of the roof per square meter	kN/m²	0.2024	0.2948	0.3359
Weight of timber products (sawn elements and OSB panels)	kN	21.557	28.495	28.152
Weight of steel connectors (plates and fasteners)	kN	0.307	3.342	8.121
Weight of timber per square meter	kN/m²	0.1996	0.2638	0.2607
Weight of steel per square meter	kN/m²	0.0028	0.0309	0.0752

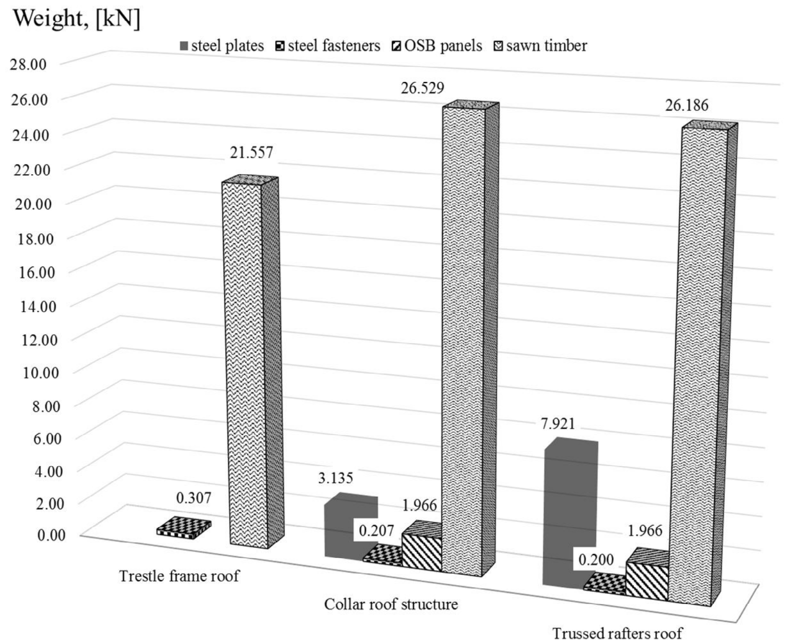

Fig. 6 – Weight of materials utilised for the analysed roof structures.

4. Conclusions

Three different types of timber structures, namely trestle frame structure, collar roof structure and trussed rafter roof structure are presented and analysed in this paper. All structures are conceived of members made of either sawn timber or industrialised wood panels and their joints are realised using steel pieces. The efficiency of the material utilization to construct the three types of pitched roofs is analysed in detail based on the types of the wood members and on the steel pieces needed for joining them in nodes. The need for the global stiffness of the roof assembly is also emphasised. It has been found that the traditional trestle frame solution for the pitched roof leads to the lightest assembly, with less timber and steel consumption, but it requires a separate floor to provide adequate rigidity and support conditions.

REFERENCES

Aghayere A., Vigil J., *Structural Wood Design: A Practice-Oriented Approach Using the ASD Method*, John Wiley & Sons, New Jersey, 2007.

Andreica H.A., Berindean A.D., Dârmon R.M., *Structuri din lemn*, Edit. U.T. Press, Cluj-Napoca, 2007.

Branco J.M., Descamps T., *Analysis and Strengthening of Carpentry Joints*, Construction and Building Materials, 97, 2015.

Darie M., Briciu M., Pană L., *Curs construcții civile – Acoperişuri cu pante mari*. Ediția a 3-a, Edit. Conspress, Bucureşti, 2013.

Ching, F. D. K., *Building Construction Illustrated,* 4th Edition, Van Nostrand Reinhold, New York, 2008.

Marusciac D., *Construcții moderne din lemn,* Edit. Tehnică, Bucureşti, 1997.

Rodriguez V., Avellaneda J., *Typological and Structural System in Traditional Timber Roof of Multiaisle Buildings in Europe,* World Conf. on Timber Engng., session 43, 2012.

Secu A, Florența I, Țăranu N., Lupăşteanu V., *Particularities of Platform Wooden Framing Structures,* Bul. Instit. Politehnic, Iaşi, **LXI** (**LXV**), *1,* s. Construcții. Arhitectură, 87-92 (2015).

Thallon R., *Graphic Guide to Frame Construction,* 3RD Edition, The Tauton Press, U.S.A., 2008.

* * * *Lemn pentru construcții. Clase de rezistență.* (*Timber. Strength classes*), SR EN 338:2010.

* * * *Design of Timber Structures*. Part 1.1: *General Rules and Rules for Buildings*, SR EN 1995:2004.

STUDIU COMPARATIV A UNOR STRUCTURI DIN LEMN PENTRU ACOPERIŞURI ÎN PANTĂ

(Rezumat)

Lemnul ca material de construcții a fost folosit din cele mai vechi timpuri datorită performanțelor sale favorabile şi a aplicabilității generoase la realizarea diferitelor elemente şi sisteme structurale pentru construcții. Nevoia de a reduce pierderile rezultate în urma procesului de punere în operă la structurile pentru construcții, dintr-un consum excesiv de material, a dus la dezvoltarea unor noi sisteme structurale pentru construcțiile din lemn şi implicit a structurilor pentru acoperişuri. Frecvent, structurile moderne ale acoperişurilor în pantă au în alcătuirea lor şi sisteme prefabricate realizate din produse şi elemente structurale din lemn. În articol se analizeaza mai multe variante de alcătuire a structurilor pentru acoperişuri din lemn, luând în considerare sistemul structural, materialele şi dimensiunile sortimentelor de cherestea, cantitățile de material, greutățile şi performanțele structurale globale ale acoperişului.