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FULL AND PARTIAL STRUCTURES OF HISTORICAL ROOF TRUSSES IN ASSESSMENT OF VOLUME OF TIMBER USED FOR CONSTRUCTION

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Abstract
Rafter framing is the basic roof frame that, through the trusses, transfers the load from the roofing to the main supports of the building. The construction material of these structures is usually wood. The development of roof framing construction for wider and wider covers has caused an increased demand for construction timber for their construction. This paper points to this economic aspect based on an example of a geometric pattern of a rafter framing based on repetitive construction of full and partial girders. For such an understanding of the use of simple trusses by carpentry masters who constructed roof framings in past centuries, it is pointed out in Ryszard Ganowicz's works titled "Historical roof trusses of Polish churches" with section by Piotr Rapp's "Historical development of roof structures in Polish churches". This work is intended to provide an initial estimate of the percentage of wood saved in this solution. This assessment will be made on the basis of the inventory documentation of the roof framing of the church of the Michael the Archangel Church in Wierzbnik.

Keywords: **Historic buildings; Rafter framing; Roof framings; Modular construction.**

1. INTRODUCTION

Rafter framings form the basic roof frame that, through the trusses, transfers the load from the roofing to the main supports of the building. The construction material of these structures is usually wood [1, 2, 3, 4]. Historically analyzing the development of these structures, it needs to be indicated that wood was the only material from which these trusses were made. Their shape and dimensions were mainly dependent on the span of the supports, which were mainly the supporting walls of the structure on which these elements were supported. This paper points to the economic aspect in the historical development of roof structures relying on an example of a geometric pattern of a truss based on repetitive construction of full and partial roof framings. This approach used by carpenters, who constructed roof rafter framings in past centuries, is indicated in the work of Ryszard Ganowicz "Historical roofs of Polish churches" with part of Piotr Rapp's "Historical development of roof structures in Polish churches". These activities consisted mainly in the use of alternating full and partial roof framings, usually in rhythm: one full and two incomplete trusses. This work is intended to provide an initial estimate of the percentage of wood saved in this solution. This assessment will be made on the basis of the inventory documentation of the rafter framing of the Michael the Archangel Church in Wierzbnik.

2. DEVELOPMENT OF MODULAR RAFTER FRAMING

Roofings that were constructed in the early stages of construction development were carried out by arranging several or more horizontal (or inclined) beams between the supporting walls. Such laid beams were covered with various types of material that isolated the

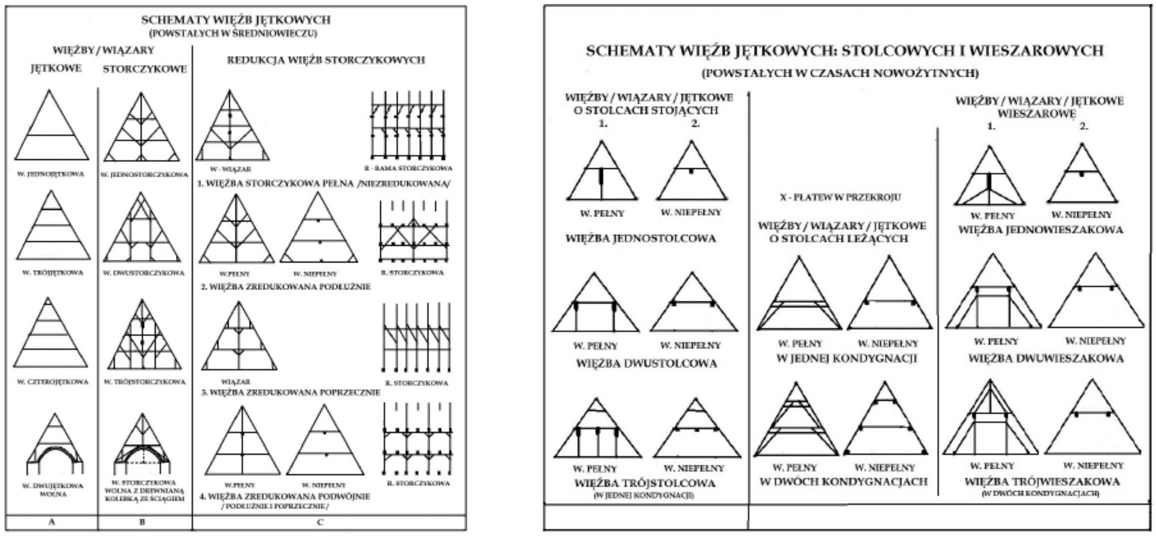

Figure 1.
Classification of rafter framings according to J. Tajchman (source: J. Tajchman 2010) a) scheme of rafter framing with collar tie (made in Middle Ages) b)scheme of rafter framing made in modern times

building from precipitation. Such a roofing structure had two main drawbacks: it limited the permanent (undisturbed) covering of naves with wider spacing and poorly drained rainwater.

Buildings in which an ever larger group of people lived, and these were mainly sacred buildings, required the expansion of their internal surfaces. Compliance with this requirement could have been made by widening the naves which led to the development of gable roofs. The first solutions – rafters – were characterized by low spatial stability of the arrangement. In order to increase their geometric consistency, both rafters were joined with a horizontal beam called a "collar beam" [5]. In this way, a triangle was formed which further strengthened the girder. The introduction of a collar beam between rafters, however, changed the static pattern of the girder. With unstoppable support of the rafters in the collar beam, there was a compressive force, and with one sliding support – a stretching force.

Further development of the spatial stability of roof framings, due to the increasing width of the nave, and which is closely connected with the roof framing span, consisted in the introduction of additional collar beams, post bars, angle braces, queen posts, suspension rod, etc. [5, 6, 7, 11]. Without knowing the analytical methods of assessing the strength of such solutions, they relied on the experiences of the masters using beam cross sections that exceeded the dimensions for the required load capacity. Such strengthening of the structure required not only the carpenter's high skills but also the increased amount of building material. In order to counteract such an increase in the demand for "whole timber" (hollow beams with large cross-sectional dimensions), roof framings with a full structure were intertwined with roof framings with no specific components. In this way, the so-called full" and "partial" roof trusses of rafter framing were developed. With this concept, the sequence of such elements in a truss is closely related. This sequence allows for the separation of repetitive groups of roof framings, which can be called a "rafter framing module".

3. RAFTER FRAMING MODULES

The first trial of possibility of types classification of historic large rafter framings we can find in elaboration by R. Ganowicz [5] J. Tajchman in his article "Truss trestle or full truss? The proposal of the systematic structure of roof carpentry structures" [8], and next in the "Proposal for the classification and ordering of carpentry terminology in Poland from the 14^{th} to the 20^{th} century" [9, 10], presented the systematics of applied geometrical patterns of static roof trusses from the early medieval times to modern times. The diagrams presented clearly show the full and partial trusses (Figure 1).

The presence of full and partial roof framings in the rafter framings of historic buildings is indicated by many authors. P. Rapp [1], in the part of his work concludes that "the creation of full and empty roof framings was another step in the development of roof structures". This is justified by the possibility of lower wood consumption by stating: “It has been found that vertical stiffening grid is more effective and less wood can be used to build the roof when the king posts are separated from one another (for example, they appear in every second or third roof framing). Many authors state that most often the full and empty girders occur in the following sequence: one full roof framing, two empty roof framings, and so on”. Repeatability of such trusses in modules, found in the preserved church structures, is described by many researchers dealing with conservation of monuments. In particular, such solutions are included in descriptions of historic churches both in Poland and in Europe [4, 5, 7, 8, 9, 12].

By developing this paper, it has been considered that, based on a review of available literature, there are no studies presenting a quantitative estimate of the amount of such savings in addition to the claim of timber savings as a result of the use of full and partial girders. This observation was the basis for determining the percentage savings of construction timber in relation to the roof truss of the Parish Church building of Michal Archangel in Wierzbnik as a goal of this work.

4. ANALISIS OF TIMBER SAVINGS PERCENTAGE FOR THE SELECTED CHURCH TRUSS

The timber saving analysis was performed for modules formed on the basis of diagram of the collar tie and hanging king post roof framings[12]. Both these solutions were implemented in the roof truss of the parish church of the Michael Archangel in Wierzbnik in Grodków Commune in Opole Region – Figure 2). It is a building whose origin dates back to the middle of the 14th century.

There are two rafter framing structures on this building. Both are made from roof framings set in the following sequence: full-incomplete-incomplete. By omitting extreme girders, which are usually full girders, a repetitive module (due to carried load) can be considered a symmetrical system: incomplete-full-incomplete. Over the nave, the main pattern of the rafter framing is based on the developed of lying secondary rafters diagram (in the lower zone below the first collar tie) and the hanging king post pattern diagram (zone above the first collar tie) shown in Figures 3a and 3b. Over the porch, the pattern of rafter framing corresponds to a typical pattern of lying secondary rafters diagram, shown in Figures 4a and 4b. The dimensions of the individual components

Figure 2.
Church of the Archangel Michael in Wierzbnik (source: D. Bajno archives)

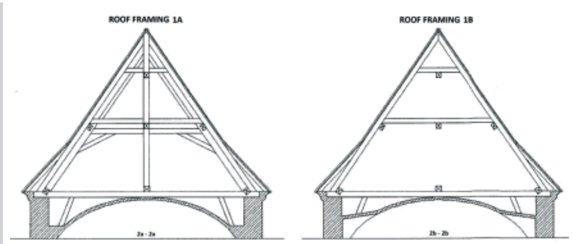

Figure 3.
Roof framings based on lying secondary rafters and hanging king post pattern (source: D. Bajno archives)

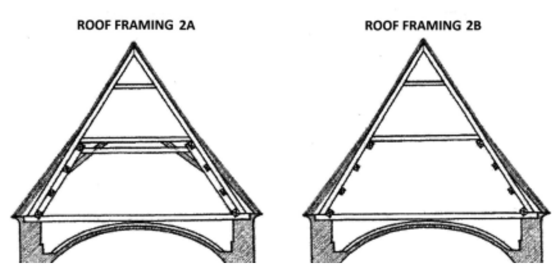

Figure 4.
Roof framings based on collar tie pattern (source: D. Bajno archives)

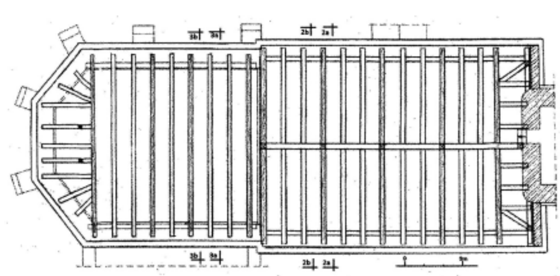

Figure 5.
Sequence of full and partial patterns in the analyzed rafter framing (source: D. Bajno archives)

Table 1.
Consumption of construction timber for the construction of roof framing type 1 (Figure 3)

TIMBER VOLUME IN ROOF TRUSSES BY MODULE 1						
	Type of module: full-full-full (module length – 3 m)			Type of module: incomplete-full-incomplete (module length – 3 m)		
	Number of units	Roof truss volume	Module volume	Number of units	Roof truss volume	Module volume
Full roof framings of type 1A	3 trusses	4.39	13.17	1 truss	4.39	4.39
Incomplete roof framings of type 1B	-	-	-	2 trusses	2.34	4.68
Purlins connecting trusses spatially (7pcs)	3 m	0.38	1.14	3m	0.38	1.14
	TOTAL MODULE VOLUME		14.31 m^3	TOTAL MODULE VOLUME		10.21 m^3
PERCENTAGE OF TIMBER USED						
module consisting of three full roof framings		100.0%	module consisting of one full and two incomplete roof framings			71.3%

Table 2.
Consumption of construction timber for the construction of truss type 2 (Figure 4)

TIMBER VOLUME IN ROOF TRUSSES BY MODULE 2						
	Type of module: full-full-full (module length – 3 m)			Type of module: incomplete-full-incomplete (module length – 3 m)		
	Number of units	Roof truss volume	Module volume	Number of units	Roof truss volume	Module volume
Full roof framings of type 1A	3 trusses	2.01	6.03	1 truss	2.01	2.01
Incomplete roof framings of type 1B	-	-	-	2 trusses	1.28	2.56
Purlins connecting trusses spatially (8pcs)	3m	0.34	1.02	3 m	0.34	1.02
	TOTAL MODULE VOLUME		14.31 m^3	TOTAL MODULE VOLUME		10.21 m^3
PERCENTAGE OF TIMBER USED						
module consisting of three full roof framings		100.0%	module consisting of one full and two incomplete roof framings			79.3%

are taken from the inventory documentation carried out by D. Bajno [12]. Schemes marked with “a” are the solutions of full girders, while the letters “b” – mean incomplete (empty) trusses. The sequence of full and partial girders is presented in Fig. 5.

On the basis of the measures contained in the above documentation, two material lists were drawn up covering the volumes of built-in wood for both trusses. These include: basic structural members of full girders, incomplete girders and purlins connecting these girders into separate modules of the rafter framing. Preparaing a material specification, it has been assumed that the length of the component to be ordered is equal to the length of the component available for direct measurement on the building plus the approximate technological elongation necessary to join the carpentry beams.

5. CONCLUSION

The analysis included in Tables 1 and 2 should be taken as indicative of the significant difference in the demand for building material. The difference between the material needed to make a rafter framing only from full roof framings and material sufficient to make it with partial roof framings is a function of the conversion of structural design of full roof trusses. In turn, this conversion is a function of the roof framings span and height. These two parameters affect the value of the transferred external loads such as wind and snow load and the specific load and usage load of the attic. The savings values of 20% and 30% are, however, important and could undoubtedly be the basis for carpentry masters to look for such solutions.

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