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# The Dilemma Whether to Produce Glued or Sawn Wooden Beams?

## Dilema: proizvoditi lijepljene ili piljene drvene grede?

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**ABSTRACT** • This article gives an overview of the contemporary development of wood production in the Czech Republic with the focus on the production of static structural members. This issue refers to literary sources of several authors dealing with the history and development of sawmills and adaptations of production strategies to the current trends. The study is based on information collected and assessed during the sawmill operations used by wood processing companies to make strategic decisions. Interaction of these input data and information acquired from the available literature indicates the possibility of development and specialization of the existing sawmills in upcoming years. Nearly 20 per cent of round timber is processed into static structural members, wooden beams. Considering the rising prices of input raw material, the question of the extent of cost-effectiveness and economy of sawn structural members arises. This article is aimed to clarify the issues and compare the production costs of sawn and glued structural members used in common wooden constructions, such as roof frames, prefabricated houses, etc. This may have an impact not only on sawmills but also on the extent of use of this type of wooden construction products. The question is whether the new restructuring of sawmills is coming or not?

**Key words:** production of static structural members, trends, production of BSH and KVH, sawn wooden beams, timber costs, wooden structures, cost-effectiveness.

**SAŽETAK** • U radu se daje pregled suvremenog razvoja drvne proizvodnje na području Republike Češke, s naglaskom na proizvodnju statičkih strukturnih elemenata. U pregledu se navode radovi nekoliko autora koji obrađuju povijest i razvoj pilana te strateške prilagodbe proizvodnje trendovima. Studija se koristi informacijama prikupljenima tijekom proizvodnje u pilani, na temelju kojih tvrtke za preradu drva donose strateške odluke. Povezivanjem tih ulaznih podataka i informacija iz dostupne literature dobiva se perspektiva razvoja i specijalizacije suvremenih pilana u idućim godinama. Gotovo 20 % volumena oblog drva prerađuje se u statičke strukturne elemente – drvene grede. S obzirom na rast cijena ulazne sirovine, postavlja se pitanje isplativosti i ekonomičnosti proizvodnje piljenih strukturnih elemenata. Cilj je ovog članka objasniti tu problematiku i usporediti troškove proizvodnje piljenih i lijepljenih strukturnih elemenata koji se obično upotrebljavaju u drvenim konstrukcijama kao što su krovne konstrukcije, montažne kuće i sl. To može utjecati ne samo na proizvodnju u pilanama, već i na masovnost uporabe takvih vrsta drvenih građevnih proizvoda. Pritom se nameće pitanje hoće li doći do novog preustroja pilana ili ne.

**Ključne riječi:** proizvodnja statičkih strukturnih elemenata, trendovi, proizvodnja BSH i KVH greda, piljene drvene grede, troškovi drvne sirovine, drvene konstrukcije, isplativost.

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# 1 INTRODUCTION

## 1. UVOD

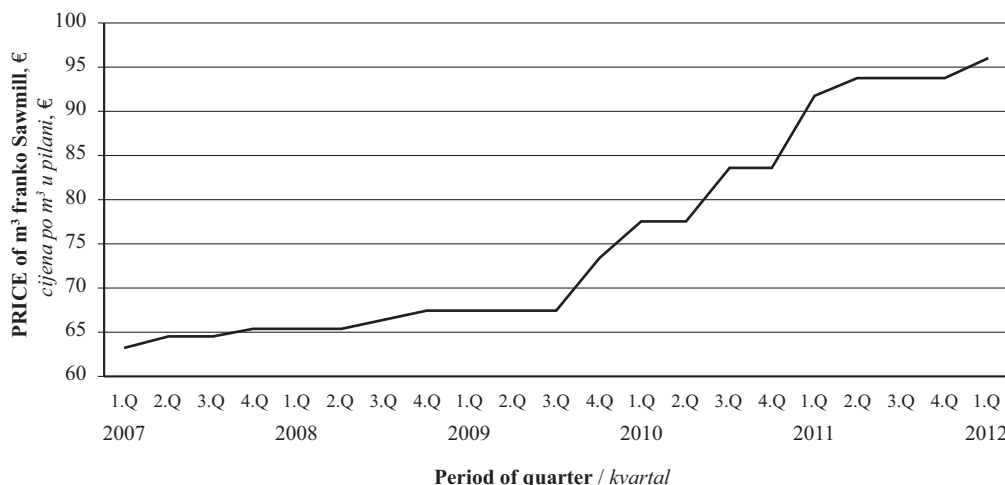
Every man dealing with wood processing is sure to be familiar with the timber market in the central Europe and the impact it has on wood processing companies. The current development does not meet the expectations of sawmills. The price of unprocessed timber and wood chips has been rising throughout the last two years and this fact has affected adversely the development of sawmills and advanced processing plants. During the past few years, sawmill production has gone through significant changes, and a large number of small-scale production plants were set up as a response to the changing demands of customers. Due to the new technology, such as the use of mobile saws, entrepreneurs had to redirect their production to a new way of cutting wood corresponding to new customers' requirements. However, as a result of the price of timber, a large number of companies have some serious financial difficulties and are on the verge of bankruptcy. However, such stagnation is equally damaging for some medium sawmills dealing with the production of structural members. Low demand for these products, which used to be a cash cow for many companies in the building market, resulted in the fact that nowadays wood-companies are incapable of sustaining their volume of production, as the increase of end product prices is considerably lower than the rise of costs of input raw materials. Naturally, large-scale sawmills have also been facing the price increase of input materials and annual turnover drop. The dynamic expansion of sawmills in the Czech Republic has been replaced by stagnation or decline, which is still going on. Many companies have gone in search of new products hoping that a wider product range would make them more successful. A possibility might be the production of glued structural members. The objective of this article is to show how the Czech sawmills can benefit from such a production and why a glued static structural member (i.e. a structural member that bears static load) can re-

place a sawn static structural member. The point I want to make here is that the production of glued static elements has the potential to initiate a new development in this business.

Lumbering has undergone great changes both in the working procedures and extraction technology in the past decade. We have been witnessing a rapidly increasing proportion of harvester logging and, as far as round logs are concerned, logs of 3 to 6 m have become the most common sawmill products. A large number of sawmill companies currently processing logs of this length and do not have to shorten them in further process of long round timber. Nowadays, they can purchase logs of the required quality, length and diameter. On the contrary, the companies processing long logs have to deal with the problem of requiring the assortment whose price has risen along with its demand. Looking for timber, they have to face its price increase caused by rising demand. The development of the sawmill product range is one of the reasons for the stagnation of the Czech sawmill industry. In the recent years (2007-2009), the average round timber price was EUR 65.5 (shipping included). In the following years, the price has rapidly increased to EUR 94 (shipping included). Such an astonishing increase of the round log price occurred in only two years and consequently many companies may go out of business. Figure 1 gives a survey of the recent development of round timber price, according to data of the three largest Czech wood industry companies.

As the German website ([www.euwid-holz.de](http://www.euwid-holz.de)) reads, the development of the timber price in Poland, Germany, Austria, Sweden, Norway and Great Britain has been quite similar. The timber market has been at a standstill as well. So, for instance, a significant decline in lumber output can be noticed in Austria in the third quarter of the last year ([www.euwid-holz.de](http://www.euwid-holz.de)).

Table 1 presents an overview of the Czech sawmills in order of their annual wood processing capacity. The data come from several sources (Pražan *et al*, 2007; Bomba *et al*, 2009). Based on the results of the



**Figure 1** Development of round timber price in the Czech Republic  
**Slika 1.** Rast cijena oblovine u Republici Češkoj

**Table 1** Survey of Czech sawmills based on their timber capacity (Pražan *et al*, 2007; Bomba *et al*, 2009)

**Tablica 1.** Podjela čeških pilana na temelju kapaciteta (Pražan *et al*, 2007; Bomba *et al*, 2009)

Company size <i>Veličina pilane</i>	Annual timber capacity, thousands of cubic meters a year <i>Godišnji kapacitet proreza izražen u tisućama kubičnih metara</i>	Annual timber output, cubic meter a year <i>Godišnji izlaz piljene građe izražen u kubičnim metrima</i>	Number of companies within the category <i>Broj tvrtki</i>
The largest sawmills <i>najveće pilane</i>	200-1,100	3,760,000	5
	80-100	370,000	4
	50-75	295,000	5
Medium sawmills <i>srednje velike pilane</i>	20-50	1,000,000	30
Small sawmills <i>male pilane</i>	10-20	750,000	60
The smallest sawmills <i>najmanje pilane</i>	<10	1,000,000	1,400-2,000

research, assessment was made of most small or medium sawmills dealing with the production of sawn static structural members, or to be specific, the production of structural beams for building purposes. Building timber or beams for building purposes (roof frames, carpenter's structures, etc.) account for 52 % of the output of these sawmills. This means that almost 20 % of sawmill round timber is processed into structural lumber by the logging companies in the Czech Republic. It represents an inconceivable volume of timber that ends up in the building industry market. The falling demand for the sawn static structural members has a strong impact on small and medium wood processing companies. In addition to that, the growing price of the input raw material intended for cutting structural members and the struggle to break into this market caused the increase of the end prices of structural and building timber. The prices of end products, such as beams and structural timber, increased by 25 % in average, although the price of the round wood entering the production rose by 43 %. The decrease of price of end products has forced the companies to put the product prices down. Consequently, this should have led to the optimization of timber processing, or possibly to a modification of the procedure technology. Unfortu-

nately, due to low technology equipment of most small and medium plants, their managers or owners were not able to cut down on expenses and it resulted in the fact that such companies are on the verge of bankruptcy or going out of business.

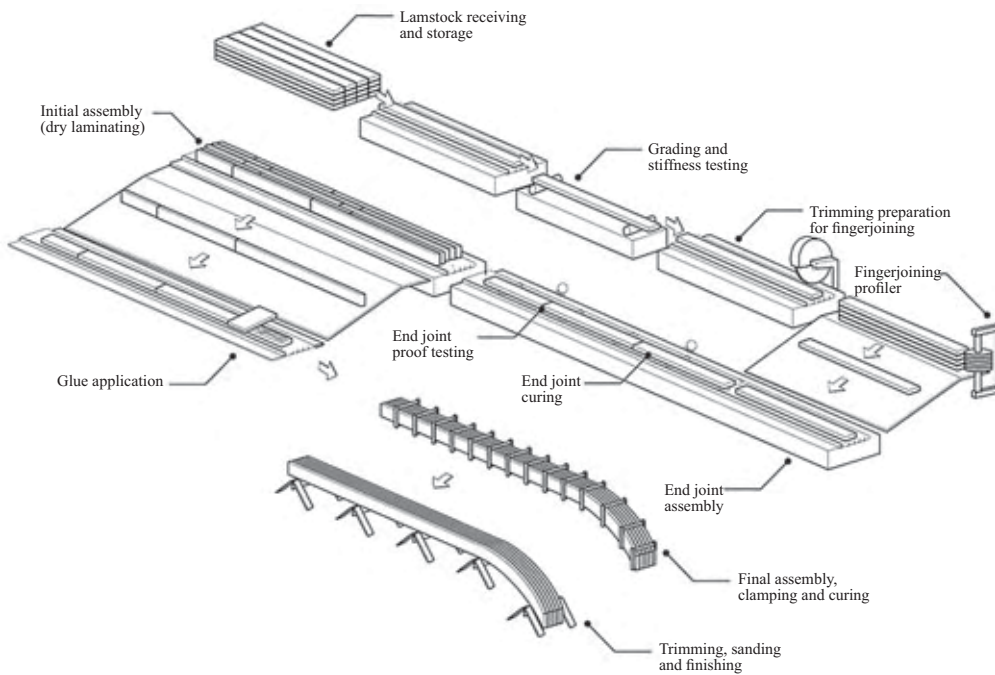
As a consequence of ever increasing round wood prices, there is a serious increase of prices of end products, such as beams, structural elements of great size and length. These products are facing strong competition of products such as KVH (structural extended timber) and BSH (layered lamellar timber) at these times. According to Table 2, the products BSH are being available in the market at extraordinarily low prices. The general scheme of glued beam technology is shown in Figure 2.

Comparing the characteristics of BSH, KVH beams and sawn beams, the glued beams proved to have significantly higher strength than the sawn beams, as shown in Table 3. Evidently, the use of glued structural members of KVH or BSH would save material in a common building construction (roof frames, ceilings, wooden constructions and so on). Another benefit of glued structural members is that it enables to select the visual aspect quality or industrial quality. What do those terms stand for? Visual aspect quality puts an emphasis on re-

**Table 2** Survey of prices of BSH beams in Germany (<http://www.euwid-holz.de>)

**Tablica 2.** Pregled cijena BSH drvenih greda u Njemačkoj (<http://www.euwid-holz.de>)

EUWID Preis mirror of BSH beams in Germany December 2011					
in €/m <sup>3</sup>	22.12.2011	17.11.2011	29.9.2011	2.12.2010	comp.% 2011/2010
<b>Beams SI</b>					
60x100-160 mm	390-400	400-410	405-410	405-415	-4
80x100-200 mm	385-400	395-410	400-410	400-410	-3
100/120x120-320 mm	380-385	390-395	390-395	395-405	-4
140/160x140-400 mm	375-380	385-390	385-390	395-405	-6
180/240x200-400 mm	370-380	380-390	385-390	390-400	-5
Total price SI	380-395	390-405	395-405	400-410	-4
Total price nSI	365-375	375-385	375-385	385-395	-5
<b>Commissions</b>					
Commissions SI	395-410	405-415	405-420	410-435	-5
Total price of beams SI/nSI of all standard profiles selected, length selected < 3 m <sup>3</sup> contract volume average purchase price in stores, franco					
2011 Europischer Wirtschaftsdienst GmbH					



**Figure 2** Manufacture of glued beams BSH (<http://www.cwc.ca/index.php/en/wood-products/glulam/manufacture>)  
**Slika 2.** Shema proizvodnog procesa lijepljenih greda BSH (<http://www.cwc.ca/index.php/en/wood-products/glulam/manufacture>)

removal of flaws that could lower the strength as well as flaws that could lower the aesthetic quality or visual appearance of the beam. The greatest concerns are related to coloring, dark knots, outpouring of resin, etc. As opposed to it, industrial beam quality can include the above mentioned aesthetic flaws, which do not affect the strength. A significant aspect of the visual quality is the fact that follow-up processing, such as fixing of aesthetic flaws, is not necessary. Apart from the differences mentioned above, the end price makes the main difference between the visual aspect and industrial quality.

The quality of the industrial and visual aspects can also be found in sawn structural members. To be specific, the quality of the visual aspect does not include any roundness. The industrial beam usually includes such a roundness without lowering the timber strength. The roundness that originates from a round trunk provides higher strength based on the fact that wood fibers have not been broken by cutting. However, the industrial quality production of sawn beams was almost given up by lumbermen, although it considerably increases the cutting yield and lowers the end product costs. The reason lies in its poor marketability. Most customers consider that a sawmill manager wants to cheat them trying to sell them the beam below the required quality and strength because it has no edges. As there is almost no way to change the customer's mind, nothing else remains but to meet his demands.

**2 MATERIALS AND METHODS**  
**2. MATERIJALI I METODE**

Twelve sawmill companies and three major manufacturers of BSH and KVH products were questioned directly for the purpose of this research, which was conducted in the period 2009-2011. In addition to it, contact

was made with the structural engineer who carried out the calculation of the carrying capacity of sawn wood beams as well as glued beams KVH and BSH. Furthermore, other thirty sawmill companies were interviewed in order to collect information on the development of round timber purchase price in the years 2007-2012. This way significant and essential information was obtained with the aim to develop an analytical model for comparing the beams of BSH, KVH and sawn beams.

On the basis of static calculations, comparison was made between the carrying capacity of glued beams and sawn wood beams. The static calculations were applied to the constructions of ten different house roofs in order to compare the material savings when using sawn beams or glued beams. Subsequently, comparison was made between the manufacturing technologies of sawn beams and glued beams in terms of the production costs and timber yield. These data were then transferred into the economic calculation of the end product price – for this purposes, a computing model was built complemented with timber yield data, the actual price of input materials and the actual production costs. The actual prices and production costs were obtained from the manufacturers in the Czech Republic. For the sake of objectivity, using different technological systems, only the above average values of the production expenses were used in the calculations. In conclusion of this research, comparison was made of all available information and general conclusions that might be used in practice.

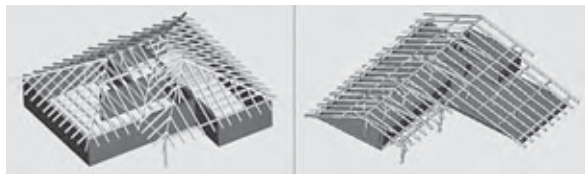
**3 RESULTS AND DISCUSSION**  
**3. REZULTATI I RASPRAVA**

According to Table 3, the glued structural members show better strength than sawn wood beams. This

**Table 3** Comparison of mechanical properties of sawn beams and glued beams of KVH and BSH (ČSN EN 1995-1-1, Praha 2006)

**Tablica 3.** Usporedba mehaničkih svojstava piljenih i lijepljenih greda, KVH i BSH

Properties / svojstva	Sawn wood <sub>w=50%</sub>	KVH <sub>w=15%</sub>	BSH <sub>w=12%</sub>
Bending strength $f_{m,k}$ , MPa / Čvrstoća savijanja, MPa	22	24	24
Fracture strength parallel with fibers $f_{t,0,k}$ , MPa Čvrstoća loma paralelno s vlakancima, MPa	13	14	16.5
Fracture strength vertical to fibers $f_{t,90,k}$ , MPa Čvrstoća loma okomito na vlakanca, MPa	0.5	5	0.4
Compressive strength parallel with fibers $f_{c,0,k}$ , MPa Čvrstoća na tlak paralelno s vlakancima, MPa	20	21	24
Compressive strength vertical to fibers $f_{c,90,k}$ , MPa Čvrstoća na tlak okomito na vlakanca, MPa	2.4	2.5	2.7
Shear strength $f_{v,k}$ , MPa / Čvrstoća na smicanje, MPa	2.4	2.5	2.7



**Figure 3** Roof construction  
**Slika 3.** Krovne konstrukcije

implies that it is possible to economize with wood material used in building industry. To prove this point, the static calculation was carried out in order to compare sawn beams and glued beams under the same static load and the same span. To provide practical evidence, the computing was accomplished on several construction models of a no name company. Gable and hip roof constructions of bungalows including a habitable attic and a wooden ceiling were also considered. Using statistical computing tools, the expected economic effects of the material used for the construction in question were proven with the roof frame or the ceiling load. A better use was confirmed of both KVH and BSH beams compared to sawn wood beams. However, the efficiency of KVH beams was only proven if used for structural members of the roof frame such as rafters and purlins of small size. Given the range of commonly produced dimensions of KVH beams, it was not possible to substitute all structural members of calculated

constructions. In contrast to it, with the help of commonly available dimensions of BSH beams, the structural members in question could be fully replaced.

All structural elements of the roof frame such as rafters, purlins, ribbands, collar-beams and piers were gradually substituted by the glued BSH beams. In this way significant savings of material were achieved ranging from 12.5 to 25 % of the total volume. Table 4 can be used as an illustration, as it presents the results of all static calculations of the structural members made of sawn beam and BSH beam. Positive economic effects can be readily identified.

Taking into account the economic effects, comparison was made of production costs of sawn wood beams and glued BSH beams based on static calculations. If the end price of BSH products used for a wooden construction is lower or equal, this new strategy can have an impact on future trends and development of sawmills.

The production of glued and sawn beams is already characterized by the process of sawing. Comparing all the three technologies of beam production, most similarities are found between the sawn prism and glued prism of KVH, although there are some differences as well. On the contrary, the manufacturing of BSH beams is completely different because it is made of 40-52 mm thick lamellas. It is the first variance that can influence cutting.

**Table 4** Comparison of static computation results for sawn and glued BSH beams

**Tablica 4.** Usporedba statičkih izračuna za piljene i lijepljene BSH grede

	Sawn wood/ Piljena greda					BSH / Lamelirana greda BSH					Economy Ušteda %
	b mm	h mm	l mm	S m <sup>2</sup>	V m <sup>3</sup>	b mm	h mm	l mm	S m <sup>2</sup>	V m <sup>3</sup>	
Purlin / Sljeme	180	260	8000	0.047	0.3744	160	260	3000	0.0416	0.3328	12.5
	180	240	7000	0.043	0.3024	160	240	7000	0.0384	0.2688	12.5
	160	200	5400	0.032	0.1728	140	200	5400	0.028	0.1512	14.3
Rafter / Krovna greda	100	180	7000	0.018	0.126	80	180	7000	0.0144	0.1008	25.0
	100	160	6000	0.016	0.096	80	160	6000	0.0128	0.0768	25.0
	120	180	8000	0.022	0.1728	80	200	3000	0.016	0.128	35.0
Pier / Stup	160	160	3000	0.026	0.0768	152	152	3000	0.0231	0.0693	10.8
	140	140	3000	0.020	0.0588	135	135	3000	0.0182	0.0546	7.5

b – beam width / širina grede; h – beam height / visina grede; l – beam length / duljina grede; S – cross-sectional area / površina poprečnog presjeka; V – beam volume / volumen grede.

Whereas cutting of sawn and KVH beams show similarities, their manufacturing is completely different. The first difference lies in drying. The sawn beam is left to dry out spontaneously, while the KVH beam is dried artificially to the moisture of  $15 \pm 3 \%$ . The process of drying indicates that during the production of KVH beams, the cutting should go through the beam centre in order to cut out the beam pith. If the pith is left inside the beam, it can leave wider cracks after drying. During manufacturing of structural timber, beams with cracks must be shortened in order to sustain the strength of the final product. The best way of manufacturing KVH beams is to remove the pith by inserting a central plank or board. Unfortunately, putting any component inside KVH timber influences adversely the size of the prism loading area. This loading area is growing and therefore the round timber with bigger pin diameter must be chosen. It lowers the timber yield during the production of KVH prism and raises the production costs. With the price of round timber, which is rising proportionally to the increase of round timber diameter, the costs of input raw material for the production of KVH prisms are also increasing. Therefore, the money spent on round timber, cutting, drying and manufacturing of KVH reaches the same value or higher than the production of BSH prisms.

Subsequently, the costs were compared of entry raw material intended for the production of KVH and BSH prisms with dimensions  $100 \times 180 \times 6000$  mm, which can be used for a common roof rafter. For cutting KVH, which requires cutting through the pith and putting two prisms next to each other, round timber is needed with the cog diameter of 31 cm (bark excluded) and the length of 3.7 m (based on available technology). This length can more or less cover the clogged joint and shortening of flaws. On the contrary, BSH beam can be cut into 5 pieces of round timber with cog diameter of 13 cm and the length of 3 m. Despite the fact that it is necessary to saw more logs from large round timber volume, significant economic effects can be achieved, reaching approximately EUR 16, due to lower raw material costs (the difference in thickness 1a:2b).

Comparing the cutting of timber intended for manufacturing of sawn prisms and KVH or BSH prisms of the same dimensions, the following conclusion was made. Assuming that sharp-edged timber is produced with the help of standard technology, cutting of 20-55 cm cog diameter by frame saw and of 10-20 cm cog diameter by prism or aggregate assembly line, the production of KVH beams would have the biggest cog diameter of cut timber as shown in Figure 3. This fact arises the question of production effectiveness of KVH beams.

Apart from cutting, the drying process is also crucial as due to large cutting dimensions it must be performed slowly so as to prevent creating big cracks. Drying increases the costs 2.5 to 3.5 times compared to lamellar cutting intended for the production of BSH beams (Janik, 1960). The current rise of energy prices has an adverse effect on the costs of KVH prism production. The expenses of drying of lamellar cutting are approximately EUR 15.5 for 1 cubic meter down to a



**Figure 3** Different crosscuts  
**Slika 3.** Razlike u presjeku piljenja

moisture of 10 %, whereas the cost of a KVH beam dried down to a moisture of 15 % is approximately EUR 52. The above are average prices and differ with respect to cutting dimensions, type of heating, drying procedure technology, input moisture, outside temperature, etc. Anyway, the manufacturing costs of KVH prisms reach the expenses of manufacturing BSH prisms, which is a far more complex and demanding procedure. The question remains whether it is still convenient to produce structural beams (KVH) for building purposes and carpenter structures since the economic effects of the use of KVH of larger dimensions are not up to our expectations.

The question of production effectiveness of KVH prism is and will be left to answer by the very manufacturers of this product. The following paragraphs are focused on BSH beams and sawn static beams, particularly an illustrative comparison, optimization and production calculations.

For comparing a sawn beam and a glued beam (BSH), it is necessary to consider all their characteristics. The consideration must be based on the following facts. The sawn beam has to be cut with an excess for drying. Such excesses are determined by the Czech State Norm (CSN 49 1109). The glued timber is dried (the temperature is usually above  $60 \text{ }^\circ\text{C}$ ), meaning that after such drying no insect embryos or fungi can be left hidden. This is why at least the costs of wood impregnation (Kozárek, 2009) via soaking must be added to the end price of the sawn beam. The BSH beam has no flaws, such as excessive or rotten knots, which would decrease its strength. BSH beams can be ruled out because they are made in accordance with CSN EN 386. Therefore, the use of sawmill round timber of AB quality guarantees to eliminate all flaws that can reduce the strength. Another advantage of the BSH beam is the planed surface. This is why it can also be used in constructions requiring visual quality. When comparing the beam properties, the roof construction with visual elements was taken into consideration, and hence the price of sawn beams has been increased by the price of planing.

Czech state standards were used for the calculation and optimization of manufacturing of sawn beams and glued BSH beams. These standards specify excesses required due to drying, timber takeover, BSH prism production procedures, sawn prism production procedures (Fronius, 1989; Friess, 2003), etc. According to these standards it is possible to make impartial judgments of timber and manufacturing parameters. The

**Table 5** Dependence of the yield on diameter and length (Fronius, 1991)

**Tablica 5.** Ovisnost iskorištenja o promjeru i duljini trupaca (Fronius, 1991)

Tenon <i>Promjer na tanjem kraju</i> cm	Area <i>Površina</i> m <sup>2</sup>	Side <i>Strana</i> cm	Square area <i>Površina kvadrata</i> m <sup>2</sup>	Yield <i>Iskorištenje</i> %	Maximum theoretical yield depending on length <i>Najveće teorijsko iskorištenje ovisno o duljini trupca,</i>			
					%			
					3 m	4 m	5 m	6 m
14	0.015394	9.90	0.0098	63.66	51.93651	48.74120	45.83195	43.17560
16	0.020106	11.31	0.0128	63.66	53.21622	50.30082	47.61860	45.14534
18	0.025447	12.73	0.0162	63.66	54.24452	51.56620	49.08145	46.77206
20	0.031416	14.14	0.0200	63.66	55.08879	52.61320	50.30082	48.13760
22	0.038013	15.56	0.0242	63.66	55.79429	53.49374	51.33261	49.29984
24	0.045239	16.97	0.0288	63.66	56.39262	64.24452	52.21687	60.30082
26	0.053093	18.38	0.0338	63.66	56.90644	54.69222	52.98307	51.17182
28	0.061575	19.80	0.0392	63.66	57.35247	55.45666	53.65331	51.93651
30	0.070686	21.21	0.0450	63.66	57.74329	55.95291	54.24452	52.61320
32	0.080425	22.63	0.0512	63.66	58.08854	56.39262	54.76989	53.21622
34	0.090792	24.04	0.0578	63.66	58.39575	56.78491	55.23982	53.75694
36	0.101788	25.46	0.0648	63.66	58.67088	57.13707	55.66262	54.24452
38	0.113411	26.87	0.0722	63.66	58.91870	57.45493	56.04505	54.68643
40	0.125664	28.28	0.0800	63.66	59.14308	57.74329	56.39262	55.08879

data on manufacturing of glued structural members and input costs of cutting is gained from the statistics made by three companies operating in the Czech Republic and Germany.

The possibility of reducing the production price of long beams lies in cutting, trunk convergence and price of input round timber. Based on the statistical analysis of electronic takeovers of timber carried out in six companies, it can be affirmed that the convergence of spruce round timber commonly exceeds 1 cm/m. This finding confirms the affirmation that the yield of central beam falls proportionally to its length. For the purpose of objectivity, the theoretical convergence value of 1 cm/m, set by the Czech state standard, was lowered in our calculations proportionally to the beam length especially in case sharp-edged beams (with no rounding). No claim is made that convergence of short cuttings does not equally affect the yield. The effect is absolutely the same, yet the yield of central cutting is a little higher. It can be concluded that in cutting long static structural members the yield falls but the price of the very product rises. As opposed to it, in cutting the lamellas for the production of BSH beams, short round timber can be used because lamellas can be extended up to the required length with the help of cogged joints in the production of beams. For BSH beams with smaller diameter, cutting can be made with smaller tenon diameter and the length of 3- 4 m. In this way, the costs of input round timber are reduced. Despite the lower yields achieved with smaller diameters of round timber, it is always suitable to select such round logs because their input price is significantly lower. Proportionality of the yield to the diameter and length is presented in Table 5 (Fronius, 1991). The difference between the price of cutting long beams and lamellas can pay the manufacturing of the BSH glued beams.

Based on the above, many calculations have been executed considering timber cutting at the length of 3 or 4 meters. Subsequently, it was concluded that a good

price difference can be achieved in cutting provided that the cut beam is longer than 5 meters. Price difference of input raw materials grows with the increase of the beam length and the production of BSH beams is becoming less costly than the production of sawn beam. This is the turning point when, due to its economic efficiency, the production of glued beams instead of sawn beams started to be taken into consideration. This is why the following comparison and calculation will be only carried out with the beams longer than 5 meters.

The illustrative example of calculation and comparison is made with standard dimensions of a rafter at the crosscut of 100x180 mm and the length of 7 meters. The static computing proves that a glued beam with the diameter of 80x180 mm and the length of 7m can be used for supporting the same load. Using the glued prisms brings the savings of the volume of 0.025 m<sup>3</sup> per 1 piece. As for the whole roof frame construction, in which 34 pieces are used, the saving of 0.857 m<sup>3</sup> can be achieved. Compared with sawn beams, manufacturing of BSH beams with the diameter of 80x180x7000 mm requires more timber. This is the result of excesses caused by planing and drying. In spite of that, the input timber costs of manufacturing BSH beams are lower than the costs of sawn beams.

As far as cutting is concerned, the glued beam is produced from lamellas with the diameter of 40x90 mm and dimensions installed 38x85 mm (the excess for drying is specified by the standard). The installed size is cut to final dimensions 36x80 mm by planing. The thickness of 36 mm is obtained after manufacturing of an "endless" lamella and the width of 80 mm after sticking a beam. As opposed to that, the sawn beam is manufactured with the excess intended for drying, specified by the standard, and with the excess for planing, and namely the sawn dimensions of 107x189 mm. Just one prism is cut and then it is split into two beams. Thereby, an almost square cut is obtained rais-

ing the yield of central cutting. To make such cutting and manufacture sharp-edged lumber, it is necessary to provide round timber with the length of 7 m and pin diameter of 31 cm.

The volume of round timber intended for manufacturing beams is 0.654 m<sup>3</sup>. The price of the beam is derived from the cutting calculation. The total is reached by summing the average cutting price per 1 m<sup>3</sup> (in the Czech Republic it comes to EUR 32.6), and the volume of the cut piece multiplied by the central cutting yield (43.28 %) and the input price of round timber (93.8 EUR/m<sup>3</sup> x 0.654 m<sup>3</sup>). The price of two central cutting beams equals EUR 48.9. After adding the price of planing (2 EUR/m<sup>2</sup>), the total price of EUR 16.9 is obtained. Then the price of colorless impregnation is added, which provides protection against ligniperdous insects and fungi. The going price is 20.4 EUR/m<sup>3</sup> so the total cost of impregnation amounts to EUR 5.4. Altogether the price of two beams installed with the dimensions of 100x180 mm comes to EUR 48.9 + EUR 16.9 + EUR 5.4 = EUR 71.2. It corresponds to the price of EUR 279 recalculated to 1m<sup>3</sup> of timber according to dimensions installed. Cost price and standard profit of about 20 % makes the total price of 334.6 EUR/m<sup>3</sup>.

The manufacturing of BSH beams is again an issue. It is necessary to make a sufficient quantity of lamellas with the dimensions 40x90 mm. There are two options for manufacturing the beam. The first is to cut a thin round timber, namely lamellas of 40x90 mm, and the second is to cut a thick round timber, lamellas of 42x180 mm. It can raise the question why to cut these lamellas to a specific size when it is possible to glue the prism of the dimension 166x180 mm and then split it up and plane. Unfortunately, this alternative is financially more demanding. This leads back to the idea of cutting the lamellas to the size of 40x90 mm. Two lamellas have to be cut in parallel in order to get sharp-edged cuttings. Round timber with the length of 3 m or 4 m and of C quality is used for cutting. When calculating timber required for the production of lamellas, bonding timber must also be taken into account and it ranges from 78 to 85 %, planing excluded (cutting the flaws). Better quality of timber results in a better yield. In this paper, the yield of 78 % will be taken into account. To achieve objectivity and efficiency, the computing is related to the manufacturing of two beams. It means that 15 pieces needed to be cut out of a 3 meter long round timber with the pin diameter of 13 cm, or 11.2 pieces out of 4 meter long round timber. The volume of cut round timber is 0.741 m<sup>3</sup> with 3 m round timber and 0.793 m<sup>3</sup> with 4 m round timber. Despite the larger volume of round timber compared to the manufacturing of sawn beams, the cost of timber is considerably lower. This is due to the fact that the price of round timber for the C quality with the thickness class 1a amounts to EUR 59.2. Hereby, the difference can be seen between input raw material needed for glued beams and sawn beam: 93.8 EUR/m<sup>3</sup> against 59.2 EUR/ m<sup>3</sup>. Although the consumption of input round timber is higher by approximately 0.139 m<sup>3</sup>, the savings are still considerable. The price of timber, assuming the same price of cutting,

comes to EUR 43.3 with 3 m round timber and EUR 45 with 4 m timber. However, to reach the final product, the BSH beam, there is still a long way to go. The cut timber needs to get dry. Drying is done according to the set of rules for this procedure, namely at the maximum temperature of 90 °C. Based on our own statistics (information from 5 woodworking companies) of timber drying, the average price of drying 40 mm thick timber is approximately 16.5 EUR/m<sup>3</sup>. Then timber is processed with the aim to eliminate the flaws such as knots, cross-grains, rot, etc. After that, timber is planed to the desired thickness and shortened to desired length. The adhesive is then applied on each lamella and then comes the pressing in a vertical press. After pressing, the beam is planed to the right thickness in order to match the second set of dimensions. In order to calculate the production of BSH beams, renowned manufacturers of these products were contacted and they provided the data for the calculation and optimization. The computing includes melamine-formaldehyde adhesive and the recommended layer applied on 1 m<sup>2</sup>, which ranges around 380 g/m<sup>2</sup>. The amount of adhesive consumed in the production of two beams comes to the price of EUR 4.1. Production costs for 1 m<sup>3</sup> of glued structural member range between 40 and 62 EUR/m<sup>3</sup> depending on the dimensions of the manufactured product. The price of this manufacturing section was statistically derived and it is 49-53 EUR/m<sup>3</sup>. For the purpose of this paper, the higher value (53 EUR/m<sup>3</sup>) is taken into account and therefore the manufacturing price of EUR 62.6 is reached for two beams. By adding the profit of 20 %, the price of 373 EUR/m<sup>3</sup> of a glued BSH beam is obtained on the condition that 3 meter round timber is used and 383 EUR/m<sup>3</sup> if 4 m round timber is used. The price of the glued BSH beam can be checked in Table 2, where the marketable price of the beams with the dimensions of 80x100-200 mm amounts to around EUR 385.

The price difference of comparable products, as far as their quality and load is concerned, such as sawn and glued BSH prisms, is approximately EUR 48 in favor of sawn beams. It means that the production of the glued BSH beams still seems to be less profitable. However, if the price is calculated with respect to consumption of the material consumed during construction, a very interesting conclusion can be made. An actual roof frame breakdown was used to illustrate the comparison of volumes and prices of the sawn and glued BSH beams, longer than 5 m, as shown in Table 6. The other beams were kept in the form of sawn static structural members.

Based on the comparison, computing and calculations mentioned above, certain conclusions can be drawn. These conclusions can have an impact on the decision-making as to whether to produce the glued or sawn beams. As mentioned above, a limiting factor is given by the length of the beam. The limiting length from which it is profitable to manufacture glued beams is 5 meters. Furthermore, it is convenient to use glued beams instead of sawn beams with larger diameter exposed to bending and spacing from square section cut-



**Table 6** Overview of savings: sawn beam vs. glued BSH beam

**Tablica 6.** Pregled ušteda: usporedba piljenih i lijepljenih BSH greda

Structural Member <i>Strukturni element</i>	Sawn beam <i>Piljena greda</i>					Glued beam <i>Lijepljena greda</i>			Prism price <i>Cijena prizme</i>		Total costs <i>Ukupni trošak</i>	
	Height <i>Visina</i> m	Width <i>Širina</i> m	Length <i>Duljina</i> m	Pieces <i>Kom.</i>	Volume <i>Volumen</i> m <sup>3</sup>	Height <i>Visina</i> m	Width <i>Širina</i> m	Saving <i>Ušteda</i> %	Sawn <i>Piljena</i> €/m <sup>3</sup>	BSH €/m <sup>3</sup>	Sawn <i>Piljena</i> €	BSH €
Joist / <i>greda</i>	0.180	0.260	9.50	15	6.669	0.160	0.260	11	338	379	2 254	2 247
Purlin / <i>sljeme</i>	0.160	0.200	7.80	5	1.248	0.140	0.200	13	345	391	431	434
Prop <i>potporanj</i>	0.140	0.160	4.10	8	0.735							
Pier / <i>stup</i>	0.140	0.140	2.00	4	0.157							
Wall beam <i>zidna greda</i>	0.140	0.100	36.00	1	0.504							
Rafter <i>krovna greda</i>	0.100	0.180	7.00	34	4,284	0.080	0.180	20	335	383	1 435	1 313
Rafter <i>krovna greda</i>	0.100	0.180	6.10	8	0.878	0.080	0.180	20	335	383	294	269
Skew prop <i>kosi potporanj</i>	0.100	0.120	1.70	6	0.122							
Collet / <i>kolut</i>	0.080	0.180	7.20	30	3,110	0.070	0.180	13	338	405	1 051	1 119
Collet / <i>kolut</i>	0.060	0.160	2.00	18	0.346							
Sum / <i>zbroj</i>											5 465	5 382

ting. Cutting such beams decreases the yield and increases the production costs.

It can be concluded that it is advantageous to manufacture glued beams if the height and width ratio is approximately 2:1. In such a case, the round timber with significantly smaller tenon diameter can be used for cutting compared to cutting of sawn beams. Trying to get as close as possible to square cutting, cutting two beams in one cutting is preferred. This way, the costs of input raw material can be considerably lower, and by using prism or aggregate technology, cutting costs can also be decreased.

On the contrary, the selection of glued beams is not quite convenient for manufacturing piers because most of them are used as angle braces, less than 5-meter long. In case of cutting round timber under 5 m, the economy achieved by trunk convergence is not reached and this is why the economic effect of cutting is markedly lower. The limiting factor for manufacturing piers is the volume economy (influence of different strengths of two referred products), which is confirmed by the pier dimensions of 220x220x3000 mm when the economic effect comes to 17 % of the volume. Shorter piers with smaller diameters do not yield effects that could justify the replacement of sawn piers by glued piers.

In producing roof frame structures intended for traditional family houses and industrial buildings, 50-80 % of sawn beams can be replaced by glued beams. In all-wooden structures such as prefabricated family houses, pergolas, garages, etc. this value is lowered to the range of 20 to 50 %. The decrease is caused by a small span of such constructions and a large number of piers and crosswise beams of short span used in such constructions. What matters is the quantity of structural members and their parameters made by a particular sawmill. On the basis of available data, it can be stated

that sawmills can replace 37 to 63 % of sawn beams by glued beams. This volume is large enough to make the sawmill managers consider the significance of glued lamellar structural members (BSH). These findings could lead to a drastic change of sawmill development in the Czech Republic and Europe.

#### 4 CONCLUSION 4. ZAKLJUČAK

Although it is not possible to achieve economic effects in producing each glued structural member, the costs are nearly equal and this fact could induce the sawmill managers to consider the possibility of producing structural elements and introduce serious changes in sawmill production. The optimization of producing BSH beams can result in further economic effects and however it has been ruled out. Anyway, using the glued beam technology, the sawmill managers could meet the orders of large diameter and span structures.

To conclude, in producing sawn timber for wooden constructions such as roof frames or whole prefabricated houses, it is effective to combine sawn and glued structural members despite the rising price of round timber. Such a change can yield higher profit or financial effects, which will be appreciated by end costumers.

The question, whether the glued beams should be produced by sawmills or purchased from renowned producers, remains to be answered by sawmill managers.

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