

## **An analysis of selected traits of typical supply of oak logs and a comparison of the efficiency of their processing into flooring**

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**Abstract:** *An analysis of selected traits of typical supply of oak logs and a comparison of efficiency of their processing into flooring.* The research was performed on typical supply of oak wood logs of WC02 class, diameter from 29 to 34 cm, measured in the middle of its length (full log length 2.3 m). Wood came from Bobolice forest district, Lubowo forest subdistrict. This type of raw wood is used in standard machining processes (sawing) of multi-layer flooring face layer (top layer, lamella). The application of X-ray computed tomography allows to perform full valuation of raw material quality. The introduction of partially chip-less machining technology leads to significant savings in wood in comparison with standard machining (sawing).

**Keywords:** wood raw material, European oak wood, wood flooring, multi-layer parquet elements, X-ray computed tomography

### **INTRODUCTION**

Along with systematically growing demand for wooden flooring grows the production and supply. It is estimated that European market demand for wooden flooring is over 75 million m<sup>2</sup>. At present, most of wooden flooring (about 80%) is produced as the multilayered floorboard. Poland ranks first in its production in Europe – market share is 20.08%, which is about 13 million m<sup>2</sup> (FEP report 2016). The European leader of flooring production is Barlinek S.A. company, with their dominant product – Barlinek floorboard (Fig. 1). It is multilayered floorboard produced with the use of ‘chip’ machining technology – lamellas for both construction and face layers are obtained through sawing with the use of band-saws, circular saws and frame mini-sawmills. For construction layers, Scots pine (*Pinus sylvestris* L.) is used. This species is cheap and at the same time meets strength requirements. An analysis of loss of material in the machining processes depending on the processing technology (chip and chip-less) used was performed in earlier research (Kozakiewicz et al. 2018).

The face layer of a multilayer floorboard is manufactured from wood of high aesthetical value and very good mechanical properties, hardness and abrasion resistance. Although there are many exotic wood species meeting these requirements, it is mainly European oak that is used in the production. It is most commonly used wood for flooring which dominates in both solid wood and multilayer composite boards. It meets both aesthetical and mechanical requirements (Wagenfür 2007, Kozakiewicz et al. 2012). In 2016, according to EFP, oak wood constituted 80,8 % of the total wooden flooring produced – and it is an increase from 77.7 % in 2015. This generates a enormous demand for this species, and that means an immense increase of its price (Wrochna 2014, Kozera 2016). This situation forces manufacturers to search for more efficient ways of processing wood into flooring. As

of today, other wood species, for example suitable species of exotic wood, are not a serious competition for oak wood in Poland (Kozakiewicz 2020).

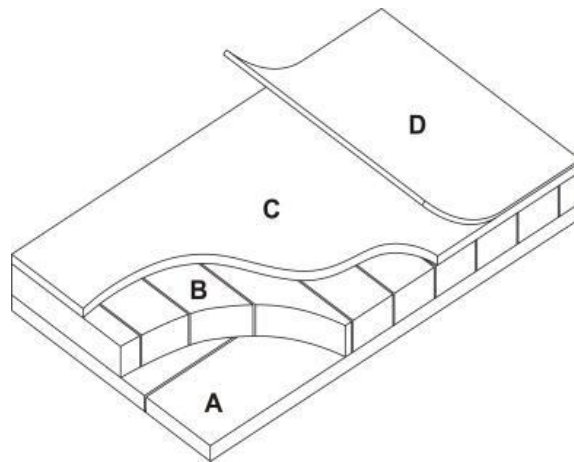


Figure 1. Construction of the multi-layer ‘Barlinek floorboard’: A – construction bottom layer (Scots pine wood), B – construction middle layer (Scots pine wood), C – face layer (European oak wood; 4 mm thick), D – varnish layer (7 coatings of lacquer/varnish system) optionally finish with oil coating (natural oil or UV hardened oil) (<https://www.barlinek.com.pl/wykonczenie/>).

European oak wood (code QCXE according to EN 13556:2003) is acquired from two tree species: pedunculated oak (*Quercus petraea* (Matt.) Liebl.) and sessile oak (*Quercus robur* L.) (Kozakiewicz, Romanovski 2016). The share of these two species in Polish forests in 2017 was 7.7 % (Rocznik Statystyczny Leśnictwa – GUS 2018). Sales of class W0 European oak wood in Polish National Forest (PGL LP) in years 2015–2016 remained stable at 55.000 m<sup>3</sup>. What is worrying, in 2015 there was threefold increase of deciduous stands, mostly oak, threatened by herbivores (up to 139.000 ha). The area of diseased stands were 1.564 ha. Fortunately, there were no observations of endangered oak stands (Tomaszewski 2016, Andrzejczyk 2009).

At present, the most popular method of acquiring lamellas for multi-layer floorboard face layer is sawing with band-saws, circular saws and frame mini-sawmills. All of those are ‘chip’ methods of wood processing, in which significant losses of material occur due to a loss on kerf. The desired lamella is 4.1 mm thick (3.0 mm thick after sanding), where kerf width varies from 0.9 mm to 4.4 mm, depending on the used sawing method. Development of chip-less or partially chip-less methods of wood manipulation, i.e. methods where post-production material leftovers are limited and costs of material are decreased, have a significant influence on productivity and ecology.

## MATERIAL AND METHODS

For analysis of material loss during the processing of oak wood into face layer of a multi-layer floorboard, the typical oak wood supply for Barlinek SA factory were measured. 40 logs were chosen from a standard delivery of declared WC02 class raw wood. Logs diameters were within the range of 29–34 cm and the length of the logs was 2.3 m (proper dimensions for factory machining and processing). The wood was acquired in Bobolice forest district, Lubowo forest subdistrict. All measurements were performed *in situ* at the date of delivery – 22.9.2016. The logs were measured using the method shown below (Fig. 2).

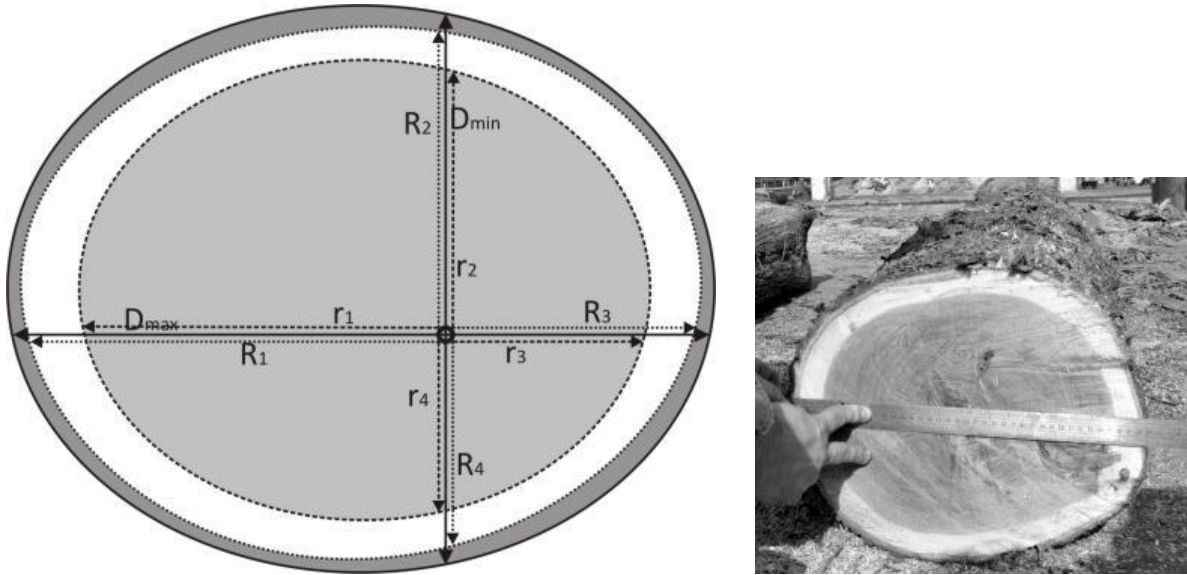


Figure 2. Log measurement method:  $D_{max}$  – longest cross-section axis with bark,  $D_{min}$  – smaller cross-section axis, perpendicular to axis  $D_{max}$ , with bark,  $R_n$  – external radius of sapwood in  $n$  direction,  $r_n$  – heartwood radius in  $n$  direction. The photograph taken during measurements *in situ*.

All measurements were taken at the thinner end of the log. The longest axis of cross-section were found – the longest possible line that could be drawn on cross-section and goes through log core. Subsequently, the smaller axis was set, perpendicular to the longest axis and going through the log core as well. The measurements of both axes were taken including the bark –  $D_{max}$  and  $D_{min}$ . Another measurement has been taken along the axis starting with log core. The distance from the log core to the external boundary of sapwood and the external boundary of heartwood were measured in four directions. On the basis of those measurements, calculations and analysis of chosen traits of typical wood supply were performed: average diameter, heartwood ratio, average sapwood thickness, flattening and eccentricity.

The average diameter was described with two parameters: average larger diameter (av.  $D_{max}$ ), average smaller diameter (av.  $D_{min}$ ).

Heartwood ratio is the percentage of heartwood area in the whole cross-section area of thinner end. The cross-section area without bark was considered.

Average sapwood thickness is the average from all four measured directions for each log, then whole population.

Flattening described as a subtraction between the maximal and the minimal diameter of the cross-section (Method I –  $F$ ), and as a ratio of that subtraction to the maximal diameter (Method II –  $f$ ) – according to PN-D-01011:1979 (EN 844-5:1997 and EN 844-8:1997):

$$F = D_{>} - D_{<} \quad (1)$$

$$f = \frac{D_{>} - D_{<}}{D_{>}} \cdot 100\% \quad (2)$$

where:  $F$  – flattening in millimetres,

$f$  – dimensionless relative flattening ratio,

$D_{>} = R_1 + R_3$  – the biggest centric diameter in millimetres (without bark),

$D_{<} = R_2 + R_4$  – perpendicular (smaller) centric diameter in millimetres (without bark).

Eccentricity is one of wood defects parameters, similar to flattening, and was calculated according to the following formulas:

$$E = \frac{R_1 - R_3}{2} \quad (3)$$

$$e = \frac{R_1 - R_3}{R_1 + R_3} \cdot 100\% \quad (4)$$

where:  $E$  – absolute eccentricity in millimeters,  
 $e$  – relative eccentricity ratio,  
 $R_1$  – the bigger radius of wooden log (without bark),  
 $R_3$  – the smallest radius (see Fig. 1).

The quality of logs was verified with the use of X-ray computed tomography (assessment of type, collocation and size of defects, also annual rings width and density). For that part of research, 6 logs have been selected from an assessed part of a typical wood delivery. The tests were carried out with the use of X-ray computed tomography apparatus Nueusoft with an integrated DAS system detector (16-row tomography apparatus – acquisition of 16 layers with one turn of gantra during 0.5 s – minimal resolution of 0.75 mm). The testing parameters were: scanning mode Helical, no contrast, 120 kV, 40 mA, CTDI val.: 40.3 mGy, the thickness of the scanned layer 1 mm, scanning diameter 400 mm.

The outcome of XRCT were grayscale images. Hounsfield tomographic point density scale have been assigned for different tones of gray on the image. Thanks to a previously performed calibration for wet oak wood, it was possible to calculate the real density value from Hounsfield scale, according to the following equation:

$$d = 0,926 \cdot Hp + 1008 \quad (5)$$

where:  $d$  – wood density in  $\text{kg/m}^3$ ,  
 $Hp$  – Hounsfield scale, generally negative for wood ( $Hp < 0$ ).

The correlation coefficient was close to 1,  $r=0.99$ .

The moisture content of wood was measured with the use of resistance method in accordance with EN 13183-2:2002 and stereo metric method in accordance with ISO 13061-1:2014.

In this research, two methods of the acquisition of oak lamellas were compared. The first one is an actual processing scheme currently used in Barlinek SA factory in the production of face layer lamellas. It is referred as the ‘chip technology’ later in this paper. This method uses only sawing with different machines (chip machining technology). The second method is a procedure using flat slicing (sawing is used only for leftover board from slicing process and dividing it for proper lamellas). It is referred to as the ‘chip-less technology’ later in this paper. Both methods are shown in the schematics below (Fig. 3).

The initial acquisition stage for both methods is the same. An initial beam of 220 mm thickness is cut out from a log with the of a band saw. Then the final beam – sawn prism – of maximal width is cut from the initial beam. The final beam cannot contain sapwood.

In chip technology, a beam is divided into boards. Their dimensions are 220×31.5×2300 mm and it is sawn with the of a multi-circular-saw with a kerf 4.4 mm wide. Next, those boards are divided into lamellas 4.1 mm thick with the use of frame mini-

sawmills with a kerf 0.9 mm wide. The final operation for the production of half-product is sanding. The face layer is 3.0 mm thick after sanding.

In the chip-less technology, an acquired beam undergoes hydrothermal treatment in accordance with the following procedure: 5 h preheating in temperature 60°C, 42 h heating in temperature 90°C, 1 h of cooling in temperature of 60°C. Next, the plasticized beams are flat-sliced with the use of a FEZER Lumber Slicer FM 30 into lamellas of 4.1 mm thickness. Additionally, after slicing the end board of 10 mm thickness is left. This element is finally cut on a band saw with a kerf of 0.9 mm into two lamellas. Similarly to the chip technology, the final product is 3.0 mm thick after sanding.

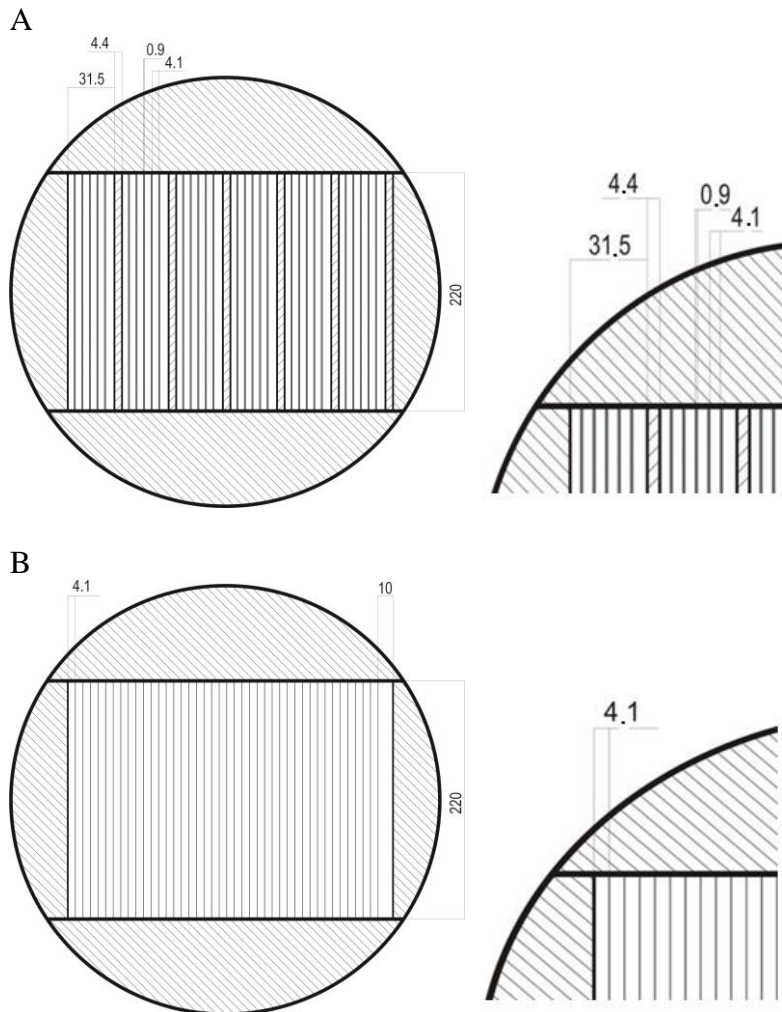


Figure 3. Schematics for acquiring face-layer lamellas with chip technology ‘A’ currently used in Barlinek SA factory; schematics for chip-less technology ‘B’ – developed solution.

Efficiency and loss relative to the log were calculated using the following formulas:

$$efficiency = \frac{V_p}{V_l} \cdot 100\% \quad , \quad loss = \frac{V_l - V_p}{V_l} \cdot 100\% \quad (6)$$

where: *efficiency* – total output relative to the log,  
*loss* – total waste relative to the log,

$V_l$  – log volume (without bark),

$V_p$  – product volume (lamellas).

Efficiency and losses were also calculated relative to the beam:

$$efficiency^* = \frac{V_p}{V_b} \cdot 100\% \quad , \quad loss^* = \frac{V_b - V_p}{V_b} \cdot 100\% \quad (7)$$

where:  $efficiency^*$  – output relative to the beam,

$loss^*$  – waste relative to the beam,

$V_p$  – product volume,

$V_b$  – beam volume.

In both machining processes (sawing and cutting) the losses were divided into three groups:

$$loss = loss_E + loss_P + loss_S \quad (8)$$

where:  $loss$  – total waste (in sawing or cutting technology),

$loss_E$  – endings waste (the same for both sawing and cutting),

$loss_P$  – raw waste in specific machining process of beam  
(kerf in sawing or end board in cutting),

$loss_S$  – sanding waste (different for sawing and cutting).

Sometimes it is worth combining specific losses:

$$loss_{EP} = loss_E + loss_P \quad , \quad loss_{PS} = loss_P + loss_S \quad (9)$$

where:  $loss_{EP}$  – endings waste together with raw processing waste,

$loss_{PS}$  – processing waste together with sanding waste.

The wastes for beam marked with a star ( $loss^*$  - calculated according to formula (7)) do not include endings waste. In addition, the other specified losses (without endings) calculated in this way are of greater value, for example:

$$loss_P < loss_P^* \approx 2loss_P \quad (10)$$

This approximation is true if the losses on the endings are about half.

## RESULTS AND DISCUSSION

Round oak wood – logs – was characterized with a typical moisture content of 85%, where no significant differences were found between sapwood and heartwood. The exception from this rule were log ends, where moisture content varied. At the depth of 50 – 100 mm there was lower moisture content. It is natural consequence of moisture loss at cross-section of lumber.

Tomographic images of the tested oak logs (Fig. 4) allowed for a precise display of crucial traits of the macroscopic structure of wood: annual growth rings, moisture distribution, knots location, crevice cracks, core location and wood fibres.

The performed analysis of tomographic images confirmed the visual assessment of the tested logs and its classification into WC02 class. Brighter areas visible on reconstructed tomographic images are connected with higher density of wood around healthy knots and near core annual growth rings with higher ratio of latewood. Black lines and patches indicate the

presence of cracks or empty spaces near unhealthy or decayed knots. Average density of tested logs of approximate moisture content of 85 % assessed on the basis of Haunsefield point scale ( $H_p$ ) was  $980 \text{ kg/m}^3 \pm 70 \text{ kg/m}^3$  and is typical (Kozakiewicz, Romanovski 2016). Assessed density shows significant cyclical variation in the width of the annual growth rings (between  $900 \text{ kg/m}^3$  in early wood to  $1120 \text{ kg/m}^3$  in latewood) and in the whole cross-section area (periphery cross-section zone has density around  $950 \text{ kg/m}^3$ , inner, near core zone has density around  $1080 \text{ kg/m}^3$ ). In air-dry wood those differences are greater. In wet wood those differences are smaller due to higher moisture content in more porous parts of the wood.

Diverse density of wood may have negative influence on the quality of acquired lamellas, especially with chip-less technology (flat slicing).

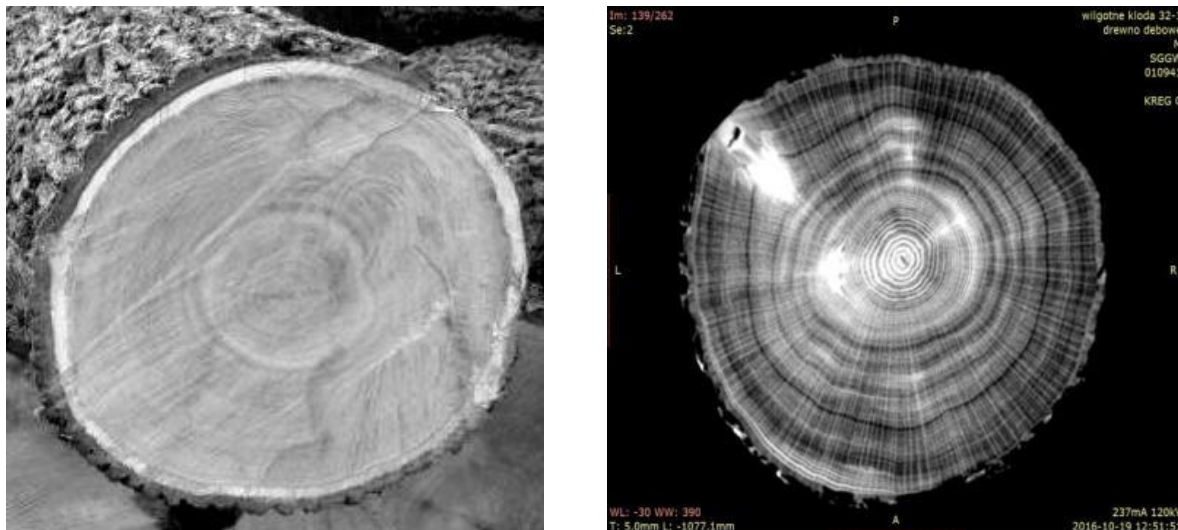


Figure 4. An example of a reconstructive image of the cross-section of a typical selected oak log, obtained with X-ray computed tomography: a) oak log, b) reconstructive image after tomography.

X-ray computed tomography through precise valuation of round wood quality gives a possibility of effectively optimise sawing processes, which leads to significant material savings and translates into an increase of sawing processes performance, both qualitative and quantitative. This technology can be used also with planning chip-less machining, like flat slicing, because it allows for targeted material selection.

Based on the measurements performed on typical wood supply, an analysis and calculations of its traits were performed. The results are presented in Table 1.

Table 1. Average values of selected parameters of typical oak wood supply for Barlinek SA factory (Bobolice forest district, Lubowo forest subdistrict)

Trade name of wood according to EN 13556	Quantity of logs [pcs]	Investigated properties of logs – average value (standard deviation)						
		Larger diameter $D_{max}$ [mm]	Smaller diameter $D_{min}$ [mm]	Hart-wood ratio [%]	Sapwood [mm]	Flattening $F$ [cm]	Flattening $f$ [-]	Eccentricity $E$ [mm]
European oak	40	315.21 (39.94)	293.90 (34.28)	73.46 (14.51)	22.90 (8.80)	2.35 (1.72)	0.073 (0.049)	16.81 (10.46)

Based on shown values, an analysis of material loss for both methods of oak wood processing into face-layer lamellas was performed. Losses have been calculated as a total loss on edgings and kerfs in full log and in beam. The average loss value for both processing technologies are show in Table 2.

Based on the analysis of typical oak wood supply, used schematics and technologies, average material performance for chip technology was 31.6% and for chip-less technology 47.0%.

Theoretical material performance of flat slicing used for acquisition of face-layer lamellas destined for multilayer floorboards is 15.42 percentage points more than sawing (full log). When only loss from beam are taken into analysis, the chip-less technology has 30.70 percentage points better material performance. Average material loss for chip-less technology when only beams are taken into consideration can be reduced to below 7%.

During processing of oak wood into lamellas destined for multi-layer floorboards face layer one of the most important part is sanding. In both chip and chip-less technology acquired lamellas are sanded to thickness 3.0 mm (from 4.1 mm). Average loss value with loss on sanding are shown in Table 3.

Table 2. The value of average raw processing loss for both technologies: sawing and cutting (chip and chip-less). Average loss from the whole log and from 220 mm thick beam.

Wood processing technology	Average log volume and raw processing loss values (standard deviation)			
	Log volume $V_l$ [m <sup>3</sup> ]	Material processing raw waste in beam $loss_p^*$ [%]	Material processing raw waste in log $loss_p$ [%]	Material processing and endings waste $loss_{EP}$ [%]
Chip technology - sawing	0.195 (0.04)	37.28 (3.59)	18.76 (2.07)	68.42 (2.67)
Chip-less technology - cutting	0.195 (0.04)	6.58 (1.41)	3.33 (0.80)	53.00 (2.49)

Table 3. Average value of loss for sanding only and average value of total loss (processing and sanding) for chip and chip-less technology calculated for whole log and beam. Acquired lamellas are sanded to thickness 3.0 mm.

Wood processing technology	Average log volume and average loss values (standard deviation)			
	Log volume $V_l$ [m <sup>3</sup> ]	Sanding material waste in beam $loss_s^*$ [%]	Total material waste in beam $loss^* = log_{ps}^*$ [%]	Total material waste in log $loss$ [%]
Sawing with sanding	0.195 (0.04)	16.83 (0.96)	54.11 (2.63)	76.90 (1.95)
Cutting with sanding	0.195 (0.04)	25.06 (0.38)	31.65 (1.03)	65.61 (1.82)

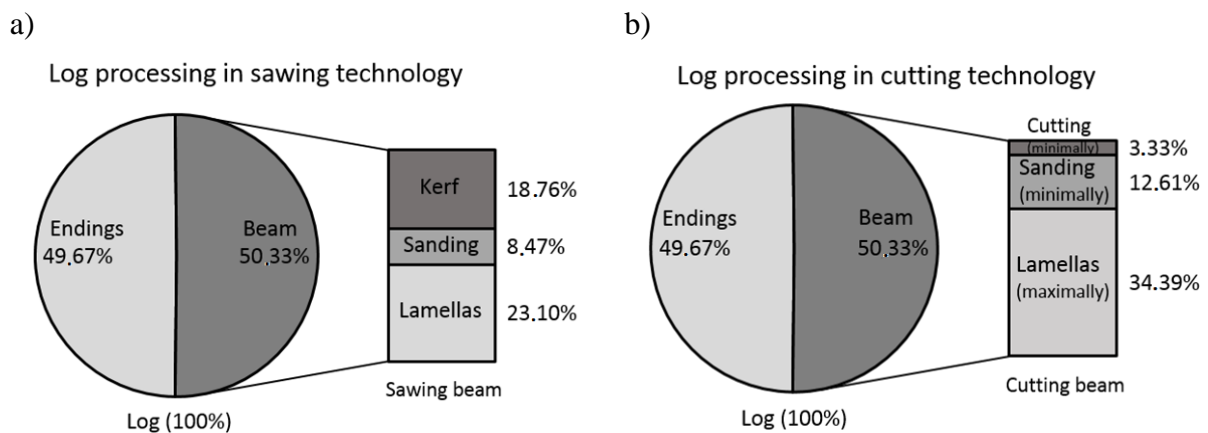


Figure 5. Graphs showing efficiency and losses in log and beam in two different technology processes: a) chip technology – sawing, b) chip-less technology – cutting.



The average loss value for beam sanding for the chip-less technology is higher than for the chip technology because of a greater number of lamellas acquired during the chip-less processing. On average, 29 lamellas were produced with the chip processing and 44 lamellas with the chip-less processing. Lamellas count during the chip-less processing increased by 52%. Despite increased loss on sanding for the chip-less technology, its material performance when calculated for log is better by 11.30%. A synthetic comparison of both processing methods is shown in the graphs below (Fig. 5).

Optimization of raw wood selection for machining can be performed through selecting wood origin, heartwood / sapwood ratio or log shape, with flattening being taken into account. In this paper, financial aspects connected to time and energy consumption are not taken into consideration. However, one should be aware that in real production conditions such aspects as energy expenditure for additional processes (e.g.: hydrothermal treatment or additional sanding) have significant influence on costs.

An analysis of wettability and the contact angle of surfaces of lamellas obtained with both chip and chip-less processing technologies according to the schematics used in this research were performed by Jankowska et al. (2018). These analyses showed a low usefulness of lamellas for face layer obtained with the use of chip-less technology. This may be due to improper parameters of flat slicing of beam into thick lamellas or improper parameters of the hydrothermal treatment.

## CONCLUSIONS

Based on the performed analysis of typical oak wood supply and a comparison of material performance in chip and chip-less technology processing for the production of lamellas for face-layer of multilayer floorboards, the following conclusions were formulated:

1. The average material loss with chip technology is typical for this kind of processing. Hence, the analysed typical wood supply is suitable for assumed production process parameters.
2. X-ray computed tomography enables full assessment of oak raw material (also in terms of density), particularly significant for analysing usefulness for production of flooring with assumed production parameters.
3. The application of chip-less machining technology allows for significant material savings. The average loss in chip-less technology may be about 15 percentage points lower when the log is taken into account, and about 31 percentage points lower when the beam is taken into account.
4. An increase in material performance in chip-less machining technology justifies further research on the improvement of process parameters guaranteeing proper quality of acquired oak lamellas destined for the face-layer of multilayer floorboarding.

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**Streszczenie:** *Analiza wybranych cech typowej dostawy kłód dębowych oraz porównanie wydajności ich przerobu na materiały podłogowe.* Badania przeprowadzono na drewnie dębowym WC02 o średnicy w połowie długości bez kory od 29 do 34 cm i długości 2,3 m z Nadleśnictwa Bobolice, Leśnictwa Lubowo (reprezentatywny surowiec). Tego typu surowiec jest stosowany w standardowej technologii obróbki wiórowej przy wytwarzaniu warstw licowych (lameli) desek warstwowych. W pracy przeanalizowano jak wpłynęłaby na wydajność ilościową, zamiana technologii na częściowo bezwiórową. Zastosowanie obróbki częściowo bezwiórowej pozwala na zaoszczędzenie znaczących ilości surowca. Straty przy obróbce częściowo bezwiórowej w odniesieniu do całej kłody dębowej mogą być o ok. 15 punktów procentowych niższe niż w przypadku obróbki wiórowej. W odniesieniu do przyzmy różnica wielkości strat może wynosić nawet do 31 punktów procentowych. Sama analiza ilościowa nie daje odpowiedzi o celowości wprowadzania nowej technologii, bowiem nie uwzględnia wielu czynników np.: energochłonności obróbki hydrotermicznej niezbędnej przy skrawaniu. Równie istotna jest jakość pozyskiwanych lameli dębowych, co było przedmiotem analiz w innej pracy (JANKOWSKA i inni 2018).

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