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Economic Efficiency of Pine Wood Processing in Furniture Production

Marek Wieruszewski [1], Wojciech Turbański [2], Katarzyna Mydlarz [3] and Maciej Sydor [2,4,*]

[1] Department of Mechanical Wood Technology, Faculty of Forestry and Wood Technology, Poznań University of Life Sciences, 60-637 Poznań, Poland; marek.wieruszewski@up.poznan.pl
[2] Euroline sp. z o.o., 64-100 Leszno, Poland
[3] Department of Law and Organization of Agribusiness Enterprises, Faculty of Economics, Poznań University of Life Sciences, 60-637 Poznań, Poland
[4] Department of Woodworking and Fundamentals of Machine Design, Faculty of Forestry and Wood Technology, Poznań University of Life Sciences, 60-637 Poznań, Poland
* Correspondence: maciej.sydor@up.poznan.pl; Tel.: +48-618466144

Abstract: The wood industry faces challenges due to rising prices and limited wood availability, putting pressure on material efficiency in wood processing. This justifies the analysis of the relationship between efficiency and economy in pine wood processing. The study aimed to measure the impact of variations in the thickness of logs, changes in the technology of their further processing, and changes in prices of raw materials and products on the material efficiency in the context of large-scale production of furniture elements made of pinewood. The raw material input consisted of three categories of log sizes, from which the specialized purpose lumber was produced. The lumber was then processed into semi-finished furniture elements with three technologies: without detecting natural wood defects, with human detection, and with automatic detection. The study was conducted in Poland from 2020 to 2022. The material efficiencies in every stage of the analyzed wood processing and the cost efficiencies were calculated and analyzed based on the results obtained under real industrial conditions. The main findings are as follows: (1) when comparing the logs in the three tested diameter ranges (14–23 cm, 23–30 cm, and more than 30 cm), it can be observed that the overall material efficiency of sawing is in the range of 70%–85% and increases with the thickness of the log; (2) the share of 38 mm specialized sawn timber in the total amount of sawn timber was 41%–58% and increased with increasing log diameter; (3) the economic efficiency of the technological process is 170%–290%, based on the log size and the technology of further processing employed. The determining factor affecting cost efficiencies is unexpected changes in raw material prices and product demand in 2022. The findings suggest that while improvements in processing technology can boost efficiency, they cannot fully offset the rise in raw wood material prices.

Keywords: pinewood; lumber; prefabrication; material efficiency; cost efficiency; cost-effectiveness

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1. Introduction

Scots pine (*Pinus sylvestris* L.), native to Europe and Asia, is Poland's most abundant tree species and covers more than 60% of forest areas. The Scots pine tree can grow up to 50 m tall and live for more than 300 years. Pinewood, which has a straight grain and reddish-brown color, is a softwood that exhibits good dimensional stability, strength properties, and durability. The machinability of pinewood is medium relative to other wood species [1,2]. Due to its availability, it is commonly used in Europe for paper production, construction [3], furniture [4,5], and firewood [6].

Currently, increased prices and reduced availability of wood negatively affect Europe's wood industry [7]. In 2017–2022, the average annual prices of wood in Poland did not change, but in 2022, the average price of wood increased by 52% compared to 2021 (Figure 1).

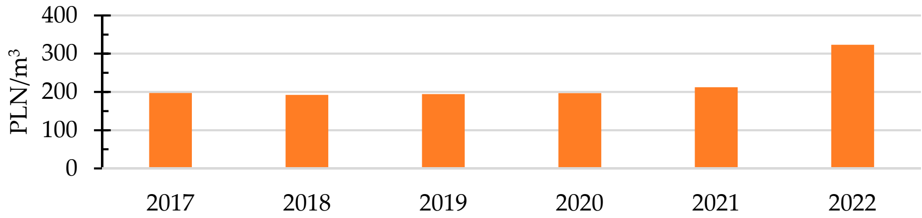

Figure 1. Average annual log prices in Poland in 2017–2022 (data source: Statistics Poland [8]).

The direction of softwood lumber price changes is similar to that of the log price changes, as shown in Figure 2.

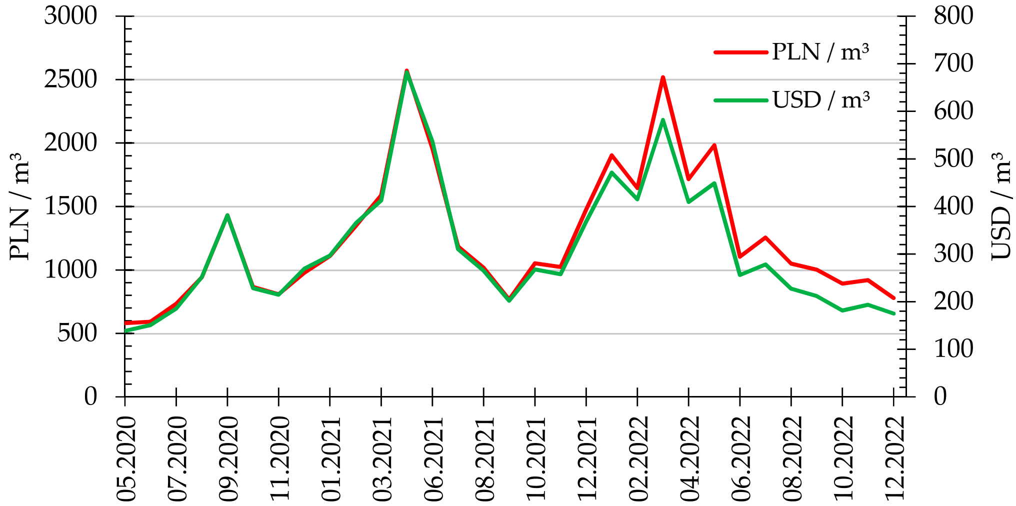

Figure 2. Change in average timber prices on the Polish market (data sources: [8,9]).

The world's forests are under increasing pressure from various forms of exploitation, including clearcutting, over-harvesting, and conversion to other land uses. Promoting responsible forest management through certification programs such as FSC and PEFC helps protect biodiversity, prevent deforestation, and preserve vital ecosystem services such as carbon sequestration, water regulation, and soil conservation. As of 31 December 2022, 53,403 FSC certificates covering 89 countries and regions were issued [10], and 12,600 PEFC certificates covering 78 countries and regions were issued. Products that carry the FSC label have been independently certified by the FSC to come from forests managed to meet the needs of present and future generations. Marketing research confirms consumers' increased interest in products made of certified wood [11], justifying the use of certified wood from the producers' perspective.

Mass furniture production involves collaboration between specialized furniture component manufacturers and large furniture manufacturers [12]. The structure component supplier produces parts to the manufacturer's specifications and quality standards. The furniture manufacturer then utilizes these parts to assemble the final product, which is later sold to retailers. This partnership enables the furniture manufacturer to focus on core competencies such as furniture design, improvement, and marketing while outsourcing the production of specific furniture parts to a specialized supplier. The supplier's specialization in producing specific parts also contributes to cost savings and improved efficiency.

The increase in wood prices and the need for sustainable management confirm the demand for the rational use of the valuable wood raw material, namely pine wood. High material efficiency might significantly reduce the environmental impact of wood industries and increase carbon storage in forests and wood products. The circular economy aims to create closed-loop systems in which waste is minimized and resources are conserved and reused as much as possible [13]. Circular business models reduce the dependence on finite resources, create more sustainable and resilient economic systems, minimize the industry's negative environmental impact, and create economic benefits through greater resource efficiency [14]. All elements of optimization of wood processing, or the principles of wood management, can be implemented in the framework of circular business models [15]. Crucial in a sustainable process and product design competitive and sustainable bio-economy development are the following: an open dialogue and a commitment by industry to innovation that drives efforts on sustainable development of the bio-economy [16].

Existing research on the impact of optimization policies on timber enterprises is limited in the context of enterprise economic efficiency. Sirking and Hooten [17] examined the implications and applications of cascading concepts and principles as a tool for appropriate product design and policies for sustainable forest resource management. Gedermann et al. [18] took an interdisciplinary perspective on the efficiency of renewable resource utilization, but in general terms rather than the context of the timber industry. Risse et al. [19] demonstrated the potential for reduced resource consumption compared to virgin wood, as indicated by higher resource efficiency (46% vs. 21%).

Most studies have been conducted to examine resource scarcity and environmental impacts [20]. There is no significant research based on comparative economic efficiency before making a managerial decision on how to use wood's potential in producing furniture components under resource-constrained conditions. The complex effect of evaluating the benefits and opportunity costs in the lumber industry should be evaluated to justify the commitment to sustainable materials management principles [21]. The current work examines the role of each optimization principle implemented in the enterprise's development in terms of direct costs resulting from analyzing the primary cost driver—wood raw material. This topic is approached by studies pointing in the direction of complementing the cost analysis of wood processing carried out by Daian and Ozarska [22], Kharazipour and Kües [23], and Babatunde [24].

Economic efficiency is a parameter that helps achieve the planned financial result using the least available resources. In this sense, economic efficiency is achieving a particular goal using the most efficient processing methods, providing the most valuable product and useful byproducts with minimalization of waste. This efficiency is also called productive efficiency [25]. In the study, economic efficiency is measured with the cost-effectiveness parameter showing the ratio of the cost of the input raw material to the prices of products. This approach is often used in wood technology [26–29].

Lumber enterprises still do not express great willingness to adopt and implement optimization practices at the level of material flow circulations, which determines the role of the current study as solid proof of their usefulness. The results would support the implementation of rational throughput in the studied case and other wood enterprises. Cascade utilization can thus be defined as the efficient use of resources to expand the total availability of biomass within a given throughput system [30,31], is probably the most widespread practice, and is taking place in the countries of the European Union.

The achievement of high material efficiency depends on the quality of the raw material and the qualitative capacity of the technological process, and in the case of wood materials, on the technical ability to identify the location, type, and size of the wood defects and the ability to modify the process quickly to avoid the impact of defects on production efficiency. Wood defects damage the manufactured sawn assortments or hinder the processing of furniture components in the use process. They also cause unwanted aesthetic effects affecting customer perception. The elimination or reduction of defects in the product is brought [32–37].

This study analyzes the impact of changes in the parameters of the wood raw material on the fundamental processing indicators. In the group of parameters that shape the processing indicators, the change in log thickness was taken into account. The positions of the cut according to the core affect the proportion of knots. The thickness of a tree affects the placement of knots and their increasing diameter. The log thickness also affects the placement of the knots relative to semi-finished lumber and the material efficiency. In the rational reworking of wood, this factor plays a crucial role in large-scale wooden furniture production. The novelty of this article is the inclusion of annual changes in the prices of input materials and products in the analyses.

The work aimed to measure the impact of variations in the thickness of logs, changes in the technology of their further processing, and changes in prices of raw materials and products on the material and cost process efficiency in the conditions of large-scale production of furniture elements made of pinewood.

2. Materials and Methods

2.1. Input Materials and Production Technologies

The material efficiency study involved two technological processes. In the first process, the logs were cut into lumber, and in the second process, the lumber was used to produce semi-finished furniture elements. The study was carried out in industrial conditions in a company specialized in processing pine wood into semi-finished elements sold to a producer of upholstery furniture. The byproducts of all processes were sold on the market in Poland. The Polish State Forests National Forest Holding supplied FSC-certified Scots pine.

Material efficiency (E_V) measures how much material is used effectively in technological processes:

$$E_V = \frac{\Sigma V_w + \Sigma V_z}{\Sigma V_s} \cdot 100\ (\%) \quad (1)$$

where V_w—a volume of products, V_z—a volume of byproducts, V_s—a volume of raw material.

Equation (1) expresses the material efficiency as a percentage and compares the actual amount of all products to the amount of raw material used in a process. A higher percentage indicates a higher degree of material efficiency.

It is convenient to analyze material efficiency with cost indicators. In this way, the efficiency of raw material processing technology is determined as an easy-to-interpret percentage indicator [38]. During the production of elements of wooden furniture, the cost-effectiveness (E_p) is the sum of the commodity value of products and byproducts, related to the cost of purchasing the raw material for their production [39,40], which the following equation can express:

$$E_p = \frac{\Sigma V_w \cdot C_w + \Sigma V_z \cdot C_z + \Sigma V_o \cdot C_o}{\Sigma V_s \cdot (C_s + T_r)} \cdot 100\ (\%) \quad (2)$$

where V_w—a volume of products, C_w—a volumetric value of products, V_z—a volume of byproducts, C_z¯a volumetric value of byproducts, V_o—a volume of waste, C_o—volumetric waste disposal cost (negative value), V_s—a volume of raw material, C_s—a volumetric value of raw material, T_r—a volumetric value of raw material transport.

Logs with a nominal length of L_k = 3.5 m and diameter d_k more than 14 cm at the thinner end (Figure 3) meet the requirements of "Technical specification—softwood large-size logs" [41].

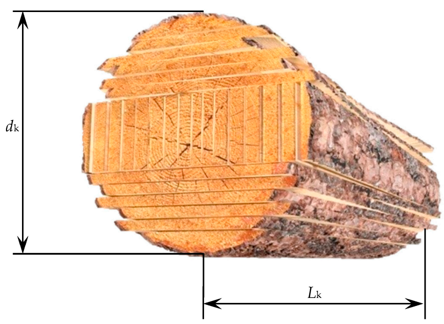

Figure 3. Dimensions and the scheme of sawing a log into the center and side-sawn lumber (d_k—log diameter at its thinner end, L_k—log length).

In the stage of wood processing, boards with a thickness of 38 mm were produced from the central part of the log (center-sawn lumber). At the same time, from the side part of the logs, boards with a thickness of 25 mm were formed (side-sawn lumber). The center-sawn lumber was the specialized lumber as 38 mm boards intended to produce semi-finished furniture elements. Three production variants, "A", "B", and "C", were analyzed. Industrial devices and technology were the same in the compared variants; the variable in the cut material efficiency of cutting was the diameter of the log. In this stage, three thickness grades of logs were cut and kiln-dried. Figure 4 schematically shows the described production variants.

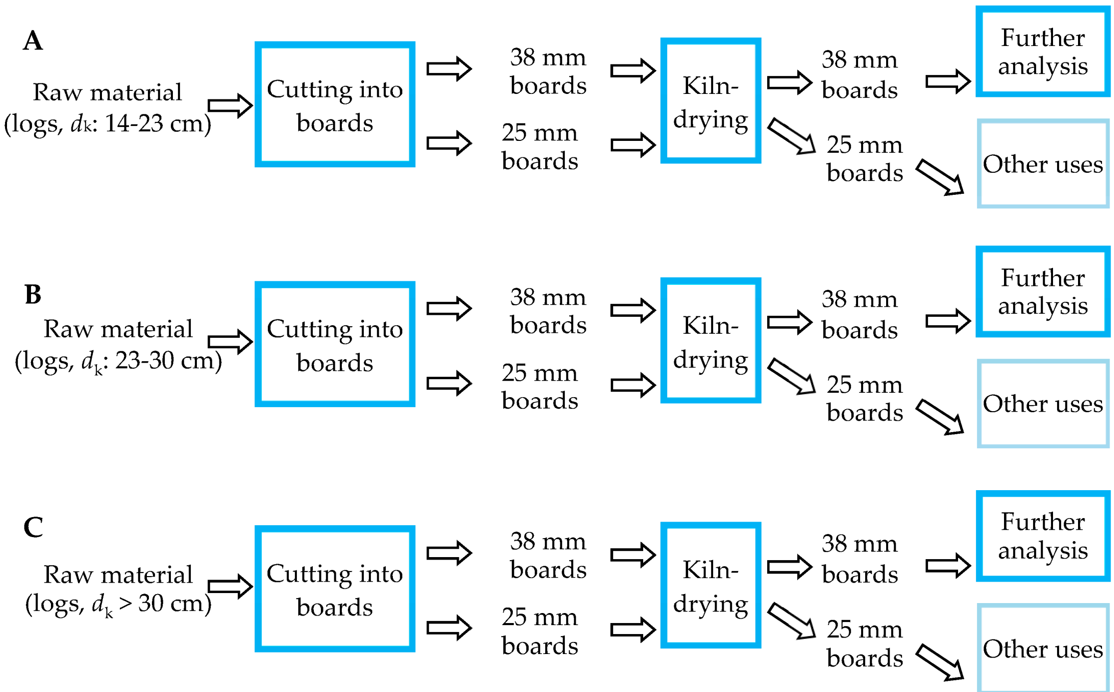

Figure 4. The analyzed variants of the first stage of wood processing (producing the specialized lumber as 38 mm board).

The round wood was cut using a band saw (CZ-1/ZM 20 kW, W-IREX, Kiełczygłów, Poland) according to the sawing pattern shown in Figure 3 and with a kerf of 3 mm. The kiln drying schedule included the following:

- Initial heating: The lumber was placed in the kiln and exposed to heat to increase the temperature of the wood and begin evaporating the moisture (duration 12 h).
- Drying phase: The temperature and humidity in the kiln were adjusted to create the optimal conditions for removing moisture from the lumber, a drying temperature of 60 °C, and a duration of 6–7 days.
- Final conditioning: The lumber was cooled and exposed to higher humidity to prevent cracking and warping (7 days). The final moisture content was around 12%–14%.

The 25 mm thick lumber was diverted to other uses, while boards with a thickness of 35 (+3) mm were sorted into two groups with appearance quality classes according to EN 1611-1 with the G2 method [42]:

- Classes "0", "I", and "II" for processing into semi-finished furniture elements (further analysis);
- Class "III" is intended for products of low quality and as firewood.

The main features of the "0" class are no wane on edges, the inadmissibility of defects caused by fungi and insects, no curves, and no falling out knots. Sawn lumber must be 4-sided clean, and knots are allowed at the ends of the board to be easily removed during further mechanical processing. The "I" and "II" classes feature a 3-sided clean board from which a 4-sided clean section with a minimum length of 100 cm can be cut. Class "III" includes other sawn timber that does not meet the requirements of higher classes. The air-dried boards, 38 mm thick, were rough planed with an allowance of 1.5 mm per side.

Figure 5 shows the target dimensions of the semi-finished furniture elements assigned as cot rails of upholstery frames.

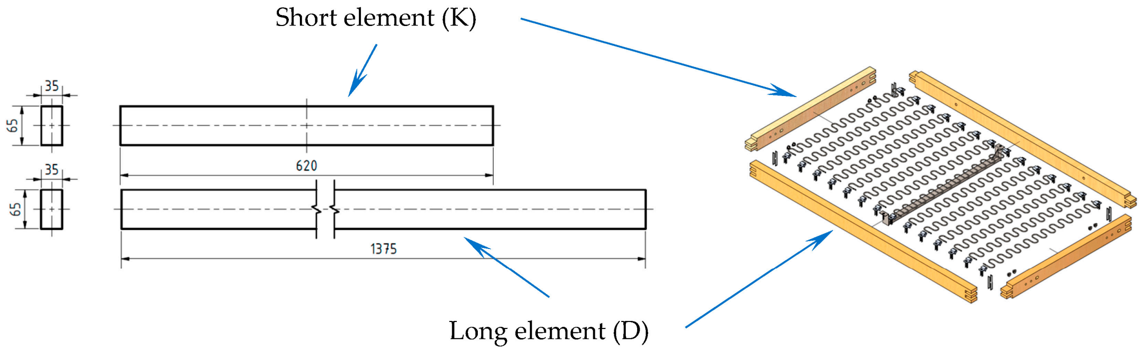

Figure 5. The target dimensions and the usage of the analyzed semi-finished furniture elements.

In addition, shortboards were produced as a byproduct of producing short elements (K) and long elements (D). These byproducts were processed into other furniture components after gluing with finger joints. Therefore, they were also included in the material efficiency calculations.

Three methods of manufacturing semi-finished furniture elements, marked as "Ap", "Bp", and "Cp", were subjected to a further comparative analysis of the material efficiency of wood processing. Figure 6 shows these methods.

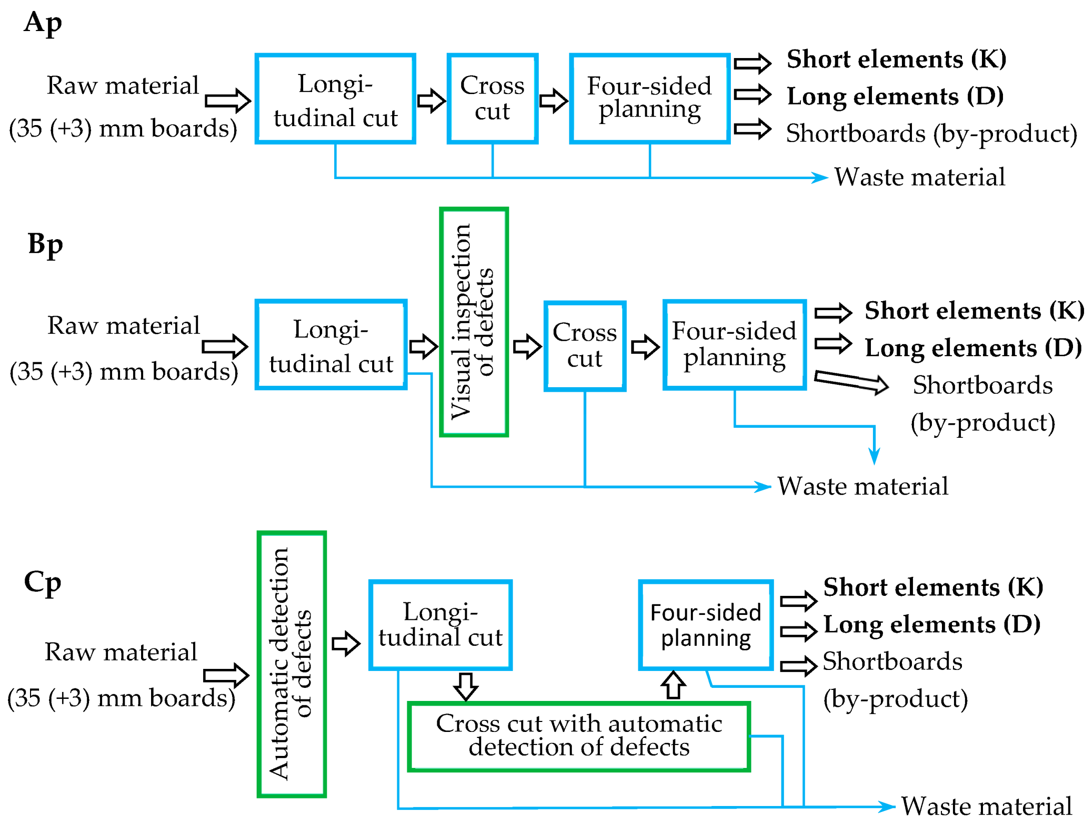

Figure 6. The analyzed variants of the second stage of wood processing (producing semi-finished furniture elements).

The processing marked as Ap consisted of (1) introducing boards with a thickness of 38 mm into longitudinal circular saws and sawing them into assortments with a width of 68 mm with a length equal to the length of the input raw material, (2) transverse division into elements with lengths of 1375 (+5) mm and 620 (+5) mm, followed by (3) four-sided planning to target size 38 × 65 mm. The Bp processing, furthermore to the "Ap" method, included visual inspection by a human inspector visually inspecting the sawn timber for defects, such as knots, splits, and rot. The inspector marks any defects they find with a marker and then directs the assortments to be cut in marked places on cross-cutting saws into elements with target lengths. The "Cp" processing, in addition to the "Ap" method, included a system for automatic detection of defects using the QSCAN 60 device (Woodinspector, Lublin, Poland) and transverse cutting using a transverse optimizer. A technological line based on saws was used: longitudinal (SA350 300/130, Gabiani, Villa Verucchio, Italia) and transverse in methods "Ap" and "Bp" (DMDK 50C, Rema S.A., Reszel, Poland), transverse optimizer in method "Cp" (OptiCut 450 DimterLine, Micha-el Weinig AG, Tauberbischofsheim, Germany), and a four-sided planer (Powermat 700, Michael Weinig AG, Tauberbischofsheim, Germany).

Production waste was directed to the chipper to produce byproducts (wood chips, a raw material for producing energy briquettes, and cellulose pulp).

2.2. Prices for Material Efficiency Calculations

As mentioned, the analyses described in the article cover the following:

- Purchase of pine logs at market prices in Poland in 2020, 2021, and 2022;
- Processing these logs into lumber and selling byproducts;
- Processing lumber into semi-finished furniture elements and selling these elements and byproducts of this process.

The actual transaction prices for purchases and sales in the analyzed years were used to calculate the material efficiency of both analyzed production processes. The prices were identified and averaged for the analyzed years for the described production conditions. Table 1 presents the prices used to calculate the material efficiency of sawing pine logs into lumber, while Table 2 presents the prices used to calculate the material efficiency of semi-finished furniture element production. Both tables present the annual average prices in Poland for 2020, 2021, and 2022.

Table 1. List of average annual prices for the processing of logs into lumber.

Cost/Price Component	2020		2021		2022	
Cost of logs (C_r in PLN/m^3)	257.35		292.08		697.61	
Cost of transport (T_r in PLN/25 m^3)	1036.0		1138.0		1374.0	
Price of dry lumber (in PLN/m^3)	center, 38 mm 780.0	side, 25 mm 480.0	center, 38 mm 1020.0	side, 25 mm 620.0	center, 38 mm 1680.0	side, 25 mm 1180.0
Price of wood chips (C_z in PLN/m^3)	140.0		145.80		309.40	

Table 2. The average annual prices for processing lumber into semi-finished furniture elements.

Cost/Price Component	2020	2021	2022
Cost of 38 mm boards (center lumber) C_s (PLN/m^3)	780.0	1020.0	1680.0
Short element (K) price C_{wI} (PLN/m^3)	1982.91	3546.23	3559.91
Long element (D) price C_{wk} (PLN/m^3)	1012.68	1322.85	1375.0
Price of wood chips C_{ww} (PLN/m^3)	135.20	153.30	332.40
Cost of internal transport of lumber (T_r) (PLN/ 40 m^3)	518.0	569.0	687.0

2.3. Statistical Analysis

Statistical analysis was performed to assess the differences in cost-effectiveness (Ep) between variants of the two processes. The analysis involved a one-way analysis of variance (ANOVA), followed by post hoc Tukey tests. The normality of the dependent variables was assessed using the Shapiro–Wilk test. Variants A, B, and C were analyzed for the production of specialized lumber (the first technological process analyzed, Figure 4), while for the production of semi-finished furniture elements (the second process, Figure 6), variants Ap, Bp, and Cp were analyzed.

3. Results and Discussion

3.1. Material Efficiency of Lumber Production

Table 3 shows the quantitative and efficient sawing of the raw pine material in the "A" test for d_k in the range of 14–23 cm. The total material efficiency of sawn timber from sawing thin logs is 62.6%.

Table 3. The results of the wood sawing process in the "A" test.

Processed Material	Volume (m^3)		Material Efficiency (%)
Input raw material (logs)	189.180		62.60
Center-sawn lumber (38 mm boards)	77.836	118.431	41.14
Side-sawn lumber (25 mm boards)	40.595		21.46

Table 4 shows the quantitative and efficient sawing of the pine raw material in the "B" test for d_k in the range of 23–30 cm. The total material efficiency of sawn timber from sawing medium-diameter logs is 74.3%.

Table 4. The results of the wood sawing process in the "B" test.

Processed Material	Volume (m^3)		Material Efficiency (%)
Input raw material (logs)	211.663		74.29
Center-sawn lumber (38 mm boards)	105.810	157.227	49.99
Side-sawn lumber (25 mm boards)	51.417		24.30

Table 5 shows the quantitative and efficient sawing of the raw pine material in the "C" test for d_k greater than 30 cm. The total material efficiency of sawn timber from sawing thick logs is 86.1%.

Table 5. The results of the wood sawing process in the "C" test.

Processed Material	Volume (m^3)		Material Efficiency (%)
Input raw material (logs)	207.360		86.09
Center-sawn lumber (38) mm boards)	121.058	178.252	58.38
Side-sawn lumber (25 mm boards)	57.467		27.71

The center-sawn material was used to create assortments with a thickness of 38 mm, intended for use in the production of semi-finished furniture products. The 25 mm thick side lumber was a byproduct of this process. The resulting sawdust was used for the production of briquettes and cellulose pulp.

The sawing efficiency of pine raw materials ranges from 62.6% to 86.1%. Log diameter has a significant impact on material yield. Larger-diameter logs yield more lumber. Smaller-diameter logs' yield decreases due to more byproducts (sawdust and wood chips). However, cutting larger-diameter logs can be more complex and require specialized equipment. The choice of technology can affect the overall efficiency of the sawing process. In addition, productivity and usability are affected by the proportion of defects; larger-diameter logs have more defects in the bypass zone.

However, the thin logs from the trunk's higher parts have more knots. These two opposing factors also affect the efficiency and yield of the sawing process, which has been confirmed in previous studies [43,44]. The efficiency is also affected by the level of automation in the control of the sawing process [45,46]. Hence, such significant differences in performance indicators can be observed not only between tree species but also between the wood of the same species growing in different places [47,48].

At the same time, a high share of intended sawn lumber (41%–58%) and a stable share of side sawn lumber 22%–27% were found, proving the correct level of matching the wood raw material to the sawing.

3.2. Material Efficiency of Production of Semi-Finished Furniture Elements

With three compared technologies, sawn lumber 38 mm thick was processed into long (D) and short (K) furniture elements. In addition, shortboards for gluing were created. Three technological variants were compared. The sawn timber was cut using a classic cross-cutting saw in the "Ap" and "Bp" variants. In the variant "Bp", additionally processed lumber was optimized in point of view wood defects. In the "Cp" test, the OptiCut automatic optimizer was used. The technological tests were carried out for two months (Ap variant) and three months (Bp and Cp variants). During these many months of observations, no assembly of the manufactured elements into frames was carried out. As a result, an overproduction of short elements (K) was revealed. These elements are easier to produce because it is easier to cut shorter than longer elements (D) from sawn timber, which contains wood defects.

Table 6 summarizes the material efficiency in the "Ap" variant, presenting the process of prefabricating lumber into furniture components. Table 7 summarizes the material performance in the "Bp" test.

Table 6. The results of sawn timber prefabrication for furniture elements according to the variant "Ap".

Month	Raw Material (m^3)	Long Element (D) (m^3)	Short Element (K) (m^3)	Shortboards (m^3)	Material Efficiency (%)
1	771.126	200.301	352.668	44.231	77.50
2	693.282	310.869	186.822	71.024	81.69

Table 7. The results of sawn timber prefabrication for furniture elements according to the variant "Bp".

Month	Raw Material (m^3)	Long Element (D) (m^3)	Short Element (K) (m^3)	Shortboards (m^3)	Material Efficiency (%)
1	616.963	336.457	217.969	62.537	84.45
2	772.344	302.983	278.365	62.969	83.42
3	689.534	258.522	267.820	43.910	82.70

The "Cp" variant introduced the automatic detection of defects with an optimizing cross-cutting saw. Table 8 shows the performance of this saw in the first three months of operation.

Table 8. The results of sawn timber prefabrication for furniture elements according to the variant "Cp".

Month	Raw Material (m^3)	Long Element (D) (m^3)	Short Element (K) (m^3)	Shortboards (m^3)	Material Efficiency (%)
1	371.07	198.37	55.06	61.30	84.82
2	716.85	277.82	238.03	74.64	82.37
3	785.51	232.14	378.63	46.12	83.75

The "Ap" variant provided material efficiencies of 77.5%–81.7%. In the "Bp" variant, the efficiency reached 82.7%–84.5%, while in the "Cp" variant, the range was 82.4–84.8%. The results of the material efficiency measurements indicate that the lowest value occurs in the "Ap" variant, while the "Bp" and "Cp" variants are similar in terms of material efficiency.

Larger log diameters tend to result in higher material efficiency in lumber production because larger logs have less waste due to knots, rot, and other defects and can be sawn into broader, longer boards. Additionally, larger logs tend to have fewer knots and more clear wood, which can result in higher-grade lumber.

Another aspect to consider is that smaller logs are easier to handle and transport, which can increase efficiency in some cases, mainly when the sawmill is located near the forest where the logs are extracted.

However, it is worth noting that log diameter is not the only factor that affects material efficiency. The obtained material efficiency may depend on the sawn lumber's quality and the defects' distribution. Different origins of the lumber, different diameters of the logs, and the distribution of knots affect the material yields. The share of defects in the wood structure, especially the volume of knots, increases when the log comes from a part higher than the ground [49]. Additionally, some larger logs can also have more waste in sawing because they have more complex structural defects. The impact of these factors was minimized by conducting observations for many months.

3.3. Cost-Effectiveness of the Lumber Production

Tables 9–11 summarize the cost-effectiveness of sawing pine raw material in the compared variants of sawing the round wood.

Table 9. Cost-effectiveness (E_p) of the sawing process according to the variant "A".

Material Type	Volume (m^3)		Cost-Effectiveness (%)		
			2020	2021	2022
Amount of sawn raw material	189.18		184.13	204.93	170.09
Center-sawn lumber	77.84	118.43	107.41	124.31	91.85
Side-sawn lumber	40.60		34.47	39.41	33.65
Byproducts (firewood)	42.45		21.32	19.74	20.30
Byproducts (wood chips)	28.30		20.92	21.47	24.30

Table 10. Cost-effectiveness (E_p) of the sawing process according to the variant "B".

Material Type	Volume (m^3)		Cost-Effectiveness (%)		
			2020	2021	2022
Amount of sawn raw material	211.66		270.93	294.66	254.91
Center-sawn lumber	105.81	157.23	130.50	151.04	111.59
Side-sawn lumber	51.42		39.02	44.61	38.09
Byproducts (firewood)	127.0		49.39	45.67	45.99
Byproducts (wood chips)	84.67		52.02	53.33	59.25

Table 11. Cost-effectiveness (E_p) of the sawing process according to the variant "C".

Material Type	Volume (m^3)		Cost-Effectiveness (%)		
			2020	2021	2022
Amount of sawn raw material	207.36		209.81	239.86	186.93
Center-sawn lumber	121.06	178.25	152.40	176.39	121.06
Side-sawn lumber	57.47		44.52	50.90	57.47
Byproducts (firewood)	17.47		6.15	5.68	5.64
Byproducts (wood chips)	11.64		6.73	6.90	7.52

The cost-effectiveness in 2020–2022 reached 170%–290% (Table 12). The high volatility of this efficiency results from changes in the prices of raw wood materials (logs) and fluctuations in the prices of center-sawn timber.

Table 12. List of efficiency indicators E_p for sawing of pine lumber in 2020–2022.

Process Variant	2020	2021	2022
	Cost-Effectiveness E_p (%)		
Variant A	184.13	204.93	170.09
Variant B	270.93	294.66	254.91
Variant C	209.81	239.86	186.93

Tables 13 and 14 present the statistical analysis results of data obtained for three variants of the wood sawing process.

Table 13. Effect of ANOVA of process selection size on log sawing efficiency index ($p < 0.05$).

Summary of Data				
	Process Variant			
	A	B	C	Total
∑X	673	1068	894	2635
Mean	112.2	178.0	149.0	146.4
$\sum X^2$	113,271	245,138	158,004	516,413
Std. Dev.	86.9285	104.9133	70.4244	87.6753
Result Details				
Source	**SS**	**df**	**MS**	
Between variants	13,063.4444	2	6531.7222	F = 0.83302
Within variants	117,614.8333	15	7840.9889	
Total	130,678.2778	17		

"SS"—Variability", "df"—number of independent results" and "MS"—intergroup variance.

Table 14. Pairwise comparisons of sawing process variants with Tukey test.

Pair		$HSD_{0.05}$ = 132.7939	$Q_{0.05}$ = 3.6734
A:B	M_A = 112.17 M_B = 178.00	65.83	Q = 1.82
A:C	M_A = 112.17 M_C = 149.00	36.83	Q = 1.02
B:C	M_B = 178.00 M_C = 149.00	29.00	Q = 0.80

The ANOVA test had an F-value of 0.833 for $p < 0.05$. The Tukey HSD procedure for comparing wood sawing in variants "A", "B", and "C" indicates that there is a significant statistical difference between the mean values of economic efficiency in the tests (Table 13).

The cost-effectiveness ratio analysis shows that the lowest values were obtained in 2020, the highest values were obtained in 2022, and values have increased yearly. This is due not only to the increase in the prices of wood raw materials and finished products but also to the difference between the price of finished products and the price of wood raw materials, which was the highest in 2022. The higher product value and lower raw material prices resulted in a high sawing efficiency index in 2022, which exceeded 255% due to an increase in the share of center-sawn timber. Therefore, it can be concluded that the efficiency of raw material processing is affected by material prices and material efficiency, which indicates the share of the main product and only then the value of byproducts generated during the processing of the initial raw material. The higher the quality and diameters of the raw material, the higher the efficiency indices can be obtained, which will affect the amount of semi-finished products [50], the volume of byproducts generated in the production process, and finally, the level of cost-effectiveness.

3.4. Cost-Effectiveness of the Production of Semi-Finished Furniture Products

Tables 15–17 present the cost-effectiveness of three variants of the production of semi-finished products for furniture production, and Table 18 compares the efficiency indicators of the analyzed prefabrication processes.

Table 15. Results of producing semi-finished furniture elements according to the variant "Ap".

Month	Cost-Effectiveness E_p (%)		
	2020	**2021**	**2022**
1	132.35	156.60	96.99
2	161.08	202.86	124.82
Average	145.95	178.50	110.17

Table 16. Results of producing semi-finished furniture elements according to the variant "Bp".

Month	Cost-Effectiveness E_p (%)		
	2020	**2021**	**2022**
1	157.53	193.93	119.60
2	156.50	193.14	119.08
3	153.42	188.43	116.24
Average	155.78	191.81	118.30

Table 17. Results of producing semi-finished furniture elements according to the variant "Cp".

Month	Cost-Effectiveness E_p (%)		
	2020	**2021**	**2022**
1	175.94	225.86	138.70
2	154.56	190.75	117.61
3	145.07	172.75	106.92
Average	154.81	190.16	117.31

Table 18. List of efficiency indicators E_p for producing semi-finished furniture elements in 2020–2022.

Process Variant	2020	2021	2022
	Cost-Effectiveness E_p (%)		
Variant A_p	145.95	178.50	110.17
Variant B_p	155.78	191.81	118.30
Variant C_p	154.81	190.16	117.31

Tables 19 and 20 present the statistical analysis results of data obtained for analyzed variants of producing semi-finished furniture elements.

The test procedure in the ANOVA test using the Tukey HSD test allows us to conclude that there is no statistically significant effect between the prefabrication stages "Ap", "Bp", and "Cp" and the obtained economic efficiency indicators Ep. In the Tukey HSD post hoc test, the value of the F coefficient was 0.05386 with $p < 0.05$. The relationship (Table 17) between the change in the prefabrication test and the economic efficiency of the process was not confirmed.

Table 19. Effect of ANOVA analysis of efficiency index of producing semi-finished furniture elements ($p < 0.05$).

Summary of Data				
	Process Variant			
	A_p	B_p	C_p	Total
$\sum X$	595	653	589	1837
Mean	99.1667	108.8333	98.1667	102.056
$\sum X^2$	76,623	87,975	81,283	245,881
Std. Dev.	59.3613	58.1495	68.5023	58.6139
Result Details				
Source	**SS**	**df**	**MS**	
Between variants	416.44	2	208.22	$F = 0.05386$
Within variants	57,988.5	15	3865.9	
Total	58,404.94	17		

Table 20. Pairwise comparisons of producing semi-finished furniture elements with Tukey test.

Pair		$HSD_{0.05} = 93.2434$	$Q_{0.05} = 3.6734$
A_p:B_p	$M_{Ap} = 99.17$ $M_{Bp} = 108.83$	9.67	Q = 0.38
A_p:C_p	$M_{Ap} = 99.17$ $M_{Cp} = 98.17$	1.00	Q = 0.04
B_p:C_p	$M_{Bp} = 108.83$ $M_{Cp} = 98.17$	10.67	Q = 0.42

In all compared processing variants, the cost-effectiveness increased in 2021 and decreased significantly in 2022. This indicates a significant impact of the raw material price increase, which was not compensated by the increase in product prices.

Data in Tables 15–18 allow assuming that the average cost efficiencies at 110% in the "Ap" variant in 2022 result from the low level of wood raw material use compared to the "Bp" and "Cp" variants. The improved technology in the Bp variant and the automation of cutting in the "Cp" variant made it possible to obtain an average annual economic cost-effectiveness index of production exceeding 117%. After analyzing data from different years, it is evident that the rise in raw material prices has a more substantial impact on cost efficiency than the effect of improving material efficiency. The high values of economic efficiency obtained, exceeding 100%, resulted from increased sawn wood prices on the markets while low prices of wood raw materials were maintained in Poland (long-term contracts for selling wood with the State Forests of Poland). The economic efficiency is expected to decrease due to the decrease in demand for wood in the construction industry and the increase in prices of wood raw materials [51,52].

Optimization processes can help improve economic effects by reducing costs, increasing efficiency, and improving the final product quality. This can be achieved through controlling to achieve the desired cost-effectiveness, quality, and efficiency. It is worth mentioning that the improvement of production technology is a factor that can be controlled within the production company; the prices of raw materials are independent factors [53,54].

The results demonstrate that it is imperative to prioritize the highest material efficiency indices during both the log sawing process and the subsequent production of semi-finished furniture components for optimal outcomes. Continuous improvement of material efficiency is vital in reducing the risk of unfavorable changes in the prices of raw wood materials. The research results indicate how to measure the development of technological ideas and competitive strategies based on wood, which aligns with previous studies [55,56].

4. Conclusions

The work studied the impact of higher wood prices on wooden furniture production and the pressure this price increase puts on increasing economic efficiency in wood processing. Specifically, the study analyzed two sequential processes: the conversion of logs into specialized lumber and the subsequent transformation of this lumber into specific furniture components. The aim was to understand to what extent higher wood prices impact the cost and efficiency of these two processes and, in turn, the furniture industry. By examining these processes, the study aimed to identify ways to optimize production and cost efficiency in the face of rising wood prices. The work aims to measure the impact of changes in the thickness of logs, changes in the technology of producing semi-finished furniture elements, and changes in prices of raw materials and products in the conditions of large-scale production of wooden furniture. The input raw material was analyzed in three classes of log diameters, from which specialized sawn timber was produced and then processed into semi-finished furniture products. Material efficiencies were calculated based on the monitoring results of these two processes. Taken together, the results of the study indicate the following:

1. The choice of dimensional kinds of logs influences the efficiency of sawing. The highest rates were obtained in producing lumber from logs with larger cross-sections since large dimensions allow more rational management of the cross-section of wood raw materials. In addition, logs with smaller cross-sections come from higher parts of the tree trunk, so they usually have many knots, which reduces the material efficiency of processing. When comparing sawn logs in all three analyzed diameter ranges (14–23, 23–30, and above 30 cm), it can be seen that the material efficiency of sawing is within 70%–85% and increases with the thickness of the log.
2. Specialized lumber with a thickness of 38 mm was used to produce semi-finished furniture components of the finished furniture frame. The share of 38 mm lumber in the total amount of lumber is 41%–58% and increases with the log diameter. Prefabrication from domestic raw materials is essential to maintain the material flow chain.
3. When sawing pine wood in 2019–2022 into specialized lumber, the economic efficiency of the technological process is 170%–290%. However, with the dependence of log dimensions and the technology used taken into account, the determining factor is the changes in the prices of raw materials and products. Improvements in processing technology cannot fully compensate for the increase in prices of raw wood materials in 2022.
4. The introduction of automatic systems to optimize the processing of pine wood into semi-finished furniture products increased the economic efficiency of the technological process from 110% to 117%. The adaptation of lumber processing to the needs of furniture production is limited by the dimensions used and the high quality of semi-finished products. The efficiency in producing long elements determines the ability to complete the sets of frame elements without excess elements. It is their share that significantly limits the economic efficiency index obtained.

Economic efficiency was defined as the ratio of the cost of the raw wood material to the price obtained for products and byproducts. Therefore, economic efficiency should, by definition, exceed 100% so that the effect of product sales can justify the cost of purchasing raw materials and cover the cost of its processing. The cost of the processing itself has been omitted because it depends on many parameters such as machinery and processing volumes, type of wood, type of products, and other factors not mentioned in the article. This study provides a basis for further work to define technological change's dependence on economic efficiency fully.

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Data Availability Statement: All data generated or used during the study appear in the submitted article.

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