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Design Opportunities for Added Value By-Products in Woodworking Industry

Mogućnosti dizajna nusproizvoda s dodanom vrijednošću u drvoprerađivačkoj industriji

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ABSTRACT • *The present work describes several possible options for using waste wood from the woodworking industry as a raw material for manufacturing design products with high value-added. In the production of plywood, as well as engineered wood products (EWP), low final yields are obtained. A large portion of wood waste consists of peeler cores, veneer pieces, large and small pieces with defects, cut pieces, shavings, etc. This study offers the author's approach to the use of this raw material, as the planning, design and fabrication were carried out in laboratory conditions. The resulting products have the necessary physical and mechanical properties that satisfy the needs of both the furniture and construction industries. The information presented could be a foundation for introducing and implementing the products described in the industry.*

KEYWORDS: *cut pieces; peeler cores; construction materials; EWP*

SAŽETAK • *U radu se opisuje nekoliko mogućnosti iskorištavanja otpadnog drva iz drvoprerađivačke industrije kao sirovine za izradu dizajnerskih proizvoda visoke dodane vrijednosti. U proizvodnji furnirskih ploča i kompozitnog drva (EWP) ostvaruju se niski profiti. Velik dio drvnog otpada čine drveni valjci preostali od ljuštenja trupaca, komadi furnira, krupni i sitni komadi drva s greškama, odresci, strugotine i dr. Ovo istraživanje nudi autorski pristup iskorištavanju te sirovine jer su planiranje, projektiranje i izrada obavljeni u laboratorijskim uvjetima. Dobiveni proizvodi imaju fizička i mehanička svojstva koja su zadovoljavajuća i za industriju namještaja i za građevnu industriju. Na temelju prezentiranih informacija, proizvodnja opisanih proizvoda moći će se implementirati u industriju.*

KLJUČNE RIJEČI: *odresci; drveni valjak preostao od ljuštenja trupca; konstrukcijski materijali; EWP*

1 INTRODUCTION
1. UVOD

Wood is a widely accessible building material, used from the earliest years of human existence. At the same time, there is a global trend of continuously increasing consumption of this natural material. This leads to a decrease in wood resources, and from an unlimited resource it becomes more and more limited due to the reduction of forested areas. The qualities of wood are well known. It is probably the only building material that can be renewed naturally within a human

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generation. The need for various types of wood and derivatives of their products will continue to increase due to the heightened demand from the market. As environmentally friendly materials with the necessary physical and mechanical properties, they are finding increasing application not only in the construction and furniture industries, but also in transport.

In order to overcome the shortage of wood raw material worldwide, measures are being taken in several main directions – search for new raw material sources, reducing wood waste during processing, more complete application of the waste in other efficient productions, and closing the wood use cycle with zero waste.

2 GLOBAL WOOD CONSUMPTION
2. SVJETSKA POTROŠNJA DRVA

An interesting fact is the predictions of the Global Forest Products Model (GFPM) for wood consumption by 2050. During this period, consumption is expected to reach 3.124 billion m^3 of wood raw material, an increase of about 37 % compared to the wood consumption recorded in 2020 (2.286 billion m^3). The use of round assortments for the production of solid wood materials is expected to increase by about 0.5-0.9 billion m^3 by 2050 (FAO, 2022). According to forecasts made by FAO (2022), the production of wood composite panels is expected to experience the largest growth by 2050, nearly +102 % for veneer/plywood and +72 % for particleboard and MDF, respectively. Moreover, consumption of solid wood and EWP intended for the construction industry is expected to increase from 41 to 123 million m^3 by 2050.

The utilization of solid wood materials in different regions around the world by 2020 is presented in Figure 1.

The chart shows the highest consumption in countries from East Asia, Europe, and North America (Figure 1). These three regions account for approximately 82 % of global consumption, considering that they represent only 36 % of the world's population.

The displayed values for the utilization of solid wood and wood-based panels in different regions of the world for the period from 1965 to 2030, as shown in Table 1, reveal interesting dependencies.

The presented results show that the consumption of both EWP and composite wood panels worldwide is expected to increase. The production growth is anticipated to be the highest in the Russian Federation, Eastern Europe, and South America. The utilization is projected to rise in Africa, Asia, and the Pacific region. Consumption of wood in developed countries is expected to be significantly more moderate due to rational and comprehensive utilization of wood resources in these regions (State of the World's Forests, 2009).

3 BY-PRODUCTS IN WOODWORKING
3. NUSPROIZVODI U OBRADI DRVA

The intensive growth in the demand for various types of wood-based products, as well as the expansion of the spheres of its consumption and processing, inevitably leads to an increase in timber harvesting in the forests. The consumption of timber from forest areas will continue to rise due to the growing market needs. It should not be forgotten that forests as ecosystems

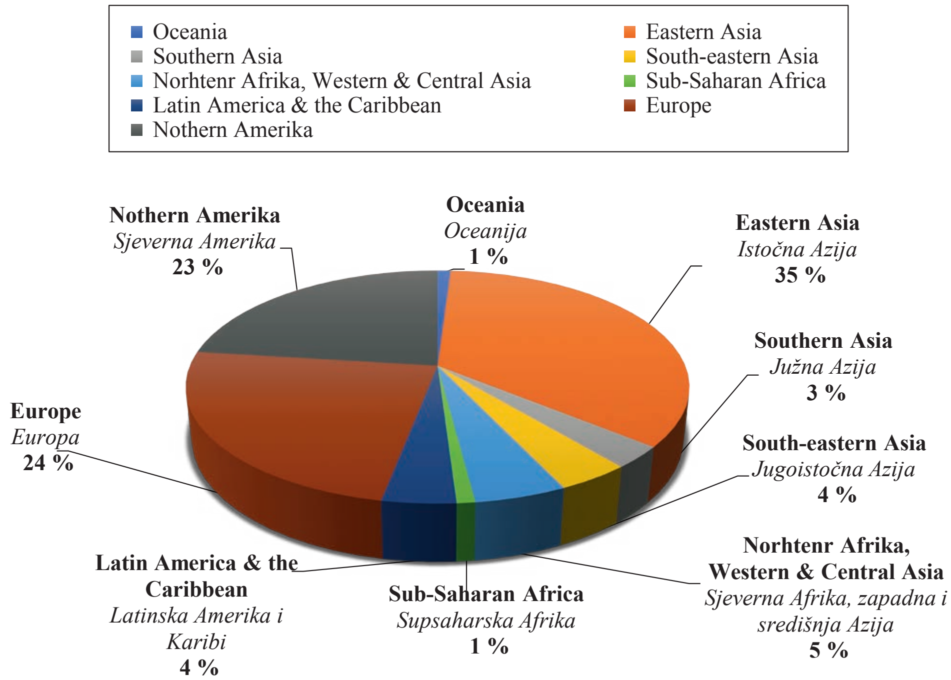


Figure 1 Global consumption of primary treated wood by region in 2020 (FAO, 2022)
Slika 1. Svjetska potrošnja drva u primarnoj proizvodnji po regijama 2020. (FAO, 2022.)

Table 1 Consumption of solid wood and wood-based panels for the period 1965 - 2030 (State of the World's Forests, 2009)
Tablica 1. Potrošnja cjelovitog drva i drvenih ploča za razdoblje 1965. – 2030. (State of the World's Forests, 2009.)

Region *Regija*	**Production and consumption of sawnwood** *Proizvodnja i potrošnja piljene građe*					**Production and consumption of wood-based panels** *Proizvodnja i potrošnja drvenih ploča*				
	Amount (million m^3)/ *Iznos (milijuni* m^3*)*									
	Actual *Stvarno*			**Projected** *Planirano*		**Actual** *Stvarno*			**Projected** *Planirano*	
	1965	**1990**	**2005**	**2020**	**2030**	**1965**	**1990**	**2005**	**2020**	**2030**
Africa / *Afrika*	3	8	9	11	14	1	2	3	4	5
Asia and the Pacific / *Azija i Pacifik*	64	105	71	83	97	5	27	81	160	231
Europe / *Europa*	189	192	136	175	201	16	48	73	104	129
Latin America and the Caribbean *Latinska Amerika i Karibi*	12	27	39	50	60	1	4	13	21	29
North America / *Sjeverna Amerika*	88	128	156	191	219	19	44	59	88	110
Western and Central Asia *Zapadna i Centralna Azija*	2	6	7	10	13	0	1	5	11	17

perform increasingly important, water conservation, protective, climate-regulating, sanitary-hygienic, aesthetic, and other useful functions. Therefore, our efforts and scientific research urgently need to focus on searching for the most rational utilization of both the wood and the waste raw materials in its processing. According to data from the Bulgarian Executive Forest Agency (2020), in Bulgaria, the age structure as well as the average tree diameter have significantly decreased over a period of several years. This, in turn, is associated with increasing difficulty in obtaining solid wood materials with the necessary dimensional and quality characteristics. This trend of shortage of medium and large building timber for industrial needs is observed not only in Bulgaria, but also in other countries around the world. (Warde, 2006; Nazir *et al.*, 2018; Alberdi *et al.*, 2020; Odppes *et al.*, 2021).

3.1 Waste wood in production of EWP
3.1. Drvni otpad u proizvodnji EWP-a

As mentioned above, one of the largest consumers of large and medium-sized construction timber are woodworking companies producing solid wood materials and engineered wood products (EWP), as well as manufacturing rotary veneer for plywood. There is a significant amount of waste in the form of caps, cutouts, offcuts, shavings, etc. during the initial cutting of round wood for solid wood materials. Their percentage share is directly dependent on a number of factors, such as: dimensional and quality characteristics of the raw material; specification of the finished product; technical characteristics of woodworking machines, and many others (Campbell, 2013; Heräjärvi *et al.*, 2004; Hernandez *et al.*, 2005; Starkova, 2004; Trichkov and Koynov, 2016 Trichkov and Koynov, 2018). With the continuation of the technology and further processing of the solid wood materials to obtain EWP, the same go through a number of technological operations, in which the wood consumption in the form of cut pieces with the presence of defects, cuts, shavings, etc. significantly increases (Figure 2).

According to data from wood processing companies in Bulgaria, in the production of EWP, in some cases, the final quantitative yields reach only up to 20-30 % (Koynov *et al.*, 2023). As the diameter of the round wood decreases, and therefore its quality, the percentage of waste increases inversely proportional. Several authors have conducted studies on the influence of the quantity, size, and number of defects in the wood on the physical and mechanical properties of the final products (Koman *et al.*, 2013; As *et al.*, 2006; Kaiser, 2020; Wright *et al.*, 2019; Montero *et al.*, 2015). It follows that

Figure 2 Cut pieces with presence of EWP manufacturing defects
Slika 2. Odresci s greškama u proizvodnji kompozitnih ploča

the presence of numerous defects in the wood, specifically knots, sharply reduces the mechanical properties of the solid wood materials. With this raw material, if the low-quality wood is removed from the high-quality one, then the final quantitative yields are greatly underestimated. Waste wood in the form of cuttings, large and small cut pieces, shavings, sawdust, etc., is mainly used for saturating them in technological chips for subsequent production of wood-based panels, pellets, and as a raw material for burning.

The problem of their utilization is that there is a lack of adaptation of modern technologies in the woodworking industry. Several authors have focused their research in this direction, searching for options for more rational application of this waste raw material (Pandey, 2022). Many proposals have been examined for optimal use of wood waste in products with high value-added. For example, studies in Finland have been carried out (Cai *et al*., 2013) on the implementation of new products in textiles, chemicals, biofuels, and plastic substitutes, based on wood. Studies in Japan have found that every year there are about 15 million m^3 of wood waste from the furniture industry, of which over 90 % have found application in the production of wood-based panels and as a raw material for burning (Hiramatsu *et al*., 2002).

Now, there is not enough information based on which to implement a precise and clear approach for optimal utilization of waste wood. It is necessary to search for more opportunities to use it as optimally as possible in the production of EWP. This goal is driven by the fact that production capacities on a global scale will continue to increase due to the growing consumption of such products. It is imperative to search for options for the utilization of waste wood not only in the aforementioned ways but also as a basis for obtaining high value-added products that meet the needs of consumers. Globally, opportunities are being sought for a more sustainable and circular economy (Bowyer *et al*., 2023), which requires taking into account various aspects, such as their impact on the environment and human health, as well as their practicality and economic feasibility.

3.2 Waste wood in plywood production
3.2. Drvni otpad u proizvodnji furnirskih ploča

Another major consumer of large and medium-sized construction timber is plywood production. The technological process is associated with significant raw material losses, which come in the form of veneer pieces during and after log peeling, cutting, trimming, slicing, and last but not least – peeler cores. According to data from leading manufacturers in Bulgaria, the final quantitative yields do not exceed 47-49 %. They are also directly dependent on the dimensional and quality characteristics of the peeled timber. Peeler cores are an inevitable by- product obtained in the process of log peeling (Figure 3). Their percentage ratio (1-30 %) is directly dependent on both the diameter of the logs and the technical characteristics of the peeling machine (Syafii and Novari 2021; Fonseca, 2005; Melo *et al*., 2014).

The diameter of the peeler cores varies within different limits. It mainly depends on the technical characteristics of the peeling machines, but the wood species of the raw material also has an influence. According to data from some global veneer producing companies (Tolko Industries Ltd; Thebault group; Welde - The Wood Company, etc.), the diameter of the obtained peeler cores ranged from 80 to 140 mm. Modern technologies provide an opportunity for spindleless peeling, where the diameter of the peeler cores can be reduced to 30-40 mm. It should be noted that in the central zone of the wood (the first 5 to 20 annual rings), there is a large percentage of juvenile wood, which leads to very low physical and mechanical properties of the wood (Yang, 1994; Zobel, 1998). In its first years of growth, the tree produces so-called juvenile wood, which is the area of the stem extending outward from the heartwood. This wood is prone to cracking, splitting and easy destruction, which lowers its quality and economic characteristics. Studies on the mechanical properties of juvenile wood show that its hardness and strength are 50-70 % lower compared to mature wood (Barbour, 2003; Hernandez *et al*., 2005).

Figure 3 Peeler cores from poplar wood
Slika 3. Središnji valjci preostali nakon ljuštenja drva topole

For this reason, peeling the logs to a minimum diameter of the peeler cores on the one hand increases the quantitative yield of the veneer, but on the other hand, it can lead to a deterioration of its quality. Results from industrial studies show that a large portion of veneer pieces obtained with minimal peeling of the peeler cores diameter (up to 30 mm) are discarded after drying up to 7-8 %. The reasons for this are the formation of large cracks, splitting, or structural damage. Another drawback is the appearance of a "striped" texture on the face side during the drying process. Rough calculations show that, when reducing the peeler cores from 100 to 30 mm, only about 5-10 % of the veneer pieces from this zone are suitable for plywood production after drying. The rest go into chippers to be processed into technological chips.

According to data from global veneer-producing companies (Tolko Industries Ltd), the quantity of veneer with an average diameter of 80-85 mm can reach up to 3 million pieces per year. Information from other companies (Thebault group) shows that the number of veneer pieces obtained within a year is smaller, around 500 thousand pieces, which is still a significant amount of wood raw material. Depending on the wood species, some of the veneer finds application as: stakes for trees; wine stakes; for agricultural production; in gardening; fence posts, signs, as well as for the production of pallets, packaging, etc. The remaining quantity is crushed into technological chips for use in the production of composite panel materials or as raw material for pellets, briquettes, and burning (Torgovnikov and Vinden, 2014; Darzi *et al*., 2020; Ross *et al*., 2005; Wolfe *et al*., 2000).

From the above, it becomes clear that the sectors in which veneer is used are significantly limited. The manufactured products have limited applications, low value-added, and short longevity due to the mentioned shortcomings of this wood. Therefore, it is necessary to explore different options for the most optimal and rational utilization of by-products obtained in the woodworking industry. Conditions should also be created to form final products with the highest possible value-added, having the necessary physical and mechanical properties to meet consumer needs.

4 OPPORTUNITIES FOR PRACTICAL APPLICATION OF CUTTING PIECES WITH DEFECTS AS A RAW MATERIAL FOR MANUFACTURING DESIGN PRODUCTS

4. MOGUĆNOSTI PRAKTIČNE PRIMJENE ODREZAKA S GREŠKAMA KAO SIROVINE ZA IZRADU DIZAJNERSKIH PROIZVODA

During the technological process of producing glued products from solid wood, a large percentage of waste is generated. The dimensions and quantity of these wastes depend directly on the specification of the final product and the quality characteristics of the raw material. For the purpose of our research (Koynov *et al*., 2023), panels of glued solid wood using large waste pieces with defects were obtained. Selected cut pieces with the same thickness and width but varying length, depending on the size of their defects, were used. The cross-sections of these large waste pieces have a shape close to ideal geometry, as the obtained lamellae were pre-treated on four sides. The methods of gluing and forming three types of proposed solid wood panels are described in detail in Koynov *et al*., 2023. The dimensions of the cut pieces with defects can be smaller than those used in the mentioned paper, but they must be produced from lamellae with the same cross-sections. This condition guarantees their potential for creating a technology for combining and gluing them lengthwise. In the described paper, PVA: "*Moment Wood Express*" was used as an adhesive, but other fast-drying and two-component adhesives can also be applied (Lubis *et al*., 2022; Savov *et al*., 2022).

The results of testing some of the more important physical and mechanical properties clearly showed that these products can find various applications as load-bearing structural elements, enclosing structures, as well as in the furniture industry. Depending on the selected type of panel, the average values of modulus of elasticity (MOE) ranged from 2982 to 5580 N/mm^2, and modulus of rupture (MOR)- from 8.8 to 28.6 N/mm^2 (Koynov *et al*., 2023).

The possibility of using waste wood from EWP to obtain a final product for the needs of the furniture industry is presented in Figure 4a.

The production technology was presented, as well as the possibility of potential applications of these products as a raw material for the manufacturing of a design product intended for furnishing homes and offices (Figure 4b).

After removing the high-quality from the low-quality wood in the production of EWP, all the waste has the same cross-sectional dimensions but different lengths. In order to produce the final product, initially, large wastes were stuck together in the foreheads by smoothing until obtaining a lamella of the desired length (Figure 4a-1). After forming and subsequent mechanical processing, the lamellae were glued together along the edge (Figure 4a-2). Finally, panels of glued solid wood of the desired width were obtained (Figure 4a-3), (Koynov *et al*., 2023).

In the present version (Figure 4b), a final product - coffee table with overall dimensions of the tabletop: 560 mm × 560 mm × 35 mm and a height of 430 mm, was manufactured. The legs of the table were of the "hairpin" type, hand-made from rebar and subsequently painted. The surface of the tabletop was a)

b)

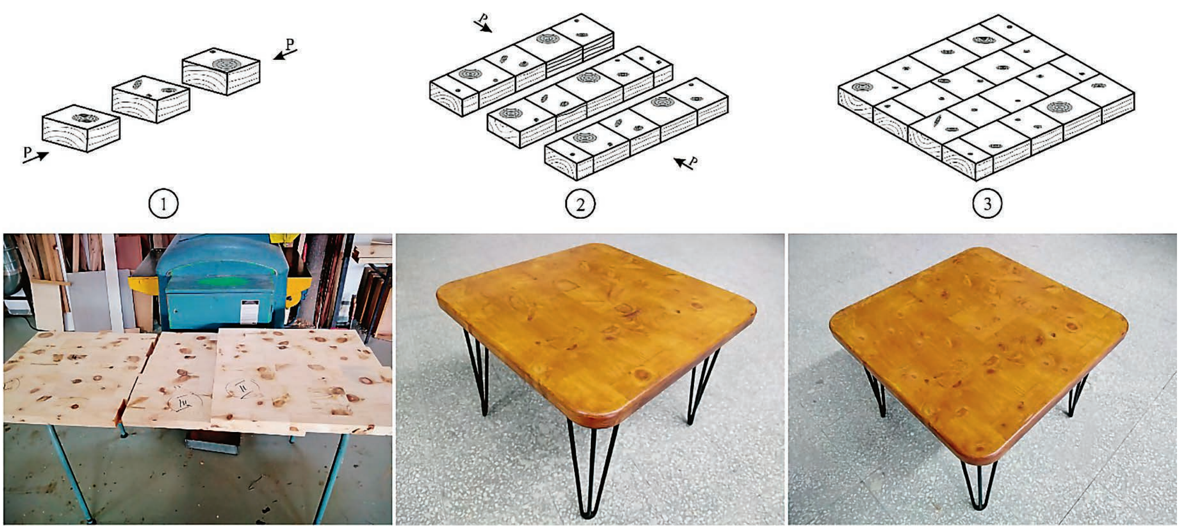


Figure 4 Technology for obtaining glued panels from solid wood from waste and potential application for the final product (Koynov *et al*., 2023)
Slika 4. Tehnologija izrade lijepljenih ploča od otpadnoga cjelovitog drva i mogućnosti njihove primjene za izradu finalnog proizvoda (Koynov i sur., 2023.)

further refined. Depending on the choice of varnish and the client's preference, the prominence of the defects can either be clearly accentuated or slightly concealed.

Utilizing waste wood in this way allows for the formation of laminated panels from solid wood with final dimensions that meet the demand. They can be used in the furniture industry as kitchen countertops, exterior and interior doors, furniture doors, tabletops, and many other products. The presence of numerous defects, including falling knots, holes, gaps, cracks, etc., certainly deteriorates the external and aesthetic appearance. For this reason, the laminated panels from waste wood can be veneered, thus not only hiding the negative impact of the defects but also enhancing the mechanical properties of the products (Koynov *et al*., 2023).

The proposed method for obtaining final products from waste wood not only allows for the utilization of this wood but also saves some technological operations. Firstly, the solid wood materials for EWP production were previously dried to a final moisture content of 8-9 %, which is also the moisture content of the waste wood. Secondly, before removing the defects, the lamellae were previously four-sided planed, resulting in cut pieces with a proper geometric shape, including parallelism between the sides and perpendicularity between the sides and their ends. Thirdly, the steps mentioned so far facilitate the possibility of bonding them by planing. Fourthly, when matching the waste wood end to end, it is not necessary to cut finger-joints, which on the one hand saves this technological operation, on the other hand reduces the cost of cutting teeth, and finally reduces the amount of bonding material (Koynov *et al*., 2023).

5 DESIGN APPROACH FOR USING PEELER CORES AS A RAW MATERIAL FOR OBTAINING HIGH VALUE-ADDED PRODUCTS

5. DIZAJNERSKI PRISTUP ISKORIŠTAVANJU DRVENIH VALJAKA PREOSTALIH NAKON LJUŠTENJA TRUPACA KAO SIROVINE ZA DOBIVANJE PROIZVODA VISOKE DODANE VRIJEDNOSTI

Plywood manufacturing is another industry in the woodworking sector and a major consumer of softwood. In the technological process of peeling the logs for veneer, peeler cores are inevitably produced. Several authors have conducted research on the more rational utilization of this raw material, but as a whole, the proposed options do not provide the opportunity for their use in the industry, due to some specific features (Darzi *et al*., 2020; Wolfe *et al*., 2000; Piao *et al*., 2013; Torgovnikov and Vinden, 2014). In one case, the peeler core sections have been used in the core layers in composite laminated wood panels (Darzi *et al*., 2020). The presented products have significantly good mechanical properties, but glued solid wood, cross-laminated timber (CLT), as well as various types of plywood for the face layers have been used. By applying these materials, the cost of the final product will significantly increase. Other authors (Wolfe *et al*., 2000) present the possibility of using peeler cores in cylindrical form as fasteners in the construction industry. The disadvantages of this raw material listed above are a prerequisite for numerous defects in structural elements, such as distortion, warping and, last but not least, a shorter life cycle of operation. Piao *et al*., 2013 Piao *et al*., 2013 have conducted experiments on direct finger-

a)
b)
c)

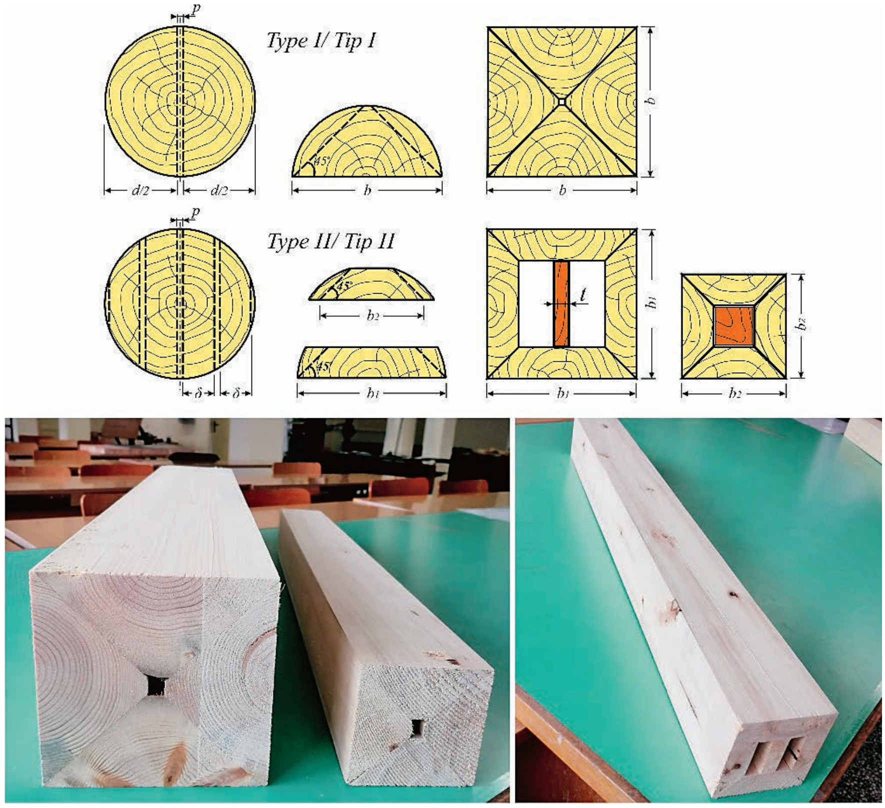


Figure 5 Variants for producing glued beams with a hollow cross-section from sawmill wood (Koynov and Valyova, 2022)
Slika 5. Varijante proizvedenih lijepljenih greda od piljenog drva sa šupljim poprečnim presjekom (Koynov i Valyova, 2022.)

joint splicing along the peeler cores length in their cylindrical form. The established mechanical properties are satisfactory, but again, conditions for subsequent defects in the final products are created.

Some of the main reasons of defects in peeler cores, when used in cylindrical form are: the wood in the central zone of the tree has reduced mechanical properties and many stresses; presence of heartwood; large difference in early and late wood; annual rings with large width and irregular shape. All this will inevitably lead to warping or twisting of peeler cores when applied in their cylindrical form. It is necessary to search for options for their optimal cutting with minimal labor, energy, and wood consumption, in order to minimize the impact of the listed deficiencies.

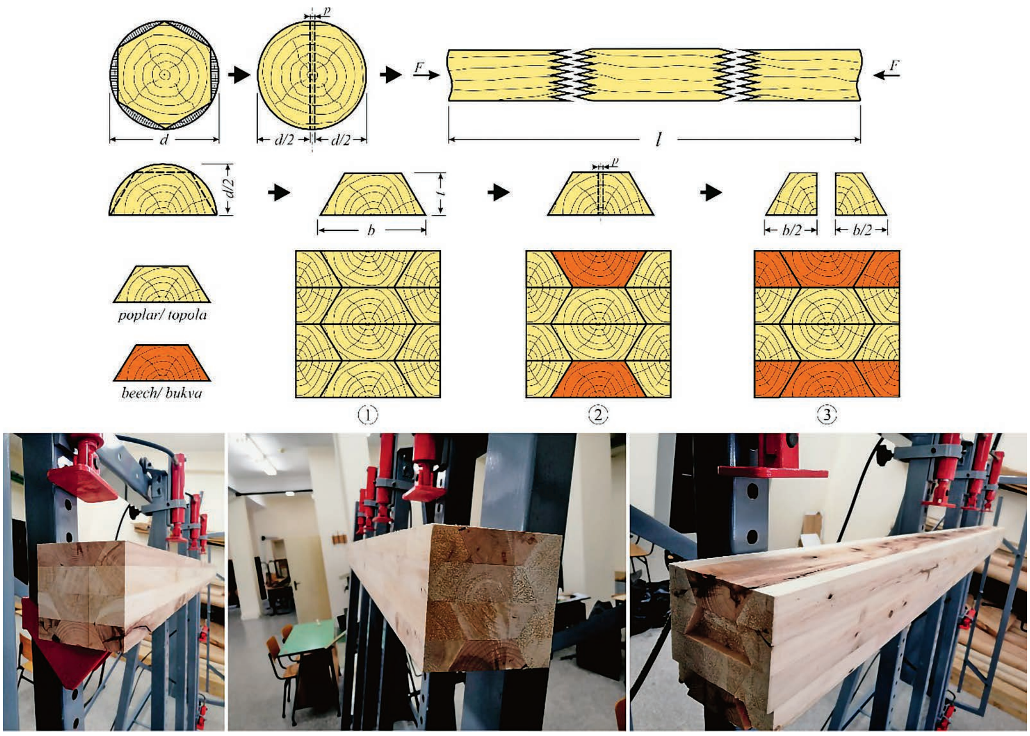
In our previous research, our efforts were oriented towards these issues (Koynov and Valyova, 2022; Koynov *et al*., 2022; Koynov *et al*., 2024a; Koynov *et al*., 2024b). We were looking for options to obtain high value-added products that would find application in both the furniture and construction industries. One of the proposed methods had several variants for longitudinal cutting of peeler cores and gluing the lamellae in order to produce beams with a hollow cross-section (Figure 5a). In this case, the diameter of the peeler cores is directly dependent on the dimensional cross-sections of the glued beams.

In the presented method - *Type I* (Figure 5a), the peeler cores were initially cut longitudinally into the two semicircles. The resulting materials were notched at an angle of 45°, thus forming cross-sections close to that of an isosceles triangle. Finally, the same were combined into a glued beam, the direction of the annual rings being oriented so that there was a correct radial cut on each side of the beam.

In method - *Type II* (Figure 5b), the peeler cores were initially cut longitudinally into four boards of equal thickness. To achieve maximum quantitative yield, the same were notched at an angle of 45° to trapezoidal cross-sections. Two peeler cores make it possible to join two hollow beams, but one of them will have a cross-sectional area exceeding the cross-section of the peeler core. Cutting methods and established quantitative yields for different peeler cores cuttings are described in detail by Koynov and Valyova, 2022.

Three types of bonded beams with hollow cross-sections were obtained as final products in laboratory conditions (Figure 5c). Some of the basic physical and mechanical properties on the beams were determined, but subsequent experiments with the necessary number of beams from each series were conducted for more accurate and comprehensive results.

Other variants for optimal cutting of the peeler cores in order to manufacture glued laminated timber (GLT) are presented by Koynov *et al*., 2022; Koynov *et al*., 2024b. Three methods for bonding characterized by the trapezoidal cross-sections of the lamellae form-



a)

b)

Figure 6 Glued-laminated timber manufactured from peeler cores (GLPC) with different percentages of trapezoidal cross-section lamellae from beech and poplar wood (Koynov *et al*., 2024b)
Slika 6. Lijepljeno lamelirano drvo proizvedeno od središnjih valjaka preostalih nakon ljuštenja trupaca (GLPC) s različitim postotcima lamela trapeznog presjeka od drva bukve i topole (Koynov i sur., 2024b)

ing in the construction package were proposed. The latter were made of beech and poplar wood with different percentage share. Peeled veneer is mainly obtained from the above wood species in Bulgaria. The cutting methods and subsequent technological operations are described in detail in the papers.

Laboratory bonded hybrid beams from glued-laminated timber manufactured from peeler cores (GLPC), as well as the technology for their production, are presented in Figure 6b.

The purpose of this study was to determine the effect of the amount of beech wood on the physical and mechanical properties of glued beams produced from peeler cores.

Laboratory bonded GLPCs were manufactured by different combinations of poplar and beech: 100 % poplar (Figure 6a-1); 25 % beech/ 75 % poplar (Figure 6a-2) and 50 % beech / 50 % poplar (Figure 6a-3).

The shape of the lamellae cross-sections was chosen based on the minimal wood consumption when cutting the peeler cores (Koynov *et al*., 2022). The established results for the physical and mechanical properties of these products clearly indicate that they can be easily used as structural beams in the construction industry. With different percentages of beech and poplar, the MOE results showed values ranging from 8062 to 10985 N/mm^2. The average values of MOR were in the range of 35 to 57 N/mm^2. The density of the glued beams is very low (425 - 544 kg/m^3). The results conclusively showed that these beams meet strength classes *GL* 32*c* and *GL* 32*h* (Koynov *et al*., 2024b).

A variant for utilizing the peeler cores as a core layer to produce hybrid plywood was developed. The technological process was described in detail by Koynov *et al*., 2024a. Three options for different quantities and thicknesses of peeler core sections to form the final product were proposed. The results for density-to-strength ratio after establishing the physical and mechanical properties of the hybrid plywood from all series showed a clear dependence. In this case, the most optimal variant was obtained with 80 % filling of the core layer with peeler core sections. The MOE results ranged from 2312 to 3088 N/mm^2, and the MOR- from 10.7 to 17.9 N/mm^2. The density of the hybrid plywood is close to that of very lightweight panels (304 and 378 kg/m^3). Overall, these products can find applications not only in furniture, but in some cases also in the construction industry (Koynov *et al*., 2024a).

Several coffee tables have been produced as final product options shown in Figure 7b. The selected item is based on the dimensional characteristics of the laboratory press used for gluing.

On the one hand, the aim of the present study was to rationally use peeler cores to produce hybrid plywood, and on the other hand, to determine the influence of the washer amount on the physical and mechanical parameters of the final products.

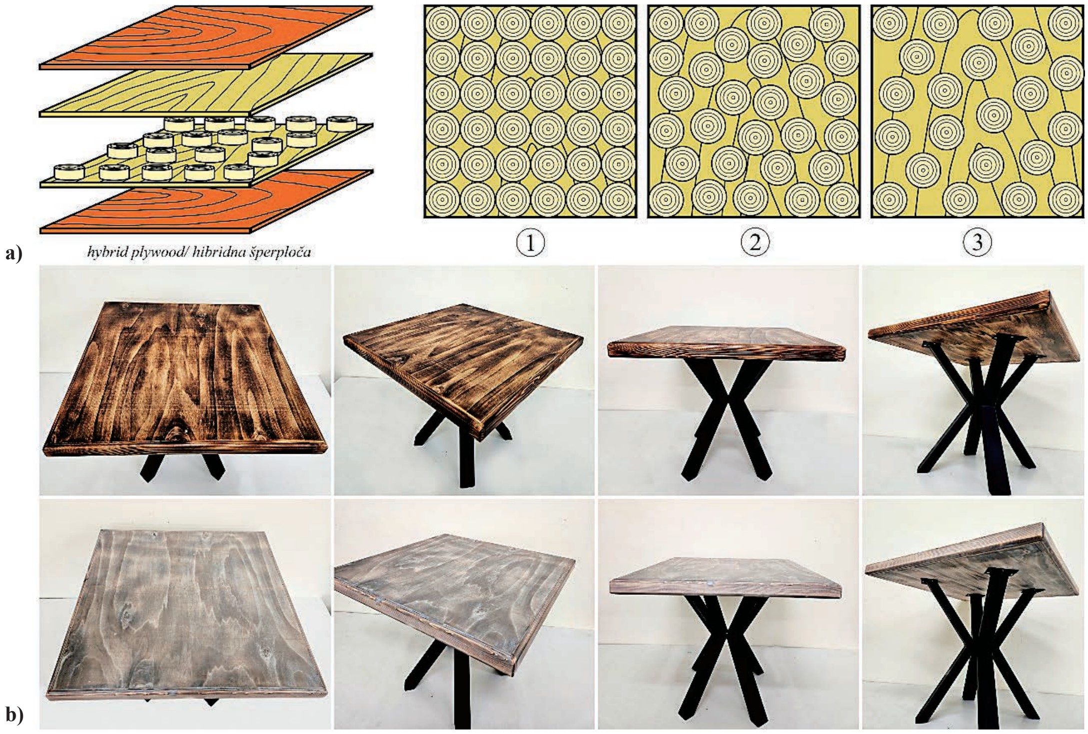


Figure 7 Laboratory produced tables from hybrid plywood (Koynov *et al*., 2024a)
Slika 7. Laboratorijski proizvedeni stolovi od hibridne furnirske ploče (Koynov i sur., 2024a)

In the first case, the veneer sheets were filled to the maximum with washers from peeler cores in the intermediate layer of the hybrid plywood or the so-called 100 % (Figure 7a-1). All washers were stacked tightly together with as few gaps as possible between them. The maximum number of washers reached 36 pieces. In the second case, the goal was to reduce the amount of washers to approximately 80 % of the maximum number, i.e. 29 pieces (Figure 7a-2). The amount of washers in the last version was reduced to 60 % or 22 pieces (Figure 7a-3), (Koynov *et al*., 2024a).

The dimensions of the coffee tabletop were 600 mm × 600 mm × 40 mm with a height of 450 mm (Figure 7b). The legs were once again hand-made and painted in the desired color. The tabletops were formed from five-layer hybrid plywood with minimal use of veneer sheets (4 pieces). Poplar veneer sheets were used for the face. With minimal additional processing and surfacing of the top layer, a significantly improved aesthetic appearance is achieved, resembling that of valuable wood species. The main point in this specific case is the use of waste raw material in the form of peeler core sections, which on one hand act as fillers in the core layer, and on the other hand, due to their size, can easily adjust the desired final thickness of the panel. By increasing the number of veneer sheets, the strength characteristics will significantly increase, but the goal of this study was to achieve a product with good physical and mechanical properties as well as an aesthetically pleasing appearance while minimizing the use of high-quality raw materials.

6 CONCLUSIONS
6. ZAKLJUČAK

The conducted review presents optimal opportunities for utilizing waste in the woodworking industry to obtain high value-added products. The proposed options for final products obtained from waste wood in the woodworking industry can find applications in both the furniture and construction industries. These products can be used for both decorative and non-structural elements, as well as for structural components. They have very good characteristics in terms of density to strength properties. Research in this direction should continue to provide the final products ideally tailored to the needs of consumers. On the other hand, their manufacturing should involve minimal wood consumption, optimal labor and energy expenditure, as well as technological efficiency.

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