Universitatea
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HABILITATION THESIS

Title: SUSTAINABLE WOOD-BASED THERMAL INSULATION STRUCTURES AND SURFACE QUALITY ASSESSMENT

Domain: Forest Engineering

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CONTENTS

(A) REZUMAT

Teza de abilitare „**Structuri sustenabile termoizolante pe bază de lemn și evaluarea calității suprafețelor**” sintetizează rezultatele cercetărilor autoarei desfășurate după obținerea titlului de Doctor inginer în Inginerie Industrială (în februarie 2005). Cercetările acesteia vizează calitatea suprafețelor din lemn prelucrate prin așchiere, proprietățile fizice și mecanice ale compozitelor realizate din materiale lignocelulozice și deșeuri agricole, precum și proprietățile unor structuri tip sandwich privind capacitatea acestora de izolația termică.

Teza de abilitare este structurată în patru părți după cum urmează:
Primul capitol intitulat „Performanța unor structuri inovative sustenabile”, prezintă rezultatele cercetărilor autoarei în domeniul structurilor inovative sustenabile realizate din coji de floarea-soarelui. Prima parte prezintă rezultatele investigațiilor privind influența dimensiunii cojilor de floarea-soarelui asupra performanțelor plăcilor realizate într-un strat și în trei straturi folosind un adeziv uree-formaldehidic. Rezultatele au indicat că plăcile cu un singur strat și cu trei straturi fabricate din particule fine au avut o structură omogenă, ceea ce a dus la îmbunătățirea performanțelor acestora. Acestea pot fi utilizate în structuri de panouri dar și ca componente de mobilier care nu vor fi supuse încovoierii. In a doua parte a capitolului s-au investigat proprietățile fizice și mecanice ale panourilor în care adezivii utilizați (uree-formaldehidă, fenol-formaldehidă, melamină-uree-formaldehidă modificată și difenilmetan diizocianat polimeric) au fost adăugați în proporții diferite. Rezultatele au indicat faptul că tipul și conținutul adezivului au influențat în mod semnificativ proprietățile investigate și au arătat că cojile de floarea-soarelui reprezintă un material alternativ pentru lemn în fabricarea plăcilor aglomerate.

Al doilea capitol intitulat „Structuri termoizolante sustenabile”, prezintă rezultatele cercetărilor efectuate cu scopul de a găsi noi structuri ecologice pentru izolarea termică a clădirilor. Cercetările s-au concentrat pe dezvoltarea de structuri de pereți tip sandwich cu diverse materiale de umplutură, cum ar fi așchii de lemn, lână, vată minerală și panouri ABS inovatoare, precum și pe dezvoltarea de noi structuri compozite care conțin așchii de lemn, fibre de lemn, cânepă, stuf și lână armată cu ciment, respectiv compozite din așchii de lemn și paie de cânepă armate cu gips. Rezultatele testelor privind conductivitate termică au arătat că deși acest coeficient este mai mare decât coeficienții materialelor tradiționale utilizate pentru izolarea termică a clădirilor, încorporarea materialelor ecologice în diverse structuri de panouri și compozite este o soluție eficientă care în final va conduce la reducerea emisiilor de carbon și a emisiilor de gaze cu efect de seră.

Al treilea capitol intitulat „Cercetări privind calitatea suprafețelor lemnoase", prezintă rezultatele cercetărilor asupra calității suprafețelor din lemn prelucrate prin diferite tipuri de prelucrări mecanice. Investigarea calității lemnului de fag prelucrat prin frezare profilată cu diferite regimuri de lucru în diferite faze ale stării tăișului sculei așchietoare (frezare cu tăișuri ascuțite și frezare după prelucrarea a 600 de metri liniari de fag), prin parametrii de rugozitate Ra (deviația medie aritmetică a profilului de rugozitate), Rv (cea mai mare adâncime absolută a văii profilului), Rsk (asimetria profilului) și Wa (deviația medie aritmetică a profilului ondulației), precum și prin Rk (adâncimea rugozității miezului), Rpk (înălțimea redusă a vârfului), Rvk (adâncimea redusă a văii), A1 (aria vârfului) și A2 (aria văiilor), au arătat că o creștere a vitezei de avans va conduce la mărirea ondulațiilor, dar și la apariția fibrelor ridicate. S-a observat că rugozitatea suprafețelor s-a îmbunătățit după ce freza a prelucrat în scopul uzurii țăișurilor 600 de metrii liniari de fag. In a doua parte a capitolului se prezintă cercetărilor cu privire la investigarea calității celor două suprafețe ale furnirelor de frasin și stejar, pentru a determina dacă compresia exercitată de bara de presare în timpul tăierii plane va conduce la diferențe între rugozitatea măsurată pe suprafața pe care actionează bara, respectiv pe suprafața tăiată de cuțit. Rezultatele au arătat că nu există diferențe semnificative între parametrii Rk, Rpk și Rvk măsurați pe ambele fețe ale furnirului. Un alt studiu din acest capitol se referă la investigarea calității suprafeței panourilor decorative cu secțiune transversală realizate din lamele de plop și molid, respectiv din lamele de cireș și nuc prelucrate prin șlefuire cu hârtie abrazivă de diferite granulații. Rezultatele au indicat că odată cu creșterea granulație hârtie abrazive se observă o scădere a rugozității de prelucrare, iar valorile parametrilor Ra și Rz sunt mai mici pentru panoul de cireș-nuc în comparație cu panoul de plop-molid pentru toate cele patru dimensiuni ale granulelor hârtiei abrazive.

Al patrulea capitol al tezei de abilitare, intitulat „Evoluția în cariera profesională", prezintă direcțiile viitoare de dezvoltare a carierei în plan didactic și în activitatea de cercetare.

Din 2005, activitatea profesională și de cercetare a autoarei, s-a materializat în: 7 cărți, 1 capitol de carte publicat de Springer Nature Switzerland, 7 îndrumare de laborator, 17 articole publicate în reviste ISI, 26 articole publicate în reviste indexate BDI, 4 articole publicate în reviste B+ și 25 articole publicate în lucrările conferințelor internaționale; 2 proiecte internaționale în calitate de manager de proiect, 2 proiecte cu terți în calitate de manager de proiect, 3 proiecte internaționale în calitate de membru al echipei, 8 proiecte naționale în calitate de membru al echipei, 4 brevete de invenție și participarea la 16 conferințe internaționale și naționale în calitate de membru al comitetului științific sau al comitetului de organizare.

(B) SCIENTIFIC AND PROFESSIONAL ACHIEVEMENTS AND THE EVOLUTION AND DEVELOPMENT PLANS FOR CAREER DEVELOPMENT

(B-I) SCIENTIFIC AND PROFESSIONAL ACHIEVEMENTS

1. INTRODUCTION

The habilitation thesis "**Sustainable wood-based thermal insulation structures and surface quality assessment**" represents a synthesis of the research areas that the author has addressed since obtaining her doctoral degree, representing a logical development of her previous research, as well as research in related areas.

The evolution of manufacturing technologies and the development of concepts such as sustainable materials, eco-composites, circular economy and carbon footprint reduction have led the author's research in this direction. Wood, as an ecological material, is a very important product for humanity, having been exploited since ancient times, which is why it must be protected and sustainable solutions must be found to avoid irrational exploitation. Thus, finding solutions whereby wood or wood-based panels can be replaced with composites containing sustainable materials derived from agricultural waste or from the wood processing process is an important goal that must be integrated into the circular design process.

The first research included in this chapter referred to the effect and geometry of sunflower husks on the performance of single-layer and three-layer particleboard. For this research, two types of sunflower seed husks were used, some coarse and others fine, which were mixed with a urea-formaldehyde resin adhesive. The physical tests applied to the particleboards were aimed at determining their density, water absorption and thickness swelling, as well as their thermal conductivity coefficient. The mechanical tests investigated included bending strength, modulus of elasticity, internal bond strengh perpendicular to the plane on the board, and screw holding strength. The results showed that the size and shape of the sunflower particles influenced the performance of the particleboards. The best results were obtained for particleboards made of fine particles in one layer and in three layers. In terms of application, these particleboards can be used for paneling structures and furniture components which are not subjected to bending stresses.

In the second issue addressed, concerning the performance of innovative sustainable structures, the author presents research carried out with the aim of creating structures from sunflower husks with physical and mechanical properties similar to those of wood-based panels. Urea-formaldehyde adhesives (UF in three commercial variants: UCL, U96 and AG), phenol-formaldehyde (FF), modified melamine-urea-formaldehyde (VM) and polymeric diphenylmethane diisocyanate (pMDI) were used in the manufacture of these particleboards.

The panels obtained were tested to physical properties, such as water absorption and thickness swelling, density determination and vertical density profile. A series of mechanical tests were also carried out to determine the bending strength, modulus of elasticity, modulus of rupture, internal bond strengh perpendicular to the plane on the board. The results of the research showed that the type of adhesive had a significant influence on the physical and mechanical properties of the panels. Sunflower husks also proved to be compatible with urea-formaldehyde, phenol-formaldehyde and diphenylmethane diisocyanate polymer adhesives, which means that they represent an alternative material to wood for the manufacture of particleboards.

Another topic covered in the habilitation thesis refers the design of ecological and sustainable structures that improve the energy performance of buildings. According to data collected at European level, buildings currently generate more than a third of greenhouse gas emissions. In this regard, the rules adopted at European level envisage that by 2030 all new buildings will have zero emissions, and by 2050 the EU's building stock should be transformed into a zero-emission stock. Thus, according to these regulations, the average primary energy consumption of residential buildings will be reduced by 16% in 2030 and by 20-22% in 2035 across European countries.

In this chapter, the research aimed to create sandwich wall structures with different types of core filling materials, which were then tested to determine their thermal conductivity coefficient. The filling materials used were spruce and beech wood shavings, panels made from acrylonitrile butadiene styrene (ABS) waste combined with wood shavings and rock wool. The structure was sealed with a polypropylene foil for anti-condensation and gypsum board, respectively with OSB panel. The average test temperatures chosen simulated the two specific situations of the winter and summer seasons. The results showed that the best thermal performance was recorded for structures with rock wool inside, and rock wool and ABS board, respectively. The structure with a core of wood shavings and ABS panel on the outside recorded a smaller variation in the thermal conductivity coefficient throughout the entire test cycle. Thus, wood shavings compressed at a low density could be a sustainable solution for sandwich structures for the thermal insulation of buildings.

Other research presented in this chapter focused on ecological composites reinforced with cement and gypsum, which incorporated materials such as wood shavings, wood fibres, hemp, reeds and wool, as well as wood shavings and hemp particles. The aim was to manufacture eco-friendly composites and test them to determine their thermal conductivity coefficient for use in the thermal insulation of buildings. Research has shown that the presence of wood, wool, and hemp fibers in composite structures has led to good thermal conductivity coefficient results. Also, the composites with reeds had lower thermal conductivity values compared to the composites that had wood shavings in their structure. In the case of composite panels with gypsum as a binder, the best results were recorded by the structure with equal amounts of shavings and hemp. Even though the thermal conductivity coefficients recorded for the composites are higher than those of expanded polystyrene, its disadvantages in terms of negative environmental impact make the use of these eco-friendly materials a solution that fits into the concept of the circular economy and involves reintroducing these materials into the life cycle of products, thus reducing the carbon footprint on the environment.

Another topic covered by the author in her habilitation thesis refers to research on the quality of wooden surfaces. Investigations into the influence of cutting tool wear (milling with sharp and wear cutting edges after 600 ml of material processed) and the cutting regime (feed speed and tool rotation speed) on the quality of beech wood surfaces obtained by profile milling were another topic addressed by the author of the habilitation thesis. The roughness parameters taken into account for the characterisation of surfaces, namely Ra (the arithmetic average of the absolute values of the roughness profile), Rz (the maximum profile height, which is the sum of the largest profile peak height and the absolute of the largest profile valley depth within a sampling length), Rv (the depth of the deepest profile valley of the roughness profile within one sampling length), Rsk (asymmetry of a profile height distribution around its mean line; a negative Rsk indicates more valleys, a positive Rsk means more peaks and a value near zero suggests a symmetrical, balanced surface - like a Gaussian distribution - with fewer extreme peaks/valley) and Wa (arithmetic mean deviation of the waviness profile) (ISO 4287:2009) and the parameters of the Abbot curve Rk (arithmetic mean deviation of the waviness profile), Rpk (reduced peak depth - the mean height of the peaks protruding from the roughness core profile), Rvk (reduced valley depth, is the mean depth of the valleys protruding from the roughness core profile), A1 (represents the upper area calculated as the area of the triangle equivalent to the peaks above the roughness core profile, measured in μm^2/mm) and A2 (valley area measured in μm^2/mm) (ISO 13565-2:1998), were measured on MarSurf XT20 equipment manufactured by MAHR Gottingen GMBH, Göttingen, Germany. The research results showed that an increase in feed rate causes increased tool vibration, which leaves deeper waves on the surface. The surface waviness, Wa, more than doubled when the feed rate increased by approximately 3.6 times, causing the wood fibres to rise and the Rpk parameter to increase by 2.4 times. With regard to the condition of the cutting tool edges, it can be stated that their influence is clearly evident in terms of surface quality.

Another study included in this chapter aimed to investigate the surface quality of ash (*Fraxinus Excelsior*) and oak (*Quercus Robur* L.) veneers obtained industrially, in order to determine the influence of the compression applied by the press bar during slicing on the roughness measured on the surface on which the bar presses, respectively on the surface cut by the knife. The results obtained showed that there are no significant differences between the roughness parameter values (Rk, Rpk and Rvk) measured on both sides of the ash and oak veneers, which confirms that the working parameters were correctly selected.

The quality of the sanded surfaces (with 50, 80, 120 and 150 grit sizes) analysed on the surfaces of decorative composite panels was another area of research addressed by the author of the thesis. This consisted of measuring the roughness of the surfaces of decorative composite panels with a cross-section made of poplar (*Populus nigra*) and spruce (*Picea abies* L.), and cherry (*Prunus avium*) and walnut (*Juglans regia* L.) lamellas with a cross-section of 20 mm x 22 mm. The roughness parameters investigated were Ra, Rz, Rk, Rpk and Rvk. The results showed that as the abrasive paper grit size increases, there is a decrease in processing roughness. The Ra and Rz roughness parameter values are lower for the cherry-walnut panel compared to the poplar-spruce panel for all four abrasive paper grit sizes. The same situation is found for the Rk, Rpk and Rvk parameters, whose values are lower for the cherry-walnut panel compared to the poplar-spruce composite panel.

2. SCIENTIFIC PAPERS ON WHICH THE HABILITATION THESIS IS FOUNDED

The habilitation thesis is founded on 8 publications, of which 5 scientific articles were published in Web of Science indexed journals and 3 articles were published in BDI indexed journals, 1 scientific research contract, 2 patents, 1 book and also 1 European Erasmus+ project (in which the results of the research presented in Chapter 1 were disseminated), as follows:

1. **Brenci, L.M.**; Gurău, L. A Stratified Characterization of Surface Quality of Beech Processed by Profile Milling. Applied Sciences, 2024. 14(1) 129. https://doi.org/10.3390/app14010129
2. Zeleniuc. O.; **Brenci. L.M.*;** Coșereanu. C.; Fotin. A. Influence of Adhesive type and Content on the Properties of Particleboard Made from Sunflower Husks. BioResources 2019a, 14(3):7316-7331. http://doi.org/10.15376/biores.14.3.7316-7331
3. **Brenci, L.M.**; Coșereanu, C.; Zeleniuc, O.; A., Georgescu, S.V.; Fotin, A. Thermal conductitity of wood with ABS waste core sandwich composites subject to various core modification. BioResoures Journal 2018, 13(1), 555-568. http://doi.org/10.15376/biores.13.1.555-568
4. **Brenci L.M.** Eco-composites designed for thermal and acoustic insulation of buildings. Bulletin of the Transilvania University of Brașov 2016, 9(58), No.2, 45-52. ISSN 2065-2135 (Print), ISSN 2065-2143. https://webbut.unitbv.ro/index.php/Series_II/article/view/815
5. Coșereanu, C.; **Brenci, L.M.;** Zeleniuc, O.; Fotin, A. Effect of particle size and geometry of single-layer and three-layer particleboard made from sunflower seed husks. BioResources Journal 2015, 10(1), 1127-1136.

http://doi.org/10.15376/biores.10.1.1127-1136

6. **Brenci, L.M.,** Cismaru, I., Fotin, A., Zeleniuc, O. The influence of ecological materials embedded into composite upon the thermal insulating capacity. PRO LIGNO Journal **2014**, 10(4), 63-68.
http://proligno.ro/ro/articles/2014/4/brenci.pdf
7. **Brenci, L.M.;** Cismaru, I.; Cosereanu, C.; Fotin, A.The experimental research upon the quality of veneer obtained by slicing methods. 18th International Conference (KBO) Jun. 14-16-Sibiu, România. The knowledge-based organization: applied technical sciences and advanced military technologies, conference proceeding 3. Book Series: Knowledge Based Organization International Conference 2012. pp: 29-33. ISSN: 1843-6722
https://drive.unitbv.ro/s/9KS4RZnHmQam9XT
8. **Brenci, L.M.**, Cismaru, I., Coşereanu, C. Experimental Research upon the Quality of the Sanded Surfaces of Some Decorative Composite Panels. PRO LIGNO **Journal, 2011.** 7(2): pp 21-29. ISSN 1841-4737 (print), 2069-7430 (online).
http://proligno.ro/en/articles/2011/2/brenci_full.pdf
9. Contract nr. 7/ 09.01.2014 privind valorificarea deșeurilor de coji de semințe de floarea soarelui în patru produse diferite, în valoare de 13105 lei, cu SC Prutul SA
10. Coșereanu, C.; Lica, D.; **Brenci L.M.;** Fotin, A.; Zeleniuc, O.; Lunguleasa, A.; Budău G.; Apostu, I. Placă ecologică din deşeuri de floarea soarelui, destinată placărilor exterioare şi procedeu de obținere. Brevet de invenție nr. 130259, 30 iulie **2019**
https://drive.unitbv.ro/s/Xfyz8azqAKMgo4b
11. Zeleniuc, O.; **Brenci, L.M.;** Coşereanu, C.; Fotin, A.; Lica, D.; Budău, G.; Lunguleasa, A.; Apostu, I. Panou tristratificat din așchi şi coji de semințe de florea-soarelui pentru utilizări în interior şi procedeu de obținere. Brevet de invenție nr. 130258, 30 septembrie 2019b
https://drive.unitbv.ro/s/rCH4Cqqgtxxj6yE
12. **Brenci, L.M.** Frezarea profilată a lemnului. Construcția și exploatarea sculelor. Editura Universității Transilvania Brașov, **2005**. 189 pag. ISBN 973-635-482-2
https://drive.unitbv.ro/s/dGyd8mLxYCQWios
13. Proiect ERASMUS+ KA202, Cooperation for Innovation and the Exchange of Good Practices, Strategic Partnerships for vocational education and training, cu titlul "TAckling Environmental sustainability through Blended Learning opportunities for ivEt in the furniture and wood sector (TABLE)" – director proiect din partea Universității Transilvania Brașov, derulat în perioada 2019-2021, în valoare de 29024 Euro (partea UNITBV).
https://drive.unitbv.ro/s/9bdDgeHf3oyfztr

In summary, the author's scientific contributions cover the areas of expertise. Thus, her editorial activity includes the following categories of publications:

- 1 book chapter as co-author published by Springer Nature Switzerland;
- 7 books published by Transilvania University Press Brașov, of which: 5 as sole author, 1 as lead author and 1 as co-author
- 7 laboratory guidelines, of which 1 as sole author and 6 as co-author;
- 17 ISI articles, of which 10 were published in ISI journals and 7 were published at international conferences with ISI proceedings;
- 26 articles published in BDI-indexed journals;
- 4 articles published in B+ journals;
- 25 articles published in the proceedings of international conferences;
- 2 international projects as director, of which 1 project of 29024 Euros for UNITBV and 1 project of 62493 Euros for UNITBV;
- 2 projects with third parties as director, 1 project worth 4166 lei and 1 project worth 8566.8 lei;
- 11 projects as a team member, of which: 3 projects won at international level and 8 won in national competitions;
- 4 patents;
- 16 international and national conferences as a member of the scientific committee and the organising team, of which 13 were international conferences and 3 were national conferences.

The results obtained in *teaching and professional activity*, in *research activity*, as well as in *recognition and impact of activity (Plant and Animal Resource Engineering*) have led to the fulfilment of the criteria corresponding to the minimum standards of CNATCDU, for the Specialised Commission for *Plant and Animal Resource Engineering*, with a total of **1501.364 points**, compared to the minimum total of 420 points. The distribution of points for each field of activity is presented in the table below.

No.	Category		
	Field of activity	**Teacher/habilitation conditions**	**Score achieved by the candidate**
1	Teaching/professional activity (A1)	Minimum 100 points	**374.63**
2	Research activity (A2)	Minimum 260 points	**687.794**
3	Recognition and impact of activity (A3)	Minimum 60 points	**438.94**
TOTAL		**Minimum 420 points**	**1501.364**

CHAPTER 1. PERFORMANCE OF INNOVATIVE SUSTAINABLE STRUCTURES

1.1 GENERAL ASPECTS REGARDING SUSTAINABLE MATERIALS

Wood, as an ecological material, is a very important resource for humanity, but under unsustainable exploitation conditions, it can become an exhaustible resource. Thus, in order to maintain a healthy ecosystem and a sustainable environment, it is important to conserve forest resources while simultaneously developing new, innovative, and sustainable products. According to the Food and Agriculture Organisation of the United Nations (FAO 2023), in 2023 global production of wood-based panels reached 381 million m^3, an increase of 1% over the previous year and 4% over 2019. The Asia-Pacific region accounted for 60% of global production in 2023, followed by Europe (86 million m^3 or 23%), North America (43 million m^3 or 11%), Latin America and the Caribbean (20 million m^3 or 5%) and Africa (4 million m^3 or 1%). The five producers of wood-based panels (China 43%, the United States, the Russian Federation, India and Turkey) accounted for 64% of global production in 2023. Turkey saw the highest growth, with production increasing by 36% in 2023 compared to 2019. Plywood, particleboard and fibreboard account for approximately 30% of global wood-based panel production, followed by OSB production. Between 2019 and 2023, plywood and fibreboard production fell from 63% to 58%. OSB and chipboard recorded the fastest growth in production, with 19% and 16% respectively between 2019 and 2023. MDF/HDF production, which accounted for 87% of total fibreboard production in 2023, declined by 9% between 2019 and 2023.

According to UNECE/FAO Forest Products (2024), at European Union level, wood-based panel production fell by a further 6% in 2023. OSB production increased by 2% in 2023 compared to 2022. Germany and Romania continue to have the largest OSB production capacities in Europe. In 2023, European plywood production fell by almost 15% compared to 2022. Particleboard production fell by 5.1% compared to 2022, with Germany remaining the largest producer with 5.05 million m^3. In the case of MDF, production in the EU, the United Kingdom, Iceland, Liechtenstein, Norway and Switzerland fell by 11% million m^3 compared to 2022.

Even though, in general, global production of wood-based panels has declined due to the continuing downturn in the construction sector combined with uncertain economic prospects, efforts to find and promote new raw materials to replace wood must continue, and an effective alternative is the use of agricultural waste.

The latest FAO Cereal Supply and Demand Brief (2025) forecasts for global cereal production in 2025 have been revised upwards by 35.6 million tonnes compared to July, which means that this year's production will reach a record high, with an anticipated 2961 million tonnes, 3.5% higher than in 2024. In 2023, 76.5% of the EU's agricultural production was generated by seven countries, including France, Germany, Italy and Spain, with Romania ranking seventh with a production value of €22.2 billion (Performance of the agricultural sector 2025). According to the National Institute of Statistics (2025), in 2023, Romania ranked third in sunflower and maize production and fourth in wheat production. Given that in Romania (PAC Strategic Plan 2024), 13.5 million hectares are destinated to agricultural crops, agricultural waste reserves such as straw, cereal stalks and cobs from corn, wheat, barley, sunflower and soybean crops are an important resource that can be used to make new ecological composites.

A study by Manickaraj *et al.* (2025) presents a series of properties of agricultural waste (Tab. 1) that can be used to create new innovative sustainable structures, which will lead to a reduction in the carbon footprint on the environment, as well as the development of the circular economy in the furniture sector. These have high potential and should be used as intensively as possible in order to reduce, as much as possible, the percentage of agricultural waste left in the fields, burned or thrown away, actions that can have a negative impact on the environment, such as air pollution, soil degradation and water contamination (Arzumanova 2021).

Tab. 1. Properties of some agricultural waste based composites (Manickaraj *et al.* 2025)

Property	Rice husks	Coconut husks	Sugarcane bagasse	Corn husks	Wheat straw
Density (g/cm³)	0.8 – 1.2	0.9 – 1.3	0.7 – 1.1	0.8 – 1.2	0.9 – 1.2
Water absorption (%)	10 - 15	8 -12	12 - 18	15 - 20	14 - 19
Porosity (%)	5 - 10	4 - 9	6 - 12	8 - 15	7 - 13
Tensile strength (MPa)	20 - 40	25 - 45	15 - 35	18 - 38	15 – 30
Bending strength (MPa)	5 - 10	6 - 12	4 - 8	5 - 10	4 – 9
Thermal conductivity (W/mK)	0.2 – 0.4	0.25 – 0.35	0.18 – 0.3	0.2 – 0.35	0.22 – 0.37
Sound absorption coefficient	0.6 – 0.8	0.5 – 0.7	0.65 – 0.85	0.6 – 0.75	0.55 – 0.8
Biodegradabilitate (%)	70	60 - 80	75 - 95	70 - 90	65 - 85

The literature presents research on the production of composite materials from agricultural waste using: rice husks, wheat and safflower (Tammali *et al.* 2024); rice husks, walnut and coconut shells, and sugar cane bagasse (Manickaraj *et al.* 2025); rice straw (Hassona *et al.* 2024); corn stalks and reeds (Nourbakhsh and Ashori 2025); orange wood, cotton stalks, casuarina wood (Australian pine) (Ghoneim *et al.* 2024); cotton stalks (Ibrahim *et al.* 2022; Gansberger *et al.* 2015; Nazerian *et al.* 2016); macadamia nut shells, rice straw, corn straw, wheat straw, barley straw, and coconut husks (Jabu *et al.* 2025); miscanthus (Velásquez *et al.* 2003); kenaf core (Okuda and Sato 2006), sunflower stalks (Bektas *et al.* 2005; Nozahic and Amziane 2012; Mati-Baouche *et al.* 2016; Güler 2017; Zeleniuc *et al.* 2019; Papadopulos *et al.* 2019; Hasanin *et al.* 2022; Bekhta *et al.* 2023; Evon *et al.* 2023). Another study conducted on three- layer and five-layer hybrid composites made of date palm fibres (*Phoenix dactylifera* L.) combined with Kevlar fibres (Zeleniuc *et al.* 2023), recorded good mechanical performance and high resistance to water immersion, which makes them suitable for outdoor use in marine environments and for the manufacture of flooring or tiles.

Research conducted on wheat straw indicates that, when combined with epoxy resin and hybrid resins, it has led to the creation of composite materials with improved mechanical properties (Bolcu *et al.* 2022). Another research presents composite materials made from agricultural waste combined with mycelium (Jones *et al.* 2018), which have resulted in lightweight and durable products. Rice husk flour combined with wood shavings for the manufacture of chipboard was the subject of another study, which revealed that these boards have weaker properties than chipboard, but when used in small quantities of 5% to 10% of their weight, they will not have a negative impact on them (Lee *et al.* 2003).

Sunflower (*Helianthus annuus* L.), another agricultural resource, has a relatively short growth cycle and adapts easily to different soil conditions, making its stems one of the most common resources of residual lignocellulosic biomass, and their use as raw material in the wood industry can bring sustainable, ecological and economic benefits (Klimek *et al.* 2016). Given the pressure on forest resources and the intensification of tree harvesting to meet production demand, sunflower seed husks may be a new potential resource for the manufacture of particleboard. The main components of the husks are cellulose (27.43%), lignin (24.23%), hemicellulose (29.04%) and extractives (9%) (Popescu *et al.* 2013), similar to those of hardwood species. The percentage of husks in sunflower seeds varies between 10% and 30%, depending on the shelling process used (Wan *et al.* 1979; Isobe *et al.* 1992; Kumar 2018). The density of the husks is very low (212 kg/m^3 at a moisture content of 10%) (Gamea 2013). Based on the proportion of husks in seeds, it can be estimated that approximately 3.42 million tonnes of husks become available annually from the shelling process in the EU. As a result, oil producers need a large storage area, so sunflower husk waste could degrade over time and pollute the environment. In general, these husks are used for fuel pellets, briquettes, xylose extraction, fertilisers and animal feed. The husks have a high fibre content and low protein content, thus having a very low commercial value as feed (Le Clef and Kemper 2015).

A review of the literature indicates that research has been conducted to produce composites from sunflower residues (*e.g.*, stalks, husks, and by-products obtained after oil extraction from seeds). These residues have been combined with poplar wood shavings (Gertjejansen *et al.* 1972; Bektas *et al.* 2005), cement (Sisman and Gezer 2013), cotton waste (Binici and Aksogan 2014), Calabrian pine (Bektas *et al.* 2005; Güler *et al.* 2006), polypropylene (Kaymakci *et al.* 2013), pure and recycled polyethylene (Hasanin *et al.* 2022), and chitosan (Mati-Baouche *et al.* 2014) to form composites. Most of the composite boards developed using sunflower waste are combined with a variety of other raw materials, such as agricultural waste (corn, rice, wheat), wood shavings (poplar, pine, aspen), and inorganic materials (plaster and concrete). The use of these raw material mixtures in the manufacture of composite boards involves time and costs for collection, storage, grinding, defibration, sorting, heat treatment and pressing operations.

According to research, the adhesives used in Europe for the production of particleboard are urea-formaldehyde (UF) (90-92%), melamine-urea-formaldehyde (6-7%) and polymeric diphenylmethane diisocyanate (pMDI) (1-2%) (Kutnar and Burnard 2013). Phenolic resin (PF) is the second most important adhesive after UF used in the manufacture of wood-based panels (Athanassiadou *et al.* 2015; Sandberg 2016). The amount required for this technology is between 9 and 12% (Ayrilmis and Nemli 2017; Laskowska and Mamiński 2018). The physical and mechanical properties of sunflower-based particle boards are inferior to those of wood-based particle boards when UF and PF adhesives are used (Bektas *et al.* 2005; Kwon *et al.* 2014; Güler 2017). Water-emulsified polymeric diphenylmethane diisocyanate (pMDI) adhesives (EMDI) have proven to be good substitutes for formaldehyde-based adhesives, leading to improved mechanical properties of the formed panels (Franke *et al.* 1994; Tongboon *et al.* 2002; Papadopoulos *et al.* 2002; Preechatiwong *et al.* 2007; Garay *et al.* 2009; Dukarska *et al.* 2017). Another study by Bekhta *et al.* (2023) used sunflower stalks in different proportions which, combined with wood shavings and urea-formaldehyde (UF) resin as an adhesive, resulted in the production of agglomerated boards with densities of 350, 450 and 550 kg/m^3. These stems were used as core material, and the results showed that the physical and mechanical properties were improved. Papadopoulos *et al.* (2019) conducted a series of studies using acetylated sunflower stalks and polymeric diphenylmethane diisocyanate (pMDI) adhesive in the manufacture of boards as an alternative to particleboard. The results showed that this agricultural resource can be used to manufacture P1 general-purpose boards for use in dry conditions and P2 boards for interior applications.

1.2 RESEARCH ON THE EFFECT OF PARTICLE SIZE AND GEOMETRY ON THE PERFORMANCE OF SINGLE-LAYER AND THREE-LAYER PARTICLEBOARDS MADE FROM SUNFLOWER SEED HUSKS

This research was conducted under contract no. 7/9.01.2014 between the Pro Ligno Foundation of Transilvania University of Brașov and Prutul S.A. company, in which the author was a member of the project team. The research outcomes were materialised in two invention patents Zeleniuc *et al.* (2019b) and Coșereanu *et al.* (2019) to which the author contributed, as well as in the development of the course module 'Waste Management in the Furniture and Wood Sector'. This module was created within the framework of the European ERASMUS+ KA202 project *Cooperation for Innovation and the Exchange of Good Practices', Strategic Partnerships for Vocational Education and Training, entitled 'Tackling Environmental Sustainability through Blended Learning Opportunities for IVET in the Furniture and Wood Sector (TABLE)*. The author coordinated this project as Manager on behalf of Transilvania University of Brașov, a partner institution in the consortium."

The main objective of this research (Coșereanu *et al.* 2015), in which the author was a co-author, was to produce chipboard made entirely from sunflower husks. Their performance was investigated by testing their density, water absorption (WA), thickness swelling (TS) after 24 hours of immersion in water, thermal properties, bending strength (BS), modulus of elasticity (MOE), internal bond strength (IB) and screw holding strength (SH). These properties were influenced by the structure of the respective particleboards and the dimensions and geometry of the sunflower husks.

The experiments were conducted under laboratory conditions, with the structures being built in the laboratories of the Faculty of Furniture Design and Wood Engineering, and the tests being carried out at the Research and Development Institute of Transilvania University of Brașov.

1.2.1 Research methodology

Raw materials and materials

Two categories of sunflower seed husks were used to manufacture the boards. The first category included whole sunflower seed husks as coarse particles, and the second consisted of ground husks as fine particles. The fine particles were obtained by grinding the coarse particles in the hammer mill provided by the faculty's composites laboratory. The measured moisture content was approximately 8.6% for coarse particles and 7.6% for fine particles. Both coarse and fine particles were sieved separately using a sieve system with mesh sizes of 4 x 4 mm^2, 3 x 3 mm^2, 2 x 2 mm^2, 1 x 1 $mm^2$and 0.5 x 0.5 mm^2. The sieving was performed on a device (Fig. 1) on which five sieves were mounted, the process being carried out at the highest amplitude. The process began with the 4 x 4 mm^2 sieves, the operation being continued with sieves of decreasing mesh size. Three samples of 25 g each were weighed and sieved. The percentages of seed husks particles in the analysed samples are presented in Fig. 2.

The thickness of the husks was measured with a caliper and fell within the range mentioned in the literature (Wan *et al.* 1979). In the case of coarse particles obtained from 4 x 4 mm^2 and 3 x 3 mm^2 and 2 x 2 mm^2 sieves, the ratio between length and width was between 1.07 and 4.9. After sieving, the coarse particles were scanned and the file was imported into AutoCAD to measure the dimensions at a scale of 1:1 (Fig. 3a).

Fig. 1. Equipment for sieving sunflower seed husks

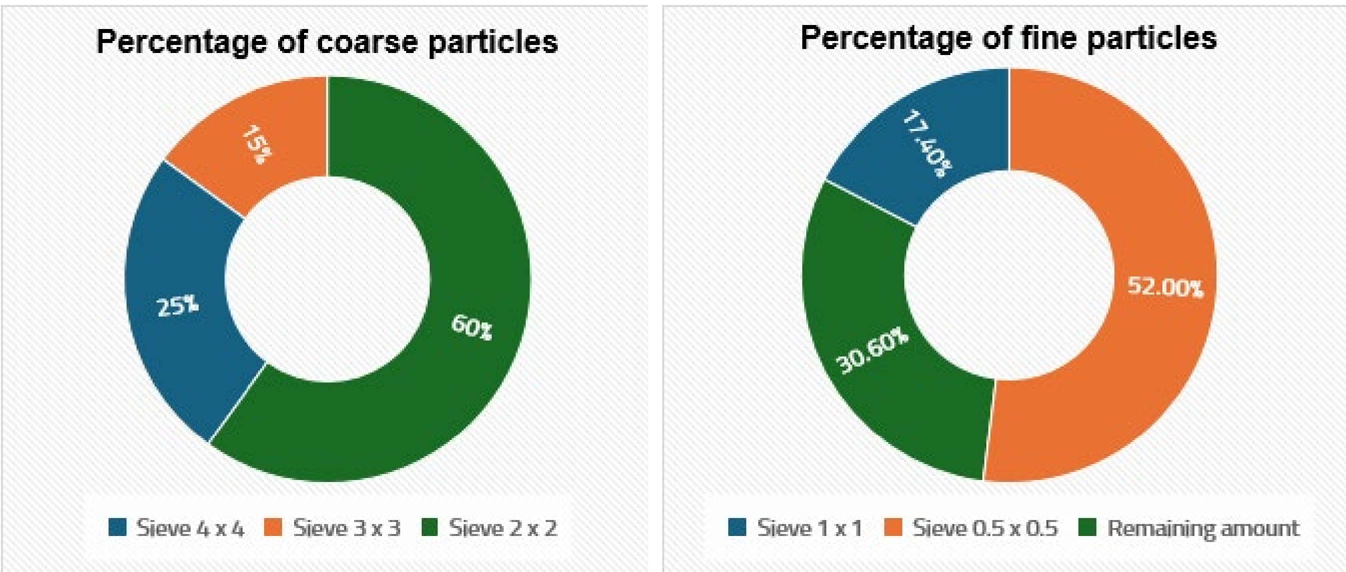
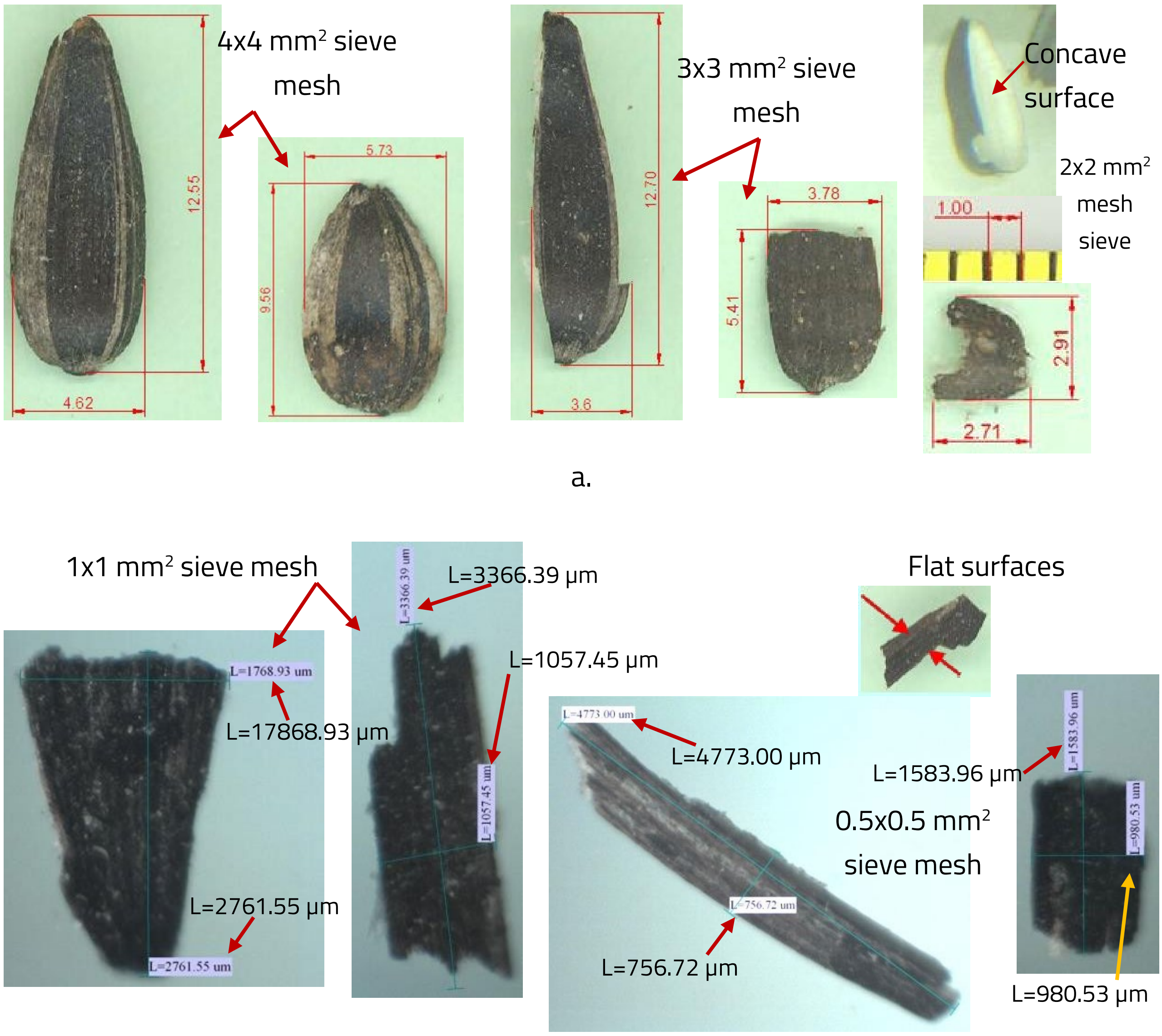


Fig. 2. Percentage of coarse and fine husks obtained after sieving
(according to Coșereanu *et al.* 2015)

The fine particles collected from the 1 x 1 mm² and 0.5 x 0.5 mm² sieves were measured using an Optika microscope (SMZ-2, Italy), equipped with a high-resolution Optika PRO 3 digital camera. Its software (Optika Vision) allowed the measurement of particle geometry, with dimensions ranging from 0.98 mm to 4.77 mm in length, 0.7 mm to 1.7 mm in width, and 0.2 mm to 0.5 mm in thickness (Fig. 3b). The length/width ratio of these particles was between 1.03 and 6.3. The fine particles obtained were used as faces for three-layer particleboards and as raw material for single-layer particleboards.



b.

Fig. 3. Geometry and dimensions of sunflower seed husks
(a) coarse particles; (b) fine particles (according to Coșereanu *et al.* 2015)

The boards manufacturing

During the research, seven types of single layer and three-layer boards were manufactured (Tab. 2). Sixteen percent of urea-formaldehyde resin with a solid content of 66±1% was added to the single-layer boards, the percentage being determined based on particle weight. For the three-layer structure, the ratios of the amount of adhesive added were 14% for the core and 16% for the faces. The 16% adhesive percentage was determined based on previous research, which showed that this percentage is an optimum one. Ammonium chloride was used as an additive, with a participation of 1% of the dry resin quantity. No wax or other hydrophobic substances were used. The boards were made under laboratory conditions, and after a homogeneous mixture was obtained, it was placed into a frame. The dimensions of the panels obtained were 620 mm x 620 mm with a thickness ranging from 50 mm to 60 mm. The particleboards were placed in a press with hot plates heated to a temperature of 180°C. After pressing at 30 bar and holding in the press for 6 minutes, the particleboards were removed and conditioned for two weeks at a temperature of 20°C and a relative humidity of 65%, after which they were cut to their final dimensions of 600 mm x 600 mm x 16 mm. Five of each of the seven types of particleboards were produced (35 boards in total), of which two were used for thermal conductivity tests and three for physical and mechanical tests.

Tab. 2. Characteristics of the manufactured boards (Coșereanu *et al*. 2015)

Particleboard type	Particleboard configuration	Amount of urea-formaldehyde (UF) resin	Final dimensions of the particleboards
SLFP – 100% fine particles	1 layer	16%	600 x 600 x 16
SLCP – 100% coarse particles	1 layer	16%	600 x 600 x 16
TPL – 30% fine particles (faces) and 70% coarse particles (core)	3 layers	16% for faces and 14% for core	600 x 600 x 16
½ SLC-FP - 50% fine particles and 50% coarse particles	1 layer	16%	600 x 600 x 16
½ SLF-WP - 50% fine particles and 50% wood particles	1 layer	16%	600 x 600 x 16
½ SLC-WP - 50% coarse particles and 50% wood particles	1 layer	16%	600 x 600 x 16
WP – 100% wood particles	1 layer	16%	600 x 600 x 16

Testing of physical and mechanical properties

The physical properties investigated were, as follows:

- Density was calculated according to SR EN 323 (1996). The test was performed on specimens measuring 20 mm x 20 mm;
- Water absorption (WA) and thickness swelling (TS) after 24 hours of immersion in water were tested on five test specimens, with the tests being performed according to SR EN 317 (1996);
- The thermal conductivity coefficient (λ) was measured according to DIN EN 12667

(2001) and ISO 8301 (1991).

The mechanical properties were determined on six test specimens from each board and investigated on the Zwick/Roell Z010 universal testing machine (Germany) (Fig. 4). These tests were, as follows:

- Bending strength (BS) and modulus of elasticity (MOE) - determined according to SR EN 310 (1996) (Fig. 5);
- Internal bond strength (IB) perpendicular to the plane of the board was determined according to SR EN 319 (1997) (Fig. 6);
- The screw holding strength (SH) was determined according to SR EN 320 (2011) (Fig. 7).

Fig. 4. Zwick/Roell Z010 universal testing machine for mechanical testing

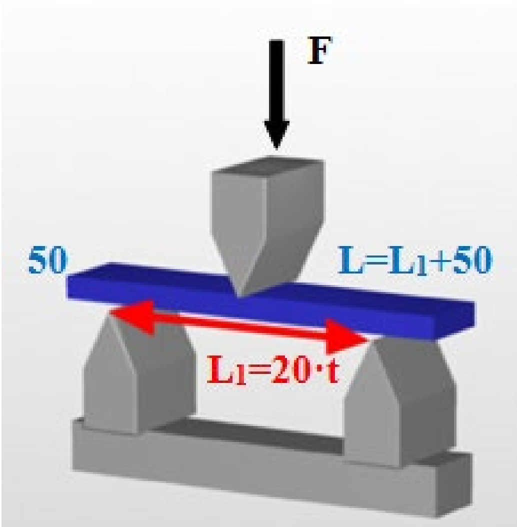


Fig. 5. Test setup for bending

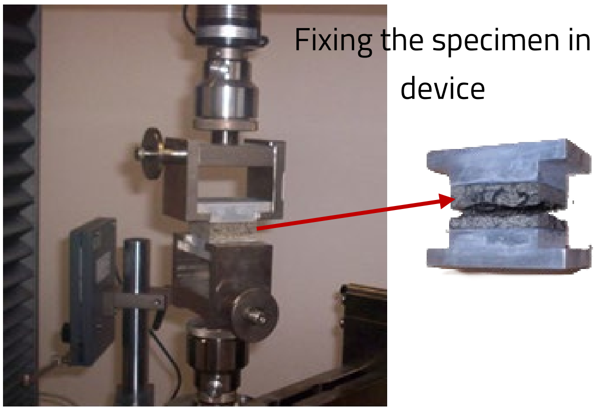


Fig. 6. Internal bond test

Fig. 7. Mechanical test for testing the screw holding strength

Water absorption and thickness swelling tests were performed by immersion of 50 mm x 50 mm specimens in water at ambient temperature (20°C) for 2 hours and 24 hours, and the results were derived from measurements of the mass and thickness of the specimens before and after immersion. The test specimens were immersed to a depth of 20÷25 mm below the water level. All reported results were identified by the average of the tested samples, both for mechanical and physical properties.

To investigate the thermal conductivity coefficient, two particleboards of each type were analyzed. These had dimensions of 600 mm x 600 mm x 16 mm and were tested on HFM 436/6/1 Lambda equipment (Germany) (Fig. 8). Each particleboard was tested at eight points for a temperature difference between the upper and lower plates ΔT= 30°C.

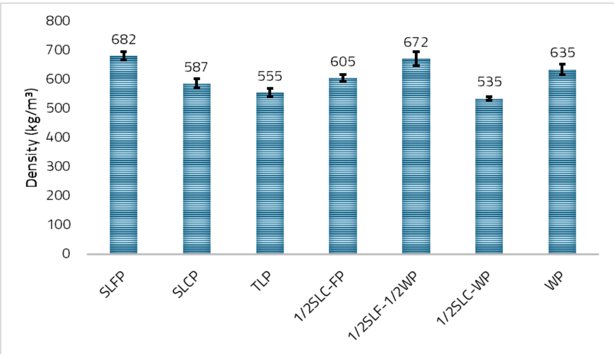
Fig. 8. HFM 436/6/1 Lambda equipment

For mechanical tests, the equipment software automatically determined the bending strength (BS) and modulus of elasticity (MOE) values for specimens with widths of 50 mm and lengths calculated according to the thickness of the particleboards (Fig. 5). In the case of the test to determine the screw holding strength (SH), the specimens had dimensions of 50 mm x 50 mm

(Fig. 7). The size of the screws used was according to the requirements of SR EN 320 (2011), with the axial force applied at a speed of 10 mm/min.

1.2.2 Results and discussions

The results of the physical and mechanical tests are presented in Fig. 9. The density analysis of the density of the particleboard (Fig. 9a) shows that the highest values were obtained for the fine particleboard (SLFP and 1/2SLF-WP) respectively for the wood particleboard (WP). In the case of coarse particle boards, the density was lower due to the reduced degree of compaction in comparison with to fine particleboards, which are easier to be compacted, a phenomenon that led to an increase of the density of the boards. (Cai *et al.* 2004).



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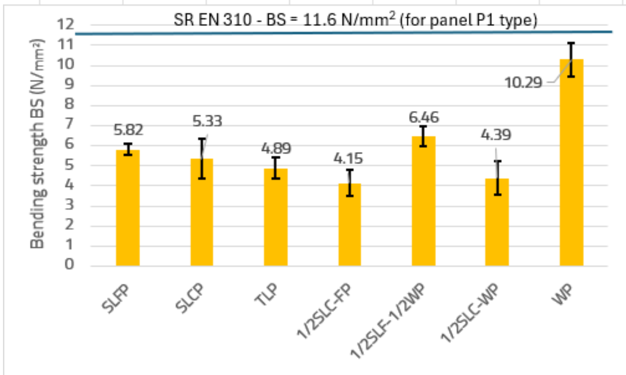

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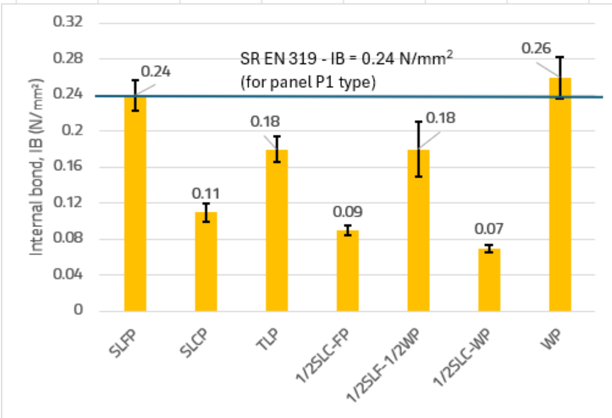

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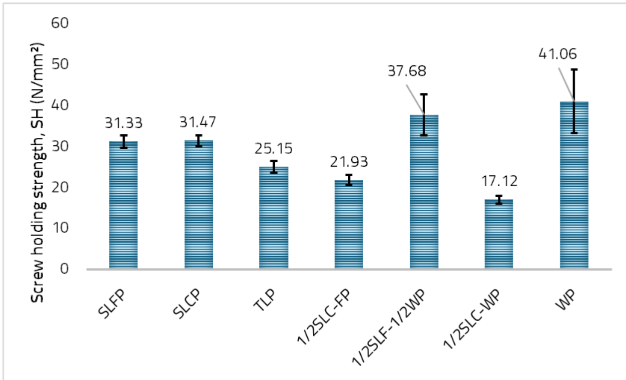

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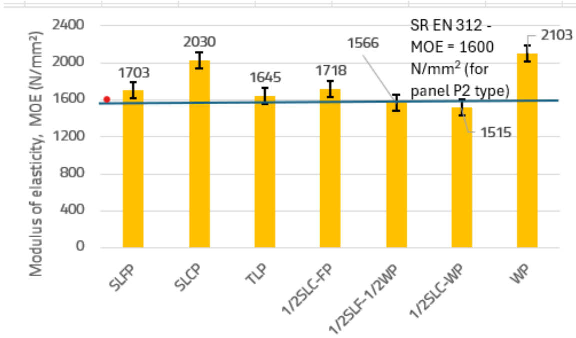

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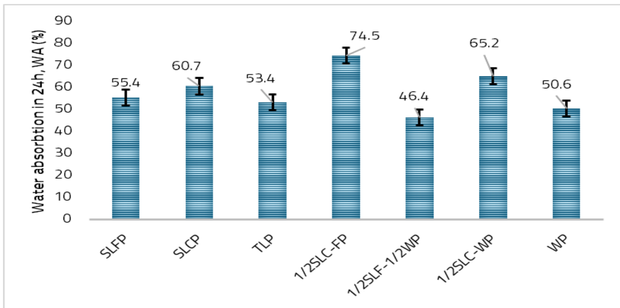

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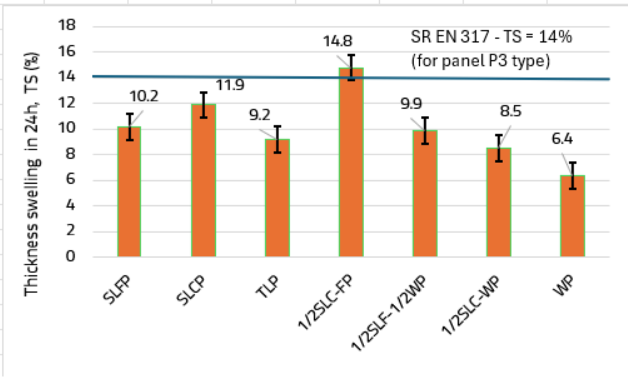

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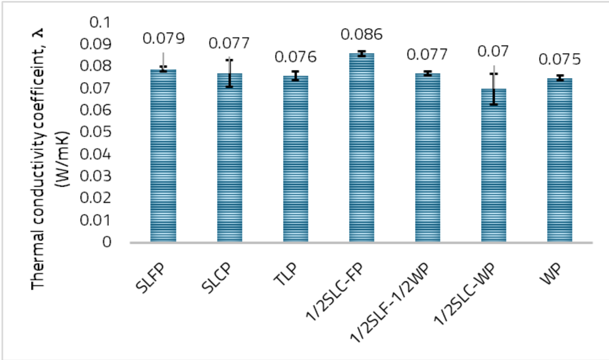


h.

Fig. 9. Physical and mechanical properties of the manufactured particleboards (according to Coșereanu *et al.* 2015)

The bending strength values (BS - Fig. 9b) were lower than the requirements of standard SR EN 312 (2011). The internal bond strength values (IB - Fig. 9c) were highest for the particleboards made of fine sunflower husks. The particleboard with 100% fine sunflower husks (SLFP), meets the requirements of the SR EN 312 standard for general-purpose boards used in dry environments of type P1 (IB = 0.24 N/mm^2). Higher screw holding strength (SH) (Fig. 9d), was achieved for SLCP, SLFP and 1/2 SLF-WP. It seems that particle size and geometry had a significant influence on both internal bond strength (IB) and screw holding strength (SH). Fine particles with flat surfaces and a fusiform shape allowed better adhesion between them, resulting in a more compact and homogeneous structure. In the case of coarse particles, they had concave geometries, which led to local agglomerations of adhesive and reduced compactness, resulting in low internal adhesion strength. In the case of the modulus of elasticity (MOE - Fig. 9e), the highest value was obtained for the coarse particleboard (SLCP), which led to an increase in the rigidity of the panels. Comparing the results obtained by the particleboards in a combination of 50% fine particles and 50% wood shavings (1/2SLF-WP) and 50% coarse particles and 50% wood shavings (1/2SLC-WP), with the corresponding values for P2 type panels (MOE = 1600 N/mm^2 according to SR EN 312 (2011), it can be seen that only these do not meet the limits set by the standard.

Structures with coarse particles had the highest values for water absorption (WA) (Fig. 9f), due to the porosity caused by the concavity and variation in the shapes of the husks. All boards with fine particles in the outer layers (TLP, SLFP) had low values for water absorption (WA) and thickness swelling (TS) (Fig. 9g), due to their higher compactness and low wettability. Similar results were obtained for particleboards made from peanut shells and pine shavings (Güler *et al.* 2008; Güler and Büyüksari 2011) and almond shells mixed with wood (Pirayesh *et al.* 2013). Three-layer particleboards (TLP) have similar performance to ½ SLC-WP particleboards, except for IB. Based on the SR EN 312 (2011) standard, the SLFP particleboards met almost all minimum requirements for modulus of elasticity (MOE), thickness swelling (TS) and internal bond (IB), but not for modulus of rupture modulus of rupture (MOR). The mechanical properties of the tested particleboards can be compared to those made from grass mixed with wood (Nemli *et al.* 2009). The thermal conductivity coefficients (with values ranging from 0.075 W/mK to 0.079 W/mK) (Fig. 9h), indicated good thermal insulation properties for all particleboards, compared to the normal range for insulation materials, which, according to bibliographic references, is between 0.035 W/mK and 0.160 W/mK (Panyakaew and Fotios 2008). According to the literature, particleboards made from agricultural waste generally have low thermal conductivity coefficients: 0.046 W/mK for coconut shells, 0.096 W/mK for bagasse (Panyakaew and Fotios 2008); 0.0764-0.1254 W/mK for durian shells and coconut fibre (Madurwar *et al.* 2013; Khedari *et al.* 2004); 0.051 W/mK for rice straw (Wei *et al.* 2015); 0.051-0.059 W/mK for kenaf (Xu *et al.* 2004); 0.06-0.542 W/mK for hemp (Benfratello *et al.* 2014).

1.2.4 Conclusions

The following conclusions were drawn from the research:

- The size and shape of the particles obtained from sunflower seed husks influenced the performance of the studied particleboards. Thus, the particleboards obtained from fine particles made in a single layer and in three layers showed improved performance.
- In the case of boards made from coarse particles, due to their concave geometry, the structure obtained was much more porous, which affected water absorption at 24 hours (WA), as well as internal bond strength (IB).
- The best performance was achieved for panels made from 100% fine particles (SLFP). These have a density approximately equal to that of panels made entirely from wood particles, 682 kg/m^3.
- Due to the low density of the three-layer panels (TLP), the bending strength (BS) was negatively affected.
- The particleboards manufactured in this research can be used for paneling structures and furniture components that are not subjected to bending stresses.

1.3 RESEARCH ON THE INFLUENCE OF ADHESIVE TYPE AND CONTENT ON THE PROPERTIES OF PARTICLEBOARDS MADE FROM SUNFLOWER HUSKS

The objective of this research, in which the author is corresponding author (Zeleniuc *et al.* 2019a), was to manufacture innovative sustainable particleboards made from 100% sunflower husks, with physical and mechanical properties similar to those of particleboards (PAL). The investigation also assessed how the use of different shares of adhesives affects the physical and mechanical properties of the resulting panels. The experiments were conducted under laboratory conditions, with the structures being manufactured in the laboratories of the Faculty of Furniture Design and Wood Engineering, and the tests being carried out at the

Research and Development Institute of Transilvania University of Brașov.

1.3.1 Research methodology

1.3.1.1 Materials

In this research, sunflower husks (*Helianthus annuus* L.) were used as lignocellulosic raw material for the manufacture of particleboards. These were obtained from the seed dehulling process carried out by a Romanian sunflower oil producer, Prutul S.A.. After grinding, the husks were sieved through sieves with mesh sizes ranging from 4 mm to 0.5 mm, in order to remove oversized and undersized particles. The accepted fraction of particles was 2.55 mm to 4.76 mm in length, 1.05 mm to 2.3 mm in width and 0.2 mm in thickness. The sieved husks were dried to a moisture content of 4%.

The following adhesives were used to manufacture the sunflower husk particleboards: urea-formaldehyde (UF), phenol-formaldehyde (PF), modified melamine-formaldehyde (VM) and polymeric diphenylmethane diisocyanate (pMDI). Three commercial variants of urea-formaldehyde adhesives (UCL, U96 and AG) were tested, the difference between them being the synthesis method and the formaldehyde/urea molar ratio (F/U) (1.15, 0.96 and 1.09, respectively). Mixtures of VM/AG (20:80 by weight) and PF/pMDI (70:30 by weight) were also used. PMDI is currently used in the European OSB board industry (Grunwald and Stroobants 2014). A higher temperature was used for pMDI boards to allow the resin to cure. PMDI offers high bond strength, faster reaction time and superior water resistance (Dunky 2003), so it was used alongside UF adhesives. The choice of adhesives for the experimental tests was based on data provided in the literature (Papadopoulos *et al.* 2002; Ressel 2008; Mendes *et al.* 2009; Korai and Ling 2011; Ayrilmis and Nemli 2017; Dukarska *et al.* 2017; Laskowska and Mamiński 2018; Solt *et al.* 2019). The types of adhesives and the pressing time and temperature are presented inTab. 3.

Tab. 3. Adhesives used in research (Zeleniuc *et al.* 2019a)

Board code	Adhesive content level (%)		Pressing parameters	
			Temperature (°C)	Pressing time (min)
UCL	9	12	150	7
U96	9	12	150	7
VM/AG	9	12	150	7
PF	9	12	160	7
pMDI	3	6	180	4
PF/pMDI	9	-	180	7

The solid resin content was based on the oven-dry weight of husk particles. Ammonium chloride (NH_4Cl) was used as hardener for urea-formaldehyde resins and was added at 1.5%

(based on the weight of the dry resin). All adhesives were obtained from Viromet SA (Victoria, Romania).

1.2.1.3 Manufacturing the innovative panels

The milled husk particles were weighed and mixed with the selected adhesive in a blender. Panels measuring 420 mm x 420 mm were formed manually with a homogeneous single-layer structure. Panels were hot pressed at 2.5 N/mm² to achieve a target density of 600 kg/m³. The pressing conditions are shown in Tab. 3. Two replicates were made for each panel type. After pressing, the panels were conditioned at a temperature of 20°C and 65% relative humidity until they reached equilibrium moisture content. After conditioning, the panels were cut to their final dimensions of 400 mm x 400 mm, with a thickness of 16 mm.

1.2.1.4 Panels testing

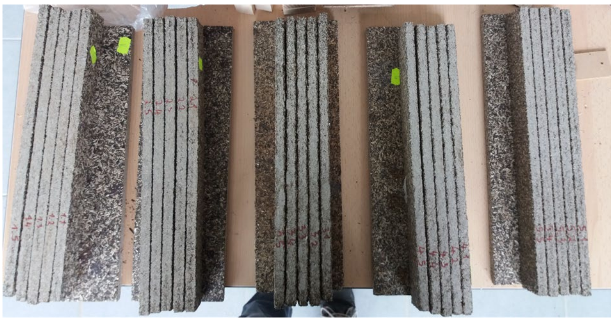
In order to determine their performance, the obtained panels were subjected to physical and mechanical tests. The following physical tests were used in the research:

- Determination of water absorption (WA) and thickness swelling (TS) according to standard SR EN 317 (1996);
- Determination of density according to standard SR EN 323 (1996);
- Determination of the vertical density profile (VDP) measured on the DPX300 X-ray equipment (Imal S.R. Modena, Italy) (Fig. 10).

Fig. 10. DPX300 equipment for measuring the vertical density profile

In order to determine water absorption, the 50 mm x 50 mm test specimens were weighed before immersion in water, and after 24 hours, they were removed from the water and weighed again. To determine the thickness swelling of the specimens, the thickness was measured before immersion, and after 24 hours the thickness was measured again.

Mechanical tests for bending (Fig. 5) and internal bond test (Fig. 6) were performed using the Zwick/Roell Z010 universal testing machine (Zwick/Roell; Kennesaw, GA, Fig. 4) equipped with a ±10 kN load cell. The modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond strength (IB) were evaluated in accordance with standards SR EN 310 (1993) and SR EN 319 (1997). Ten measurements were performed for each test (the reported values being the average of the measurements). The test specimens were numbered and cut in accordance with the requirements of standards SR EN 310 (1993) and SR EN 319 (1997) (Fig. 11).




Specimens for bending tests


Specimens for internal bond strength

Fig. 11. Specimens for mechanical bending and tensile tests

For the statistical analysis of the experimental data, the ANOVA test (one-way analysis of variance - EXCEL) was used to evaluate the effects of the type of adhesive and its content on the properties of the panels, with a significance level of $p \leq 0.05$.

1.2.2 Results and discussions

At first assessment, the panels made from sunflower husks had the following morphological characteristics (Fig. 12):

- the panels made from sunflower husk particles appeared rigid and strong. The particles showed good cohesion and were not easily detached.

- for panels made with 6% pMDI, 12% PF and 12% VM/AG, more compact structures and uniform particles distribution were observed.

Fig. 12. Outside appearance of the manufactured panels (Zeleniuc *et al.* 2019)

The adhesives were evenly distributed over the surface of the particles and filled the gaps between them, thus ensuring adequate adhesion among the particles. Furthermore, pMDI penetrated the amorphous components of the cell wall of the sunflower seed husk at the molecular level, which led to plasticisation, thus improving the swelling resistance of the panels (Frazier 2003). The internal morphologies of the different panels investigated at a resolution of 4800 dpi are shown in Fig. 13.

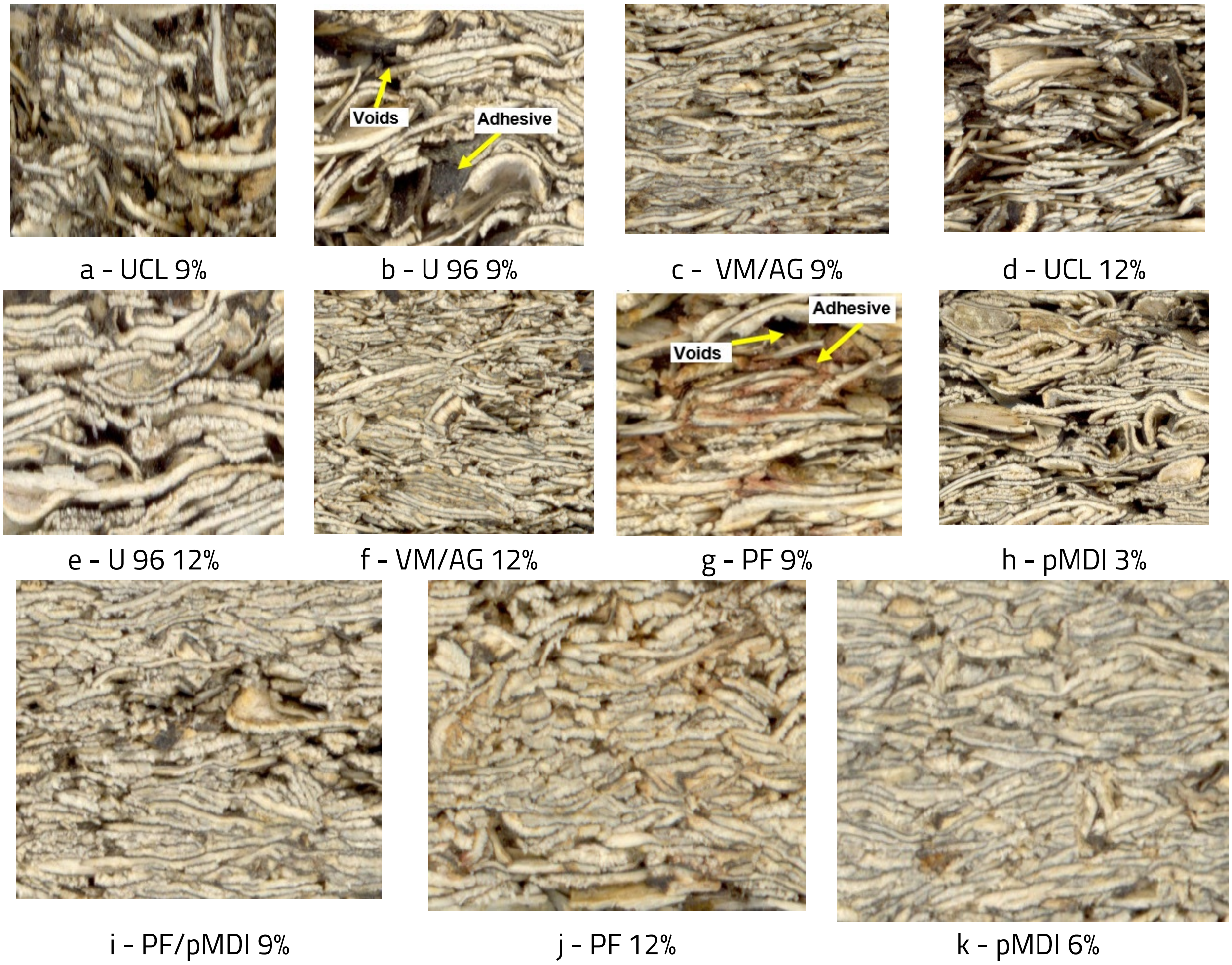


Fig. 13. Morphological details of the experimental panels (Zeleniuc *et al.* 2019a)

For panels with 3% pMDI, the structure was less compact. The adhesive partially adhered to some particles, which led to the formation of agglomerations and more voids in the structure in some places when urea-formaldehyde adhesives were used.

Physical and mechanical properties of the manufactured panels

The structures density

Following the analysis of the density profile across the thickness of the panels produced (Fig. 14), it was observed that for those with urea-formaldehyde (UF) and phenol-formaldehyde/polymeric diphenylmethane diisocyanate PF/pMDI (UCL 9%, U96 9%, VM/AG 9%, UCL 12%, U96 12%, VM/AD 12%) a maximum material density was recorded at 1 mm from the surface for UF panels (Fig. 14a to Fig. 14f – circled in red), and at 3-4 mm from the surface for PF/pMDI panels (Fig. 14g to Fig. 14k – circled in blue).

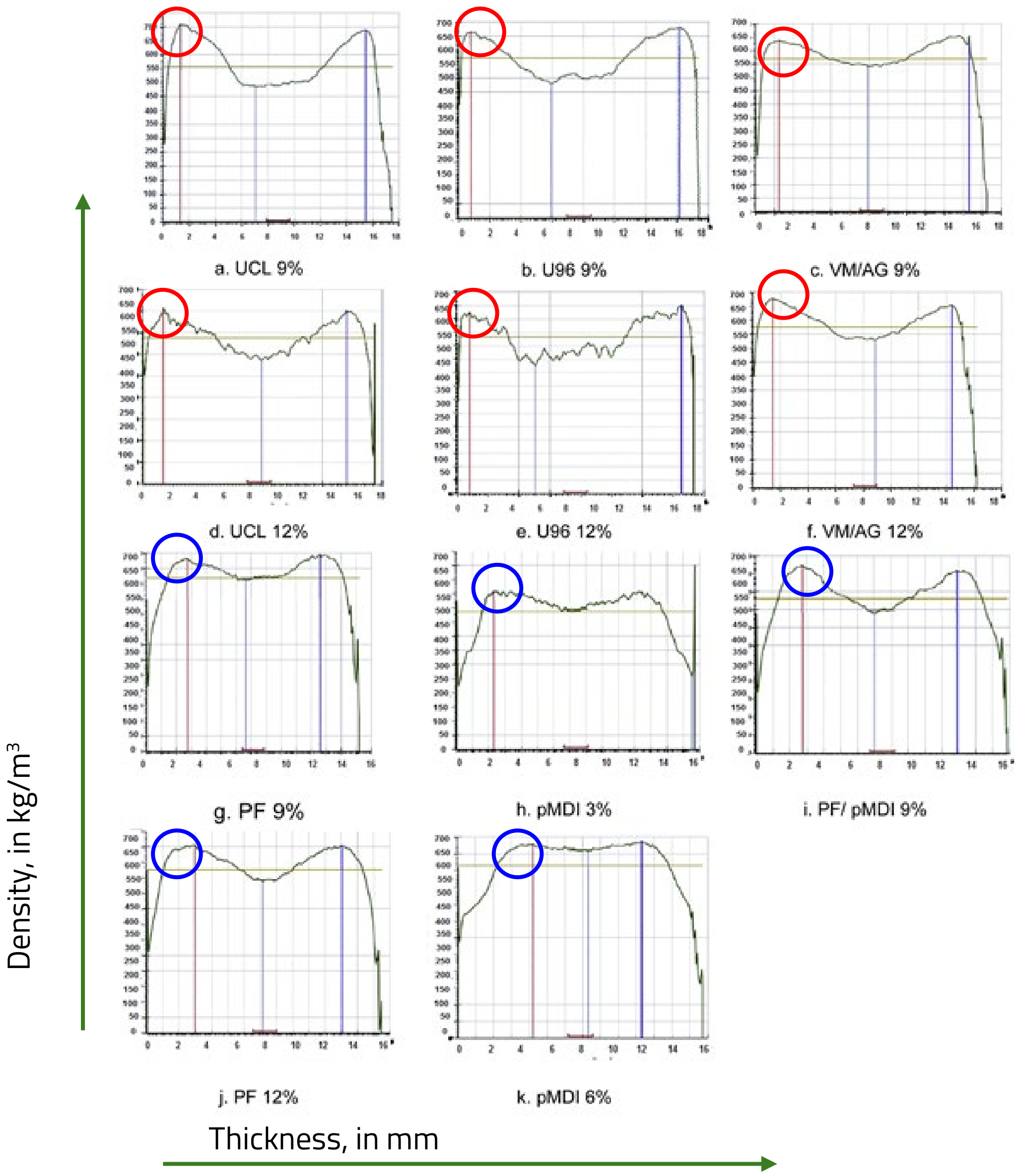


Fig. 14. Vertical density profile of the manufactured panels (Zeleniuc *et al.* 2019)

The density of the panels was approximately 550 kg/m^3, and those with pMDI had an average density of 490kg/m^3, due to the low specific gravity of the adhesive (Rachtanapun *et al.* 2012). The average values of the physical properties determined for the studied panels are presented in Tab. 4. The moisture content of all panels was approximately 6.3%. The highest values of thickness swelling (TS) and water absorption (WA) after 24 hours of immersion were observed for panels made with UF adhesives, due to their low water resistance. Similar results in terms of thickness swelling after 24 hours of immersion in water were observed in the research performed by Melo *et al.* (2014) (49% ÷ 44%), who observed highest instability of particleboards made only from rice husks with urea-formaldehyde adhesive.

Tab. 4. Physical properties of experimental structures (Zeleniuc *et al.* 2019a)

Type of used adhesive	Adhesive content (%)	Density (kg/m^3)	Thickness swelling (TS) at 24h (%)	Water absorption (WA) at 24h (%)
UCL	9	556 (27.8)	41.2 (6.1)	125.3 (11.6)
	12	573 (21.6)	38.4 (5.6)	110.5 (13.3)
U96	9	577 (39.0)	44.5 (1.5)	140.2 (3.1)
	12	580 (21.0)	41.2 (6.1)	126.4 (10.1)
VM/AG	9	570 (40.0)	40.3 (0.6)	124.9 (3.4)
	12	574 (23.8)	32.2 (1.2)	106.9 (15.4)
PF	9	570 (16.7)	19.9 (3.3)	69.5 (6.2)
	12	524 (29.3)	20.8 (3.7)	68.7 (6.0)
pMDI	3	495 (20.9)	56.0 (3.6)	131.7 (6.4)
	6	535 (19.3)	29.7 (1.6)	76.0 (14.4)
PF/pMDI	9	520 (16.5)	31.4 (0.6)	81.3 (4.9)

The values in parentheses represent standard deviations

The panels manufactured with PF had the lowest values for thickness swelling and water absorption (19.9% for Thickness swelling (TS) Fig. 15, and 69.5% for water absorption (WA) Fig. 16, almost half of the values observed for UF panels).

This behaviour is attributed to the high water resistance of the methylene carbon-carbon bonds that link the aromatic nuclei of PF (Dunky 2003). As the adhesive content increased for all panels except PF panels, a decrease in water absorption and thickness swelling values was observed. The lower density of PF boards manufactured with 12% adhesive may have induced greater water penetration into the board structure compared to the board with 9% adhesive.

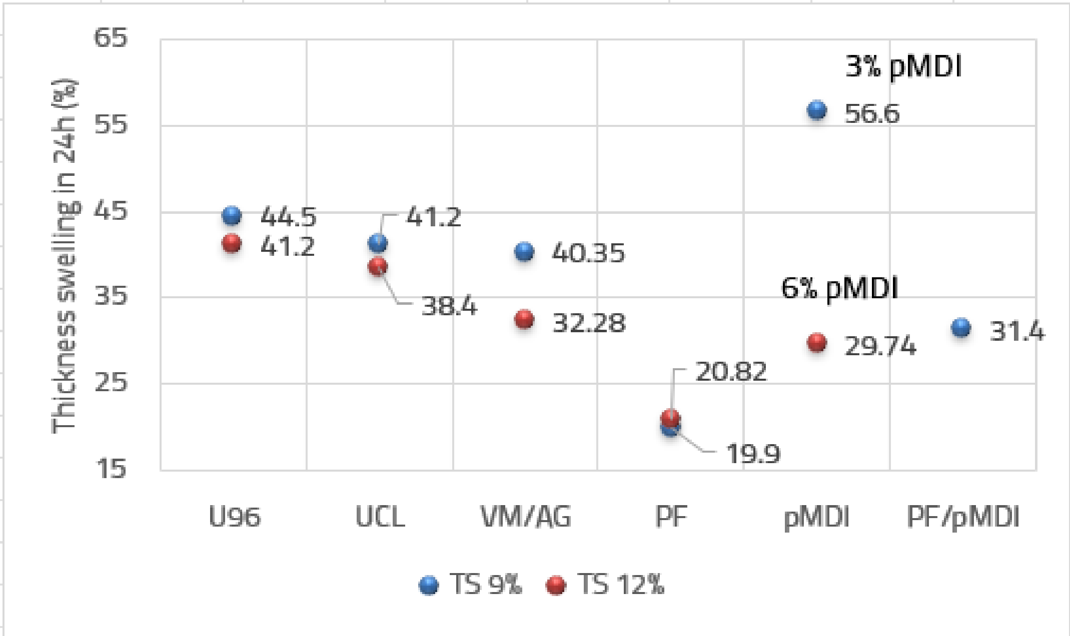


Fig. 15. Thickness swelling (TS) of the specimens measured after 24 h of immersion in water (according to Zeleniuc *et al.* 2019a)

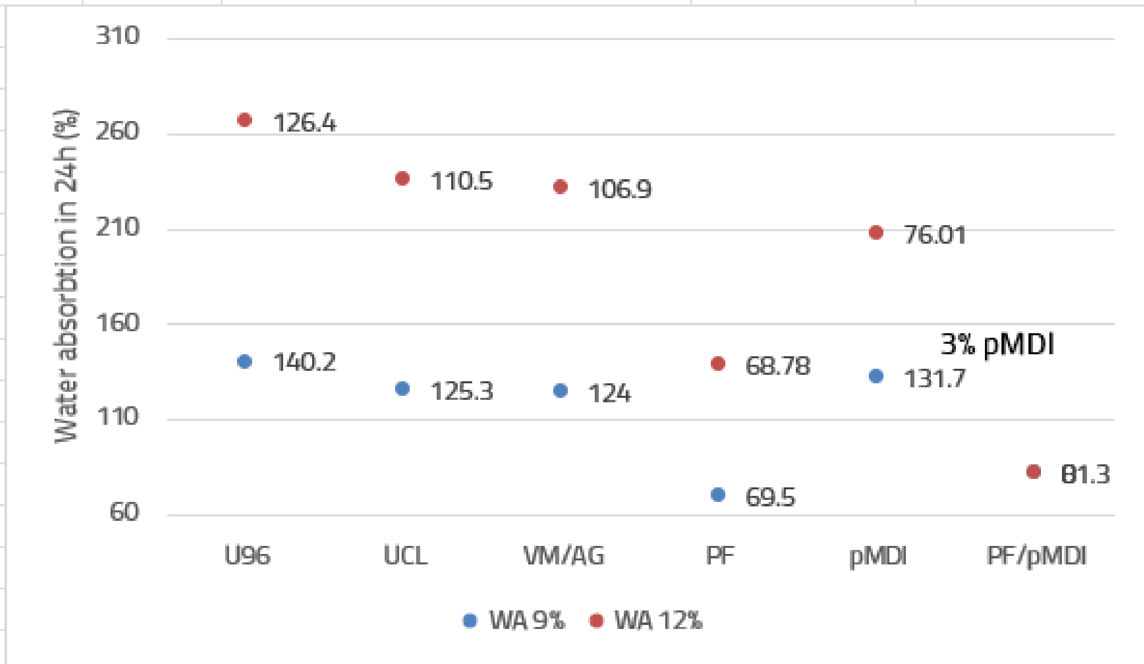


Fig. 16. Water absorption (WA) of the specimens after 24 h of immersion in water (according to Zeleniuc *et al.* 2019a)

In the case of panels with 12% UF adhesive (UCL and U96), a 7% and 10% decrease in water absorption and thickness swelling, respectively, was observed compared to panels with 9% UF adhesive. Klimek *et al.* (2016) observed that the thickness swelling at 24 hours of agglomerated boards made from sunflower stems did not show significant differences when the UF content was increased from 8% to 10%.

Better results were recorded for VM/AG and pMDI boards, for which TS and WA decreased by 24% to 47% and 24% to 42%, respectively. The components of melamine resin and polyisocyanate form strong bonds, giving stability to the formed boards. Similar results were reported by Hse and Choong (2002) and Klimek *et al.* (2016) for rice hull-wood and sunflower stalks particleboards with polyisocyanate adhesive. Unexpectedly, the panels with 3% pMDI had the highest values for thickness swelling (TS) and water absorption (WA) (56.6% and 131.7%) (Fig. 15 și Fig. 16). It seemed that the adhesive was heterogeneously distributed onto the surfaces of the husk particles, which also led to a decrease in internal cohesion.

All panels had thickness swelling values higher than the 14% limit recommended for P3 type panels according to SR EN 312 (2011). The current results for thickness swelling (TS) and water absorption (WA) were relatively high, but are consistent with the literature (Hse and Choong 2002; Guntekin and Karakus 2008; Garay *et al.* 2009; Melo *et al.* 2014; Güler 2015; Kord *et al.* 2016) and can be explained by the fact that no paraffin or other hydrophobic substances were added in the boards. In addition, the complex relationship between chemical composition, the particles size, and their interaction with adhesives influenced the performance of the boards.

The research conducted showed that the type of adhesive has a significant influence on the TS and WA values measured at a 95% confidence level. The statistical impact of the adhesive content level was more evident for pMDI (*p-value* less than 0.0001) than for UF (*p-value* = 0.004).

Mechanical properties

The values of the modulus of rupture (MOR) and modulus of elasticity (MOE) are shown in Fig. 17. The highest strength values were recorded for PF and pMDI boards at the highest adhesive content level. UF boards had the lowest mechanical strength.

Depending on the type of UF, the average decrease in strength ranged from 32% to 43% for modulus of rupture (MOR) and from 29% to 58% for modulus of elasticity (MOE), compared to panels using PF and pMDI at high adhesive content levels. Higher decreases, from 32% to 58% for modulus of rupture (MOR) and from 46% to 68% for modulus of elasticity (MOE), were also observed at low adhesive content levels. The lowest strength results were observed for U96 boards and PMDI 3% panels.

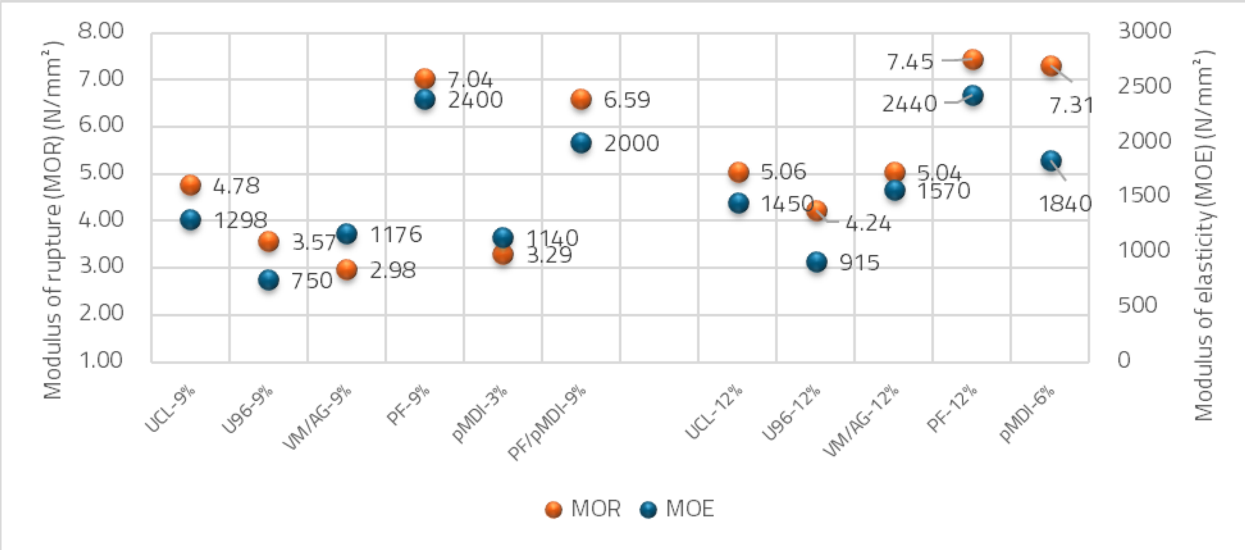


Fig. 17. Effect of adhesive type and its content level on modulus of rupture (MOR) and modulus of elasticity (MOE) (according to Zeleniuc *et al.* 2019)

U96 adhesive, which is generally used in the manufacture of high-density fibreboard, had the lowest F/U (formaldehyde/urea) ratio of the UF adhesives used. This ratio explained the poor performance of U96 when using sunflower husk particles. An insufficient amount of adhesive in the case of 3% pMDI resulted in lower mechanical properties of the manufactured panel. The combination of UF and modified melamine-formaldehyde (VM/AG) adhesive slightly improved the mechanical properties compared to other urea-based adhesives. Low modulus of rupture (MOR) and modulus of elasticity (MOE), values were reported by Güler (2015) and Melo *et al.* (2014) when other agricultural wastes (hazelnut husk, peanut hull and rice husks) were used, which were mixed with UF adhesive.

All panels examined in this study had values below the minimum modulus of rupture (MOR) requirements of standard SR EN 312 (2011). According to Ndazi *et al.* (2006), Melo *et al.* (2014) and Klimek *et al.* (2016), an increase in the percentage of agricultural waste in particleboards led to a decrease in the parameters of breaking strength and rigidity, and the boards generally did not meet the limits of the modulus of rupture (MOR) standard. The experimental boards obtained had a density lower than 580 kg/m³ and could be included in the low-density category (Rowell 2014), where modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB) values range from 3 N/m² to 5.0 N/mm², 550 N/mm² to 1025 N/mm² and 0.1 N/mm² to 0.15 N/mm².

The effect of pMDI adhesive on modulus of rupture (MOR) and modulus of elasticity (MOE) was obvious, therefore the values obtained for the 6% pMDI boards were comparable to those of the 12% PF panels. This observation is similar to the results reported by Hse and Choong (2002) for the 5.5% polyisocyanate adhesive used in particle boards made from rice husks mixed with wood shavings. Only PF and pMDI boards met the requirements for MOE

(>1600 N/mm²) in accordance with SR EN 312 (2011) for interior joint panels used in dry environments (Type P2).

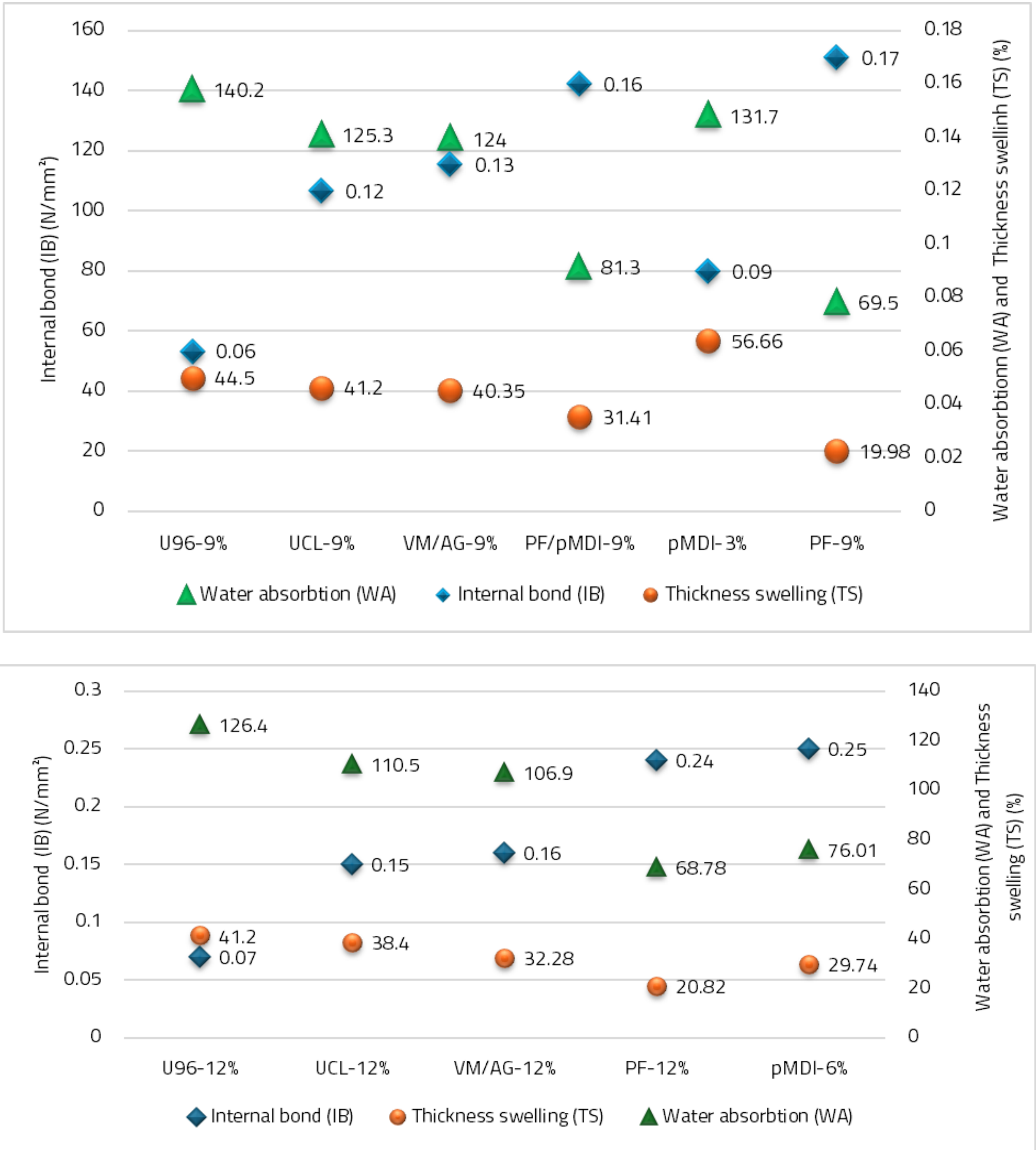


Fig. 18. Effect of adhesive type and content on thickness swelling (TS), water absorption (WA) and internal bond strength (IB) of modulus of elasticity (MOE) panels (according to Zeleniuc *et al.* 2019)

As expected, the use of pMDI and PF adhesives resulted in better panel stability in terms of water penetration (i.e., lower thickness swelling-TS and water absorption-WA) and higher internal bond (IB) when using UF adhesives (Fig. 18). In general, the internal bond (IB) value increased in a somewhat linear trend as the thickness swelling (TS) and water absorption

(WA) values decreased. The highest internal bond (IB) values were observed for pMDI and PF panels.

The average internal bond (IB) values ranged from 0.06 N/mm² (9% U96) to 0.25 N/mm² (12% PF and 6% pMDI). All panels with UF adhesives had the lowest internal bond (IB) values at both adhesive content levels (Fig. 18). An increase in adhesive content from 9% to 12% improved IB for all panels, which was more evident for PF (40% higher) than for UF panels (23% higher) (Fig. 19).

The internal bond (IB) values of pMDI boards were significantly affected by the adhesive content level. An increase in IB of 177% was observed when the pMDI level increased from 3% to 6%; the internal bond (IB) values at 6% pMDI were comparable to those at 12% PF. The mixed resin combination, pMDI/PF, was found to have a lower internal bond (IB) than the 6% pMDI boards, but was comparable to that of the 9% PF boards. According to SR EN 312 (2011), for general purpose panels used in dry environments (Type P1), a minimum internal bond (IB) value of 0.24 N/mm² is required, a requirement that is met by panels with 12% PF and 6% pMDI.

Statistical analyses showed that the mechanical properties of the experimental panels, in terms of modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB), were significantly influenced by the type of adhesive (*p-value* = 0.0009). The statistical impact of the adhesive content on these values was more evident for pMDI panles (*p-value* > 0.0001) than for UF and PF panles (*p-value* = 0.04).

1.2.3 Conclusions

The results of the research carried out with a view to developing new innovative composite panels led to the following conclusions:

- The type of adhesive had a significant influence on the physical and mechanical properties of composite panels made from sunflower husks.
- The adhesive content level had a significant effect on the properties of the panels, especially for pMDI panels than for UF and PF panels.
- Higher thickness swelling (TS) and water absorption (WA) values were observed for UF panels at the two adhesive content levels, with the commercial variants being ranked as follows (from highest to lowest) U96 > UCL > VM/AG. Slightly improved properties were observed for VM/AG panels as a result of combining the two adhesives.
- Panels with a pMDI adhesive content of 3% exhibited lower mechanical properties compared to UF panels. This was attributed to the low density and low bonding efficiency when using 3% pMDI.

- The best dimensional stability and mechanical properties of the structures were observed for PF at both adhesive content levels, followed by PF/pMDI (9%) and pMDI (6%). These results indicate stronger bonds between husk particles and adhesive. PF and pMDI panels were found to comply with the MOE and IB strength requirements for general use as prescribed by the SR EN 312 (2011) standard.
- The results obtained showed that in the production of particleboards, sunflower husks are compatible with UF, PF and pMDI adhesives and represent an alternative material to wood for the manufacture of particlboards.
- The performance of the boards was influenced by the type and content of the adhesive and the low density (below 580 kg/m^3), which contributed to a decrease in strength. The experimental particleboard presents a potential for indoor use as light panels for paneling or other decorative products.

Results dissemination

The research in this chapter was based on third-party contract no. 7/ 09.01.2014 on the recovery of sunflower seed husk waste in four different products (contract value 13105 lei), signed between Prutul S.A. company and the Pro Ligno Foundation belonging to the Faculty of Furniture Design and Wood Engineering at Transilvania University of Brașov.

The results presented in this chapter were disseminated as follows:

1. Zeleniuc. O.; **Brenci. L.M.*;** Coșereanu. C.; Fotin. A. Influence of Adhesive type and Content on the Properties of Particleboard Made from Sunflower Husks. BioResources **2019a**, 14(3):7316-7331. http://doi.org/10.15376/biores.14.3.7316-7331
2. Coşereanu, C.; **Brenci, L.M.;** Zeleniuc, O.; Fotin, A. Effect of particle size and geometry of single-layer and three-layer particleboard made from sunflower seed husks. BioResources Journal **2015**, 10(1), 1127-1136. DOI:10.15376/biores.10.1.1127-1136
3. Coșereanu, C.; Lica, D.; Brenci L.M.; Fotin, A.; Zeleniuc, O.; Lunguleasa, A.; Budău G.; Apostu, I. Placă ecologică din deşeuri de floarea soarelui, destinată placărilor exterioare şi procedeu de obținere / Eco-board from sunflower waste designed for exterior panelling and method of obtaining. Patent no. 130259, 30 July **2019b** https://drive.unitbv.ro/s/Xfyz8azqAKMgo4b
4. Zeleniuc, O.; **Brenci, L.M.;** Coşereanu, C.; Fotin, A.; Lica, D.; Budău, G.; Lunguleasa, A.; Apostu, I. Panou tristratificat din așchi şi coji de semințe de florea-soarelui pentru utilizări în interior şi procedeu de obținere / Three-layer panel made of sunflower seed husks and shells for indoor use and method of obtaining. Patent no. 130258, 30 September **2019c** https://drive.unitbv.ro/s/rCH4Cqqgtxxj6yE

5. Proiect ERASMUS+ KA202, Cooperation for Innovation and the Exchange of Good Practices, Strategic Partnerships for vocational education and training, cu titlul "TAckling Environmental sustainability through Blended Learning opportunities for ivEt in the furniture and wood sector (TABLE)" – project manager on behalf of Transilvania University of Brașov, carried out between 2019 and 2021, for a total amount of €29024 (UNITBV)). https://drive.unitbv.ro/s/9bdDgeHf3oyfztr

CHAPTER 2. SUSTAINABLE THERMAL INSULATION STRUCTURES

2.1 GENERAL ASPECTS OF SUSTAINABLE THERMAL INSULATION STRUCTURES

Buildings are the largest consumers of energy in Europe. According to data recorded at European Union level, 85% of buildings were constructed before 2000, and 75% of these have low energy performance (Energy Performance of Buildings Directive https://energy.ec.europa.eu/topics/energy-efficiency/energy-performance-buildings/energy-performance-buildings-directive_en?prefLang=ro).

Improving the energy performance of these buildings is essential for saving energy, reducing bills for citizens and businesses, and achieving the goal of zero emissions and complete decarbonisation of the building stock by 2050. However, the annual rate of energy renovation remains very low, at only 1%. According to Eurostat energy balances (https://ec.europa.eu/eurostat/databrowser/view/nrg_bal_c/default/table?lang=en) and the EEA's 2023 greenhouse gas inventory (Annual European Union greenhouse gas inventory 1990-2021 and inventory report 2023), approximately 40% of the energy consumed in the EU is used by buildings and approximately 50% of the EU's gas consumption is attributed to them. Thus, reducing energy consumption and using energy from renewable sources in the buildings sector are important and necessary measures that must be targeted at reducing greenhouse gas emissions across the Union.

According to the EU Directive on the energy performance of buildings (EU Directive 2024/1275), two-thirds of the energy consumed for heating and cooling buildings still comes from fossil fuels, which means that in order to eliminate the carbon footprint in the construction sector, these fuels must be phased out gradually. According to the same document, the EU's vision is to have zero-emission buildings, which would mean very low energy demand, zero carbon emissions from fossil fuels, and buildings with zero or very low greenhouse gas emissions. Thus, all new buildings should be zero-emission buildings by 2030, and existing buildings should be converted into zero-emission buildings by 2050. All these requirements set by international bodies were the starting point for the research carried out to help find sustainable panel and structure solutions aimed at reducing energy consumption and CO_2 emissions and, replace the materials currently used in construction for the thermal insulation of buildings.

The thermal conductivity of an insulating material is an important property that must be taken into account when evaluating materials for building construction. For materials used as thermal insulators, high heat flow resistance and a low thermal conductivity coefficient are recommended. The literature presents research on the thermal insulation capacity of materials that can replace traditional insulators such as polystyrene (extruded and expanded), mineral wool and glass wool, polyurethane and cellular glass. High CO_2 emissions during production and short life cycles make these materials less desirable for use in construction (Su *et al.* 2016).

The use of raw materials from renewable or recycled sources (environmentally friendly) for the manufacture of building structures is an important strategy for sustainable development. In a study conducted by Dikmen and Ozkan (2016), a number of agricultural wastes such as pineapple leaves, wheat straw, rice straw, rice husks/broken rice, coconut fibres, bagasse, date palm fibres, corn cobs and sheep's wool were investigated for their thermal insulation capacity. Following the research, the authors showed that, even though the thermal conductivity of petroleum-based products (polyurethane foam, expanded polystyrene EPS and extruded polystyrene XPS) is slightly lower than that of agricultural waste, the use of the latter is preferable for the thermal insulation of buildings due to its advantages in terms of long-term impact on the environment and human health. Another study conducted by Ashour *et al.* (2011) on 50 cm thick straw bales showed that these experimental materials had a low thermal conductivity of 0.067 W/mK. Other innovative materials studied as alternative solutions include composites with cellulose as a filler (Nicolajsen 2005), wood waste (Agoua *et al.* 2013, Alvan *et al.* 2025), hemp (Benfratello *et al.* 2013; Latif *et al.* 2014), bark waste (Kain *et al.* 2013), olive pits combined with wood shavings (Binici and Aksogan 2016), cork and pine wood (Limam *et al.* 2016), with palm fibres (Ali and Alabdulkarem 2017), with cereal straw (Mehrez *et al.* 2022), with rice husks, wheat, wood fibres and textile fibres (Muthuraja et al. 2019); with rice husks (Burati *et al.* 2018; Antunes *et al.* 2019; Wang *et al.* 2020; Marques *et al.* 2020; Neira *et al.* 2024). Another study conducted on composites made from sunflower stem pith and lime recorded a thermal conductivity coefficient of 0.05W/mK (Abbas *et al.* 2021), while composites made only from untreated wood fibres achieved a thermal conductivity coefficient of 0.04363 W/mK (Zach *et al.* 2013). Other cellulose-based thermal insulation materials made from recycled newspapers applied by spraying (soft fibre cellulose pulp and bulk cellulose) had thermal conductivity values of 0.040 W/mK (Roberts *et al.* 2015) and 0.050 W/mK (Nicolajsen 2005).

Most studies that have investigated thermal insulation materials (cork, bark, rice straw, hemp, etc.) have reported low densities ranging from 170 kg/m³ to 260 kg/m³ and low thermal conductivity coefficients with values between 0.0475 W/mK and 0.0697 W/mK (Kain *et al.* 2013; Wei *et al.* 2015; Ali and Alabdulkarem 2017). In another study aimed at obtaining low-density boards (212 kg/m³) made from corn stalks, a thermal conductivity coefficient of 0.139 W/mK was obtained (Pinto *et al.* 2012).

Wall systems for lightweight wooden house structures are being investigated in various variants, with the aim of achieving good thermal insulation performance. Thus, the heat transfer coefficient varies between 0.204 W/m^{2}K and 0.30 W/m^{2}K for structural walls with a thickness of 185 mm and paper filling material (Pásztory *et al.* 2015), respectively for those made with hemp and mineral wool filling material with a thickness of 100 mm (Latif *et al.* 2014). A similar heat transfer coefficient of about 0.200 W/m2K was obtained for a wall system made of 5 cm-thick reinforced concrete and 80 cm-thick glulam studs filled with polystyrene foam with a 3-cm air gap (Destro *et al.* 2015). In another study on walls for lightweight wooden house structures, bark with a density of 250 kg/m³ was used as filler material, which led to lower thermal conductivity values 0.062 W/mK and 0.096 W/mK (Kain *et al.* 2013). However, the thermal performance of bark fill was not as good as that of lightweight thermal insulation materials such as polystyrene or mineral wool, due to the relatively high bulk density of bark. In general, methods for measuring thermal parameters are based on sensors placed in the wall structure to record the temperature, moisture content, and relative humidity every hour in order to evaluate the influence of these parameters on heat transfer (Kain *et al.* 2013; Wang *et al.* 2013; Latif *et al.* 2014; Pásztory *et al.* 2015). Increasing the density, the temperature, and the moisture content in wall panels will lead to an increase in thermal conductivity, which is influenced by the porous structure and the different intermolecular distances that these materials have (Latif *et al.* 2014; Wei *et al.* 2015).

2.2 THERMAL CONDUCTIVITY OF SANDWICH STRUCTURES FOR EXTERIOR WALLS OF WOODEN HOUSES

The objective of this research (Brenci *et al.* 2018) was to create, under laboratory conditions, innovative sandwich structures for the exterior walls of wooden houses, with a thickness of 175 mm, with different types of core filling materials, which then were tested to measure their thermal conductivity. The outer frame of the wall was made of spruce (*Picea abies*) wood, and the filling materials used were wood shavings, mineral wool, and panels made of hot-pressed acrylonitrile butadiene styrene (ABS) waste. The thermal conductivity coefficient was measured automatically based on thickness, density, temperature gradient, and average temperatures. The ABS panels were obtained in the laboratories of the Faculty of Furniture Design and Wood Engineering, and the structures and thermal conductivity tests were carried out at the Research and Development Institute of Transilvania University of Brașov.

2.2.1 Research methodology

2.2.1.1 Materials used

The following sustainable materials were used in the research to make the core of the walls:

- Acrylonitrile butadiene styrene (ABS) waste panels;

- Wood shavings (WS);
- Mineral wool (RW) in bulk form.

The waste used to manufacture ABS panels and wood shavings (Fig. 19a) used for the core were provided by the small-scale furniture production site at Faculty of Furniture Design and Wood Engineering in Romania. The ABS was collected as waste from the edge banding operations on melamine-faced particleboards. The ABS particles with lengths between 2 mm and 20 mm, widths between 0.5 mm and 3 mm, and thicknesses of 0.2 mm formed a mat, which was hot-pressed for 20 minutes at a temperature of 130°C and a pressure of 20 bar (Coșereanu and Lica 2014). This resulted in ABS panels (Fig. 19b) with dimensions of 600 mm x 600 mm and a density of 240 kg/m^3, which were thereafter cut to their final dimensions of 510 mm x 510 mm x 14 mm.

OSB boards with a density of 660 kg/m^3 and a thermal conductivity coefficient (λ) of 0.125 W/mK, and gypsum board (GB) with a density of 650 kg/m3 and a thermal conductivity coefficient (λ) of 0.225 W/mK, were used for the outer layers of the sandwich structures. Polyethylene foil (P) with a specific weight of 195 g/m^2 was used as a vapour barrier inside the structure. Wood shavings from spruce (80%) and beech (20%) collected from milling machines and planer were used to manufacture the cores of the sandwich composites. Their initial moisture content (before forming the structures) ranged between 8.2% and 8.7% (greater for softwood). After forming the sandwich structures, they were conditioned at a relative humidity of 65% and a temperature of 20 °C, after which the tests were performed. The loose bulk density for wood shavings was approximately 135 kg/m^3 (for structure S2 from Fig. 20), while the compacted apparent density was 160 kg/m^3 (for a compaction ratio of 1.2 for structures S1 and S3 from Fig. 20).

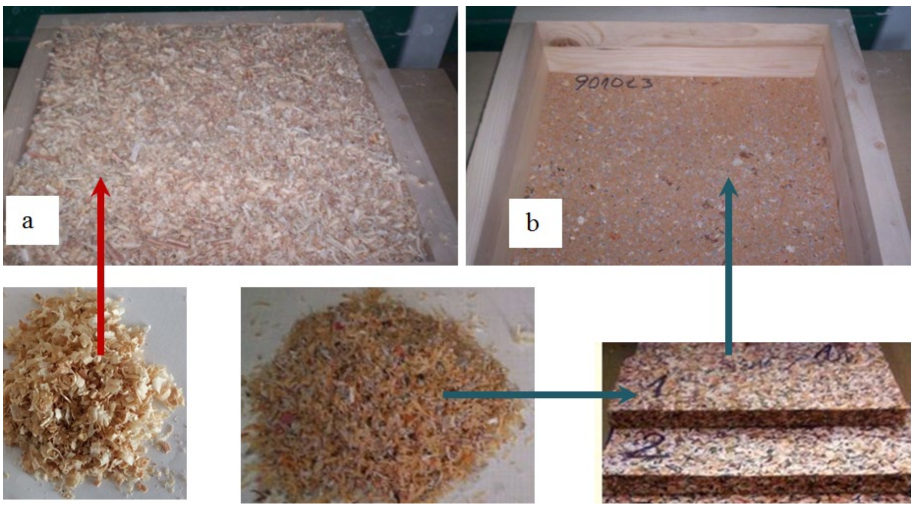
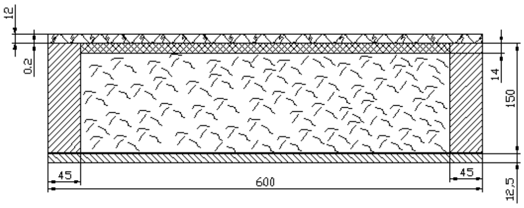


Fig. 19. Wood shavings (a) and ABS panel (b) used for the core experimental wall structures (Brenci *et al.* 2018)

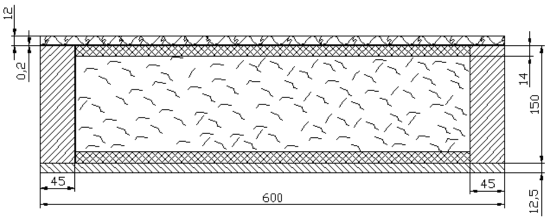
The length of the shavings ranged from 12 mm to 38.7 mm and from 1.2 mm to 12 mm for particles, with a thickness between 0.2 mm and 0.5 mm. The shares of flakes and particles into the wood shavings were 25% and 75% respectively (Fig. 19a). Curled flakes create large voids, which could be filled by mixing them with particles from milling, thus intending to improve the thermal insulation of wood shavings.

2.2.1.2 Design of the experimental walls

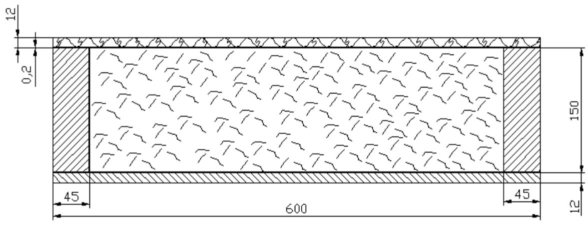
The research aimed to design and build for thermal conductivity measurements, five wall structures (Fig. 20) with a length of 600 mm, a width of 600 mm and a thickness of 175 mm.



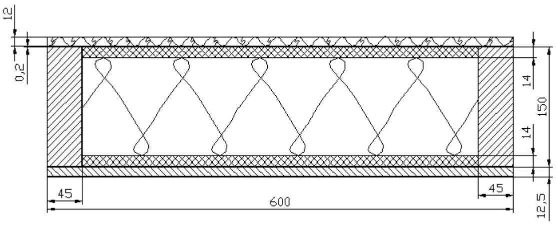
Structure 1 – S1



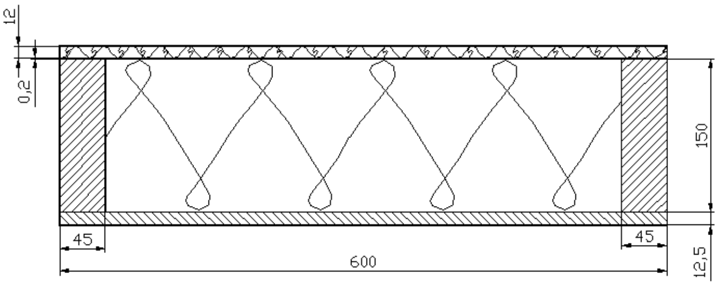
Structure 2 – S2



Structure 3 – S3



Structure 4 – S4



Structure 5 – S5

Fig. 20. Designed sandwich composite structures (Brenci *et al.* 2018)

The walls designed as sandwich structures were formed from a wooden frame, core and two outer face sheets. The wooden frames were made of spruce (*Picea abies*) with a thickness of 45 mm. Each frame was covered with a 12.5 mm gypsum board on one side and a 12 mm OSB panel on the other side. The experimental walls were designed with different core compositions, as shown in Tab. 5.

Structure S5 was considered a reference sample because of the low thermal conductivity coefficient of rock wool core, which had a measured thermal conductivity coefficient of 0.037 W/mK at a density of 30 kg/m3, and it is a material generally used for insulations.

Tab. 5. Sandwich wall structure (Brenci *et al.* 2018)

Structures build	Inside face sheet		Core				Outer face sheet
	Gypsum board	polyethylene foil	ABS	Wood shaving	Rock wool	ABS	OSB
Structure 1 (S1)	x	x	-	x	-	x	x
Structure 2 (S2)	x	x	x	x	-	x	x
Structure 3 (S3)	x	x	-	x	-	-	x
Structure 4 (S4)	x	x	x	-	x	x	x
Structure 5 (S5)	x	x	-	-	x	-	x

x – raw material used in the structure

2.2.1.3 Thermal conductivity measurement

For each of the five sandwich structures, two specimens were made, which were then subjected to measurements in order to measure the thermal conductivity coefficient (λ). The tests were performed on HFM436 Lambda equipment (Netzsch, Selb, Germania Fig. 8), according to ISO 8301 (1991) and DIN EN 12667 (2001). This testing method is based on the determination of the quantity of heat that is passed from a hot plate to a cold plate through the sandwich composite structure.

The temperature difference between the two plates is registered, and the thermal conductivity coefficient is automatically calculated based on Fourier's Law. Before the samples were tested, the equipment was calibrated depending on the temperature differences (*ΔT*) and mean temperatures (T_m) (Tab. 6).

Tab. 6. Temperatures configuration set up (Brenci *et al.* 2018)

$\Delta T = T_1 - T_2$ in °C	$T_m = \frac{T_1+T_2}{2}$ in °C													
	-5		0		5		10		15		20		25	
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
10	0	-10	5	-5	7.5	2	15	5	20	10	25	15	30	20
15	2.5	-12.5	7.5	-7.5	12.5	-2.5	17.5	2.5	22.5	7.5	27.5	12.5	32.5	17.5
20	5	-15	10	-10	15	-5	20	0	25	5	30	10	35	15
25	7.5	-17.5	12.5	-12.5	17.5	-7.5	22.5	-2.5	27.5	2.5	32.5	7.5	37.5	12.5
30	10	-20	15	-15	20	-10	25	-5	30	0	35	5	40	10

T_1 - upper plate temperature
T_2 - bottom plate temperature

Density was introduced as input data in the equipment software. The density was calculated as the ratio between mass and volume of the tested structure.

2.2.2. Results and discussion

In the experiment, parameters T2 and T1 simulated outdoor temperatures and indoor temperatures, respectively. Thermal conductivity coefficients were determined for each ΔT and and each mean temperature (T_m). The results are presented in Fig. 21.

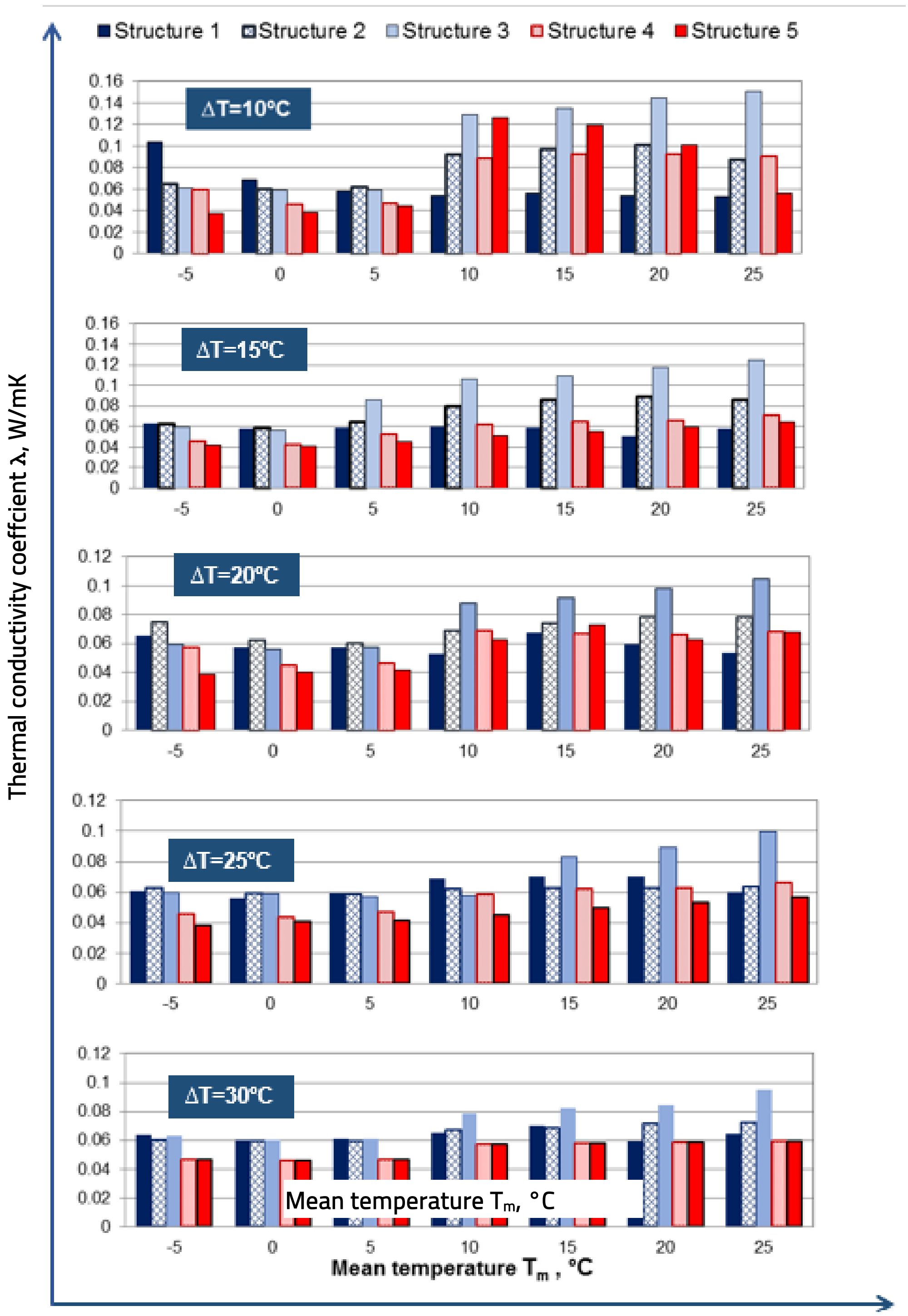


Fig. 21. Thermal conductivity coefficient values at various temperature differences between equipment hot plate and cold plate (ΔT) and at different mean temperatures T_m (Brenci *et al.* 2018)

The mean temperature values used in the experimental measurements were characterised by two ranges: T_m of -5 °C, 0 °C and 5 °C for the winter season and T_m of 15 °C, 20 °C and 25 °C for the summer season.

The test consisted of a continuous transition of the structures from negative values (T_1) to positive temperature values (T_2). The structures were subjected to successive cooling and heating processes, which influenced the thermal behaviour of the core, leading to oscillatory variations in the thermal conductivity coefficient λ (*e.g.* in the case of structure S5 at ΔT = 10°C and ΔT = 15°C). During the testing time, the structures were not removed from the equipment, moving from one test period to another until the cycle was completed.

Due to the fact that the structures are not homogeneous, their behaviour during testing led to the probable occurrence of condensation inside the structures. Thus, in the case of structures with the simplest configuration (S3 and S5), with a sudden increase in temperature (in the case of ΔT = 10°C), for T_m between 5°C and 10°C, the phenomenon of humidity circulation inside the structure was favoured, the result being reflected in an increase in the thermal conductivity coefficient. Inside the structures, thermal conductivity occurs together with other phenomena associated with moisture and heat transfer. Furthermore, heat transfer occurs through convection and capillarity. These phenomena lead to an increase in the thermal coefficient, a phenomenon that was mainly observed in structures with a core of loose bulk wood shavings as core (S1, S2 and S3).

For all structures, as can be observed in Fig. 22 when ΔT increases (from ΔT = 10 °C to ΔT = 30 °C), the negative temperature field of T_2 (blue area) extends from T_m = 5 °C to 15 °C.

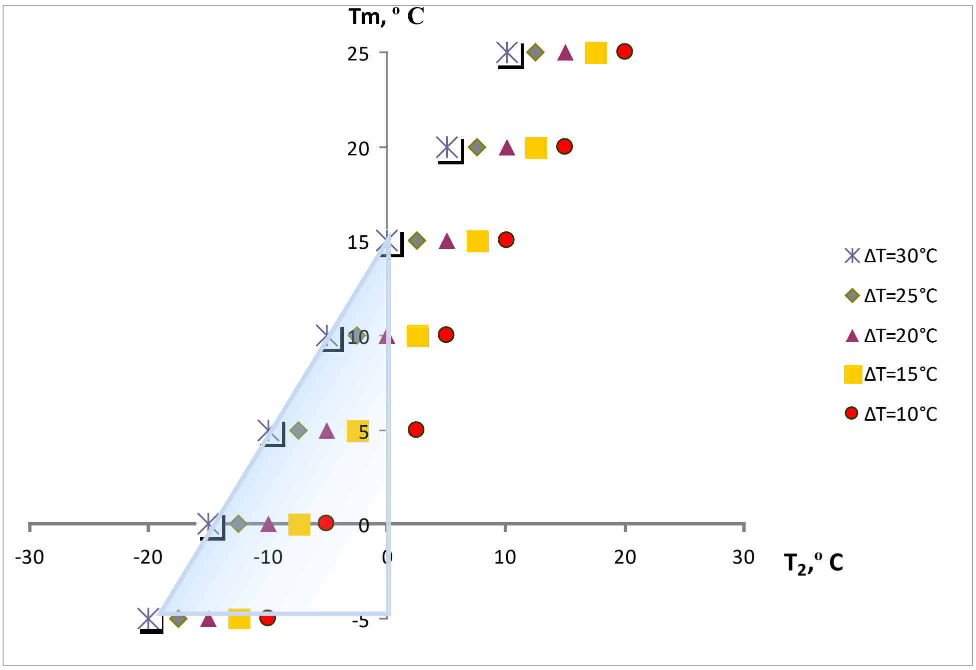


Fig. 22. The evolution of negative and positive temperature zones according to variation of ΔT (according to Brenci *et al.* 2018)

The conditions at which the structures are subjected, are more stable (negative temperatures) for a longer period of time, between ΔT = 20 °C and ΔT = 30 °C. This may have favored the conditions of thermal and humidity transfer determining a slower reaction of the structures components, resulting in a less variation of thermal conductivity coefficient.

The structures are defined in two categories based on the core components: one filled with wood shavings (S1, S2, and S3) and the other one with rock wool (S4 and S5). Analyzing the behavior of the first category, it can be observed that the structure S3 (the simplest one) does not provide the required thermal resistance to reduce convection heat losses due to the local temperature differences appeared in the structure during the summer. In summer time, accumulated heat was higher than in winter, S3 recording the highest thermal coefficient of 0.150 W/mK. The same trend can be observed in structures S1 and S2, but the phenomenon is less amplified due to the presence of the ABS layer acting as a moisture barrier. Generally, structure S1 had the lowest λ coefficient compared to S3 and S2 in both seasons (below 0.063 W/mK) (Fig. 23). The same trend can be observed in structures S1 and S2, but the phenomenon is less amplified due to the presence of the ABS layer acting as a moisture barrier. Generally, structure S1 had the lowest λ coefficient compared to S3 and S2 in both seasons (below 0.063 W/mK). The gaps between flakes for S2 with loose bulk core shavings favor the heat flow, resulting in convective heat transfer and a higher λ.

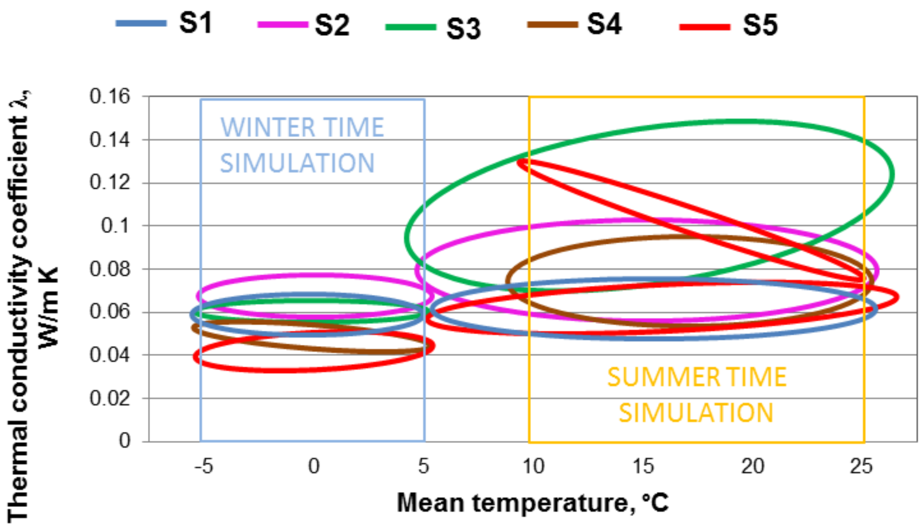


Fig. 23. Comparison between thermal conductivity coefficient limits of investigated structures in the conditions of both winter and summer season simulation (Brenci *et al.* 2018)

Structure S5 had a lower thermal conductivity compared to S4 (both with rock wool core). The mean values for the entire testing cycle were 0.0564 W/mK for S5 and 0.0605 W/mK for S4 (Fig. 24). The differences between these structures are attributed to the materials that form the core (for example, S4 has two ASB boards on both sides). The upper layer on the outside could control indoor humidity at a lower level during cold periods of time, with a conductivity coefficient below 0.06 W/mK. During the summer, the lower ABS layer (on the inside) favoured an increase in the thermal conductivity coefficient to values ranging from 0.090 W/mK (ΔT=10°C) to 0.071 W/mK (ΔT=15°C) and 0.059 W/mK (ΔT=30°C). Among the structures investigated, it can be observed that S5 and S4 had better thermal performance compared to the other structures, having the lowest values of λ during the test cycle (0.0564 W/mK for S5 and 0.0605 W/mK for S4) (Fig. 24). The densities of the experimental wall structures and standard deviations are presented in Fig. 25. The highest density (299 kg/m³) was recorded for S2 (structure with wood shavings and panels made from ABS waste).

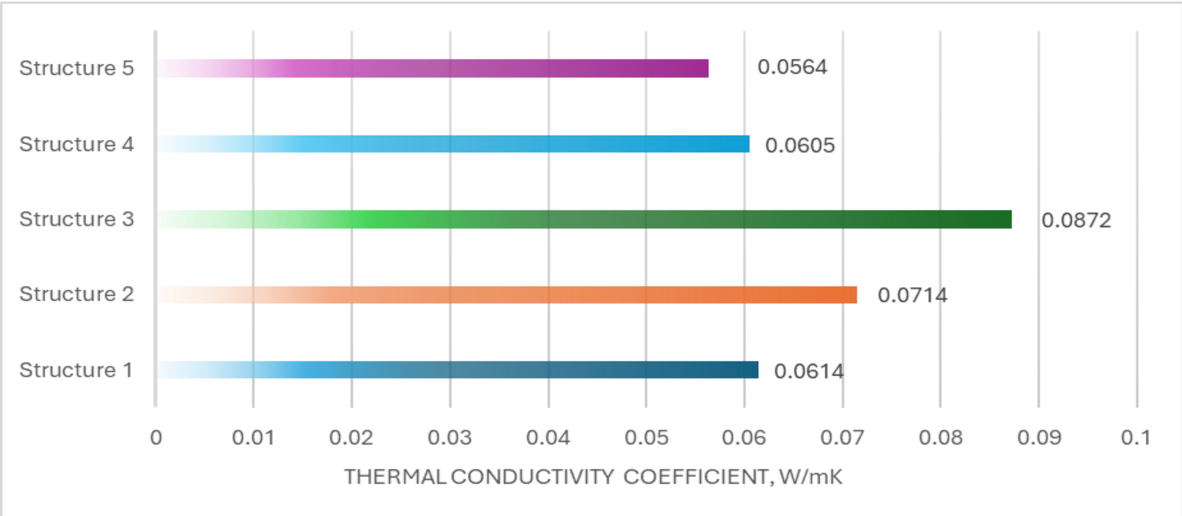


Fig. 24. Mean values of the thermal conductivity coefficient for the entire test cycle (according to Brenci *et al.* 2018)

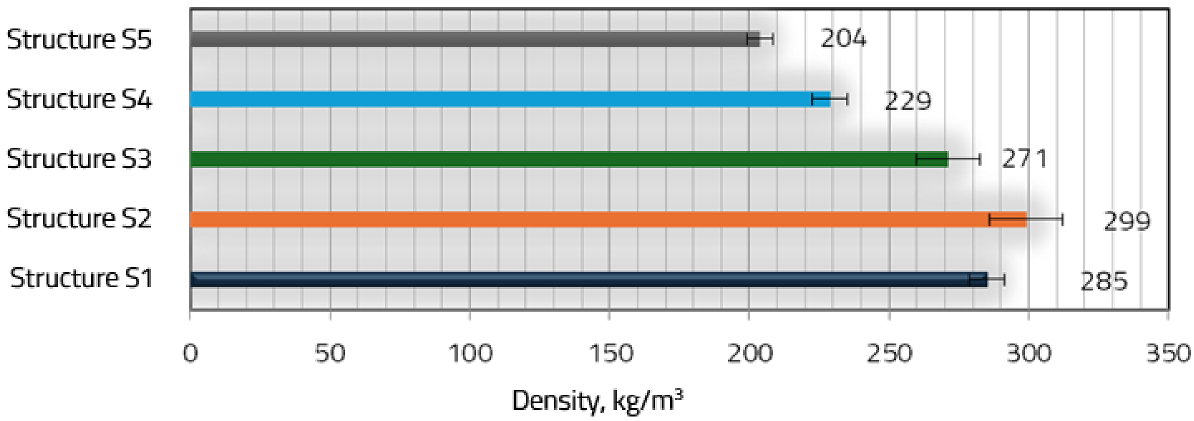
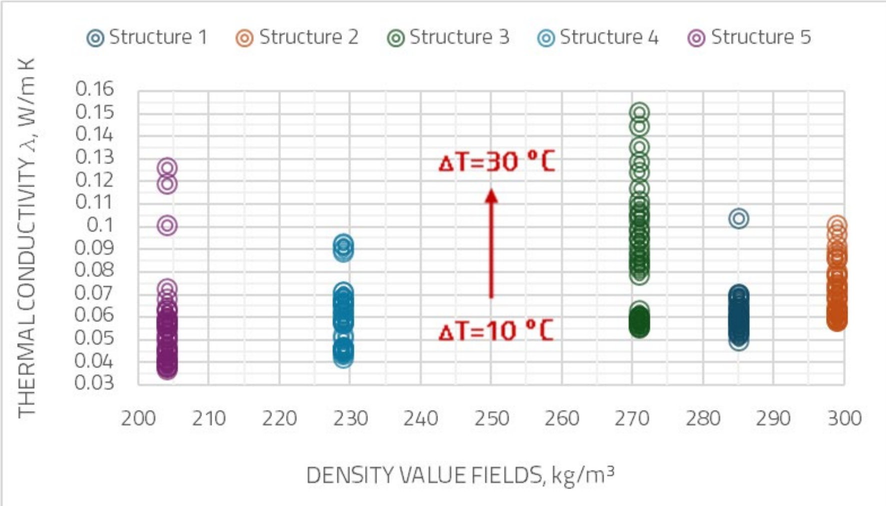


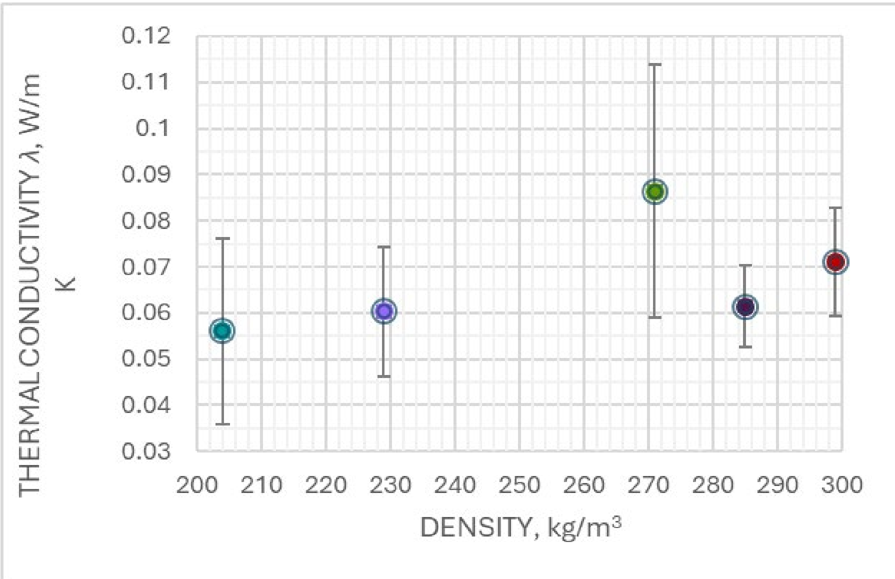
Fig. 25. Histogram of densities of the experimental wall structures (Brenci *et al.* 2018)

The lowest density value (204 kg/m³) was recorded for S5 (reference structure), which has mineral wool as its core and OSB/GB faces on the outside. The spread values of λ at different densities and ΔT limits are shown in Fig. 26a. The mean values of λ and standard deviations of all structures are shown in Fig. 26b.

The influence of the interaction of factors on the thermal conductivity coefficient was performed using the statistical ANOVA single-factor variance analysis. Differences were considered statistically significant for $p \le 0.05$.



a.



b.

Fig. 26. Histogram of thermal conductivity as a function of structure density
a – for all ΔT; b – for mean values of the thermal conductivity coefficient
(according to Brenci *et al.* 2018)

The factors that significantly affect thermal conductivity were determined using the reported p values. After performing a statistical analysis of the mean values obtained in the experiments, it was found that ΔT and density have a significant influence on the measured thermal conductivity at a 95% confidence level ($p \leq 0.05$), while the influence of the average temperature was not statistically significant.

2.2.3 Conclusions

After analysing the results of the research, the following conclusions can be drawn:

- The best thermal performance was recorded for S5 and S4, which had a rock wool core as a low-density thermal insulation layer and had the lowest thermal conductivity coefficient compared to wood shaving core structures.
- The S1 structure with a wood shaving core and ABS board on the outside, recorded a smaller variation in the thermal conductivity coefficient throughout the entire test cycle. This structure recorded better thermal behaviour compared to structures containing wood shaving in the core (S2 and S3).
- The successive cooling and heating phases during the test cycle influenced the thermal behaviour of the structures, which was perceived as an oscillatory variation in thermal conductivity. Inside the structures, there is not only the phenomenon of pure thermal conductivity, but other phenomena associated with moisture and heat transfer also occurred.
- The ABS layer applied over the gypsum board did not improve the insulation performance of structures S2 and S4.
- Both density and ΔT had a greater influence on the thermal conductivity coefficient than the average temperature T_m.
- Wood shaving compressed at a lower density, as an ecological friendly and inexpensive material, could be a sustainable solution for thermal insulation and could replace rock wool structures.

2.3 THERMAL INSULATION COMPOSITES MADE FROM ECOLOGICAL MATERIALS

The objective of this research (Brenci 2016; Brenci *et al.* 2014), was to produce, under laboratory conditions, innovative composites from environmentally friendly materials (reeds, wood fibres, wood and hemp particles), reinforced with cement and gypsum, for which thermal insulation capacity was tested. The composites were produced in the laboratories of the Faculty of Furniture Design and Wood Engineering, and the thermal conductivity tests were carried out at the Research and Development Institute of Transilvania University of Brașov.

2.3.1. General aspects of ecological composites used as insulating materials

The development of ecological materials to replace traditional materials used for thermal insulation in buildings is an important goal for humanity. Following debates and based on the data collected, the World Health Organisation (WHO) (World Health Organisation finds increased cancer risk for chemical found in plastics https://pirg.org/media-center/world-health-organization-finds-increased-cancer-risk-for-chemical-found-in-plastics/), in 2018 reclassified styrene (a component of polystyrene) from "possible carcinogen" to "probable carcinogen", risk group 2A. Another disadvantage of this material is that it is difficult to recycle, with a degradation period of 500 years (Davis 2019).

Buildings must be durable and sustainable in a way to minimise their negative impact on the environment throughout their entire life cycle, taking into account social, economic and environmental aspects (Jami *et al.* 2019). Research conducted by La Rosa *et al.* (2014) on the use of environmentally friendly materials in sandwich structures focused on the use of cork and flax as insulating materials. The structure had panels made of flax fibres with epoxy resin on the outside and cork panels on the inside. The results of the investigation showed that the thermal resistance value measured at temperatures of T = 10°C and T = 50°C to define the specific characteristics of the cold and warm periods was 2.17m²K/W. Even though this value is lower than that of other materials used in insulation, the lightweight structure (only 38.8 kg/m²) and positive environmental impact are important and must be taken into account. In another study (Zach *et al.* 2012), it was shown that the sheep wool used as thermal insulation material has characteristics comparable to those of rock wool and, in some applications, much better performance (acoustic insulation) was recorded. The results obtained for the thermal conductivity coefficient ranged between 0.034W/mK and 0.05 W/mK, with values varying depending on the thickness of the material layer and the test temperature. In addition, compared to rock wool, sheep wool is an ecological material and is not harmful to health.

In another study, Tasgin *et al.* 2024, produced epoxy composites reinforced with sheep wool, cotton and coconut fibres, with the results showing that the lowest thermal conductivity value was obtained for composites with coconut fibre (0.187 W/mK) followed by wool (0.518 W/mK) and cotton (1.017 W/mK). Jove-Sandoval *et al.* (2023) used two types of long and short fibre waste from wheat straw and sawdust mixed with clay and water in their research. The investigation of thermal insulation capacity was carried out at a temperature of T=50°C, with the results showing that the panels made from short wheat straw had a thermal conductivity coefficient of 0.05 W/mk, a value comparable to that of expanded polystyrene (EPS), whose thermal conductivity coefficient ranges between 0.030 and 0.040 W/mK (Pawłosik *et al.* 2025). For the other two panels made from long wheat straw and sawdust, Jove-Sandoval *et al.* (2023) obtained a thermal conductivity coefficient value of 0.150 W/mK. Hemp and silica xerogel nanocomposites were the subject of research conducted by Jadhav *et al.* (2023), who, after testing the thermal properties, obtained a thermal conductivity coefficient value (0.031 W/mK) close to that of expanded polystyrene, which means that the panels obtained can be used as insulating materials.

Introducing hemp into the composition of building materials has led to opportunities for the development of new innovative structures. Thus, hemp-based concrete made from lime, hemp, water and additives to improve its properties can be used to fill walls, as floor tiles or as insulation for roofs and ceilings. Hemp-based concrete has been shown to be a „carbon-negative" or „better than zero-carbon" substance, as hemp absorbs more carbon from the atmosphere than it emits during its production and use in situ (Barbhuya and Bibhuti 2022), providing an alternative to standard materials used in construction. Hempcrete is also recyclable at the end of a building's life. Because this composite is not a load-bearing material, it can be used as infill in a lightweight timber frame wall (Wang *et al.* 2018). The thermal conductivity of hemp-based concrete depends on the amount of material contained. For a hemp content between 20% and 40%, the density decreases from 611 kg/m^3 to 369 kg/m^3, and the thermal conductivity coefficient decreases from 0.1408 W/mK to 0.0947 W/mK (Bonfratello *et al.* 2013). In another study (Dhakal *et al.* 2017), the thermal conductivity coefficient for hemp concrete ranged from 0.093 W/mK to 1.570 W/mK for densities between 480 kg/m^3 and 680 kg/m^3, and between 0.093 W/mK and 1.570 W/mK for sample densities between 480 kg/m^3 and 680 kg/m^3 (Collet and Pretot 2014).

Using wood shavings in the matrix of reinforced cement composites resulted in thermal conductivity coefficients ranging from 0.24 W/mK to 0.15 W/mK (Guo *et al.* 2022). The tests were performed with three different types of cement, but the results indicated that the effect of the binder on thermal conductivity did not have a significant influence. As the amount of shavings in the composite structure increased, the thermal conductivity value decreased. In other studies, Gholami *et al.* (2024) and Dias *et al.* (2022) investigated the thermal insulation properties of cement-reinforced wood shavings composites, with results indicating values of 0.237 W/mK and 0.15 W/mK, respectively. Al Rim *et al.* (1999) observed that replacing conventional materials (sand and gravel) with wood shavings in the concrete matrix, in proportions of 20% and 50%, led to a decrease in thermal conductivity of 33% and 67%, respectively. Fu *et al.* (2019) highlighted the advantages of using beech wood particles to reduce weight and improve the thermal insulation of concrete in wood-concrete composite structures.

2.3.2 Ecological cement-based composites

2.3.2.1 Research methodology

Materials

Research conducted to develop cement-based composites (Brenci 2016) used the following environmentally friendly materials: wood shavings and fibres, hemp particles, reeds and wool, and cement as a binder (Fig. 27). These were mixed in different proportions, according to the data presented in Tab. 7.

a. b. c.

d. e.

Fig. 27. Materials used to manufacture composites
a – wood shavings; b – wood fibers; c – hemp; d – reeds; e – wool

Tab. 7. Percentage of materials used in the production of composites (Brenci 2016)

Composite code	Wood shavings (%)	Wood fibers (%)	Wool (%)	Hemp (%)	Reeds (%)	Cement (%)	Water (%)	Composite density (kg/m^3)
P1	8.8%	-	4.4	-	-	47.3	39.5	729.16
P2	-	7.2	3.5	-	-	38.3	54.0	677.08
P3	4.4	-	4.4	4.4	-	47.3	39.5	733.33
P4	2.5	-	4.4	6.3	-	47.3	39.5	718.75
P5	6.3	-	4.4	2.5	-	47.3	39.5	708.33
P6	-	-	4.4	-	8.8	47.3	39.5	716.33

After weighing, the ecological materials and cement were placed in a large container and mixed mechanically for 10 minutes using the equipment shown in Fig. 28, after which water was added and the process was continued until the mixture was homogeneous. The mixture was cast into wooden molds with internal dimensions of 450 mm x 450 mm x 30 mm, after which they were cold-pressed for 24 hours. Next, the composites were in a press with heated plates at a temperature between 40°C and 50°C for five hours. After removal from the molds, the plates were conditioned at ambient temperature for five hours and then cut to their final dimensions of 400 mm x 400 mm x 30 mm (Fig. 29).

Fig. 28. The equipment used to homogenize the mixture

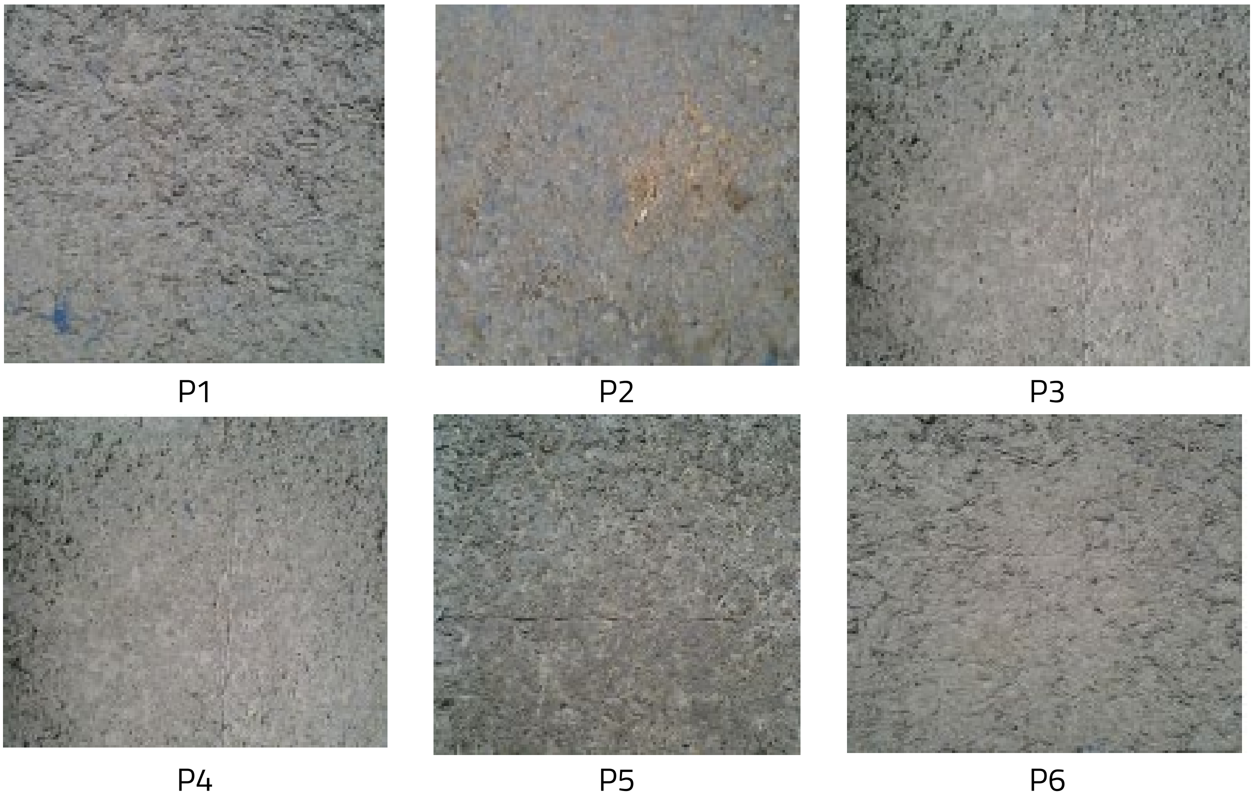


Fig. 29. Cement-reinforced composites (Brenci 2016)

The thermal conductivity coefficient (λ) was measured using HFM436 Lambda equipment (Netzsch, Selb, Germania) (Fig. 8), according with ISO 8301 (1991) and DIN EN 12667 (2001). The tests were performed for six temperature range intervals, with a temperature difference of $\Delta T = 20^0$ C (Tab. 8).

Tab. 8. Test temperatures of the manufactured composites (Brenci 2016)

Measurement points	Lower plate temperature T1 (^{0}° C)	Upper plate temperature T2 (^{0} C)	Average temperature T_m (^{0} C) $\frac{T_1 + T_2}{2}$
1	-20	0	-10
2	-15	5	-5
3	-10	10	0
4	-5	15	5
5	5	25	15
6	10	30	20

2.3.2.2 Results and discussions

After performing the tests, the measured data were recorded by the software of the equipment, then processed and graphically represented (Fig. 30).

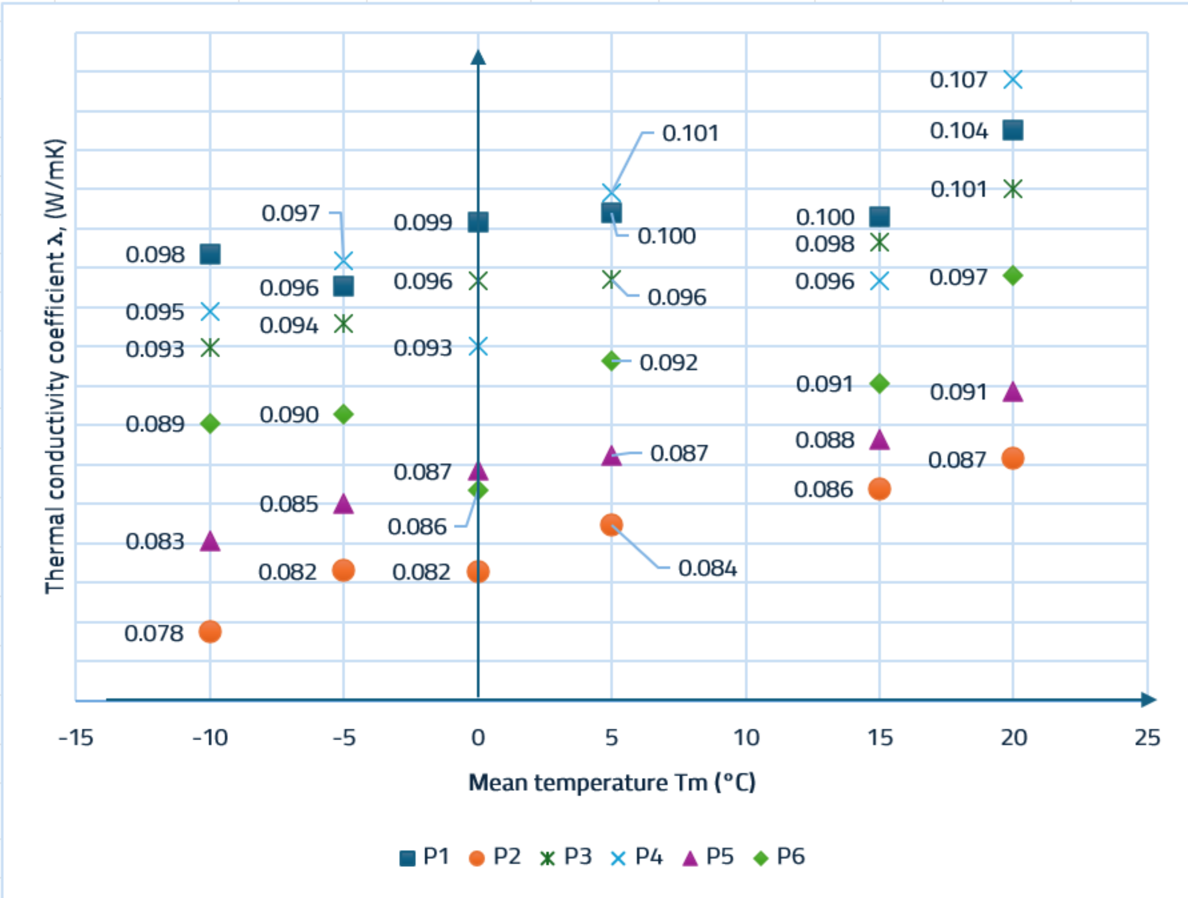


Fig. 30. Thermal conductivity coefficient of the panels manufactured (according to Brenci 2016)

Analyzing the data presented in Fig. 30, it can be observed that the P2 composite with wood fibers and wool recorded the lowest thermal conductivity values, ranging between 0.078 W/mK for an average temperature T_m= 10⁰ C and 0.087 W/mK for an average temperature T_m= 20⁰ C. The P5 composite made of wood particles, wool, and hemp also achieved good thermal conductivity coefficient values, ranging between 0.083 W/mK and 0.090 W/mK.

The highest thermal conductivity coefficients were recorded for composites P1 (wood chips and wool) and P4 (wood shavings, wool and hemp), ranging between 0.097 W/mK and 0.104 W/mK, and between 0.094 W/mK and 0.106 W/mK, respectively. Composites P4 and P5 have the same materials in their composite structure, but with different shares. The P5 composite has the highest amount of wood shavings (6.3%) compared to P4 (2.5%), which shows that the presence of this material contributes to improving the thermal performance of the panel. Comparing the results obtained for composites P1 (wood shavings and wool) and P6 (wool and reed), which have the same amount of wool, wood shavings and reed, respectively, it can be seen that the presence of reed leads to better thermal insulation capacity than the presence of wood shavings in the composite structure. Comparing the thermal conductivity coefficient results with the density of all the tested composites (Fig. 31), it ca be seen that for all mean temperatures at which the tests were performed, the decrease in density generally indicates a decrease in the thermal conductivity coefficient, as shown by the correlation coefficient R^2 of the trend lines. Its values show a good correlation between the two variables analysed (density and thermal conductivity coefficient).

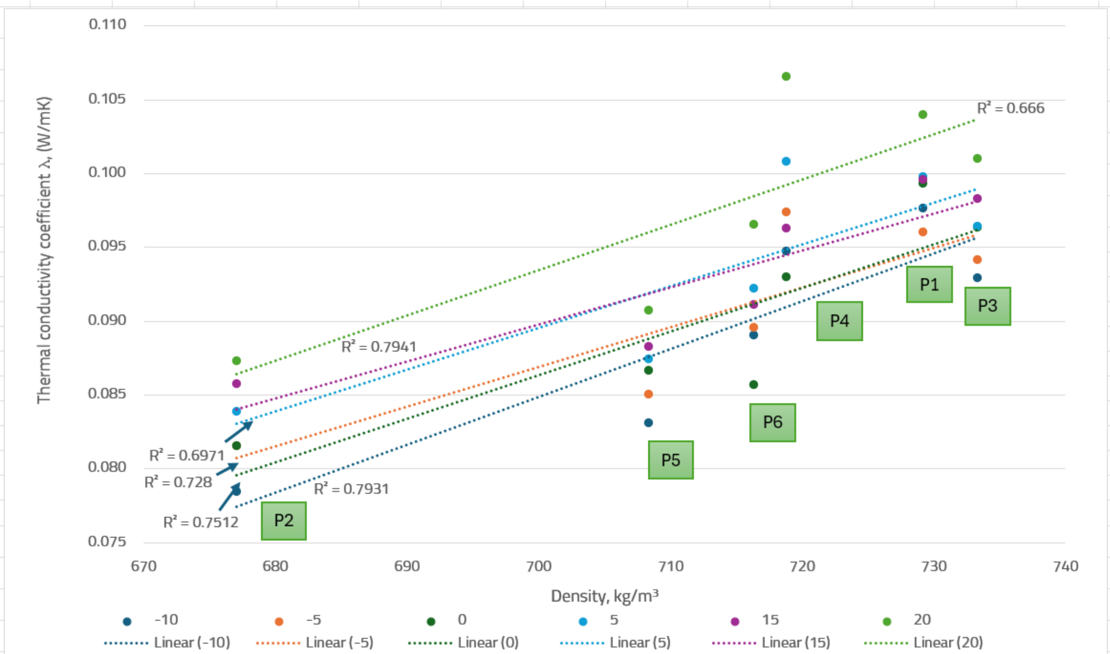


Fig. 31. Correlation between density and thermal conductivity coefficient (according to Brenci 2016)

Similar conclusions regarding the relationship between density and the thermal conductivity coefficient were also stated by Benfratello *et al.* (2013) and Dias *et al.* (2022).

2.3.2.3 Conclusions

Based on the analysis of the results obtained in this research, the following conclusions can be drawn:

- For all mean temperatures at which composites made from eco-friendly materials were tested, thermal conductivity coefficients ranging between 0.078÷0.107 W/mK were recorded. The literature presents thermal conductivity coefficient (λ) values of 1.24±0.18 W/mK and 1.09±0.09 W/mK for composites made of wood shavings and cement, and sawdust and cement, respectively (Dias *et al.* 2022). Other values for λ equal to 2.0 W/mK and 0.8 W/mK were obtained for mixtures made of concrete and sawdust (Hafidh *et al.* 2021) and cement and sawdust (Sosoi *et al.* 2022), respectively. In the case of concrete and hemp composites, the values of λ ranges between 0.09 W/mK and 0.160 W/mK (Collet and Pretot 2014) for sample densities between 480 kg/m³ and 680 kg/m³ .

- The composites produced contain environmentally friendly waste in their structure, which is in line with the guidelines of the circular economy concept of recycling these materials to obtain new products.
- The presence of wood fibres, wool and hemp in the composite structures (P2) led to good thermal conductivity coefficient results;
- The presence of reed in the composite structure led to lower thermal conductivity coefficient values compared to composites that had wood particles in their structure.
- The most efficient structure was that of composite P2, with thermal conductivity coefficient values ranging from 0.078 to 0.087 W/mK. With a density of 677.08 kg/m^3, composite P2 can be used as an insulating material for construction.

2.3.3 Ecological gypsum-based composites

2.3.3.1 Research methodology

The objective of this research (Brenci *et al.* 2014) was to determine the thermal conductivity coefficient (λ) for seven composites made in laboratory conditions, which incorporated ecological materials such as wood particles and hemp particles into their structure, with gypsum used as a binder (Fig. 32 and Tab. 9).

a. b. c.

Fig. 32. Materials used in the manufacturing of composites (Brenci *et al.* 2014)
(a) wood shavings; (b) hemp particles; (c) gypsum

Tab. 9. Quantities of materials used in the manufacturing of composites (Brenci *et al.* 2014)

Composites code	Wood shavings (g)	Hemp particles (g)	Gypsum (g)	Water (g)	Density (kg/m^3)
R1	240	240	1920	870	1044.00
R2	180	180	3240	1434	420.00
R3	240	240	1920	1400	866.67
R4	720	-	2880	2100	1100.00
R5	180	180	3240	2000	1200.00

Composites code	Wood shavings (g)	Hemp particles (g)	Gypsum (g)	Water (g)	Density (kg/m^3)
R6	360	-	3240	2000	1255.00
R7	-	360	3240	2000	1066.00

After weighing the materials, the wood shavings, hemp particles and gypsum were mechanically mixed using a mixer (Fig. 28), then water was added and mixing was continued until the mixture became homogeneous. This was poured into frames made of softwood with interior dimensions of 350 mm x 380 mm x 20 mm. The panels formed in the frame were cold-pressed for 10 minutes (Tab. 10), in a press with plates measuring 500 mm x 500 mm 500 mm x 500 mm (Fig. 33).

Tab. 10. Pressing parameters (Brenci *et al.* 2014)

Composites code	Pressure [bar]	Pressing time [min]
R1	70	10
R2	200	10
R3	40	10
R4	70	10
R5	50	10
R6	50	10
R7	50	10

Fig. 33. Pressing of composites (Brenci *et al.* 2014)

After completing the pressing cycle, the panels were left in the frame to dry at ambient temperature. After five days, they were removed from the frames and cut to their final dimensions of 300 mm x 300 mm, then calibrated to a thickness of 20 mm (Fig. 34). After these operations to obtain the final dimensions, a slight fragility was observed when handling the R2 composite.

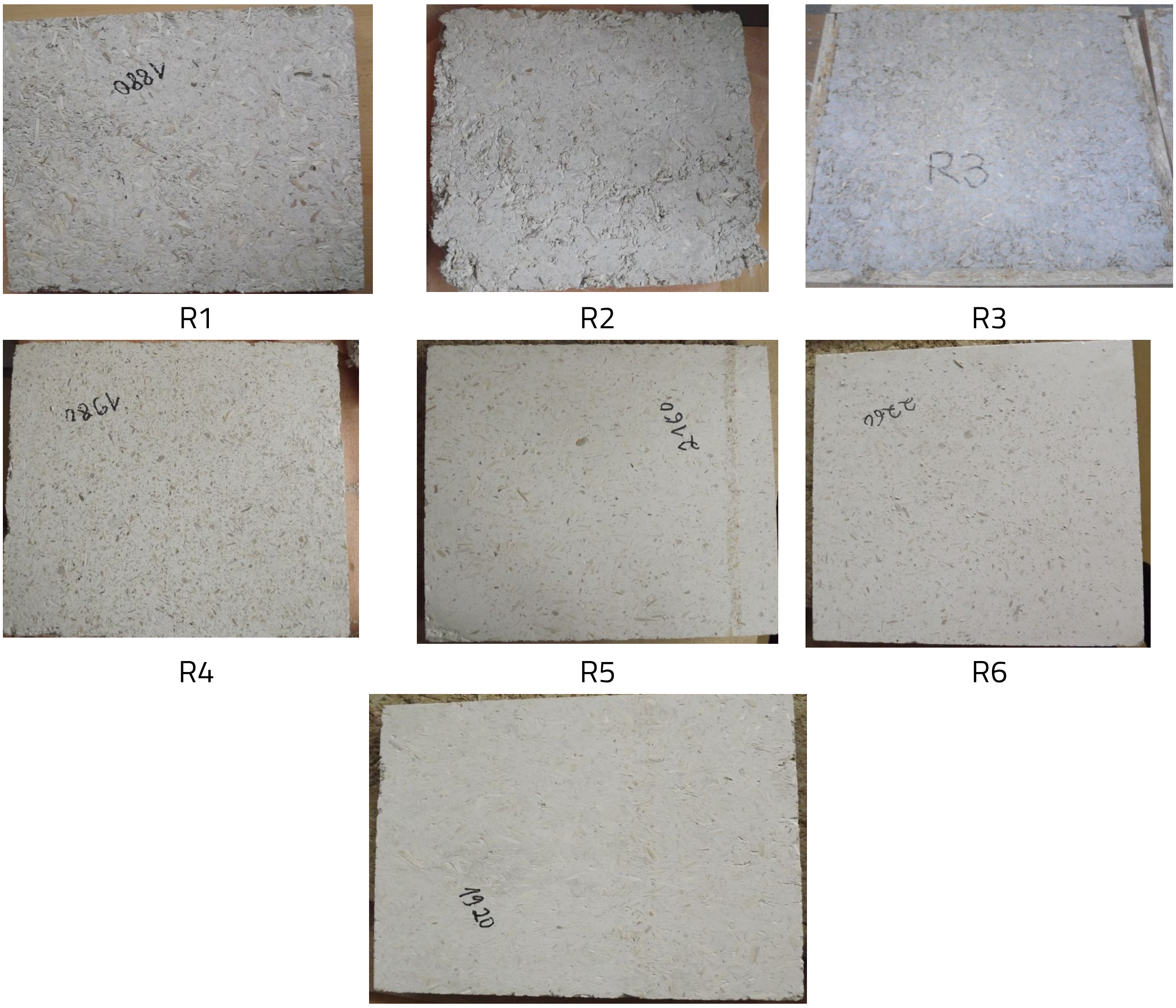


Fig. 34. Composites made from wood and hemp particles (Brenci *et al.* 2014)

2.3.3.2 Results and discussions

Thermal conductivity was measured using HFM436 Lambda equipment (Netzsch, Selb, Germany) (Fig. 8), in accordance with ISO 8301 (1991) and DIN EN 12667 (2001). Once the equipment had been calibrated and the test parameters introduced (Tab. 11), the composites were placed one by one in the equipment to measure their thermal conductivity coefficient.

Tab. 11. Thermal testing parameters for the manufactured composites (Brenci et al. 2014)

Measurement points	Lower plate temperature T1 (° C)	Upper plate temperature T2 (° C)	∆T=T2-T1 (° C)	Mean (T2+T1)/2 (° C)
1	-20	0	20	-10
2	-15	5	20	-5

Measurement points	Lower plate temperature T1 (° C)	Upper plate temperature T2 (° C)	ΔT=T2-T1 (° C)	Mean (T2+T1)/2 (° C)
3	-10	10	20	0
4	-5	15	20	5
5	0	20	20	10
6	5	25	20	15
7	10	30	20	20
8	15	35	20	25

The measurements were taken at eight temperature ranges, for a temperature difference (ΔT) of 20°C. Using the device's software, the thermal conductivity coefficient value was recorded and saved in "txt" files for further processing of the measured experimental data.

Composite panel R1 had the lowest thermal conductivity coefficient values, while R5 had the opposite values (Tab. 12). Composites R1 and R2, containing equal amounts of wood shavings and hemp particles, 240 g and 180 g respectively, recorded lower thermal conductivity coefficient values in the case of panel R1, which demonstrates that the presence of a larger amount of ecological materials leads to a decrease of this value (Fig. 35).

Tab. 12. Measured thermal conductivity values for the manufactured composites (Brenci *et al*. 2014)

Composites code	Thermal conductivity coefficient λ [W/mK]							
	P1	P2	P 3	P 4	P5	P 6	P7	P8
R1	0.139	0.140	0.139	0.143	0.145	0.144	0.130	0.139
R2	0.140	0.140	0.141	0.144	0.145	0.144	0.141	0.140
R3	0.141	0.142	0.142	0.145	0.146	0.144	0.142	0.141
R4	0.141	0.142	0.143	0.146	0.147	0.144	0.143	0.141
R5	0.141	0.142	0.142	0.146	0.146	0.144	0.143	0.141
R6	0.141	0.142	0.143	0.146	0.147	0.144	0.143	0.141
R7	0.143	0.144	0.144	0.148	0.148	0.146	0.145	0.143

Even if panels R1 and R3 contain equal amounts of ecological reinforcement and binder materials (Tab. 9), the excessive amount of water in panel R3 led to higher measured values of the thermal conductivity coefficient. A study conducted by Gourlay *et al.* (2017) on hemp-based concrete showed that the thermal conductivity coefficient value increases almost linearly with water content.

The same situation was found in the case of panels R2 and R5, which contain the same amount of wood shavings and hemp shavings, namely 180 g, but the amount of water added to composite R5 is higher than the amount added to composite R2 (2000 g compared to 1434 g).

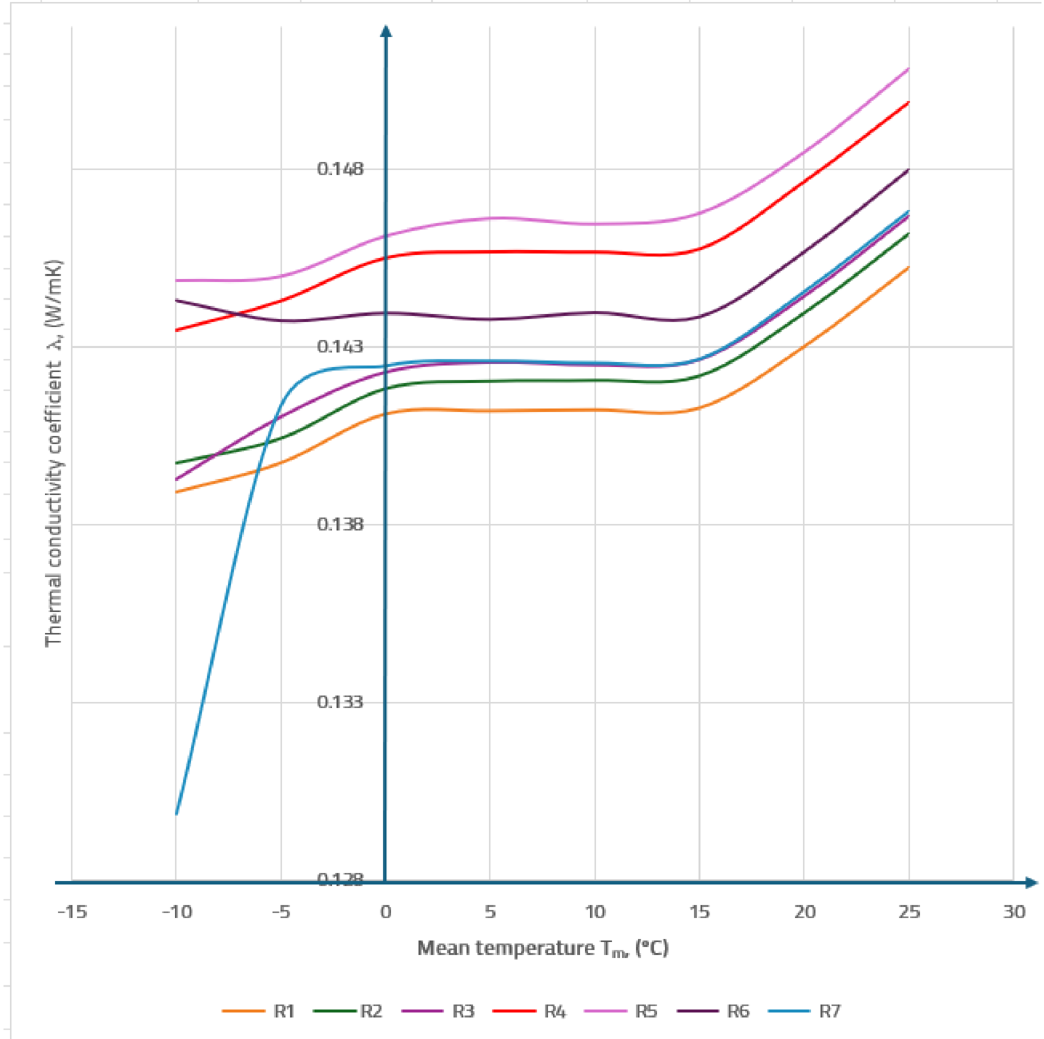


Fig. 35. Thermal conductivity coefficient of the composites manufactured (according to Brenci *et al.* 2014)

In the case of panels R6 and R5, the double amount of wood shavings incorporated into the R6 structure had a positive influence on the thermal insulation capacity of that panel. Thus, the thermal conductivity coefficient values were lower for R6 compared to those of the R5 structure. Panels R6 and R7 contain the same amount of ecological material (360 g), wood shavings for the first and hemp particles for the second. This fact proves that the hemp particles incorporated into the R7 composite have better thermal insulation properties compared to wood shavings contained in the R6 composite.

The correlation between the trend lines for composite density and the thermal performance of the composites produced (Fig. 36), shows low correlations (R^2 = 0.0008) in the case of tests performed at a mean temperature ΔT = -5 °C, and moderate for the other composites, which had an R^2 coefficient between 0.2328 and 0.4043, which indicates an acceptable correlation between the analyzed parameters. Thus, in the case of low correlation, it cannot be stated that a decrease in density is followed by a decrease of the thermal conductivity coefficient.

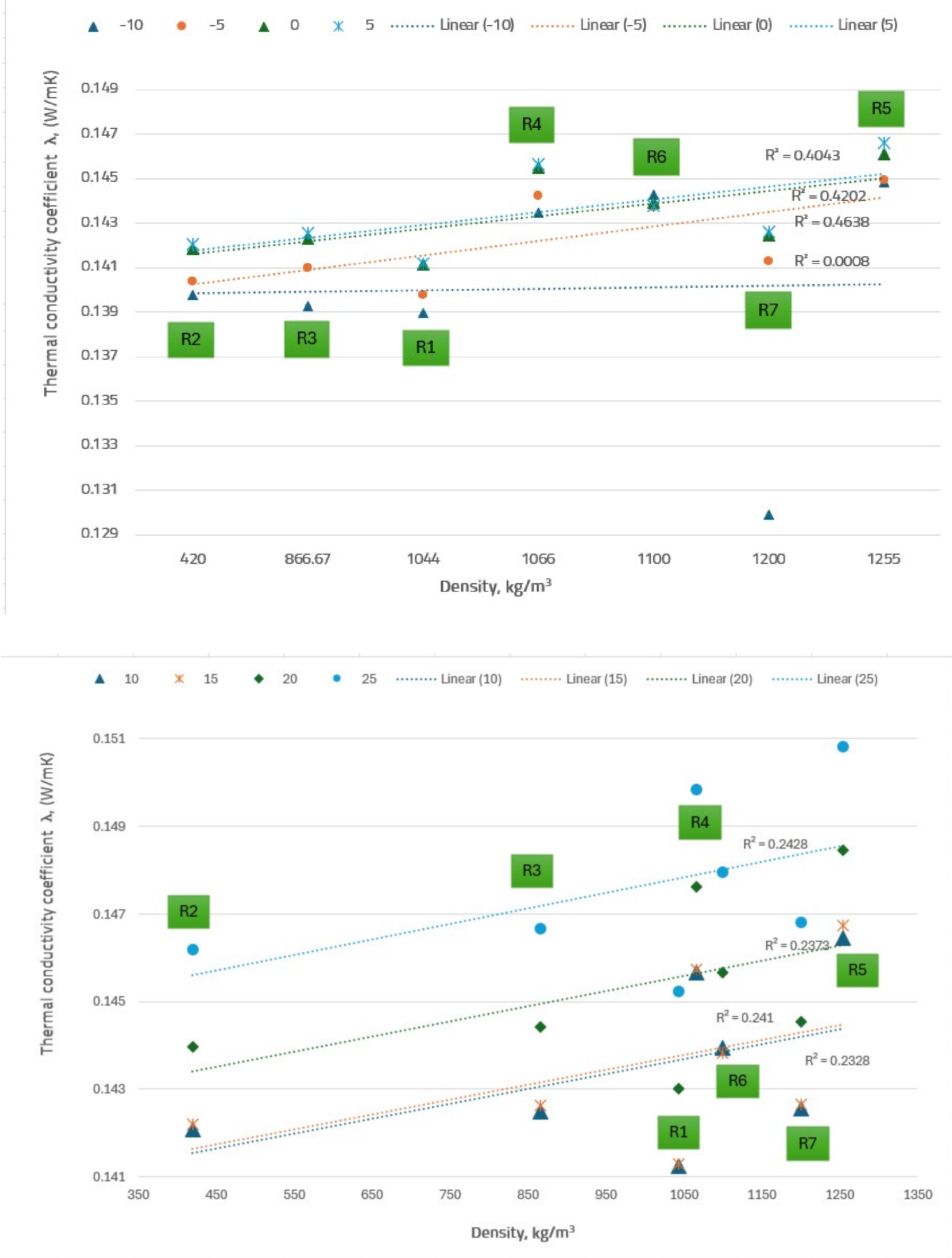


Fig. 36. Correlation between density and thermal conductivity coefficient (according to Brenci *et al.* 2014)

2.3.3.3 Conclusions

Based on the research conducted, the following conclusions can be stated:

- Using waste such as wood shavings and hemp particles in the structure of composites designed for thermal insulation aligns with the circular economy concept, which involves reintroducing them into the product life cycle, thus reducing the carbon footprint on the environmental impact.
- The lowest thermal conductivity values were recorded for structures R1 and R2, which contain equal amounts of wood shavings and hemp shavings, namely 240 g and 180 g, respectively.
- In the case of composites R3 and R1 made up of equal amounts (240 g) of wood shavings and hemp particles, the higher water content in composite R3 (1400 g water) compared to the water content in composite R1 (870 g) has a negative influence on the thermal conductivity coefficient, even if the composition of the reinforcement and binding materials was the same.
- A higher content of hemp particles (composite R7) has led to lower thermal conductivity coefficients compared to the composite that had the same amount of wood shavings in its structure (R6).
- For all average temperatures at which composites manufactured from ecological materials were tested, thermal conductivity coefficients were recorded in the range of 0.129÷0.151 W/mK. These values are slightly higher than those obtained for composites made of wood fiber and wool (λ= 0.078÷0. 107 W/mK Brenci 2016), wood shavings and cement (λ= 1.24±0.18 W/mK Dias *et al.* 2022) and sawdust and cement (λ= 1.09±0.09 Dias *et al.* 2022).
- The best thermal performance was recorded by the R1 composite, which had equal amounts of wood shavings and hemp particles (240 g), 1920 g of gypsum and 870 g of water in its structure. The thermal conductivity coefficient ranged between 0.139 W/mK and 0.145 W/mK. Due to the content of ecological materials found in its structure, the R1 composite is a sustainable product that meets the guidelines defined by the circular economy for recovering this waste in new products. Thus, the R1 composite can be used as an insulating material in construction.

Results dissemination

The results of this chapter were disseminated as follows

1. **Brenci, L.M.**; Coșereanu, C.; Zeleniuc, O.; A., Georgescu, S.V.; Fotin, A. Thermal conductitity of wood with ABS waste core sandwich composites subject to various core modification. BioResoures Journal 2018, 13(1), 555-568. http://doi.org/10.15376/biores.13.1.555-568
2. **Brenci L.M.** Eco-composites designed for thermal and acoustic insulation of buildings. Bulletin of the Transilvania University of Brașov 2016, 9(58), No.2, 45-52. ISSN 2065-

2135 (Print), ISSN 2065-2143.
https://webbut.unitbv.ro/index.php/Series_II/article/view/815

3. **Brenci, L.M.,** Cismaru, I., Fotin, A., Zeleniuc, O. The influence of ecological materiales embendded into composite upon the thermal insulating capacity. PRO LIGNO Journal 2014, 10(4), 63-68. http://proligno.ro/ro/articles/2014/4/brenci.pdf

CHAPTER 3. RESEARCH ON THE QUALITY OF WOOD SURFACES

3.1 GENERAL ASPECTS REGARDING THE QUALITY OF WOOD SURFACES

The quality of wood and wood-based surfaces is one of the most important properties of wood, having an influence on the quality of their coatings. Milling and sanding are woodworking technologies that can provide the propper quality of the coatings. Surface quality depends on a number of parameters related to both the structure of the wood and the processing method. The structure of the wood is influenced by the wood species (Gurău 2013, Magoss 2015, Kamperidou 2020, Brenci and Gurău 2024), density (Kamperidou 2020), grain direction, wood anatomy (Zhong *et al*. 2013) and wood moisture content (Shi and Gardner 2006, Zhong *et al.* 2013, Chavenetidou and Kamperidou 2024). In case of analyzing the machining process, the factors that influence surface roughness are related to the type of processing (Gurău *et al.* 2019, Adamčík et al. 2024), the characteristics of the cutting tool (tool type, cutting angle, cutting edge quality) and the parameters of the cutting regime (feed rate and cutting tool speed, cutting depth) (Salcă and Hiziroglu 2012, Kúdela *et al.* 2018, İşleyen and Karamanoğlu 2019, Gurău 2022, Brenci and Gurău 2024).

After mechanical processing, the quality of surfaces or roughness is defined by the set of irregularities with relatively small steps, which can often be seen in cross-section in the form of "peaks and valleys" (Dogaru 2003, ASME B46.1:2019). Also, according to ASME 46.1 (2109), roughness is defined as a component of surface texture characterized by shorter wavelengths or higher spatial frequencies, comparable to waviness, which is characterized by irregularities with longer wavelengths. According to the same standard (Fig. 37), the processed surface viewed in a normal plane (total profile) consists of the roughness and waviness profile and the total profile, which also takes into account geometric form errors (Gurău *et al.* 2006).

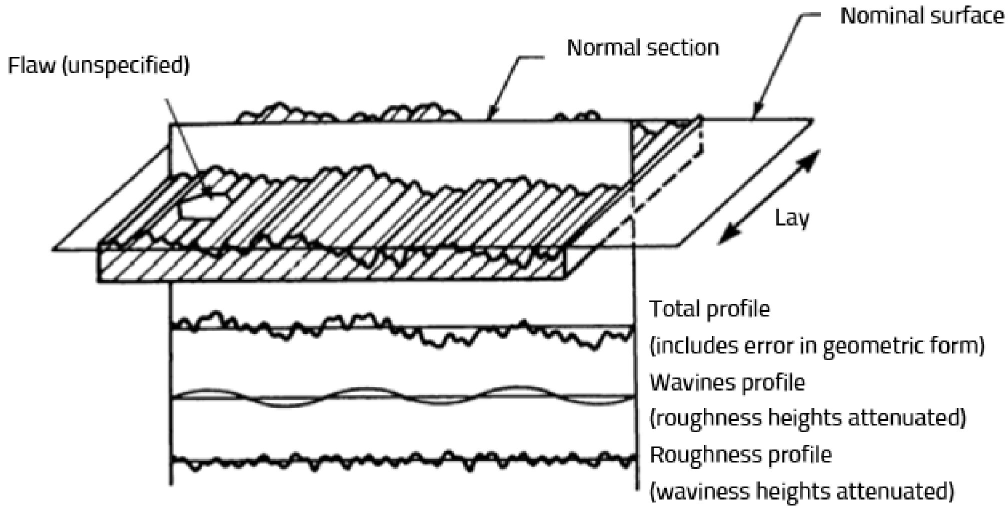


Fig. 37. Schematic diagram of processed surface characteristics (ASME B46.1. 2019)

The irregularities of wood surfaces processed by cutting are characterised, depending on their nature and size, in (Dogaru1981, Dogaru 1985, Dogaru 2003):

- **Macro-irregularities** - represents deviations of surfaces from the regular shape (ovality, concavity, conicity, convexity). These are caused by internal stresses of the wood, the working precision of the machine-cutting tool-workpiece assembly, errors in the positioning of the workpieces, tool wear, etc. Macro-irregularities do not characterize the quality of the machined surfaces, but rather the precision of the shape of the processed workpiece.
- **Waves** - appear as repeated irregularities in the form of raised areas or repeated deep areas that are similar in terms of size. These occur due to the kinematics of the cutting process, vibrations in the machine-cutting tool system and uneven deformations during cutting. Waves can occur due to the elastic recovery of the annual ring areas, vibration irregularities and kinematic undulations. The former occur as a result of uneven compression between the tool cutting edge and the wood, which has different hardness and elasticity in the early and late wood areas that constitute the annual rings. Waves are more common in softwood species and appear as repeated raised and deep areas following the shape of the annual rings. Vibration irregularities appear on the procesed surface in the form of grooves, as a result of oscillations in the machine-tool-workpiece system. The causes of these oscillations are the imbalance of the milling cutter in its rotational motion, insufficient rigidity of the tool on the machine and of the workpiece in the device, rigidity of the machine.
- **Micro-irregularities a**re small irregularities that appear in the form of processing marks, irregularities caused by damage, fuzziness and pull-off of fibres. Processing marks are formed by the cutting edge of the tool and have the shape of grooves, their direction and size depending on the cutting kinematics and the geometric parameters of the tool. (Fig. 38).

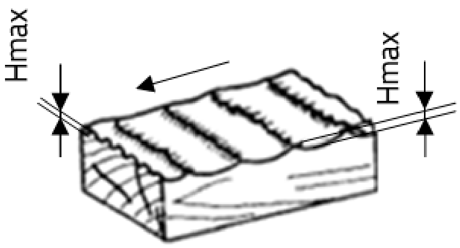


Fig. 38. Micro-irregularities in the form of processing marks (according to Dogaru 1981)

Damage irregularities take the form of cavities, pull-outs and detachments that occur as a result of the fibrous structure of the wood, low resistance to stresses perpendicular to the grain, growth defects, moisture, feed rate per tooth and condition of the tool cutting edges (Fig. 39). They can have values of up to 3 mm, significantly affecting the quality of the processed surfaces.

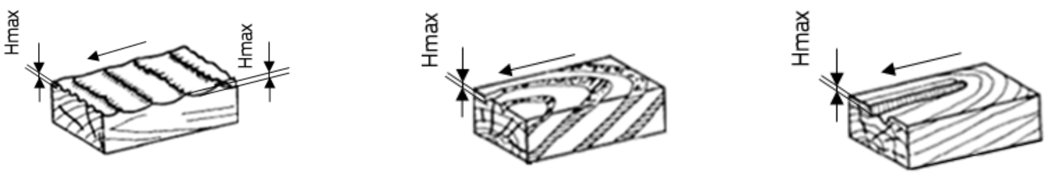


Fig. 39. Micro-irregularities in the form of damage irregularities (după Dogaru 1981)

Fuzziness appears in the form of individual fibers, attached at one end to the processed surface (Fig. 40). These can be flattened or raised on the surface of the wood. Splinters are groups of fibers or fragments of wood that are partially or completely detached from the processed surface. They are caused by the low strength of the wood perpendicular to the fibers, the use of tools with wear on the cutting edges, and inadequate cutting conditions.

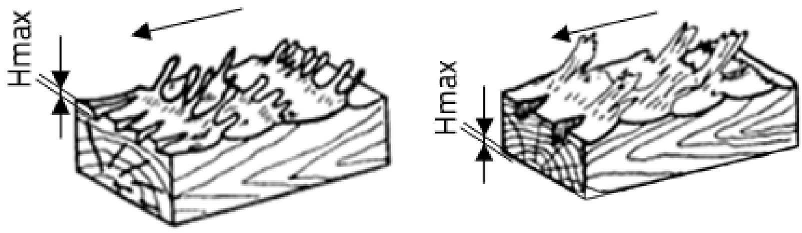


Fig. 40. Micro-irregularities presented as fuzzy grain (according to Dogaru 1981)

Shape deviations characterize the accuracy of processing, as they represent deviations from the nominal shape, which are caused by internal stresses in the wood, or errors in the machine-tool-workpiece system (Gurău *et al.* 2006). These will be removed by applying a regression using the smallest squares method (Gurău *et al.* 2006, ISO 4287:1997) to obtain the primary profile of the investigated surface. The primary profile obtained contains the waviness and roughness profiles (Gurău *et al.* 2006, Gurău *et al.* 2017).

In the case of ISO 21920:2021, which replaces ISO 4287:1997 and ISO 13565-2:1996, the method for obtaining the primary profile is different from the old ISO 4287 standard, which means that new filters have been introduced for the measured profiles (Filtration Techniques for Surface Texture (https://guide.digitalsurf.com/en/guide-filtration-techniques.html).

As can be seen in Fig. 41, the operations applied on the measured profile are the same, except that the order of application of the S and F filters has been reversed. In the case of the ISO 3274 (1996) standard, in order to obtain the primary profile, the shape must be removed, after which a λs filter (introduced by ISO 3274 and ISO 4288) is applied, which removes the micro-roughness from the profile. In the case of the new standard (ISO 21920), the primary profile is obtained by applying an S filter (λs), after which the shape errors are removed by an F operator.

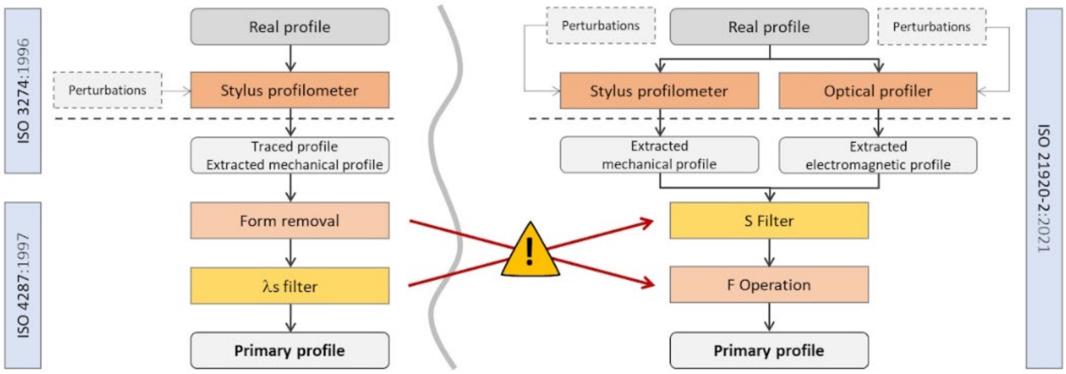


Fig. 41. Differences between ISO 4287:1997, ISO 13565-2:1996 and ISO 21920:2021 21920:2021 (according to Filtration Techniques for Surface Texture https://guide.digitalsurf.com/en/guide-filtration-techniques.html)

The development of new standards related to surface texture (ISO 25178-2:2021) led to the definition of a new vocabulary, which was then transposed into the ISO 21920 series of standards on roughness profiles. These introduced two types of filters, S and L, which are defined according to their mode of action (https://www.digitalsurf.com/blog/is-the-s-filter-equivalent-to-the-old-%CE%BBs-filter/):

- The S filter (ISO 21920:2021) is a smoothing filter that attenuates wavelengths shorter than the cut-off wavelength. If the S filter is associated with a cut-off wavelength N_{is} (the letter "s" refers to λs), then it refers to a micro-roughness filter (with a short cut-off length), and when referring to a cut-off length N_{ic} (the letter "c" refers to λc), it refers to a ripple filter.
- The L filter (ISO 21920:2021) attenuates wavelengths that are longer than the cut-off length and is used to obtain roughness with a cut-off length $N_{ic,}$

Another new feature included in the ISO 21920 standard refers to the method of estimating roughness parameters, so that a single value is calculated for them over the evaluation length. In the old ISO 4287 standard, the parameters were estimated by taking the arithmetic mean of the values measured on the five sampling lengths within the profile evaluation length. The only exception is for parameters related to peaks and valleys (Rp, Rv, Rz), which are calculated over section lengths (equivalent to sampling lengths) to avoid obtaining unreliable results.

At present, no specific standard for wood can be applied to assess the roughness of wood surfaces; instead, the general standards and recommendations for metals or other homogeneous materials must be applied (Gurău and Irle 2017). However, due to the structure of wood, the presence of anatomical cavities can:

- negatively influence the data obtained through using specific measuring instruments (Gurău *et al.* 2001, Sinn *et al.* 2009, Gurău and Irle 2017);

- distort the primary profile after shape removal (Gurău *et al.* 2009);
- distort the filtered roughness profile (Gurău 2004, Gurău et al. *2005*, Gurău *et al.* 2009, Tann *et al.* 2012);
- affect the measured results (Gurău *et al.* 2015).

All these limitations necessitated a series of measures aimed at using a longer measurement length (Gurău *et al.* 2011) and establishing an appropriate measurement resolution (Gurău *et al.* 2013). Furthermore, in a study conducted by Gurău and Irle (2017), they made recommendations on how to choose the measuring instrument (with SR EN ISO 3274:2001 probe), the investigation length (40–50 mm), and the resolution (5 μm) selected when measuring the roughness of wood surfaces. To eliminate waviness due to the processing process, it is recommended to use the Robust Gaussian Regression Filter (RGRF) (ISO 16610-31:2025), which is suitable for investigating wood surfaces, because deep valleys in the anatomical structure, as well as accidental high peaks that do not characterize the processing, can be considered aberrant values (Gurău *et al.* 2014, Gurău and Irle 2017, Tan *et al.* 2012, Piratelli-Filho *et al.* 2012, Gurău 2022).

The research carried out has revealed a series of roughness parameters that can be measured in order to determine the quality of wood and wood-based surfaces obtained through various technologies and processing methods such as turning, milling, sanding, laser cutting, and finishing. The roughness parameters used in research conducted to characterize the condition of wood and wood-based surfaces in accordance with ISO 4287 are:

- Ra – is the arithmetic average of the absolute values of the roughness profile (Gurău and Irle 2017; Gurău *et al.* 2022; Srivabut *et al.* 2022; Zhong *et al.* 2013; Magoss 2008; Salcă and Hiziroglu 2014; Gurău *et al.* 2019; İşleyena and Karamanoğlu 2019; Gurău *et al.* 2019; Gurău and Brenci 2025; Brenci and Gurău 2024; Fotin *et al.* 2013a; Fotin *et al.* 2013a; Fotin *et al.* 2010; Brenci 2009);
- Rz – the maximum profile height, which is the sum of the largest profile peak height and the absolute of the largest profile valley depth within a sampling length (Gurău and Irle 2017; Gurău *et al.* 2022; Srivabut *et al.* 2022; Zhong *et al.* 2013; Magoss 2008; Salcă and Hiziroglu 2014; İşleyena and Karamanoğlu 2019; Fotin *et al.* 2010);
- Rt – total height of the profile (Gurău and Irle 2017; Gurău *et al.* 2019);
- Rv – is the depth of the deepest profile valley of the roughness profile within one sampling length (Gurău *et al.* 2022; Gurău *et al.* 2022; Gurău *et al.* 2019; Brenci and Gurău 2024);
- Rq – Root Mean Square roughnes, is a key surface texture parameter measuring the standard deviation of profile heights from the mean line, making it more sensitive to large peaks/valleys than the common Ra (arithmetic mean). (Gurău and Irle 2017; Srivabut *et al.* 2022; Gurău *et al.* 2019);

- Rsk - asymmetry of a profile height distribution around its mean line; a negative Rsk indicates more valleys, a positive Rsk means more peaks and a value ear zero suggests a symmetrical, balanced surface (like a Gaussian distribution) with fewer extreme peaks/valley (Gurău *et al.* 2022; Brenci and Gurău 2024);
- Wa - arithmetic mean deviation of the waviness profile (Gurău *et al.* 2022; Brenci and Gurău 2024);
- Rsk – profile asymmetry (Gurău *et al.* 2019);
- Rsm - average width of profile elements. Used to characterise the effect of grinding marks in terms of their width (Gurău *et al.* 2019);
- Wa – Arithmetic Mean Waviness, measures the average deviation of a surface waviness profile from its mean line, representing broader, longer-wavelength surface variations distinct from fine roughness (Gurău *et al.* 2019);
- Wt – total height of the waviness profile (Gurău *et al.* 2019; Gurău and Brenci 2025);

The roughness parameters defined by the ISO 13565-2 standard that have been analysed in the literature are:

- Rk – core roughness, is the depth of the roughness core profile. This is the parameter that best describes machining roughness (Gurău and Irle 2017; Magoss 2008; Gurău *et al.* 2019; Gurău and Brenci 2025; Brenci and Gurău 2024, Fotin *et al.* 2013a; Fotin *et al.* 2013a; Ispas *et al.* 2011; Brenci *et al.* 2011; Brenci *et al.* 2012; Fotin *et al.* 2012; Fotin *et al.* 2011; Fotin *et al.* 2010; Fotin *et al.* 2010; Brenci 2009);
- Rpk – reduced peak depth - is the mean height of the peaks protruding from the roughness core profile. This is a parameter for assessing the raised fibres (Gurău and Irle 2017; Magoss 2008; Gurău et al. 2019; Gurău and Brenci 2025; Brenci and Gurău 2023; Fotin *et al.* 2013a; Fotin *et al.* 2013a; Ispas *et al.* 2011; Brenci *et al.* 2011; Brenci *et al.* 2012; Fotin *et al.* 2012; Fotin *et al.* 2011; Fotin *et al.* 2010; Brenci 2009);
- Rvk - reduced valley depth, is the mean depth of the valleys protruding from the roughness core profile. It is a parameter for assessing anatomical roughness (Gurău and Irle 2017; Magoss 2008; Gurău *et al.* 2019; Gurău and Brenci 2025; Brenci and Gurău 2023; Fotin *et al.* 2013a; Fotin *et al.* 2013a; Brenci *et al.* 2011; Brenci *et al.* 2012; Fotin et al. 2012; Fotin *et al.* 2011; Brenci 2009);
- A1 – peak area measured in μm^2 /mm (Brenci and Gurău 2024);
- A2 – valley area measured in μm^2 /mm (Brenci and Gurău 2024).

Once the ISO 21920:2021 standard was approved, the parameters studied in the research were:

- Ra – arithmetic mean deviation of the roughness profile (Chavenetidou and Kamperidou 2024; Adamčík *et al.* 2023; Laskowska *et al.* 2025);
- Rz – maximum profile height (Chavenetidou and Kamperidou 2024; Adamčík *et al.*

2023; Laskowska *et al.* 2025);

- Rq – the root mean square deviation (Chavenetidou and Kamperidou 2024);
- Rv – Maximum depth of the profile (Adamčík *et al.* 2023);
- Rp – average height of peaks (Adamčík *et al.* 2023);
- Rt – total height of the profile (Adamčík *et al.* 2023).

3.2 METHODS FOR MEASURING THE ROUGHNESS OF WOOD SURFACES

According to published research, there are no instruments specifically designed for measuring the roughness of wood surfaces and wood-based products. However, instruments available on the market for measuring metal surfaces can also be used for wood products. Investigations carried out over time have shown that the use of testing instruments with a tip radius of 2 µm (according to ISO 3274:2001) and an angle of 90° are suitable for investigation (Funck et al. 1993). Also, Gurău et al. (2001) showed that to detect irregularities in the wood surface and provide the most accurate data, using contact instruments is more effective than non-contact (laser) ones. Sandak and Tanaka (2002) observed that the laser beam tends to smooth out surface profile irregularities.

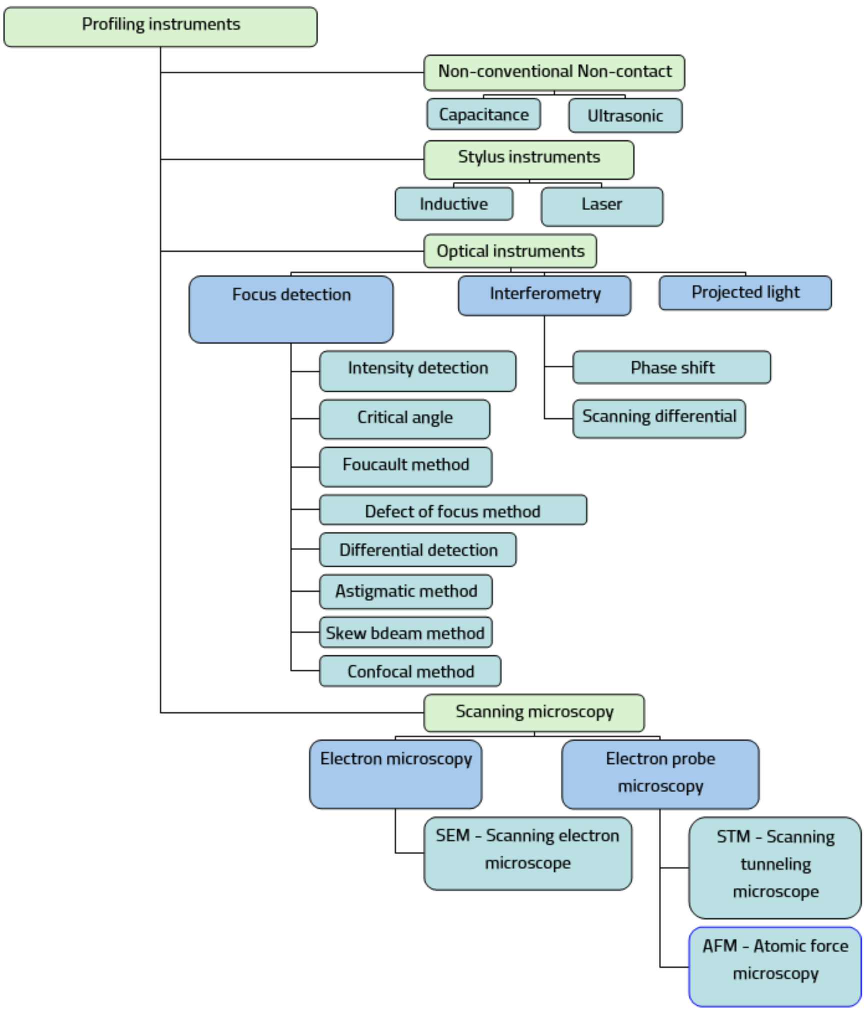


Fig. 42. Instrument classification for setting up the profile (according to MacKenzie 2008)

Measuring wood roughness with a laser involves non-contact laser displacement sensors (LDS - Laser Displacement Sensors) or imaging systems that analyse how laser light interacts with the wood surface. These provide quantitative data by tracking surface profiles or analysing scattered light. Laser measurement-based methods capture detailed information about the 3D surface, allowing for accurate assessment of wood quality. These laser investigation methods (Latticq *et al.* 2000; Goli and Sandak 2016) have shown that, due to the porosity of wood and the reflection of the wood surface, they cannot always accurately characterise surface roughness. According to MacKenzie (2008), the classification of profile analysis instruments is presented in Fig. 42.

A comparative study between 3D optical measurement using a surface roughness measuring instrument based on the triangulation method using a 3D laser, and 2D measurement using a stylus with a peak angle of 90° and a peak radius of 2 µm, on 14 wood species with sanded and planed surfaces, was conducted by Magoss et al. (2020). The results showed that the evaluation of the Abbott curve parameters, Rk+Rpk+Rvk and Sk+Spk+Svk, shows considerable deviations, especially for samples with high density. In the case of rosewood from Thailand (*Dalbergia cochinchinensis* P.), the Abbott parameters measured by the laser method were three times higher than those measured with the probe. The explanation for this phenomenon is due to the light reflection properties of these species. In the case of *Pinus sylvestris*, Magoss *et al.* (2020) observed that due to the colour difference between early and late wood, disturbances in the optical system occurred. Similarly, Sandak and Tanaka (2003) investigated 15 wood species with different densities and colours by measuring roughness using a non-contact method with a laser displacement sensor (LDS). They concluded that surface quality assessment generates errors in the case of dark-coloured and high-density wood species.

3.3 QUALITY OF MILLED SURFACES

Assessing the quality of the surface after wood processing is very important in order to determine the impact of different sets of processing parameters (Thoma *et al.* 2015; Hazir and Koc 2016; Hazi and Koc 2019). When referring to surface quality, the optimization of milling operations must take into account the minimization of finishing processes, which will also be reflected in the associated cost (Brenci 2005). Therefore, it is important to find a combination of appropriate machining parameters in order to obtain a low surface roughness. In addition, the roughness of the wood surface is very complex and represents an overlap of morphological characteristics, such as waviness, raised fibers, cutting tool marks, anatomical voids in the wood, as well as possible defects in the processing surface, such as material detached from the surface (Gurău 2004; Thibaut *et al.* 2016; Gurău and Irle 2017). Taking these aspects into account, the most commonly used roughness parameters, such as Ra or Rz, cannot provide a complete view of the source of the various irregularities present on a processed surface.

According to studies by Gawroński (2013), Sutcu (2013) and Koc *et al.* (2017), cutting parameters affect the roughness of beech wood surfaces. The study conducted by Gürgen et al. (2022) on *Pinus sylvestris* after CNC milling showed that the surface roughness decreased with increasing rotation speed and decreased with decreasing the feed speed for all machining parameters. The evaluation of surface roughness for different cutting depths revealed that the maximum surface roughness value was recorded when processing with the highest cutting depth.

Most researchers have used Ra and Rz parameters (Sutcu 2013; Koc *et al.* 2017; Gürgen *et al.* 2022; Hazir *et al.* 2016; Pakzad *et al.* 2013; Rabiei and Yaghoubi 2023; Zhu *et al.* 2022) to evaluate wood quality after milling, but these parameters do not take into account the nature of wood irregularities and include the inherent anatomical voids of wood in the evaluation. In a study conducted by Kok *et al.* (2017) on beech (*Fagus orientalis)*, Ayous (*Triplochiton Scleroxylon)* and MDF, which were processed on a CNC, it was found that the Ra and Rz parameters decreased when processimg with a lower feed speed and higher cutting tool speed. Similarly, in another study by Rabiei and Yaghoubi (2023), the roughness of CNC-machined beech wood, whose surface roughness was evaluated by the Ra parameter, decreased with decreasing feed speed and processing depth, and increasing tool spindle speed, respectively. However, these two parameters investigated by the researchers are not sufficient to properly assess the quality of wood and wood-based surfaces, which means that they must be evaluated together with other roughness parameters (Gurău 2004).

Kilic *et al.* (2006) evaluated the effect of milling on the surface roughness of beech and poplar wood. Based on statistical analysis, they found no significant differences between the surface roughness determined on tangential and radial surfaces. They also noted that a number of roughness parameters, such as Ra, Rz, Rk, Rpk, and Rvk, are useful and can be combined to evaluate the quality of the wood surface.

Magoss (2008) also studied the influence of cutting tool edge wear on surface roughness for several species (oak, larch, beech, and pine) machined by CNC milling. The experimental results showed that the Rk parameter, which measures core roughness and provides the best approximation of tool marks, can be an important indicator of tool edge wear. In the case of beech wood, the Rk value after milling with a wear tool was approximately twice as high as the value obtained when milling with a sharp tool.

Gurău *et al.* (2021) investigated the surface roughness of larch wood *(Larix decidua* Mill.) cut with a laser and milled on a CNC machine at different feed speeds, using the parameters: Ra, Rp, Rv, Rsk, Wa, Pa, Pt and the Abbot curve parameters: Rk, Rpk and Rvk, to better understand the effect of machining on the topography of the wood surface. Learning from the above studies, it can be concluded that a complex surface such as of wood, requires a larger set of roughness parameters capable to differentiate between the various layers of irregularities present on a processed surface.

3.3.1. Research on the quality of beech (*Fagus sylvatica* L.) surfaces processed by profile milling

The objective of this research (Brenci and Gurău 2024) was to analyse the quality of beech wood surfaces processed by profile milling with different cutting regimes. The influence of milling cutter wear on the processed surfaces was also investigated. A comprehensive set of standard parameters for surface characterisation was used to evaluate roughness: Ra, Rv, Rsk and Wa (ISO 4287:2009), as well as the Abbot curve parameters: Rk, Rpk, Rvk, A1 and A2 (ISO 13565-2:1998). The milling of the reference pieces was carried out in the laboratories of the Faculty of Furniture Design and Wood Engineering, and the investigations into the quality of the machined surfaces were carried out at the Research and Development Institute of Transilvania University of Brașov. These parameters allow the surface quality to be analyzed in terms of stratified levels of irregularities, thus distinguishing between the marks left by the cutting tool, the raised fibers, and the accidental voids in the surface that overlap the deep anatomical cavities of the wood, such as the pores in early wood. This type of analysis provides a deeper understanding and better quantification of the interaction between the tool and the wood material, which will contribute to the accurate selection of the most adequate cutting parameters. To avoid errors caused by the simple Gaussian filter contained in most measuring instruments, a robust Gaussian regression filter, tested and considered suitable for wood (Gurău and Irle 2017; ISO/TS 16610-3:2010), was used to measured these parameters.

3.3.1.1 Research methodology

Beech wood (*Fagus Sylvatica* L.) was processed by profile milling in two passes to obtain profiles with a maximum depth of 16 mm. Milling was performed along the grain, obtaining test pieces with dimensions of 1000 mm x 50 mm x 20 mm (Fig. 43).

Fig. 43. Test pieces milled from beech wood

Fig. 44. The cutter head used in the milling process (Brenci și Gurău 2024)

The beech wood pieces were processed on a vertical spindle milling machine, using a milling cutterhead with four profiled blades mechanically fixed in its body (manufactured by S.C. ASCO Codlea) (Fig. 44). The dimensions and geometry of the milling head and the dimensions of the cutters are presented in Tab. 13. The body of the milling cutterhead was manufactured from C45 carbon steel (EN ISO 683-1 2016), and the cutters from C120 tool steel (EN ISO 4957 2018).

Tab. 13. Geometric and dimensional parameters of the milling cutterhead (Brenci and Gurău 2024)

Milling cutterhead characteristics	Diameter D (mm)	Width B (mm)	Bore diameter d (mm)	Clearance angle α (°)	Rake angle γ (°)
Geometric and dimensional parameters	178	40	30	25	18
Cutters sizes	Length (mm)	Width (mm)	Thickness (mm)	Profile height (mm)	Cutter number
	58	40	7.2	16	4

The profiled milling was performed with two rotation speeds, namely 3308 rpm (marked with n1) and 6594 rpm (marked with n2) and two feed speeds, v_{f1} = 6.53 m/min respectively v_{f2} = 23.74 m/min. In order to study the influence of cutting parameters on the quality of milled surfaces, the cutting operations were performed taking into account the following combinations: n1-v_{f1}, n1-v_{f2} , n2-v_{f1} and n2-v_{f2} (Tab. 14). A second set of samples was prepared, by using the same cutting parameter combinations, but after the tool milled 600 m of beech wood. The intention was to observe the impact of wearing the cutter edges on the surface quality, when the same working variables are used.

Tab. 14. The machining parameters (Brenci and Gurău 2024)

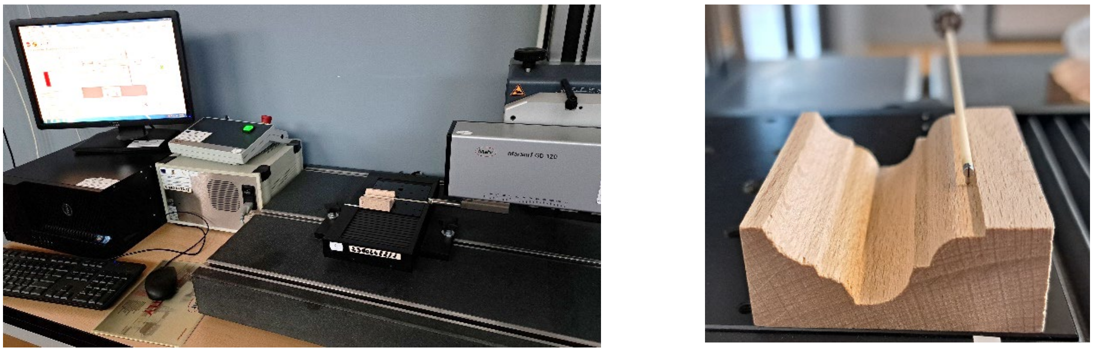
Tool rotation n (rpm)		Feed rate v_f (m/min)		Measured point	Depth profile (mm)	Cutting speed v_c (m/s)	Feed per tooth f_z (mm/tooth)	
n1	3308	v_{f1}	6.53	Point 1	2	28.39	f_{z11}	0.49
		v_{f2}	23.74				f_{z12}	1.79
n2	6594	v_{f1}	6.53			56.59	f_{z21}	0.25
		v_{f2}	23.74				f_{z22}	0.90
n1	3308	v_{f1}	6.53	Point 2	8	29.43	f_{z11}	0,49
		v_{f2}	23.74				f_{z12}	1,79
n2	6594	v_{f1}	6.53			57.66	f_{z21}	0,25
		v_{f2}	23.74				f_{z22}	0,90
n1	3308	v_{f1}	6.53	Point 4	16	30.82	f_{z11}	0.49

Tool rotation n (rpm)		Feed rate v_f (m/min)		Measured point	Depth profile (mm)	Cutting speed v_c (m/s)	Feed per tooth f_z (mm/tooth)	
		v_{f2}	23.74				f_{z12}	1.,79
n2	6594	v_{f1}	6.53			61.43	f_{z21}	0.25
n2	6594	v_{f2}	23.74			61.43	f_{z22}	0.90
n1	3308	v_{f1}	6.53	Point 3	10	29.78	f_{z11}	0.49
n1	3308	v_{f2}	23.74	Point 3	10	29.78	f_{z12}	1.79
n2	6594	v_{f1}	6.53	Point 3	10	59.35	f_{z21}	0.25
n2	6594	v_{f2}	23.74	Point 3	10	59.35	f_{z22}	0.90

The strips, of each cutting case combination, were further shortened to 60 mm x 50 mm x 20 mm specimens available for inspection. The samples were labelled to identify their cutting parameters combination. Three samples were selected from the first set of data (sharpened tool) and two samples from the second set of data (after tool wear), for each rotation speed and feed speed combination (n1-v_{f1}, n1-v_{f2}, n2-v_{f1} and n2-v_{f2}), for both tool conditions: sharpened and after wear. This meant 20 processed samples were available for the surface quality measurement.

3.3.1.2 Roughness measurement

The surface morphology of the beech samples was measured with a MarSurf XT20 equipment manufactured by MAHR Gottingen GMBH, Göttingen, Germany (Fig. 45a). It was used an MFW 250 scanning head with a tracing arm in the range of ±750 μm, and a stylus with 2 μm peak radius and 90° peak angle (Fig. 45b).



a. b.

Fig. 45. Measurements of surface morphology

(a)) MarSurf XT20 profilometer and data acquisition;

(b) linear surface scanning by stylus (zone 1 in Fig. 47) (Brenci and Gurău 2024)

For measuring the beech milled profiles, only the straight zones were considered as marked by red arrows in Fig. 46. The depth of the marked points was:

- 2 mm for point 1;
- 8 mm for point 2;

- 16 mm for point 3;
- 10 mm for point 4.

This decision was drawn from the requirement that the stylus remains normal to the processed surface. Further studies will take into consideration the possibility to measure round profiles as well, by using adequate supports. Four profiles, 30 mm long, were measured from the numbered zones (Fig. 46) along the milling direction with a speed of 0.5 mm/s, a scanning force of 0.7 mN, and a resolution of 5 µm. This meant 4 profiles taken from each sample. In case of the first set of samples, there were 12 profiles for one parameters combination. For all 4 parameter combinations (ex. n1-v_{f1}; n1-v_{f2}; etc), the total number of measurements reached 48.

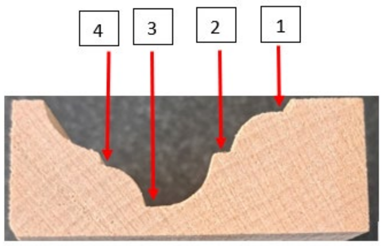


Fig. 46. Sample cross-section with four zones of linear measurement
(Brenci and Gurău 2024)

Data acquired was further processed with MARWIN XR20 software provided together with the measuring equipment. Data evaluation began with removing any unwanted form errors, followed by a procedure of filtering with a Robust Gaussian Re-gression Filter, contained in ISO/TS 16610-31 (2025). In this way, the measured data were separated by filtering the wavelengths of irregularities in waviness profiles and roughness profiles, corresponding to W parameters for the longest wavelengths, while R parameters evaluated the shortest wavelengths. The cut-off length used for filtering was 2.5 mm, recommended for wood surfaces (EN ISO 638-1:2016; EN ISO 4957:2018). After filtering, a number of useful parameters were calculated, such as: Ra (arithmetic mean deviation of the roughness profile), Rv (the largest absolute profile valley depth), Rsk (skewness of the profile), Wa (arithmetic mean deviation of the waviness profile) according to ISO 4287 (2009). In addition, Rk (the core roughness depth), Rpk (the reduced peak height), Rvk (the reduced valley depth), A1 (represents the upper area calculated as the area of the triangle equivalent to the peaks above the roughness core profile, measured in µm^2/mm), A2 (valley area in µm^2/mm) were employed according to ISO 13565-2 (1998).

The parameters from ISO 13565-2 (1998) are particularly useful to characterize the stratified structure of a processed surface. Compared with other parameters, Rk depends the least on the wood anatomical structure and measures the height of the core roughness, the region defined by the highest concentration of data points in a measured profile, which excludes isolated peaks and valleys. For a milling process it can be an approximation of the tool marks left on wood. Instead, Rpk is defined by the isolated peaks, which for a wood species, according to Westkämper and Riegel (1993), can be considered an evaluation of wood raised grain and fuzziness of the surface. The fuzziness is caused by groups of fibers that are attached to the surface at only one end. Rvk is defined by isolated valleys, which in case of wood can be caused by accidental material pull-out during processing and/or deep anatomical cell lumens.

In order to monitor the surface quality in the case of cutting tool wear, 600 linear metres of the same material were milled in the same conditions. After this process, the beech wood was processed again using the same milling combinations. The surface quality of the new samples was measured on 8 test pieces (from the same 4 combinations of speeds and feed rates) in the same way as when the tool had sharp cutting edges, resulting in a total of 32 measurements.

3.3.1.3 Stereo-microscopy analysis

A stereo-microscope NIKON SMZ 18-LOT2 (Nikon Instruments, Melville, United States) was used for the microscopic investigations of the profile milled beech samples. In focus was the straight zone 1 from Fig. 46. In order to better observe the occurrence of the raised fibers and possible surface defects such as material detachment, the samples were tilted by approximately 45°.

3.4.1.4 Statistical analysis

The surface quality parameters were tested for their significance for all processing combinations (rotation speed-feed speed). The software used was an IBM SPSS Statistics version 23.

3.4.1.5 Results and discussion

The mean values and standard deviation for parameters evaluated in this analysis are contained in Tab. 15.

Tab. 15. The mean values roughness parameters (in μm) (Brenci and Gurău 2024) (in parenthesis standard deviation is presented)

Tool condition	Processing parameters	Ra	Rk	Rpk	Rvk	Rv	Rsk	Rpk/ Rvk	Rk+ Rpk+ Rvk	A1/A2	Wa
Sharpened	3308-6.53 ($n1$-v_{f1})	5.74 (0.94)	12.10 (1.70)	6.81 (2.19)	18.43 (5.30)	46.02 (13.25)	-2.02 (0.58)	0.37 (0.41)	37.34 (6.62)	0.18 (0.22)	6.79 (1.18)
	3308-23.74 ($n1$-v_{f2})	7.4 (0.88)	14.99 (3.41)	16.51 (6.21)	20.77 (3.24)	46.98 (5.12)	-0.71 (0.91)	0.79 (1.92)	52.27 (5.48)	0.54 (1.11)	14.81 (2.20)

Tool condition	Processing parameters	Ra	Rk	Rpk	Rvk	Rv	Rsk	Rpk/ Rvk	Rk+ Rpk+ Rvk	A1/A2	Wa
	6594-6.53 (n2-v_{f1})	4.83 (0.67)	10.19 (1.94)	7.54 (2.30)	11.64 (2.52)	30,40 (7.52)	-1.08 (1.00)	0.64 (0.91)	29.37 (4.49)	0.48 (0.79)	5.38 (0.90)
	6594-23.74 (n2-v_{f2})	6.59 (0.82)	16.02 (2.38)	10,68 (3,35)	16.39 (3.29)	42.29 (10.06)	-1.01 (0.89)	0.65 (1.02)	43.09 (5.32)	0.39 (0.50)	11.83 (2.99)
After 600m milling length	3308-6.53 (n1-v_{f1})	4.46 (0.63)	10.15 (1.38)	6.24 (1.83)	12.27 (3.17)	30.43 (8.02)	-1.34 (0.97)	0.51 (0.61)	28.66 (3.71)	0.28 (0.34)	10.28 (1.85)
	3308-23.74 (n1-v_{f2})	4.93 (0.63)	12.26 (2.09)	8.67 (4,00)	13.54 (2.71)	35.37 (4.93)	-1.15 (0.87)	0.64 (1.48)	34.46 (5.33)	0.42 (1.58)	12.35 (5.65)
	6594-6.53 (n2-v_{f1})	5.03 (1.62)	10.93 (2.11)	9.71 (4.72)	14.24 (8.02)	36.09 (14.57)	-0.99 (1.49)	0.68 (0.59)	34.89 (11.90)	0.47 (0.45)	10.44 (2.31)
	6594-23.74 (n2-v_{f2})	4.97 (0.70)	11.43 (1.15)	7.12 (3.60)	14.42 (3.67)	36.38 (9.79)	-1.50 (0.88)	0.49 (0.98)	32.96 (4.66)	0.29 (0.59)	10.47 (4.20)

The surface morphology was first studied by considering the largest wavelengths irregularities produced by milling on the surface, namely the surface waviness. This can be observed directly comparing primary profiles, which contain both: roughness and waviness (Fig. 47), selected for the four groups/combinations of rotation speeds and feed speeds.

It can be seen from Fig. 47 , that an increase in the feed speed from vf1 to vf2 (3.6 times) has increased surface waviness, in the primary profiles, for both rotation speeds. The profiles are considerable wavier, containing large undulations. This observation is in agreement with the values of Wa parameter, which doubled in case of both rotation speeds (Fig. 48).

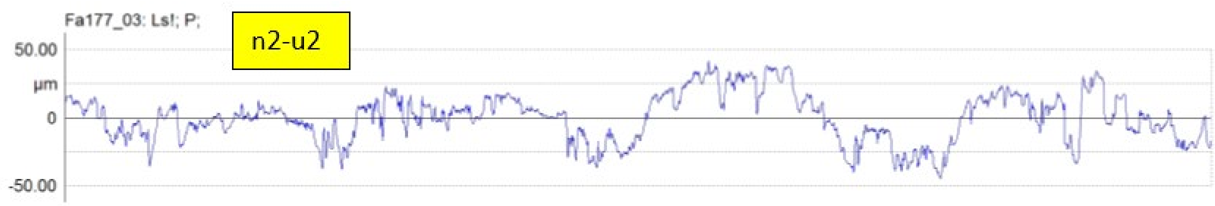


Fig. 47. Primary profiles containing waviness and roughness together, for the four combinations of rotation speeds and feed speeds (when the tool was sharpened) (Brenci and Gurău 2024)

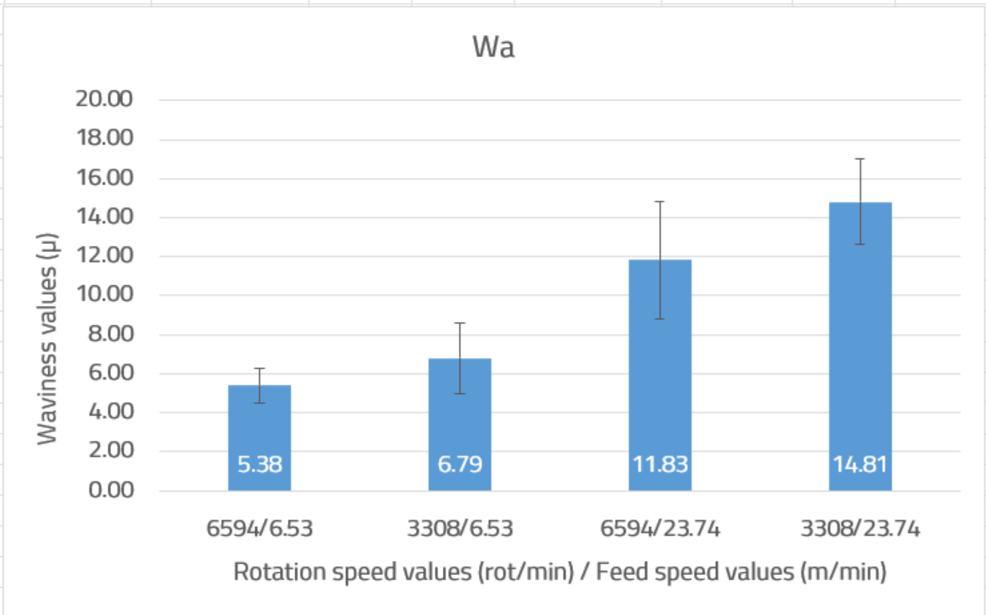


Fig. 48. The variation of waviness parameter, Wa, with combinations of the rotation speed with the feed speed (according to Brenci and Gurău 2024)

This result was statistically significant for $p<0.05$ (test ANOVA, followed by Dunnett T3 multiple comparisons) (Tab. 16 and Tab. 17). An explanation may be that an increase in the feed speed is increasing tool vibration, which leaves deeper waves in the surface. When the rotation speed almost doubled from n1 to n2, a decrease of 20% in surface waviness was measured, but this reduction had no statistical support (Tab. 15).

Tab. 16. Dependent variable Wa - Test between groups effects. (Brenci and Gurău 2024)

Source	Sum of squares	df	Mean square	F	Sig
Grupuri	693.397	3	231.132	51.894	0,000

Tab. 17. Dependent variable Wa - Dunnet T3 Post Hoc Test for multiple comparisons between groups of rotation speed-feed rate (Brenci and Gurău 2024)

Groups	Mean difference	Standard error	Sig

n1-v_{f1}	n1-v_{f2}	-8.017 [1]	0.82	0.000
	n2-v_{f1}	1.415	0.58	0.141
n2-v_{f2}	n1-v_{f2}	-2,98	1.07	0.063
	n2-v_{f1}	6.45 [1]	0.90	0.000

[1] The error term is Mean Square (error) = 4,454. The mean difference is significant at the 0.05 level

Fig. 50 displays the roughness profiles measured for each pair rotation speed- feed speed. With red ellipses isolated raised fibers are marked, while the yellow ellipses indicate isolated deep valleys.

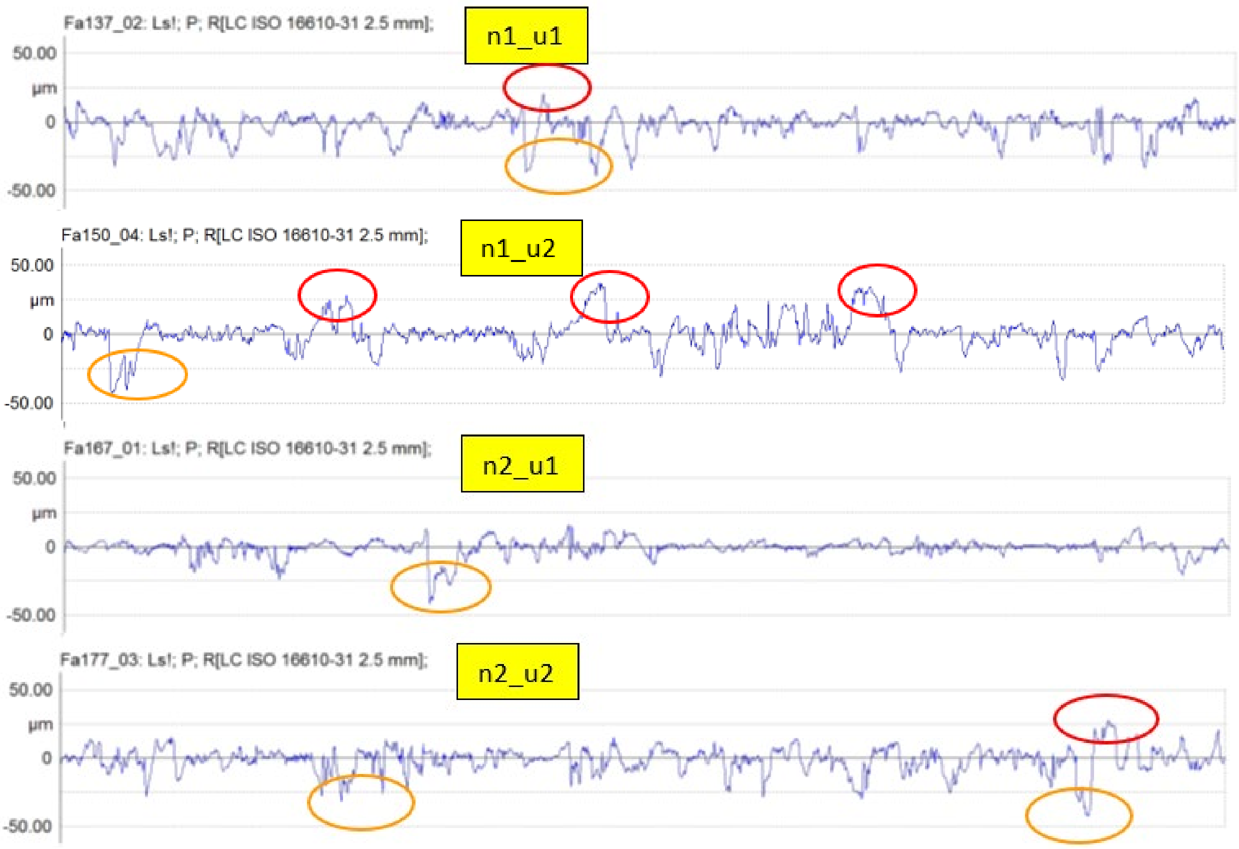


Fig. 49. Roughness profiles of each group combination, rotation speed-feed speed. Raised fibers are marked with red, deep isolated valleys are marked with yellow ellipse (Brenci and Gurău 2024)

From definition, the core roughness of the roughness profiles does not contain the isolated deep valleys associated with the deep pores from earlywood or isolated detached wood material, nor the isolated raised fibers or surface fuzziness. Instead, it can be viewed as the density of data above and below the zero line. Therefore, it appears that an increase in the feed speed is causing more dispersion above and below the zero line (Fig. 50), which translated in an increase in Rk.

These visual observations are confirmed by the measured Rk values, which increased, when the feed speed increased, by 24% for n1 and by a significant 57% for n2 (from 10.19 μm to 16.02 μm) (Fig. 49). Therefore, it can be concluded that an increase in the feed speed increases the core roughness Rk and more pronounced when the rotation speed increases as well (Fig. 50). Also, a visual examination of the roughness profiles in Fig. 49 shows a reduction in Rk when the feed speed was kept constant while the rotation speed increased. For example, an increase in the rotation speed from n1 to n2, decreased Rk by approximately 16% for the v_{f1} feed speed. However, the effect on Rk of changing the rotation speed was not significant. Similar trends to Rk were observed in the values of Ra parameter (Fig. 51), for which an increase in the feed speed has caused a significant increase, no matter which rotation speed was used.

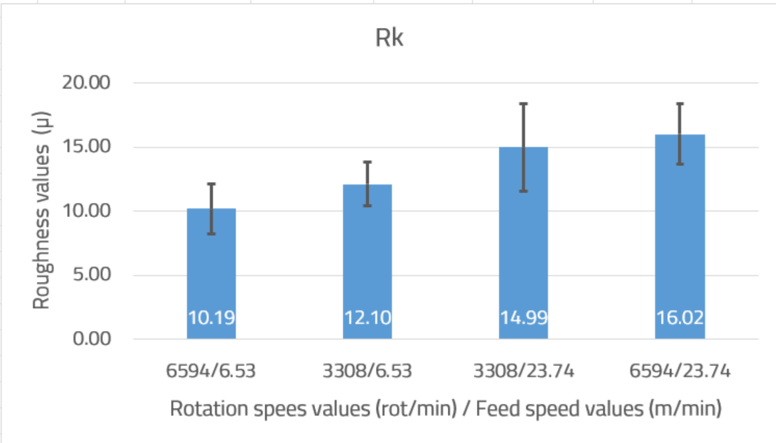


Fig. 50. The variation of the core roughness parameter, Rk, with combinations of the rotation speed with the feed speed (according to Brenci and Gurău 2024)

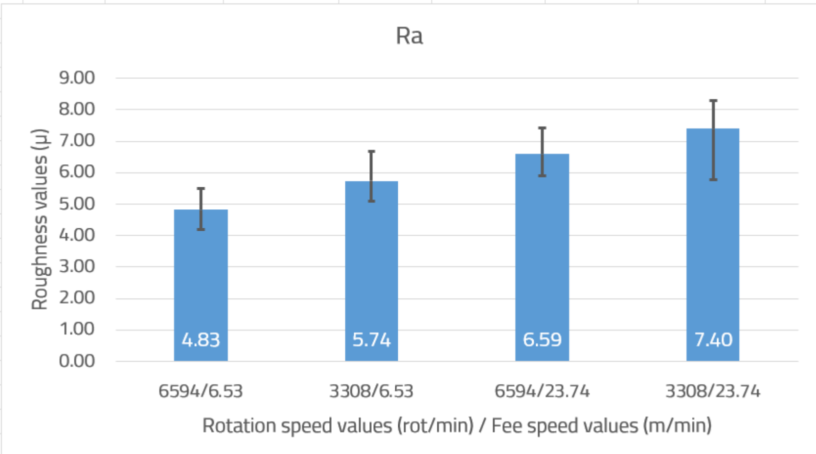


Fig. 51. The variation of the mean roughness parameter, Ra, with combinations of the rotation speed with the feed speed (according to Brenci and Gurău 2024)

Another morphological aspect studied in relation to the processing parameters was the raised fiber. For the rotation speed n1=3308 rot/min, the increase more than 3.6 times in the feed speed from v_{f1}=6.53 m/min to v_{f2}=23.74 m/min has caused Rpk to increase 2.4 times (from 6.81 µm to 16.51 µm) which was statistically significant (ANOVA followed by Dunnett T3). This means, that an increase in the feed speed is rising the wood fiber (Fig. 52).

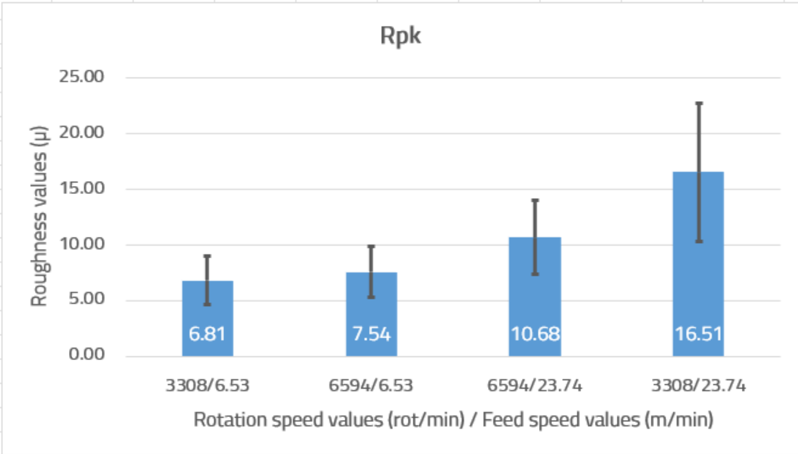
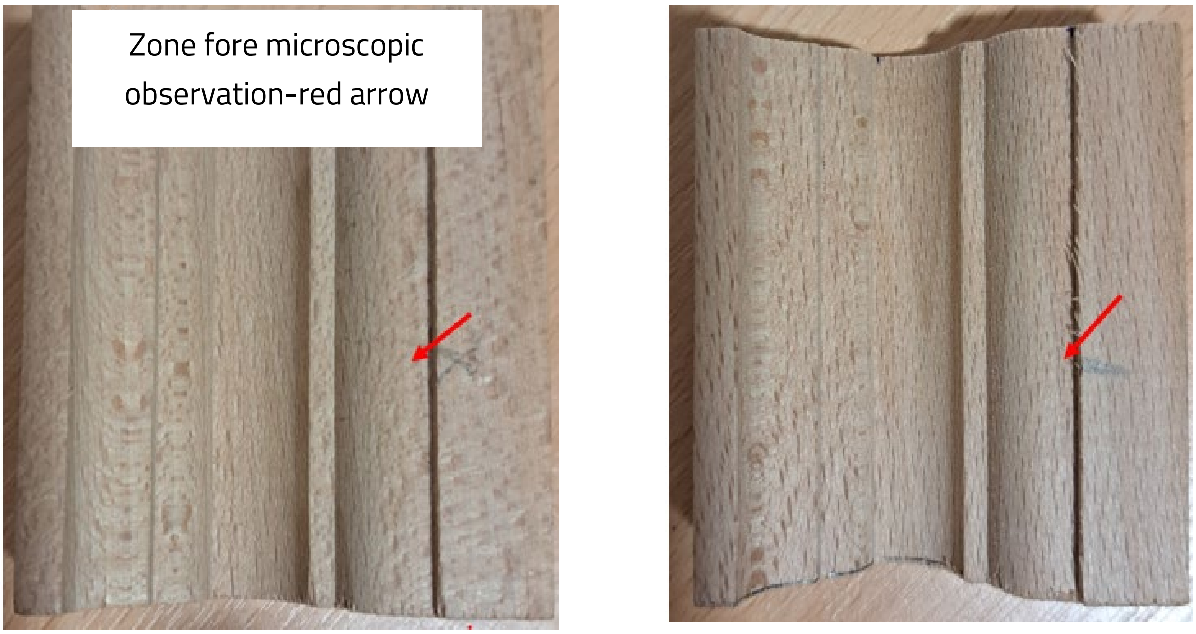
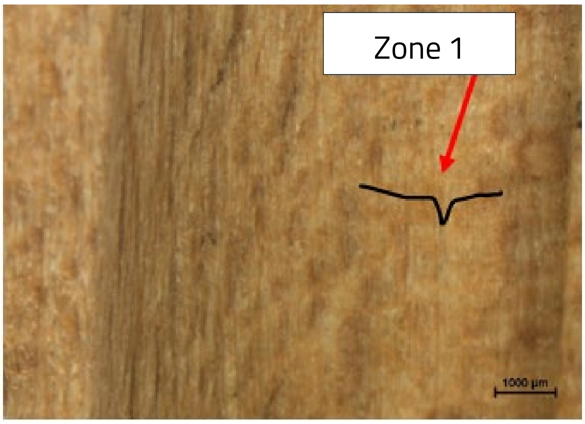


Fig. 52. The variation of the reduced peak heights parameter, Rpk, with combinations of the rotation speed with the feed speed (according to Brenci and Gurău 2024)

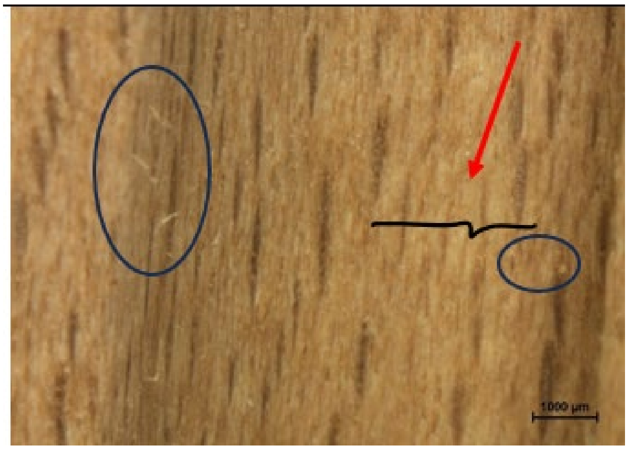
This increase can also be observed from the microscopical images in Fig. 53c și Fig. 53d, illustrating a detail of zone 1, zone depicted with red arrows in Fig. 53a, Fig. 53b. . The raised fibers also appear in the roughness profiles, where they are encircled in red (Fig. 49). For the rotation speed n2, although Rpk increased by 42% when the high feed speed was used and some raised fibers are visible in the roughness profiles, this had no statistical support. The increase in the rotation speed does not produce any significant effect regarding fuzziness or raised fiber.



a. b.



c.



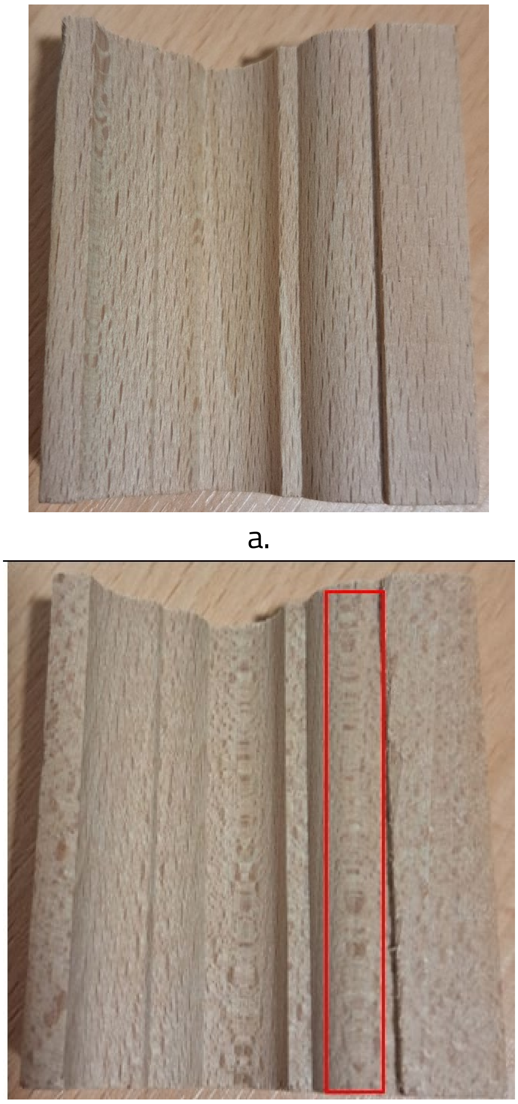
d.

Fig. 53. Images of beech milled profiles (a, b)) and microscopic details; (c, d) at magnification 22.5x; (a, c) processing by n1-v_{f1}; (b, d) processing by n1-v_{f2} (Brenci and Gurău 2024)

As is well known, wood is a stratified heterogeneous material and apart from outliers located above the core roughness it also has outliers located below the core roughness. They can be seen as surface gaps (Fig. 49 – zone exemplified by yellow ellipses). Their origin can be deep anatomical cavities going below the marks caused by the cut-ting tool, but can also include accidental surface gaps when wood material is detached leaving unwanted voids in the material. Both of them will depend on the type and proportion of anatomical cells encountered by the cutting plane. The weakest zones should be those from the earlywood and those coinciding with the wood rays (radial surfaces).

The processed samples did not consider a certain top wood surface orientation, which varied from radial to tangential and combinations like semi-radial and semi-tangential. For the above-mentioned reasons, the parameter Rv, which measures the deepest valley in the profile, had a high standard deviation (Tab. 15) in comparison with the core roughness Rk, depending on the local wood anatomy. Furthermore, Rv had values in the range of early-wood pores cavities reported for beech (8-45-85 μm) (Wagenführ 2000) (p. 707), with majority of them around the mean values given in the literature (45 μm), while some of the deepest valleys were below 70 μm.

These observations can lead to the assumption that the isolated deep valleys seen in the roughness profiles, in most cases, belong to inherent wood anatomical cavities and are not processing defects. Exception made the situations in which the cutter encountered radial surfaces and this caused detachment of some ray tissues, as can be seen in Fig. 54b, which significantly increased Rv (Fig. 55), with app.40%, for the feed speed v_{f2} in comparison with v_{f1} (Tab. 15, Fig. 54).



a.

b.

Fig. 54. Samples processed by milling with n2 rotation speed. (a) Feed speed v_{f1}; (b) Feed speed v_{f2} . The red rectangle exemplifies a radially cut surface which contains detached ray tissues (Brenci and Gurău 2024)

Wood pores went beyond the marks left by the tool on wood and this is observed by a negative Rsk and a subunitary ratio Rpk/Rvk. The same is true for the ratio A1/A2, which indicates a larger share of the area of the valleys compared to the area of the peaks (Tab. 15). An increase in the rotation speed from n1 to n2 has significantly reduced Rv (Fig. 55) with app.33% for the feed speed v_{f1} (ANOVA and Dunnett T3).

For optimization of the cutting quality and selection of the best working parameters, the tool marks are of interest. From this perspective, Rk parameter is representative and has shown it is significantly influenced by the feed speed and was less affected by the selection of the rotation speed. The surface fuzziness and accidental material detachment will be species dependent and of wood local anatomy. However, their effect on the overall surface quality cannot be neglected.

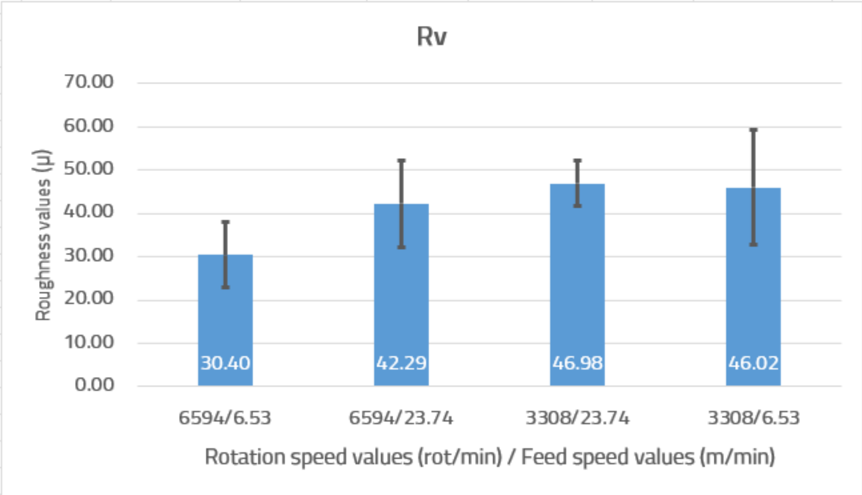


Fig. 55. Variația celei mai adânci văi, Rv, cu combinații ale vitezei de rotație cu viteza de avans (according to Brenci and Gurău 2024)

A statistical analysis ANOVA followed by Dunnett T3 test performed on the cumulative effect of processing plus the raised fiber (Rk+Rpk), has led to the same conclusions as in case of Rk alone: the feed speed was the most important factor affecting the surface quality by milling. Although the surface quality has improved by increasing the rotation speed, its effect was not significant (Tab. 18 and Tab. 19).

Tab. 18. Dependent variable Rk+Rpk - Test between groups' effects. (Brenci and Gurău 2024)

Source	Sum squares	df	Mean square	F	Sig
Grupuri	1541.92	3	513.97	30.7	0

Tab. 19. . Dependent variable Rk+Rpk - Dunnet T3 Post Hoc Test for multiple comparisons between groups rotation speed-feed speed (Brenci and Gurău 2024)

Groups	Mean difference	Standard error	Sig	Groups
n1-vf1	n1-vf2	-12.59 [1]	513.97	0.000
	n2-vf1	1.17	1.26	0.921
n2-vf2	n1-vf2	-4.80	1.99	0.134
	n2-vf1	8.96 [1]	1.55	0.00

[1] The error term is Mean Square (Error)= 16.738. The mean difference is significant at the 0.05 level

The best surface quality was obtained when combining n2 (6594 rot/min) with v_{f1} (6.53 m/min) and the worst when the rotation speed n1 (3308 rot/min) was combined with the high feed speed v_{f2} (23.74 m/min), as shown in Fig. 56.

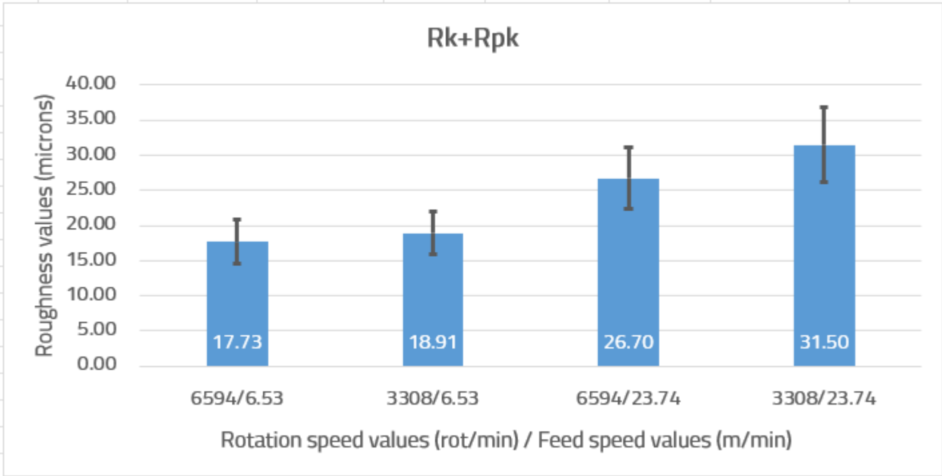


Fig. 56. The variation of the cumulative parameter Rk+Rpk with combinations of the rotation speed with the feed speed (according to Brenci and Gurău 2024)

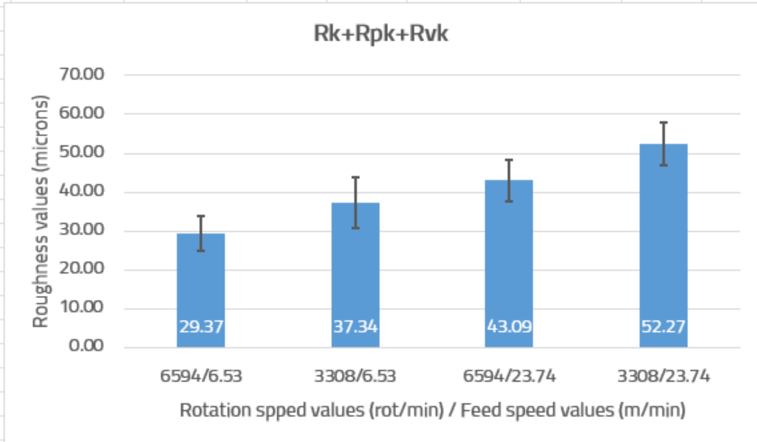


Fig. 57. The variation of the cumulative parameter Rk+Rpk+Rvk with combinations of the rotation speed with the feed speed (according to Brenci and Gurău 2024)

When the surface isolated gaps were included, together with the tool marks and the raised fiber, not only the feed speed was a significant factor, but also the rotation speed, the surface quality improving for the highest rotation speed n2 in comparison with n1 (Fig. 57, Tab. 20 and Tab. 21).

Tab. 20. Dependent variable Rk+Rpk+Rvk- Test between groups effects (Brenci and Gurău 2024)

Source	Sum of squares	df	Mean square	F	Sig
Grupuri	3350.23	3	1116.74	36.49	0.000

Tab. 21. Dependent variable Rk+Rpk+Rvk - Dunnet T3 Post Hoc Test for multiple comparisons between groups rotation speed-feed speed (Brenci and Gurău 2024)

Groups	Mean difference	Standard error	Sig	Groups
n1-vf1	n1-vf2	-14.93 [1]	2.28	0.00

Groups	Mean difference	Standard error	Sig	Groups
	n2-vf1	7.97 [1]	2.30	0.015
n2-vf2	n1-vf2	-9.18 [1]	2,20	0.002
	n2-vf1	13.72 [1]	2.00	0.00

[1] The error term is Mean Square (Error)= 30.6. The mean difference is significant at the 0.05 level

Fig. 58 presents a comparison of the roughness profiles for the two situations, namely the processing of beech wood with a cutter that had sharp cutting edges and the processing after 600 linear metres of the same material had been milled. From the profiles presented in Fig. 58 it can be seen that after milling 600 linear metres of material, the surface quality improved (Fig. 59). The improvement in surface quality was noticed both in terms of tactile and visual perception (Fig. 59c,d).

Fig. 58. Roughness profiles of each group combination, rotation speed-feed speed comparing the effect of tool condition (sharpened and after wear). Raised fibers are marked with red, deep isolated val-leys are marked with yellow ellipse (Brenci and Gurău 2024)

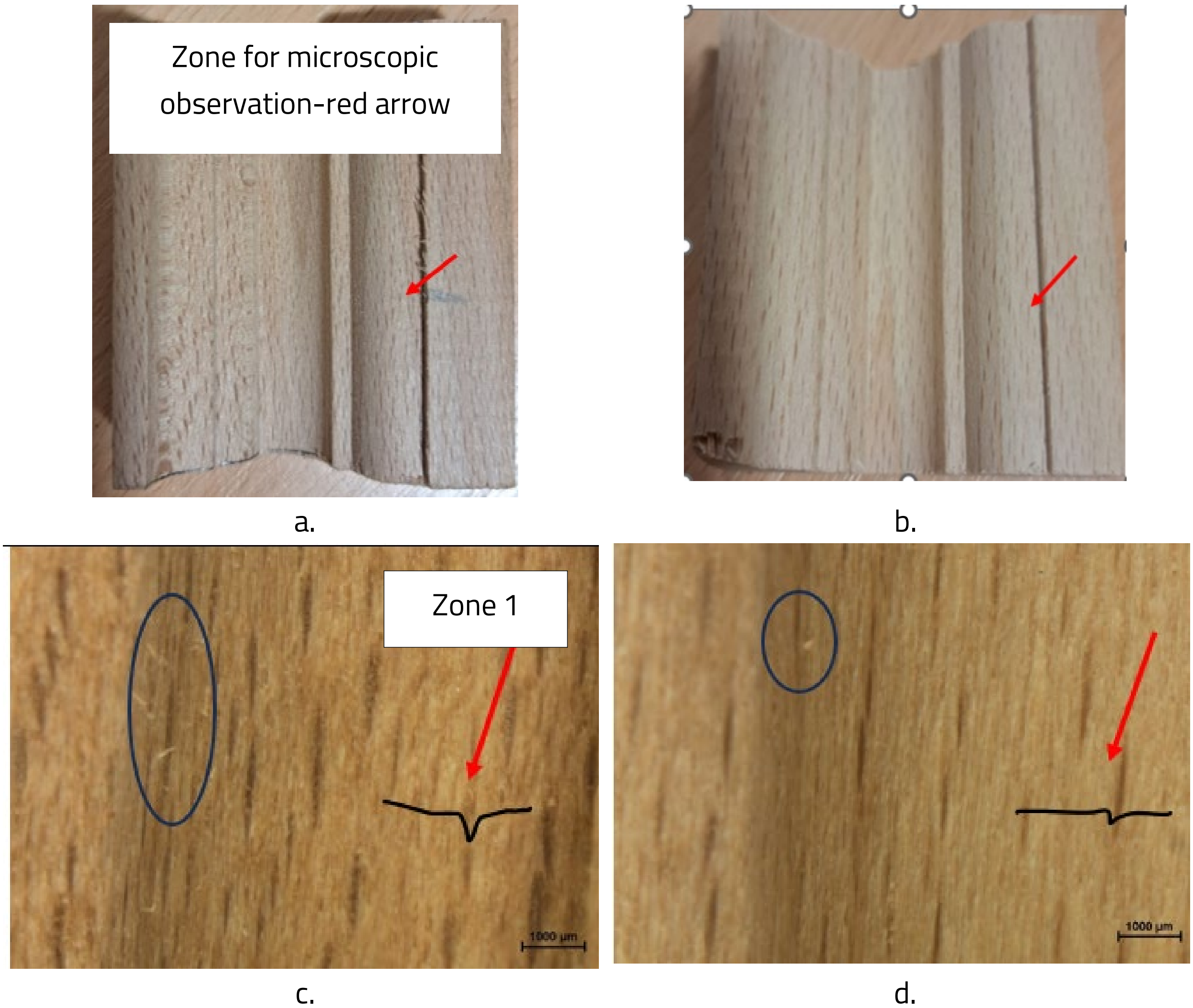


Fig. 59. Images of beech milled profiles (a, b) and microscopic details (c, d) at magnification 22.5x. (a, c) processing by n1-v_{f2}, sharpened tool; (b, d) processing by n1-v_{f2}- wear tool after 600 m profile milling. Raised fibers are encircled with blue. (Brenci and Gurău 2024)

A statistical comparison of the composed parameter Rk+Rpk+Rvk was performed in order to get a global evaluation of the surface improvement. The ANOVA test fol-lowed by a Post. Hoc test Games-Howell (groups had unequal number of measurements), indicated a surface improvement after the tool was working 600 m, which was significant when the high feed speed was used (v_{f2}=23.74 m/min). The improvement was quantified to 30% roughness decrease for the rotation speed n2 and to 34% when the rotation speed n1 was used. This result is an indication that the surface quality is not only depending on the wood material and the processing parameters, but also by the tool working load, which is expected to vary with the milling parameters, as well as with the species types.

3.3.1.6 Conclusions

The study has shown that the surface quality should be analyzed on stratified levels of irregularities differentiating between, waviness, tool marks, fuzzy grain, and accidental surface gaps overlapped onto the wood deep anatomical cavities, such as pores from earlywood. This is because the milling quality will be dependent not only on the processing parameters and tool characteristics, but also on the wood species and its anatomical structure.

The conclusions of the research carried out are as follows:

- An increase in the feed speed is increasing tool vibration, which leaves deeper waves in the surface. The surface waviness measured by Wa increased more than double when the feed speed increased app.3.6 times, from v_{f1}=6.53 m/min, to v_{f2}=23.74 m/min. Increasing the rotation speed from n1 la n2) has decreased Wa with 20%.
- An increase in the feed speed increases the toolmarks approximated by Rk and are more pronounced as the rotation speed gets higher. Rk increased with the feed speed for n2= 6594 rot/min by a significant 57%. An increase in the rotation speed from n1 to n2 has reduced Rk, but the effect was not significant. For example, an increase in the rotation speed from n1 to n2, decreased Rk by app.16% for the vf1 feed speed. Similar behaviour was noticed for Ra parameter.
- An increase in the feed speed is rising the wood fiber. Therefore, the Rpk parameter increased 2.4 times when the feed speed increased 3.6 times. The increase in the rotation speed does not produce any significant effect regarding fuzziness or raised fiber.
- Wood pores were deeper than the marks left by the tool on wood and their effect on surface quality was disregarded in the above conclusions. However, some gaps deeper than the core roughness and caused by material detachment were noticed when the milling encountered radial surfaces, so affecting the ray tissues. This did not change the conclusion that the smoothest beech surface is obtained when the smallest feed speed (6.53 m/min) is used. However, including the surface gaps in the analysis by referring to the parameter Rk+Rpk+Rvk, it attributed a significance to the rotation speed as well,

such as the higher rotation speed (6594 rot/min) is also contributing to the surface quality improvement.

- The statistical analysis helped to understand the hierarchy of influence factors and of their significance. In this respect, the most important factor affecting the surface quality was the feed speed.
- The moment of measuring the surface roughness, such as immediately after sharpening or after a working period, influences the result of surface quality. Measurements of surface quality after the tool processed 600 m of beech material improved the surface quality by 30%.

3.4 EXPERIMENTAL RESEARCH ON THE ROUGHNESS OF ASH AND OAK VENEERS OBTAINED BY SLICING

3.4.1 General aspects

Research presented in the literature shows that rough veneer surfaces influence not only the appearance of finished products but also the technological processes involved in their production, namely sanding and finishing operations, the processes of applying adhesive in correlation with adhesion strength, a phenomenon that occurs through weak interactions between the veneer and the adhesive (Lutz 1974; Aydin *et al.* 2006; Bao *et al.* 2016), and through weak strength between the veneer and its support. In addition, a veneer surface with high roughness will require additional sanding, which will cause finishing problems (Lutz 1974). In a study carried out by Tanritanir *et al.* (2006), it was found that to improve the quality of beech veneer surfaces, the optimal steaming time should be 20 hours. The quality of the veneers depends on several factors, such as their method of manufacture (rotary cutting or slicing), the properties of the wood, the geometric characteristics of the cutting tool, and the cutting regime. When obtaining veneers, the compression force applied by the pressure bar, which is placed on the surface of the wood near the point of contact with the knife edge, also has a significant influence on the roughness of the surfaces. Thus, the pressure bar has the role of preventing uncontrolled splitting of the material in front of the knife cutting edge, but also of limiting the appearance of cracks due to the tension created by the knife blocking in the material (Marchal *et al.* 2009, Gurbîi and Johansson 2015). Also, an excessive compressive force can cause significant damage to the veneer on the pressure bar side, identified by high roughness and the appearance of small cracks (Cassens *et al.* 2003). Among the roughness parameters measured and analyzed in the literature for veneers, we can mention Ra, Ry (total height of the surface profile) and Rz (Kamperidou *et al.* 2020); Ra, Rq (average practical roughness) and Rz (Kamperidou *et al.* 2022); Ra, Rz, and Rmax (Tanritanir *et al.* 2006); Ra, Rz, Rsm (average parameter of the distance between profile elements), and Rq (Li *et al.* 2018); Ra, Rz, Rk, Rpk, and Rvk (Brenci *et al.* 2009).

3.4.2 Research methodology

The main objective of this research was to establish if the compression force applied by the pressure bar during planing would lead to significant differences between the roughness measured on the surface on which the bar is applied and the surface cut by the cutters (Brenci *et al.* 2012). The investigation into assessing surface quality was conducted in the Wood Industry Manufacturing Precision Testing Laboratory at the Faculty of Furniture Design and Wood Engineering.

The research analysed two wood species, namely ash veneer (*Fraxinus Excelsior*) and oak veneer (*Quercus Robur* L.), obtained industrially by slicing, without the authors knowing the conditions under which they were processed (cutting conditions and cutting tool condition). The specifications of the investigated veneers are presented in Tab. 22. Fifteen veneers were measured from each wood species, and three analysis areas were selected from each side, resulting in a total of 90 measurements for each veneer species.

Tab. 22. Characteristics of the investigated veneers (Brenci *et al.* 2012)

Veneer species	Veneer thickness (mm)	Moisture content of veneers (%)	Dimensions L x W (mm)
Ash	0.6	8.5	550 x 150
Oak	0.6	9.3	550 x 150

To measure the roughness, the MicroProfFRT equipment with optical beam, manufactured in Germany, was used (non-contact method). (Fig. 60).

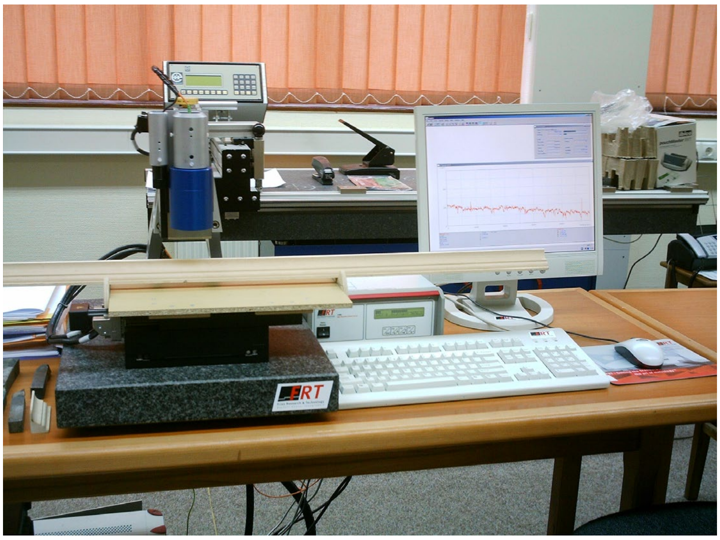


Fig. 60. Equipment for measuring the roughness of surfaces with an optical beam

The roughness parameters used to assess the quality of the two sides of the veneers were selected in accordance with ISO 13565-2 (1999): Rk (parameter for assessing processing roughness), Rpk (parameter for assessing raised fibres) and Rvk (parameter for assessing anatomical roughness). Scanning the surfaces involved defining the following parameters:

- Scanning speed: 750 μm/s;
- Number of points scanned per line: 10000;
- Length investigated: 50 mm;
- Light spot diameter: 2 μm;
- Measurement resolution: 5 μm;
- Cut-off length: Lc = 2.5 mm.

After measuring the roughness parameters, the equipment software automatically applied a Gaussian filter on the recorded values.

3.4.3 Results and discussions

To compare the roughness measured on both sides of the ash and oak veneers, the recorded values were statistically analyzed in EXCEL using the Student's t-test: Paired Two Sample for Means. The significance level was set at 0.05. The analysis of these tests is shown in Tab. 23 for ash veneers and Tab. 24 for oak veneers.

The definition of statistical hypotheses for the Student's t-test was as follows:

Null hypothesis: $H_0 : \mu_1 = \mu_2$

Alternative hypothesis: $H_1 : \mu_1 \neq \mu_2$

The null hypothesis H_0 assumes that there are no significant differences between the mean roughness values measured on the front of the veneer μ_1 and on the back of the veneers μ_2.

From the analysis of the above results (Tab. 23 and Tab. 24), it can be seen that the test variable t-Stat is smaller than the critical values (t Critical) for both the one-tailed and two-tailed tests, and the critical value of probability (P) for both tests (one-tailed and two-tailed) is greater than the selected significance level, which means that the null hypothesis H_0 assigned to the Student's t-test is accepted.

Tab. 23. Statistical analysis of ash wood t-Test Paired Two Sample (Brenci *et al.* 2012)

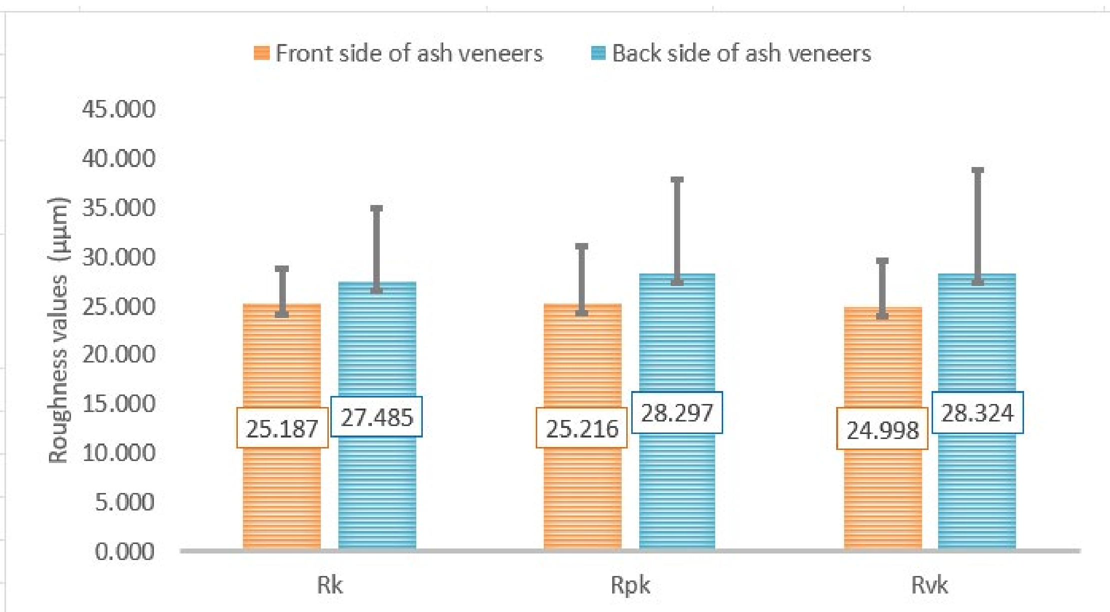
Statistical parameters	Rk (μm)		Rpk (μm)		Rvk (μm)	
	front side of veneer	back side of veneer	front side of veneer	back side of veneer	front side of veneer	back side of veneer
Average	25.187	27.485	25.216	28.297	24.998	28.324
Variance	14.779	60.501	36.395	98.791	23.381	119.792
df	14		14		14	
t State	-1.16		-1.100		-1.05	
P (T<=t) one-tailed/one	0.133	0.133>0.05	0.145	0.145>0.05	0.155	0.155>0.05

Statistical parameters	Rk (µm)		Rpk (µm)		Rvk (µm)	
	front side of veneer	back side of veneer	front side of veneer	back side of veneer	front side of veneer	back side of veneer
tail						
Critical one-tailed t-test	1.761	-1.161<1.761	1.761	-1.1<1.761	1.761	-0.667<1.761
P (T<=t) bilateral/ two-tailed	0.265	0.265>0.05	0.290	0.290>0.05	0.310	0.310>0.05
Critical t-value bilateral / two-tailed	2.15	|-1.16|<2.15	2.15	|-1.1|<2.15	2.15	|-1.05|<2.15

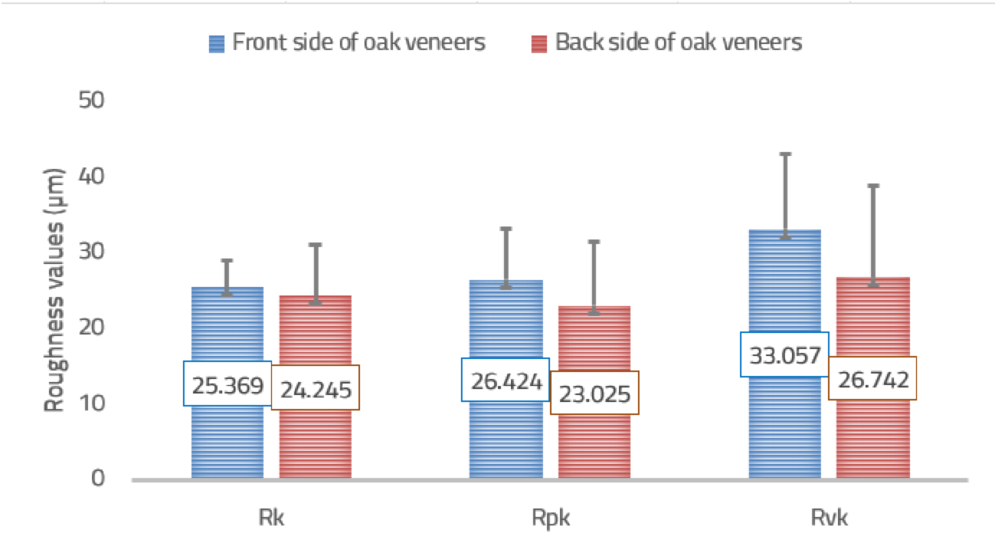
Tab. 24. Statistical analysis of oak veneer Paired Two Sample t-Test (Brenci *et al.* 2012)

Statistical parameters	Rk (µm)		Rpk (µm)		Rvk (µm)	
	front side of veneer	back side of veneer	front side of veneer	back side of veneer	front side of veneer	back side of veneer
Average	25.369	24.512	26.424	23.723	33.057	26.742
Variance	13.483	60.494	48.832	29.364	107.828	156.655
df	14		14		14	
t State	0.470		1.269		1.604	
P (T<=t) one-tailed	0.323	0.323>0.05	0.113	0.113>0.05	0.066	0.066>0.05
Critical one-tailed t-test	1.76	0.47<1.76	1.76	1.296<1.76	1.76	1.604<1.76
P (T<=t) bilateral / two-tailed	0.645	0.645>0.05	0.225	0.225>0.05	0.131	0.131>0.05
Critical t-value / two-tailed	2.15	|0.47|<2.15	2.15	|1.269|<2.15	2.15	|1.604|<2.15

The mean values of the roughness parameters measured on both sides of the veneers show the same trend for both ash and oak (Fig. 61).



a.



b.

Fig. 61. Mean values of the investigated roughness parameters
(a) roughness of ash veneer; (b) roughness of oak veneer (according to Brenci *et al.* 2012)

In the ash case (Fig. 61a), the roughness values on the front of the veneer are lower than the values recorded on the back of the veneer, where the pressing bar was applied. In the oak case (Fig. 61b), all the roughness parameters investigated had higher values on the front of the veneer than on the back. Considering the statistical analysis presented in Tab. 23 and Tab. 24, it can be stated that the differences between the mean roughness parameters measured on the front and back of the veneers are not significant, which confirms that the cutting parameters were correctly set for the slicing process.

3.4.4 Conclusions

Based on the results obtained, the following conclusions can be made:

- The presence of raised fibres, measured by the Rpk roughness parameter, was recorded on both species of veneer, both on the front and back.
- Compression of the veneer in the contact area due to the pressure bar led to the covering of the wood pores, so that in the case of oak veneers, higher roughness values were obtained on its surface.
- In the case of ash, it is possible that the wear of the cutting edge led to higher roughness values on the front of the veneer in comparison with the values obtained on the back, even if the pressure bar on the back of the veneer compressed the wood and covered its pores.
- As a result of statistical analysis, based on the Student's t-test, the null hypothesis was accepted, confirming that when comparing the mean values of the roughness parameters (Rk, Rpk, and Rvk) measured on both sides of ash and oak boards, there are no significant differences between these. which confirms that the working conditions parameters were set correctly.

3.5 EXPERIMENTAL RESEARCH UPON THE QUALITY OF SANDED SURFACES OF SOME DECORATIVE COMPOSITE PANELS

3.5.1 General aspects

The recovery of wood waste from technological processes and its reuse in the manufacturing of new composite panels is part of the concept of circularity of wood raw materials. These composite panels must meet a number of properties related to aesthetics (Cionca *et al.* 2006), rigidity, stability, good flatness and its maintenance over time, durability, and technological processing (Coșereanu *et al.* 2009; Coșereanu *et al.* 2010). Thus, by using small pieces of wood waste from rare species or species with a limited growing area, or species that are too expensive, the use of valuable wood mass is carried out in the most rational possible manner.

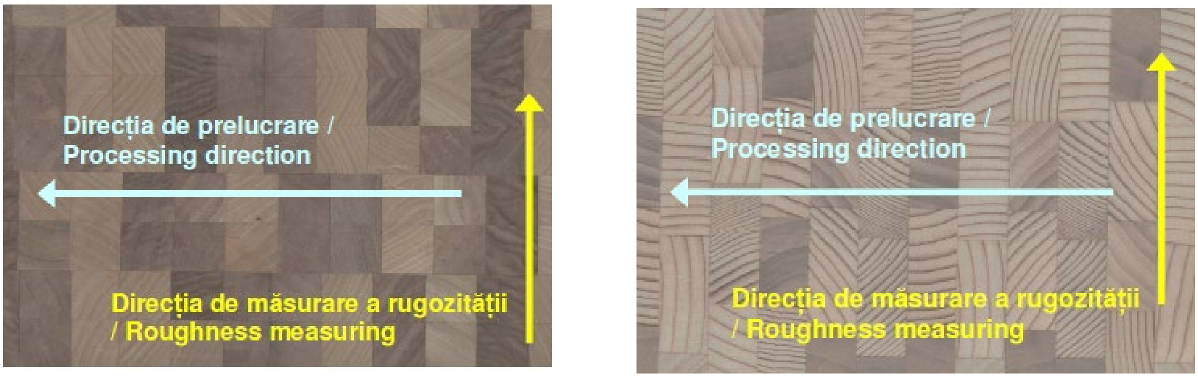
Sanding, which is considered the final operation in the technological process, results in higher quality surfaces (Adamčík *et al.* 2024). The quality of sanded surfaces depends on a range of factors: wood species (Thoma *et al.* 2015; Laina *et al.* 2017), moisture content, abrasive grit size (de Moura and Hernandez 2006; Kilic *et al*. 2006, Sulaiman *et al.* 2009, Salcă and Hiziroglu 2012, Miao and Li 2014, Gurău 2005 *et al.* 2005, Gurău 2022), the sanding conditions applied (Fotin *et al.* 2013a; Fotin *et al.* 2013b; Fotin *et al.* 2012). There are also studies which have shown that sanding parameters must be established according to the wood species (Thoma *et al.* 2015; Chun-Won *et al.* 2023), but also according to the anatomical orientation of the surface in terms of the processing direction (Aslan *et al.* 2008). The analysis of the quality of sanded surfaces, in order to determine the roughness parameters, has been investigated both with contact equipment (Gurău *et al.* 2001; Gurău 2004; Gurău *et al.* 2005; Gurău *et al.* 2011; Gurău *et al.* 2015; Gurău 2022; Luo *et al.* 2014; Kilic 2015; Kudela *et al.* 2018; Laskowska *et al.* 2025), but also with non-contact equipment (Brenci *et al.* 2011; Fotin *et al.* 2013a; Fotin et al. 2013b; Salcă and Hiziroglu 2012). In the literature, for sanded wood surfaces, the roughness and waviness parameters investigated were: Ra, Rq, Rku, Rt, Rk, Rpk, and Rvk (Gurău 2022; Gurău *et al.* 2006); Ra, Rz (Laskowska *et al.* 2025); Ra, Rq, Rv, Rt, RSm, Rsk, Rk, Rpk, Rvk, Wa, and Wt (Gurău *et al.* 2019); Ra, Ry, and Rz (Kilic 2015); Ra, Rq, Rz, RSm, and Wa (Kudela *et al.* 2018); Ra, Rp, Rv, Rz, and Rt (Adamčík *et al.* 2024); Ra, Rz, Rk, Rpk, and Rvk (Brenci *et al.* 2011; Fotin *et al.* 2013a; Fotin *et al.* 2013b); Rk and Rpk (Salcă and Hiziroglu 2012).

3.5.2 Research methodology

The objective of the research was to investigate the surfaces obtained after sanding using four grit sizes, namely: 50 (specific to calibration operation), 80, 120 and 150 (for final sanding operations), of some decorative composite panels with a cross-section made of poplar (*Populus nigra*) and spruce (*Picea abies L.*) lamellas (*Picea abies* L.), and cherry (*Prunus* *avium*) and walnut (*Juglans regia* L.) lamellas with a cross-section of 20 mm x 22 mm (Brenci *et al.* 2011). The investigation of the quality of decorative panel surfaces was carried out at the of Laboratory of Testing the Processing Accuracy in Wood Industry, within the Faculty of Furniture Design and Wood Engineering.

Small pieces of wood of varying lengths and sections measuring 23 mm x 23 mm were used to produce the panels (Coșereanu *et al.* 2009). The panels were produced in two stages. On first stage, the lamellas were finger-jointed on length and edge-jointed on width. They were machined on the four faces and than edge-jointed. The lamellas were randomly arranged in the structure of the panels, just for their innovative design purpose. The wood strips obtained after finger-jointing the lamellas were machined on the four faces and than edge-jointed into the panel shape. After drying the adhesive, the panels were calibrated to a constant thickness of 22 mm. The panels resulted in this way (with sizes of 470x320 mm) are glued on their faces and overlapped so to obtain a "reconstructed block". The result is a "reconstructed block" of rectangular section. After the adhesive had dried, the core is cross-cut, so to obtain panels with transversal structure of wood on their faces, their design being defined by the participation rate of the two constitutive species of wood into the panel.

The panels obtained this way (having the moisture content of 8-10%) were calibrated and sized to the final dimensions, resulting "wooden structural tiles" that can be used as industrial floors or floors for civilian buildings, where high traffic is required. The final calibration of the panels brought them to 22 mm thickness, resulting thus the panels with sizes of 230x155 mm (Fig. 62).



a. b.

Fig. 62. Processing and roughness measuring directions: (a) cherry and walnut wood panel; (b) spruce and poplar wood panel (Brenci *et al.* 2011)

3.5.2.1 Roughness measurement

The panels were subjected to a sanding process, where grit sizes (type P) of 50, 80, 120 and 150 were used. The roughness measurements were done perpendicular to the sanding direction. The roughness measurements were done perpendicular to the sanding direction in order to obtain the accurate values of the roughness parameters Ra and Rz according to Rk, ISO 4287 (1997), and Rk, Rpk and Rvk according to ISO 13565-2 (1999) roughness being measured on a crosscut section obtained after processing). Ra roughness is considered to be the most common parameter for the assessment of the surface quality. Together with the Rz parameter, that measures the maximum irregularities of the profile and allows for a accurate analysis of the quality of the investigated surfaces. Each of 8 samples was plane measured on five areas in order to obtain an accurate assessment of the measurements.

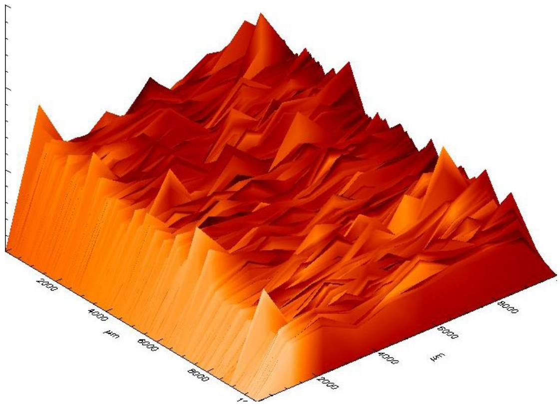
Surface scanning involved setting the following parameters:

- Scanning speed: 750 μm/s;
- Number of points scanned per line: 10000;
- Length investigated: 50 mm;
- Light spot diameter: 2 μm;
- Measurement resolution: 5 μm;
- Cut-off length: Lc = 2.5 mm.

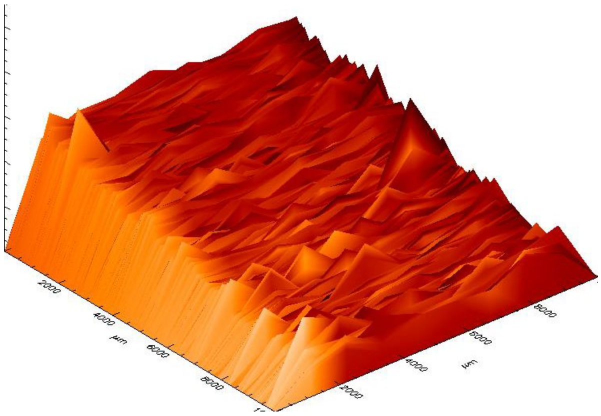
The roughness parameters analyzed in this paper are Ra and Rz according to SR EN ISO 4287 :2003, Rk, Rpk and Rvk according to SR EN ISO 13565-2:1999. The Ra roughness parameter is considered to be the most common one used for the assessment of the surface quality, but for a more accurate analysis it will be accompanied by Rz parameter (Gurău 2007), that measures the maximum irregularities of the profile. The rest of three roughness parameters are used as follows:

- Rk is a parameter that assess the processing roughness;
- Rpk is a parameter that assess the raised fiber of wood;
- Rvk is a parameter that assess the anatomic structure.

The roughness profile was obtained after filtering the data with Gaussian filter, automatically applied by the software. In order to highlight the condition of the decorative panel surfaces in the spruce and poplar combination, a 3D scan on a surface of 10 x 10 mm after sanding with 80 grit size (Fig. 63a) and 120 grit size (Fig. 63b) was performed.



a.



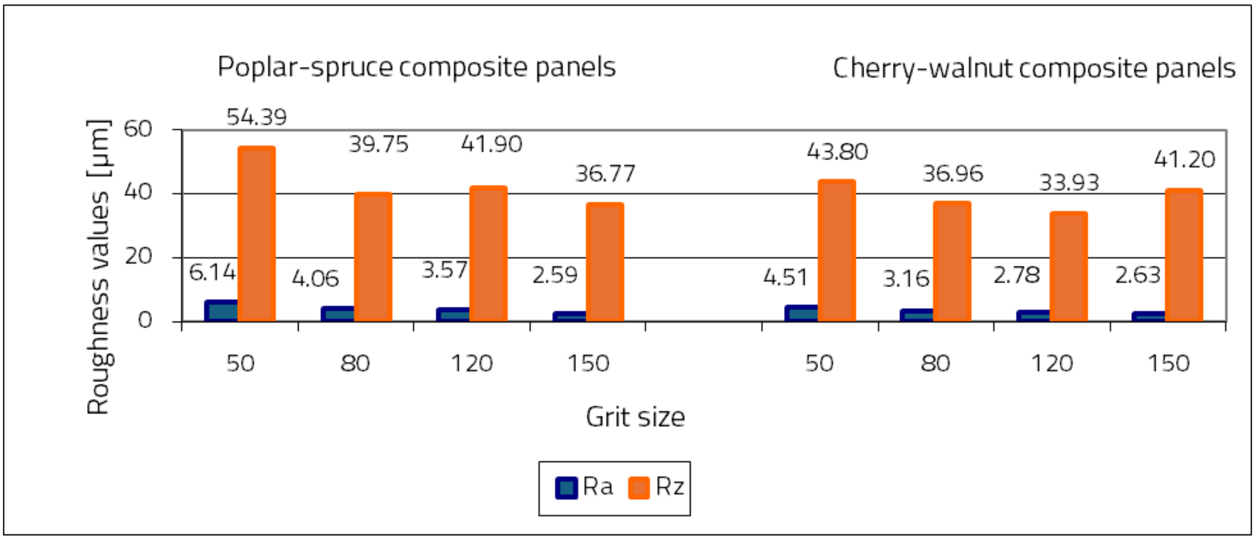
b.

Fig. 63. The surface of the panel made of spruce and poplar wood, sanded with different grit sizes. (a) 80 grit size; (b) 120 grit size (Brenci *et al.* 2011)

Considering that the section of the jointed lamellas is smaller than 50 mm (which is the length of the scanned square), the assessment process detected segments of the same species of wood (poplar with poplar, cherry with cherry), or different species of wood (poplar and spruce wood, cherry and walnut), or different orientation of the wood grains.

3.5.2.2 Results and discussions

The measured roughness parameters (Fig. 64) highlighted a decrease in values with an increase in the grain size of the abrasive cloth used to sand the decorative panels in the case of Ra, Rk, Rpk (for the cherry-walnut combination) and Rvk roughness. More significant differences are recorded for the Rz parameter, and in the case of sanding the decorative panel made of spruce and poplar with 120 grit size, respectively for the cherry and walnut panel sanded with 150 grit size, an increase in this parameter is observed, due to the orientation of the fibers of the lamellas in the panel structure in relation to the scanning direction.



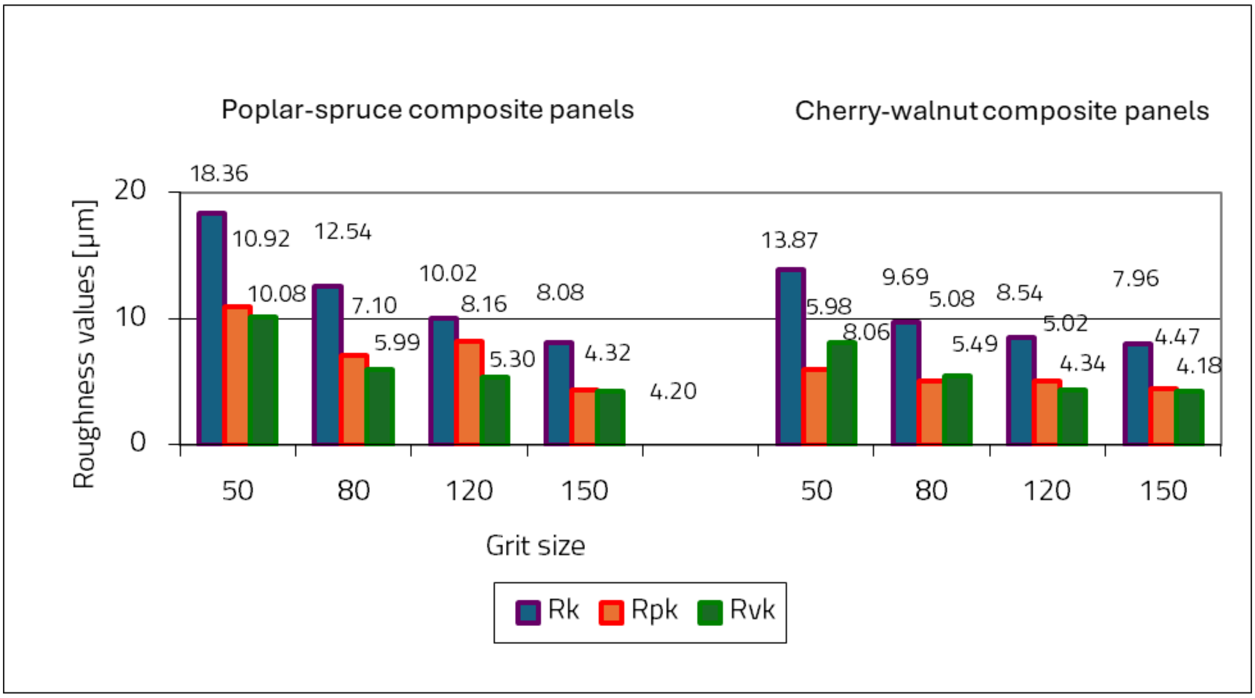


Fig. 64. Roughness parameters measured for decorative composite panels (according to Brenci *et al.* 2011)

These phenomena can be explained by the fact that in case of panels made of cherry and walnut wood sanded with 150 grit size and poplar and spruce wood sanded with 120 grit size respectively, the measurements of the roughness were done on different angles against the annual rings. In the same time, the scanning operation during the roughness measurement in order to determine the roughness parameters was not done on the same lamellas after sanding with different grit sizes.

In the case of the Rz parameter, an increase in its value is observed when sanding the cherry-walnut panel with 150 grit size compared to the cherry-walnut panel sanded with 120 grit size. The same situation can be observed in the case of the poplar-spruce composite panel, when sanding with 120 grit size compared to the surface sanded with 80 grit size.

The Ra and Rz roughness parameters are lower for the cherry-walnut panel compared to the poplar-spruce panel for all four abrasive paper grits. The roughness values Rk, Rpk and Rvk for the decorative cherry and walnut panel are lower compared to those of the poplar-spruce panel, which means that they will perform better in finishing.

The presence of fuzzy grain is shown by Rpk roughness parameter which has different values for the two types of panels sanded with the same grit sizes. The Rk roughness parameter registered a decreasing of the roughness value with the increasing of the grit size.

The statistical analysis of the experimental data (Tab. 25), was based on calculating the coefficient of variation, which showed that the mean values of Ra, Rz, Rk, Rpk, and Rvk are representative of the population analyzed (values less than 17%), and for values in the ranges of 17-35%, the mean is moderately representative of the studied population (Jaba 2002).

Tab. 25. The variation coefficient calculated for the two types of composite panels (Brenci *et al.* 2011)

Composite panel type	Number of analyzed sample	Grit size	Coefficient of variation, calculated for roughness Parameters, %				
			Ra	Rk	Rpk	Rvk	Rz
Spruce and poplar wood	Part 1	50	10.332	11.799	13.3924	7.2012	11.7827
	Part 2		4.4241	7.9233	15.8935	13.9247	9.0542
	Part 3		4.6593	8.4318	8.6999	19.7364	9.3351
	Part 4		7.1067	6.0169	19.1529	15.0532	11.5681
	Part 1	80	3.4568	2.3460	8.4653	8.8621	10.0150
	Part 2		7.2570	7.0279	22.2615	15.3972	19.1571
	Part 3		10.5187	9.1906	15.0128	14.9478	15.2624
	Part 4		5.1597	5.0520	11.3258	1.6916	13.9742
	Part 1	120	9.4624	6.1009	10.7479	34.4393	8.8922
	Part 2		11.1884	8.1736	24.0787	8.9676	17.4132
	Part 3		31.4248	8.3154	30.9519	22.5745	22.4774
	Part 4		5.0869	2.1757	18.1936	10.0146	14.0715
	Part 1	150	7.6631	8.0864	10.7615	12.5784	13.4004
	Part 2		8.7184	7.3889	11.3161	14.1480	25.7697
	Part 3		7.6631	8.0864	10.7615	12.5784	13.4004
	Part 4		8.7184	7.3889	11.3161	14.1480	25.7697
Cherry and walnut wood	Part 1	50	5.5928	5.2378	12.6431	10.5661	4.1592
	Part 2		8.0894	5.7521	13.0870	15.3400	4.4299
	Part 3		2.6020	4.8295	10.8659	14.3502	8.6186
	Part 4		8.4596	10.4005	12.9162	10.4141	8.8423
	Part 1	80	8.6272	8.7843	11.1777	20.7529	4.8003
	Part 2		6.0334	5.9597	11.6476	12.0404	9.0557
	Part 3		8.3701	5.7981	17.5547	34.5185	28.2853
	Part 4		26.9065	21.8958	42.5283	31.2860	37.8453
	Part 1	120	5.6766	5.7303	11.9781	14.2745	18.5081
	Part 2		4.9800	5.7844	3.0682	23.3783	23.9977
	Part 3		3.0830	1.4570	13.7232	30.3315	13.4055
	Part 4		6.3777	6.4971	8.9628	33.6422	17.2003
	Part 1	150	2.0145	6.5324	2.8162	36.8526	21.1851
	Part 2		4.6137	3.3879	7.5304	54.2759	57.2400
	Part 3		3.5624	2.4279	13.7345	25.0943	16.8008

Composite panel type	Number of analyzed sample	Grit size	Coefficient of variation, calculated for roughness Parameters, %				
			Ra	Rk	Rpk	Rvk	Rz
	Part 4		4.9124	7.3832	12.4854	22.2832	33.9471

The presence of values higher than 17% is explained by the wood fiber orientation in the structure of the panel and also by the variation of the wood characteristics into the annual ring structure, against the measuring direction.

3.5.2.3 Conclusions

Based on the research conducted, the conclusions are as follows:

- The measured values highlight the fact that the roughness parameters measured do not meet the recommended values for transparent finishing of panels (Rz=10÷16 μm), which is needed to show the differences of structure and colors of the species of wood used in the panel for a decorative purpose.
- With the increasing of grit size used for sanding operation, the decreasing of roughness is observed (identified by Rk parameter), but different for the two types of panels.
- The results of measuring Rz roughness parameter after the final sanding (36.77 μm for poplar-spruce wood panel when sanding with 150 grit size and 33.93 μm after sanding the cherry-walnut wood panel with 120 grit size) lead to the conclusion that an extra-sanding operation is needed. The final sanding system used for the longitudinal structure of wood is not valid for the studied panels that have a transversal structure of wood on their faces.
- The roughness parameter Rpk highlighted the presence of fuzzy grain due to the anatomical structure of the panels made of poplar and spruce lamellas and less for panels made of cherry and walnut.

Results dissemination

The results presented in this chapter are based on the following publications:

1. **Brenci, L.M.;** Gurău, L. A Stratified Characterization of Surface Quality of Beech Processed by Profile Milling. Applied Sciences, **2024**, 14(1) 129; https://doi.org/10.3390/app14010129
2. **Brenci, L.M.;** Cismaru, I.; Cosereanu, C.; Fotin, A. The experimental research upon the quality of veneer obtained by slicing methods. 18th International Conference (KBO) Jun. 14-16-Sibiu, România. The knowledge-based organization: applied technical sciences and advanced military technologies, conference proceeding 3. Book Series: Knowledge Based Organization International Conference. 2012, 29-33. ISSN: 1843-6722 https://drive.unitbv.ro/s/9KS4RZnHmQam9XT

3. **Brenci, L.M.;** Cismaru, I.; Coșereanu, C. Experimental Research upon the Quality of the Sanded Surfaces of Some Decorative Composite Panels. PRO LIGNO Journal **2011**, 7(2), 21-29. ISSN 1841-4737 (print), 2069-7430 (online) http://proligno.ro/en/articles/2011/2/brenci_full.pdf
4. **Brenci, L.M.** Frezarea profilată a lemnului. Construcția și exploatarea sculelor. Editura Universității "Transilvania" Brașov, **2005**, 189 pp. ISBN 973-635-482-2 https://drive.unitbv.ro/s/dGyd8mLxYCQWios

(B-II) THE EVOLUTION AND DEVELOPMENT PLANS FOR CAREER DEVELOPMENT

1.1 EDUCATION

1.1.1 Academic and doctoral studies

1984 - 1990	University of Braşov, Facultatea Tehnologia Construcțiilor de Maşini/ Faculty of Machine Construction Technology, Diploma of Engineer.
2005	Scientific title – Doctor (title obtained on 07.02.2005) in the field of Industrial Engineering. Thesis title: *Contributions to the study of the construction and operation of profiled milling cutters for wood cutting*. Scientific supervisor Prof. Dr. Eng. Victor Dogaru

1.1.2 Other specialisations and qualifications

15.04.1991 – 05.07.1991	Programmer analyst. Centre for Advanced Training in Management Informatics, Brașov
15.06.1994	Auto-CAD R11 Level 1. ATC "UTIL" Brașov Faculty of Wood Industry, "TRANSILVANIA" University of Brașov
21 October 1996 – 23 October 1996	AutoCAD R12, Level 1. ATC "UTIL" Brașov Faculty of Wood Industry, "TRANSILVANIA" University Brașov
25.11.1996	AutoLISP. ATC "UTIL" Braşov Faculty of Wood Industry, "TRANSILVANIA" University of Braşov
November	English for Technical and Business in the Wood Industry. "TRANSILVANIA" University of Braşov, Faculty of Wood Industry.
March	COSMOS/M – Finite Element. INICAD SOFT SRL
May	Programming in Engineering. TRANSILVANIA University of Braşov, Faculty of Wood Industry.
February	Computer-aided design programme – Solid Edge. Brașov. Ada Computer Bucharest
1 December 2025 – 30 January 2006	Web Designing and Use of Web Page Tools. Transilvania University of Brașov. Leonardo Da Vinci WBT WORLD Programme.
May	Certificate of linguistic competence – English. Transilvania University of Brașov. Continuing Education Department, Faculty of Letters, Centre for Modern Language Learning.
27 October 2006 – 20 December 2006	Internal auditor certificate. S.C. Cometam S.R.L. Bucharest
2007	Training on modern manufacturing precision testing equipment (CADESQ measuring table, DESQ and OPTO DESQ laminates) - German company HECHT ELECTRONIC A.G
September 2011	Certificate of attendance for the training course – Assuring the

	quality of the Results. The practical implementation of section 5.9. of the EN ISO/IEC 17025 Standard. Iaşi, Romania, as part of the Third International Proficiency Testing Conference PTCONF.
2011	ARACIS evaluator
19-20 September	Certificate of participation in the training course for external evaluators in the field of higher education quality. Organiser: ARACIS
1 March 2012 – 30 November 2012	DidaTec training programme organised by Transilvania University of Brașov, partner in the project *University school for initial and continuing training of teaching staff and trainers in technical and engineering specialisations – DidaTec.* Project co-financed by the European Social Fund through the Sectoral Operational Programme Human Resources Development 2007-2013

1.2 PROFESSIONAL AND TEACHING EXPERIENCE

1.2.1 Professional experience

1991 - 1995	Engineer - TRANSILVANIA University of Braşov, Faculty of Wood Industry
1995	Analyst-programmer - TRANSILVANIA University of Braşov, Faculty of Furniture Design and Wood Engineering (formerly Faculty of Wood Industry)
1997	University Assistant - TRANSILVANIA University of Brașov, Faculty of Furniture Design and Wood Engineering (formerly Faculty of Wood Industry)
2001	Lecturer – TRANSILVANIA University of Brașov, Faculty of Wood Industry
2008 - present	Associate Professor - TRANSILVANIA University of Brașov, Faculty of Furniture Design and Wood Engineering (formerly Faculty of Wood Industry)

1.2.2 Teaching activities

Teaching activity began in 1997 and consisted of teaching courses and practical laboratory and project activities within the Faculty of Furniture Design and Wood Engineering for the following study programmes:

- Wood Processing Engineering (IPL) – full-time bachelor's degree.
- Wood Products Engineering and Design (IDPFL) – full-time bachelor's degree.
- Wood Engineering (WE) – full-time bachelor's degree – programme taught in English (programme no longer running).

- Forest Engineering and Management (IMF) – full-time bachelor's degree (programme no longer available).
- Wood Processing Engineering (IPL_FR) – bachelor's degree – part-time.
- Advanced Wood Structures and Innovative Technologies (SALTI) – full-time master's degree (this programme is no longer available).
- Eco-design of Furniture and Restoration (EDMR) – full-time master's degree
- Wood Technology for Construction (TLC) – full-time master's degree.

The subjects taught since 1997 up to the present day are as follows:

1. Computer Programming and Programming Languages in the Wood Industry 2 – Year II – IDPFL and IPL;
2. Computer Programming and Programming Languages 2 – Year II – WE (Study programme taught in English);
3. 3D Modelling – Year III – IDPFL and IPL;
4. Computer-Aided Graphics – Year II – IMF;
5. Computer Programming and Programming Languages 3 – Year II – IDPFL and IPL;
6. Technical Drawing and Computer Graphics in the Wood Industry 2 – Year II – IDPFL and IPL;
7. Technical Drawing and Infographics in the Wood Industry 3 – Year II – IDPFL and IPL;
8. Drives in the Wood Industry – Year II – IDPFL and IPL;
9. Basics of Wood Cutting and Cutting Tools – Year III – IPL;
10. Environmental Modelling – Year III – IDPFL;
11. Computer-Aided Furniture Design 1 – Year IV – IDPFL;
12. Computer-Aided Programming and Design in the Wood Industry 7 – Year IV – IPL;
13. Parametric Design in the Wood Industry – Year IV – IDPFL, IPL, IMF and IPL_FR;
14. Computer-Aided Design and Programming in the Wood Industry – Year V – IDPFL and IPL;
15. CAD Modelling – Year I Master's Degree – EDMR and SALTI;
16. Research Project Management – Year I Master's Degree – SALTI;
17. CAD for Wooden Constructions – 1st year of Master's Degree – TLC;
18. Unconventional wood processing technologies – 2nd year of master's degree – SALTI.

- I also taught hourly-paid laboratory activities at the Faculty of Economics and Business Administration for the Management and International Business study programmes, in the subject Fundamentals of Computer Science – Year I, Semester I.

- Since 1998, I have been the scientific coordinator of over 50 diploma projects and dissertations for students in the IDPFL, IPL, IPL-FR, SALTI and EDMR study programmes, including coordinating one first-class dissertation (2018).

- Digital skills gained:
  - Very good skills in using the Microsoft Office suite.
  - Very good skills in using AutoCAD, Solid Works, Top Solid, IMOS, Cadwork, Kitchen Draw, Auto LISP, Mechanical Desktop, and Solid Edge design software.
  - Very good skills in using Turbo Pascal and Delphi software.
  - Very good knowledge of web design – HTML, Dreamweaver and FireWorks tools.

- Between 2010 and 2012, as part of the project "*Training and retraining of employees in the wood industry*" coordinated by the Chamber of Commerce and Industry in Brașov, I taught courses accredited by the Romanian Ministry of Education for universal carpenters.

1.2.3 Other activities related to professional and teaching activities

- Participation as a member of the faculty admissions committee for more than 10 years;
- Member of the admissions committee for master's programmes from 2018 to 2020;
- Chair of the admissions committee for interviews - EDMR and TLC master's programmes, from 2020 to present (2025);
- Member of the graduation committees for the IPL bachelor's and SALTI master's programmes;
- Head of the graduation committee for the IPL bachelor's and SALTI master's programmes in the 2016-2017 academic year;
- Coordinator of the master's programme in Furniture Ecodesign and Restoration (in English) from 2024 to present;
- Coordinator of the Advanced Wood Structures and Innovative Technologies master's programme;
- Responsible for the CEAC commission for the master's programme in Advanced Wood Structures and Innovative Technologies;
- Responsible for scheduling the faculty timetable from 2006 to present;
- Participation in developing documentation for ARACIS accreditation and maintaining accreditation for IDPFL, IPL, IPL-FR, SALTI, EDMR, and EDMRe study programs.
- Coordination of *Researchers' Night* events as coordinator of the C14 research centre "Innovative Technologies and Advanced Products in the Wood Industry".
- Internal evaluation as an auditor for the periodic external evaluation by ARACIS of six study programs at Transilvania University of Brașov:
  - 2015 – Bachelor's degree programme in *Materials Science*, field of Engineering Sciences, Faculty of Materials Science, study program coordinator Prof. Dr. Eng. Ana Vețeleanu;

- 2016 – Bachelor's degree programme in *Railways, Roads and Bridges*, field of Civil Engineering, Faculty of Construction, study program coordinator Assoc.prof.dr.eng. Adam Dosa, PhD;
- 2019 – Bachelor's degree programme in *Engineering and Design of Finished Wood Products*, field of Forest Engineering, Faculty of Furniture Design and Wood Engineering, programme coordinator Assoc.prof.dr.eng. Lidia Gurău, PhD;
- 2022 – Bachelor's degree programme in *Aerospace Construction*, Faculty of Technological Engineering and Industrial Management, study program coordinator Assoc.prof.dr.eng. Răzvan Udroiu (periodic evaluation and EUR-ACE certification);
- 2023 – Bachelor's degree programme *in Construction Installations,* Faculty of Construction, study program coordinator Assoc.prof.dr.eng. Cristian Nastac (periodic evaluation and EUR-ACE certification);
- 2024 – Bachelor's degree programme in Applied Electronics, field of Electronic Engineering, Telecommunications and Information Technology, Faculty of Electrical Engineering and Computer Science, study program coordinator Prof. Dr. Eng. Petru Adrian Cotfaș (periodic evaluation and EUR-ACE certification).

- Participation as a member of the ARACIS external evaluation team for 3 study programmes:
  - 2013 – Master's degree programme *in Advanced Design of Wood and Metal Structures*, field of Civil Engineering, Faculty of Mineral Resources and Environment Baia-Mare, Technical University of Cluj-Napoca, study program coordinator Prof. Dr. Eng. Daniela Filip Văcărescu.
  - 2017 – Bachelor's degree programme *in Applied Computer Science in Industrial Engineering*, Faculty of Engineering and Management of Technological Systems, Polytechnic University of Bucharest, study program coordinator Prof. Dr. Eng. Cristian Vasile Doicin.
  - 2021 – Bachelor's degree programme in *Textile Product Technology and Design*, Industrial Engineering, "Aurel Vlaicu" University of Arad, study program coordinator Prof. Dr. Eng. Ec. Alexandru Popa.

- Participation as a member of the organising committee for the following scientific events:

1) International Conference Wood Science and Engineering in Third Millenium, Braşov, 2025, 5-7 November – 14th Edition – Member of the Scientific Committee;
2) International Conference on Wood Science and Engineering in the Third Millennium, Braşov, 2023, 2-4 November – 13th edition;

3) International Conference on Wood Science and Engineering in the Third Millennium, Braşov, 2019, 7-9 November – 12th edition;
4) International Conference on Wood Science and Engineering in the Third Millennium, Braşov, 2017, 2-4 November;
5) International Conference on Wood Science and Engineering in the Third Millennium, Braşov, 2015, 5-7 November;
6) International Conference on Wood Science and Engineering in the Third Millennium, Braşov, 7-9 November 2013;
7) PT-CONF 4th International Proficiency Testing Conference, 18-20 September 2013;
8) International Conference of the Romanian Academy of Scientists "Eco-Economy and Sustainable Development", Braşov, 20-21 September 2013;
9) International Conference Wood Science and Engineering in Third Millenium, Braşov, 3-5 November 2011;
10) International Conference on Wood Science and Engineering in the Third Millennium, Braşov, 4-6 June 2009;
11) National Conference on Scientific Communications Wood Industry at the Dawn of the Third Millennium, 4-6 November 2005;
12) International Conference on Wood Science and Engineering in the Third Millennium, Braşov, 10-12 November 2004;
13) 8th International IUFRO Wood Drying Conference, Brașov, Romania, 24-29 August 2003;
14) National Conference on Scientific Communications in the Wood Industry at the Dawn of the Third Millennium, 20-21 November 2003;
15) International Conference on Wood Science and Engineering in the Third Millennium, Brașov, 16-17 November 2001;
16) National Conference on Scientific Communications in the Wood Industry at the Dawn of the Third Millennium, 17-18 November 2000.

- Member of the editorial team of ProLigno magazine since September 2005, serving as contributing editorial staff from 2005 to 2007;
- 2007–present: administrator of the website for Pro Ligno magazine http://www.proligno.ro;
- Administrator of the website of the Faculty of Furniture Design and Wood Engineering.

1.3 MANAGEMENT EXPERIENCE

- **Manager on behalf of UNITBV (as partner) of two international ERASMUS+** projects amounting €29024 and €62943, respectively, won through international competition;

- 2021–2024 and from 2024 to present – Vice-Dean responsible for Student Activity and Relations with the Economic and Socio-Cultural Environment, Internationalization, and Teaching Activity;
- 2008–2011 – Coordinator of the Scientific Research Department D14 – *Innovative Technologies and Advanced Products in the Wood Industry*;
- 2013 – present – Coordinator of the Scientific Research Centre C14 – Innovative Technologies and Advanced Products in the Wood Industry;
- 2011-2013 - Member of the Council of the Department of Wood Processing and Wood Product Design, Faculty of Furniture Design and Wood Engineering;
- 2015–2025 – Member of the Council of the Department of Wood Processing and Wood Product Design, Faculty of Furniture Design and Wood Engineering;
- 2016–2019 – Member of the Senate of Transilvania University of Brașov;
- 2024 – present – Member of the Senate of Transilvania University of Brașov.

1.4 AWARDS AND DISTINCTIONS

- Transylvania University Award 2007 for outstanding results in carrying out national research projects, as coordinator of the Research Department *Innovative Technologies and Advanced Products in the Wood Industry*.

1.5 RESEARCH CAREER DEVELOPMENT

1.5.1 Project Manager – internationally winning projects

No.	Project name	Period	Amount UNITBV (Euro)
1	TAckling Environmental sustainability through Blended Learning opportunities for ivEt in the furniture and wood sector (TABLE). Proiect ERASMUS+ KA202, Cooperation for Innovation and the Exchange of Good Practices, Strategic Partnerships for vocational education and training. Total project 251818 EURO	2019 - 2021	29024
2	“Circular Economy Transition Manager: guiding companies of the furniture value chain to deploy their transition strategy for a more circular economy (CirCLER),” within the ERASMUS+, A.2 – Skills and Innovation, Topic: ERASMUS-EDU-2023-PI-ALL-INNO-EDU-ENT (Partnerships for Innovation - Alliances). Project no. 101140033. Total project 1168043 Euro	2024 - 2027	62493

1.5.2 Project manager – nationally winning projects

No.	Project name	Period	Amount UNITBV (lei)
1	Research on the use of laser cutting technology in the manufacture of wood products. S.C. NORD ARIN Prod S.R.L. Contract no: 5487/18.05.2016.	2016	4166
2	Research on improving the production process for NORD ARIN PROD S.R.L. Contract no. 13747/19.10.2016.	2016	8566.8

1.5.3 Team member of internationally winning projects

No.	Project name	Period
1	Novel learning approach for ERGOnomic principles for deSIGNers working in the upholstery and sleep sectors by using Virtual Reality (ERGOSIGN), Funded by: ERASMUS+, Contract no. 2015-1-RO01-KA202-015091	2015-1017
2	Erasmus+ PN: 601011-EPP-1-2018-1-ES-EPPKA2-SSA - Programul: KA2: Cooperation for innovation and the exchange of good practices - Sector Skills Alliances. DITRAMA - Digital transformation manager: leading companies in Furniture value chain to implement their digital transformation strategy. Value 994094 Euro. No: Grant Agreement N° 2018 – 2992 / 001 – 001, Project Number 601011-EPP-1-2018-1-E	01.01.2019-31.12.2021
3	Erasmus+ PN:2018-1-IT01-KA202-006734 FACET- Furniture sector Avant-garde Creativity and Entrepreneurship Training finantator: Uniunea Europeana, Programme: KA2 - Cooperation for Innovation and the Exchange of Good Practices Strategic Partnerships for vocational education and training. Grant Agreement no. 2018-1-IT01-KA202-006734 Grant amount: **25342 Euro UNITBV.** Project amount 324163 Euro	01.11.2018-30.04.2021

1.5.4 Team member of nationally winning projects

No.	Project name	Period
1	Network of scientific excellence for the Romanian wood industry, in the context of our country's integration into the European Union in 2007. CNCSIS development project No. 1339/2004. Duration: 3 years Project manager Prof. Dr. Eng. Loredana Anne-Marie Bădescu	2004-2007
2	Laboratory for testing manufacturing precision in the wood industry. Value 793,095 lei. CEEX Structural Development Project No.	2006-2008

No.	Project name	Period
	168/2006, P-CONFORM type project, MODULE-4. Project manager Prof. Dr. Eng. Ivan Cismaru. Duration 2 years	
3	Research and testing laboratory for quality and conformity certification of wood products, aligned with European standards. Value: 795,000 lei. CEEX Structural Development Project No. 195/2006, P-CONFORM type project, MODULE-4. Project manager: Prof. Dr. Eng. Virgil Grecu. Duration: 2 years.	2006-2007
4	Platform for the sustainable use of natural resources through biotechnology and ecological processes in agrotourism, forestry and wood processing. Value: 371,000 lei. RENATSIL interdisciplinary training and research platform, project no. 18/2006. Duration: 2 years.	2006-2008
5	Biodegradable composites with textile inserts for environmentally friendly products BICOMPTEX. Value 400,000 RON. Grand PNCD12 - PC-type partnerships. Contract 72-200. Project manager Prof. Dr. Eng. Camelia Coșereanu. Duration 2 years	2008-2011
6	Research on improving technology and developing products with improved functional performance for S.C. Holzindustrie Schweighofer BACO SRL, Contract no. 8743/2015, 2015-2016, member of the team project. Project manager Prof. Dr. Eng. Mihai Ispas. Duration 1 year.	2015-2016
7	Design of innovative solid wood furniture with bio/technological finishes and design of production infrastructure. Value 15,750 lei. Contract no. 4917/28.04.2015. S.C. Biomobila S.R.L. Project manager Prof. Dr. Eng. Camelia Coșereanu. Duration: 1 year.	2015
8	Qualitative, dynamic and acoustic analysis of anisotropic systems with modified ACADIA interference. Project manager Prof. Dr. Eng. Mariana Domnica Stanciu. Duration 2 years	2023-2025

1.5.5. Project proposals in the UEFISCDI competition as manager

No.	Project name	Year of submission	Project registration number	Number of points obtained
1	ECO-Lignocellulose Panels for Interior Design and Furniture	2016	PN-III-P2-2.1-PED-2016-0561	83
2	Boards with reduced harmful emissions into the air	2019	PN-III-P2-2.1-PED-2019-0964	88.2

1.6 PATENTS

The author participated in scientific research that led to the obtaining of four patent:

1. Device and method for determining the shear strength of wood pellets/Dispozitiv şi procedeu pentru determinarea rezistenței la forfecare a peleților lemnoşi (29 July 2022) - Lunguleasa Aurel, Spîrchez Gheorghe-Cosmin, Coşereanu Camelia, Lica Dumitru, **Brenci Luminița Maria** – Patent no. 130786
2. Three-layer panel made of sunflower seed husks and shells for indoor use and method of obtaining/Panou tristratificat din particule şi coji de semințe de florea-soarelui pentru utilizări în interior şi procedeu de obținere (30 September 2019b) – Zeleniuc Octavia, **Brenci Luminița Maria**, Coşereanu Camelia, Fotin Adriana, Lica Dumitru, Budău Gavril, Lunguleasa Aurel, Apostu Ionel – Patent no. 130258
3. Eco-board from sunflower waste designed for exterior panelling and method of obtaining/Placă ecologică din deşeuri de floarea soarelui, destinată placărilor exterioare şi procedeu de oobținere (30 July 2019) - Cosereanu, Camelia, Lica. Dumitru, **Brenci, Luminița Maria**, Fotin. Adriana, Zeleniuc, Octavia, Lunguleasa, Aurel, Budau. Gavril, Apostu, Ionel – Patent no. 130259
4. Ecological plywood and method of obtaining/Placaj ecologic şi procedeu de ob inere a acestuia. (30 July 2016). Cosereanu, Camelia, Lunguleasa. Aurel, Lica. Dumitru, Cismaru, Maria, Porojan, Mihaela, **Brenci, Luminița Maria**, Iacob, Ioan, Iacob, Maria, Mihăilescu Camelia – Patent no. 127158.

1.7 CONTRIBUTIONS IN DEVELOPING THE INFRASTRUCTURE FOR RESEARCH WITHIN THE C14 RESEARCH CENTER

As Coordinator of the C14 Research Center (formerly D14) during the implementation of the project *"Research, Development, and Innovation Institute: High Tech Products for Sustainable Development," funded by the Sectoral Operational Program – Economic Competitiveness Growth, Axis 2, from ERDF funds (76.7%) and the national budget (23.3%)*," currently the Research and Development Institute of Transylvania University of Brașov (ICDT), I had developed 4 technical documents and 1 technical document in cooperation with colleagues from the C11 Research Center, which led to purchasing the following advanced research equipments:

No.	Equipment type	Amount (Euro)
1	Static load testing equipment (Zwick Roel Z010)	190000.0
2	Fixed installation for acoustic testing of wood materials (Tub Kund)	67000.0
3	Equipment for determining the heat transfer coefficient (HFM	87000.0

No.	Equipment type	Amount (Euro)
	Lambda 436)	
4	Laser system for cutting veneer Coherent, Light CELL	300000.0
5	Nikon SMZ14 stereomicroscope (in collaboration with colleagues from the C11 centre)	17127.0

As Coordinator of the C14 Research Centre within the *Digital Transformation for Innovation and Competitiveness* project, funding contract 14039/16.09.2022, I have drawn up 1 Technical document for the purchase of equipment:

No.	Equipment type	Amount (Euro)
1	Digital hydraulic (hot) press	435364

I would like to mention that the equipments purchased as a result of the technical documents are used by the faculty's doctoral students and teaching staff, and the results of these investigations have been published in doctoral theses or valuable scientific articles in prestigious international journals indexed by WOS.

1.8 SKILLS AND AREAS OF EXPERTISE

The areas of competence and skills of the author of this habilitation thesis are: wood processing; the quality of wood surfaces, materials and eco-materials; development and experimental assessment of the physical and mechanical characteristics of lignocellulosic composites; testing of processing accuracy.

2. PROFESSIONAL CAREER DEVELOPMENT PLANS

2.1 FUTURE PROFESSIONAL TEACHING DEVELOPMENT

For the author of this habilitation thesis, a major objective in her professional career development is to improve her teaching performance in order to facilitate the transfer of knowledge, skills and competences to undergraduate, masters and doctoral students. Thus, the author proposes to:

- using research results in teaching materials for courses;
- teaching courses in English for subjects taught in bachelor's degree programs, in order to support incoming ERASMUS students;
- developing the course for the master's degree program in Furniture Ecodesign and Restoration (in English);
- facilitating the teaching of modules within the disciplines of the master's degree

program in Furniture Ecodesign and Restoration (in English) by professors from relevant universities in Europe through the UNITA Alliance, as well as based on the relationships developed as director of ERASMUS+ projects;

- publishing technical books and laboratory guides;
- developing teaching materials focusing on the circular economy in the woodworking sector;
- adapting the content of the subjects taught to the requirements of the labour market, in order to ensure the successful integration of graduates in companies in the field.

2.2 PLAN FOR THE DEVELOPMENT OF FUTURE SCIENTIFIC ACTIVITY

The research activities that the author will continue to develop will focus on continuing the research in the areas of competence developed. In this regard, the author plans to:

- development of new research topics that include sustainable materials in composites with significantly improved performance;
- continuing to publish scientific research results in ISI articles with high impact factors, in order to increase international visibility;
- collaboration with interdisciplinary groups to address the issues raised by the research topics;
- continuing collaborations with the economic community, as well as with relevant clusters in the country;
- participation at international conferences in the field, with the aim of disseminating research results;
- developing new project proposals that will lead to obtaining funding in the thematic areas specific of the field.

(B-III) BIBLIOGRAPHY

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2. Adamčík, L.; Dzurenda, L.; Banski, A.; Kminiak, R. Comparison of Surface Roughness of Beech Wood after Sanding with an Eccentric and Belt Sander. Forest **2024**. 15(1), 45. https://doi.org/10.3390/f15010045
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