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FACULTY OF FOREST INDUSTRY

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ENHANCING PARTICLEBOARD ECO-FRIENDLINESS: ACTIVATED CARBON FROM ORANGE PEEL RESIDUES

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ABSTRACT

Activated carbon produced from orange peels residues using zinc chloride as activation agents were utilized in the production of particleboards at rates of 0.5%, 1%, and 1.5%. The BET surface areas of the produced activated carbon was determined to be 572 m^2/g. Additionally; their porous and chemical structures were examined via SEM and EDS. The formaldehyde emission effects of the produced particleboards were investigated immediately after production (0 month). Compared to the control group, particleboards with activated carbon reduced free formaldehyde emissions by 28.80% at 0 month. The results demonstrate the practicality of including activated carbon obtained from orange peels as an environmentally friendly addition in the manufacturing of particleboard. This emphasizes the use of waste materials and introduces an innovative method for reducing formaldehyde emissions.

Key words: Orange peels residues, activated carbon, particleboards, formaldehyde emission.

INTRODUCTION

The growing emphasis on sustainability and environmental responsibility has prompted extensive research into innovative methods for utilizing agricultural waste products in industrial applications. One such area of interest is the production of particleboards, which are widely used in construction and furniture manufacturing (Owodunni *et al.,* 2020). Traditional particleboard manufacturing relies heavily on formaldehyde–based adhesives, which emit formaldehyde gas a known carcinogen linked to respiratory issues, skin irritation, and other health problems. Consequently, there is a pressing need to develop particleboards that minimize formaldehyde emissions to protect both human health and the environment (Ergün *et al.,* 2024). Activated carbon (AC) has surface area, enhanced porosity and surface activity. Because of these properties, activated carbon has an excellent adsorption capacity, making it a valuable material for capturing pollutants from air and water. Recent advancements have explored the feasibility of producing activated carbons from various agricultural residues, offering a sustainable and economically viable alternative to conventional raw materials (González–García, 2018).

Activated carbon produced from orange peel residues has been extensively studied for its high adsorption capacities and eco–friendly nature. For instance, research by El Nemr *et al.* (2009) demonstrated the efficiency of orange peel–derived activated carbon in removing direct blue–86 dye from wastewater, showing a removal rate of 92% under optimal conditions (El Nemr *et al.,* 2009). Similarly, Khaled *et al.* (2009) found that activated carbon from orange peels could effectively remove Direct Yellow 12 dye, achieving a maximum removal rate of 96% (Khaled *et al.,* 2009).

The production of activated carbon from orange peel residues involves a series of steps, including chemical activation, which enhances the material's porosity and adsorption capacity. Zinc chloride ($ZnCl_2$) is commonly used as an activation agent due to its efficiency in developing a high surface

area and well–defined pore structure in the resulting carbon (Foo and Hameed, 2012). This process not only adds value to agricultural waste but also contributes to waste management and environmental conservation efforts.

Incorporating activated carbon into particleboard manufacturing presents a novel approach to reducing formaldehyde emissions. Activated carbon can effectively adsorb formaldehyde, thereby decreasing the amount released into the environment during the lifecycle of the particleboard. Furthermore, the use of orange peel–derived activated carbon in particleboards can significantly enhance their mechanical properties and durability. Studies have shown that such particleboards exhibit increased strength, reduced water absorption, and better overall performance compared to traditional wood–based particleboards (Al–sareji *et al.*, 2023).

The process of converting orange peel residues into activated carbon involves pyrolysis, which not only reduces waste but also produces a highly porous material with a large surface area suitable for adsorption applications (Pandiarajan *et al.*, 2018). This activated carbon can then be incorporated into the particleboard matrix, enhancing its structural integrity (Ergun *et al.*, 2023) and eco–friendliness (Ergun *et al.*, 2024).

This study aims to investigate the efficacy of orange peel–derived activated carbon in mitigating formaldehyde emissions when used as an additive in particleboard production. The research focuses on characterizing the physical and chemical properties of the activated carbon, assessing its impact on formaldehyde emissions.

MATERIAL AND METHOD

MATERIALS

Orange peel waste was sourced at no cost from households. The activation process of the orange peel waste utilized from $ZnCl_2$. Particleboard is made from wood chips that are combined with Pinus nigra, Carpinus betulus, Populus nigra, and Fagus orientalis. The UF adhesive exhibited a viscosity of 255–315 mPa•s at a temperature of 23°C. Its density varied between 1270 and 1305 kg/m^3, and it had a solid content of 65% ± 1. A 15% ammonium chloride solution was added to the adhesive at a weight ratio of 1% to cure it. The concentration of formaldehyde was measured using the Merck spectroquant test kit. Fluka (Buch, Switzerland) and Merck (Darmstadt, Germany) provided analytical purity chemicals for this study.

METHODS

Production of Orange Peel Based Activated Carbon

A mixture of 2 kg of orange peel powder, 1 kg of $ZnCl_2$, and 2.5 liters of distilled water was prepared to produce activated carbon. To facilitate the reaction between $ZnCl_2$ and the raw material, the mixture was stirred and held at room temperature for 24 hours. Following that, the mixture was dehydrated for 24 hours at 80°C in an extraction hood–equipped oven to ensure full dispersion of the chemical and remove any leftover danger. Following drying, the substance was put into an argon gas–filled environment at a 50 milliliter per minute flow rate. Then, in order to complete the activation process, it was kept at 600°C for 90 minutes. When the activated carbon attained a neutral pH, it was cooled to room temperature and cleaned with distilled water. A six–hour drying procedure at 100°C was applied to the cleaned activated carbon. Once the required particle size was reached, it was ground and prepared for usage.

Production of Three Layer Particleboards

Particleboard is made up of three layers, which are assembled by the manufacturer using surface and core chips. These chip utilization rates were 20%, 20%, and 60% for the top, bottom, and core layers, respectively. The chips were dried until they had a moisture content of 1–3 percent before the adhesive was applied. After that, they were sealed in plastic bags to keep oxygen from getting to them. Ultrafiltration (UF) with a solid concentration of 65% was used in the investigation. Depending on the dry matter content, different amounts of activated carbon – 0.5%, 1.0%, and 1.5% – were added to the adhesive. After that, the mixture was aggressively agitated for 30 minutes at 600 rpm. Adhesive gun within a revolving drum mixer (ECOMIX, 42,750 Saint–Denis de Cabanne) was used to apply the adhesive. The board was put in a 400 × 400 x 16 mm hot press after being manually distributed using a wooden mold. Then, for 240 seconds, the particleboards were made in a hot press (SSP180 Cemil Usta, Turkey) operating at a temperature between 170°C and 180 °C with a specific pressure of 4.5 N/mm^2. The boards were heated to a high temperature and then allowed to cool down before being prepared for testing. Three particle boards were produced by each group. To achieve equilibrium moisture content, the boards were conditioned and chilled at 20 ± 2°C and 65 ± 5% relative humidity after pressing.

Characterization

The structural features (BET surface area and micro–pore volume) of the Quantachrome autosorb IQ BET device was assessed by nitrogen gas adsorption/desorption isotherm studies. Degassing AC at 120°C for three hours before the test. Examining the micro structure and chemical composition of the AC at a voltage of 20.0 kV was done using a Tescan, Maıa3 Xmu type scanning electron microscope (SEM). The conductivity was improved by applying a gold covering. According to TS EN ISO 12460–5 standard, the formaldehyde concentration of the particleboards was found.

RESULT AND DISCUSSION

SEM and EDS examinations of active carbon generated from orange peel with $ZnCl_2$ activation agent are presented in Figure 1. The SEM images of the activated carbon obtained from the chemical activation of orange peel using $ZnCl_2$ activation agent (Figure 1a) reveal irregular voids and both big and tiny amorphous holes on the activated carbon's surface. According to several researches published in the literature, the pore width increases when agricultural waste materials are converted into activated carbon employing $ZnCl_2$ as an activation agent (Lopez–Gonzalez *et al.*, 1980). Caturla *et al*. (1991) reported in their research that the pores enlarged as a result of outward expansion and degradation on the activated carbon surface when $ZnCl_2$ was utilized as an activation agent (Caturla *et al.*, 1991). According to another research, they achieved a significant surface area and typically formed microporous activated carbons when they synthesized it chemically by activating kraft lignin (Yang and Lua, 2006).

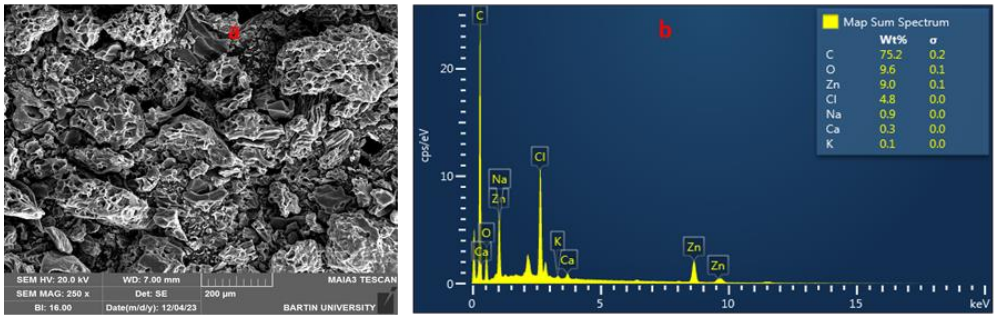


Figure 1: SEM (a) and EDS (b) analyses of produced AC

Activated carbons with the required surface area and high pore volume have recently been made from lignocellulosic materials and a variety of agricultural wastes. According to experimental research, the manufacture of activated carbon from orange peel involves identical pore and surface area parameters, and the activation process of orange peel is impacted by the addition of $ZnCl_2$ as an activation agent. The elements C, O, Zn, Cl, Na, Ca, and K may be found in the activated carbon made from orange peel, as shown in Figure 1b. Orange peel pyrolysis yields activated carbon, which has been shown to include 75.2% C, 9.5% O, 9.1% Zn, 4.8% Cl, 0.9% Na, 0.8% Ca, and 0.1% K (Figure 1b). Conversely, as a result of the high–temperature activation process, the activated carbon C content rises while its O content falls. According to the research done by Fernandez *et al.* (2014), the raw material utilized before activated carbon was produced had 43% C and 50.2% O, but after activated carbon was produced, the amounts of C and O were 82.5% and 14.1%, respectively. Because $ZnCl_2$ activation agent was utilized, it was also noted that Zn and Cl elements were present in the medium. When using the $ZnCl_2$ activation agent to manufacture activated carbons from various raw materials, similar outcomes were seen (El Nemr *et al.*, 2020).

The nitrogen gas adsorption/desorption isotherms of the produced activated carbons at 77 K are presented in Figure 2, and th isotherms are provided in Table 1.

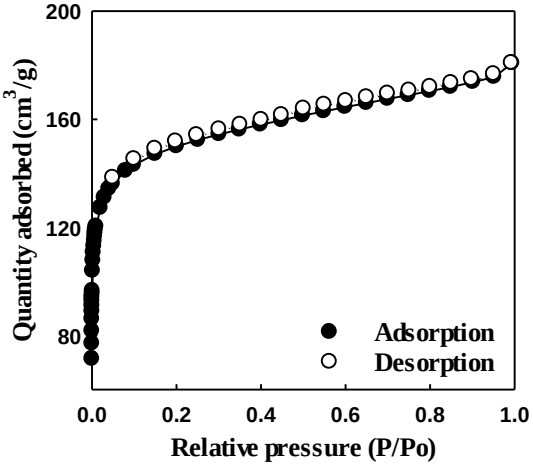


Figure 2: Nitrogen gas adsorption/desorption isotherm of produced AC

When the nitrogen gas adsorption–desorption isotherm for the produced activated carbon is analyzed, it reflects Type–I(c), representing the presence of a much smaller number of mesopores in addition to its highly developed micropores. But in the range of 0.45 to 0.90 relative pressure (P/Po), every activated carbon shows an H4–type desorption hysteresis loop, showing capillary condensation of nitrogen gas in the mesopores below the gas's saturation pressure (Koyuncu, 2022).

PA-ZnCl2-ads vs Col 6
PA-ZnCl2-des vs Col 8

Table 1: Pore characteristic of produced AC

S_{BET} (m^2/g)	V_m (cm^3/g)	V_M (cm^3/g)	V_T (cm^3/g)	V_m (%)	V_M (%)	D_p (nm)
572.14	0.225	0.055	0.280	80.36	19.64	1.48

The activated carbon is produced under the following conditions: a carbonization temperature of 600°C, a carbonization time of 1.5 hours, and an impregnation ratio of 1:0.5 (kg residues: kg activator). $ZnCl_2$ produces a stiff carbon skeleton by means of high–temperature activation and/or carbonization processes that eliminate polymeric structures and non–carbon components, particularly

those in liquid (also known as tar) and gaseous forms (Zhang *et al.*, 2005; Méndez *et al.*, 2005). $ZnCl_2$ activation causes the raw material's cellulose molecules to undergo an electrolytic reaction. This results in a greater surface area in the activated carbons by breaking down cellulose molecules and increasing the amount of intra– and intercellular voids (Saka, 2012).

The impact of adding activated carbon on the formaldehyde emissions of particleboards at 0 months was studied. Table 2 displays the formaldehyde measurement findings, which were obtained using the perforator technique.

Table 2: Formaldehyde measurement results of particleboards without and with AC addition at month 0

	Control	0.5% AC	1.0% AC	1.5% AC
Formaldehyde emission measurement	11.25	9.28	8.74	8.01

The inclusion of AC reduced the formaldehyde emission of all generated particleboards in inverse proportion to the raw material and chemical activator combination. Following production, measurements were taken in month 0 and found that the formaldehyde emission of the control particleboards was 11.25 mg/100 g, but the particleboards with 1.5% AC emitted 8.01 mg/100 g. The free formaldehyde adsorption mechanism of activated carbon is shown representatively in Figure 3.

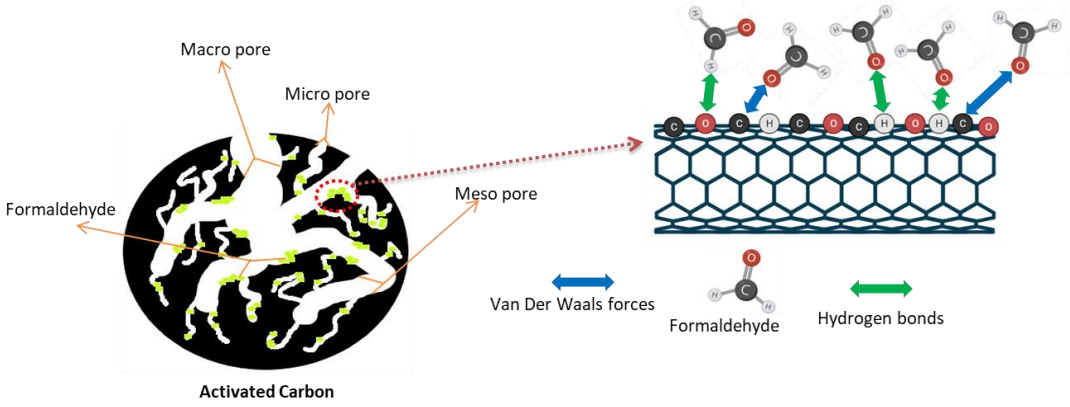


Figure 3: Adsorption mechanism of formaldehyde adsorbed on AC (Ergün *et al.*, 2024)

According to published research, formaldehyde emitted from MDF panels may be absorbed and bound by activated carbons (ACs) (Akin and Karaboyacı 2021). Formaldehyde in MDF may be adsorbed by activated carbon thanks to its microporous structure (Rong *et al.*, 2002). This results in a decrease in formaldehyde emissions. Adsorption of polar formaldehyde is facilitated by the presence of positively charged, polar chemical molecules on the activated carbon. Hydrogen bonds and Van der Waals forces may be produced by the oxygen–rich functional groups on the formaldehyde and activated carbon molecules (Kumar *et al.*, 2013).

CONCLUSION

The potential use of activated carbon derived from orange peel residues as a sustainable additive to particleboard was investigated in this study. The significant BET surface area of 572 m^2/g of the activated carbon, which was produced by chemical activation using $ZnCl_2$ as the activation agent, suggested good formaldehyde adsorption capabilities. Activated carbon was successfully applied to particleboards at various concentrations of 0.5%, 1.0%, and 1.5%, saving 28.80% of the emissions of free formaldehyde as compared to the control group. SEM and EDS measurements showed that the created activated carbon's surface included irregular gaps and amorphous holes, indicating that it was

porous. $ZnCl_2$ was used as the activation agent, which expanded the pores and increased the adsorption capacity of the activated carbon. This illustrates how well orange peel–derived activated carbon absorbs formaldehyde and reduces its release into the environment.

FUNDING

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REFERENCES

AKIN A. E., KARABOYACI M. 2021. Effects of activated carbon on medium density fiber board properties. Bilge International Journal of Science and Technology Research, 5, Özel Sayı: 7–12.

AL–SAREJI O. J., ABDULZAHRA M. A., HUSSEIN T. S., SHLAKAA A. S., KARHIB M. M., MEICZINGER M., HASHIM K. S. 2023. Removal of pharmaceuticals from water using laccase immobilized on orange peels waste–derived activated carbon. Water, 15,19: 3437.

CATURLA F., MOLINA–SABIO M., RODRIGUEZ–REINOSO F. 1991. Preparation of activated carbon by chemical activation with ZnCl2. Carbon, 29, 7: 999–1007.

EL NEMR A., ABDELWAHAB O., EL–SIKAILY A., KHALED A. 2009. Removal of direct blue–86 from aqueous solution by new activated carbon developed from orange peel. Journal of hazardous materials, 161, 1: 102–110.

EL NEMR, A. ABOUGHALY R. M., EL SIKAILY A., RAGAB S., MASOUD M. S., RAMADAN M. S. 2022. Microporous nano–activated carbon type I derived from orange peel and its application for Cr (VI) removal from aquatic environment. Biomass Conversion and Biorefinery, 12: 5125–5143.

ERGUN M. E., ÖZLÜSOYLU İ., İSTEK A., CAN A. 2023. Analysis and impact of activated carbon incorporation into urea–formaldehyde adhesive on the properties of particleboard. Coatings, 13, 9: 1476.

ERGÜN M. E., İSTEK A., ÖZLÜSOYLU İ., KOYUNCU F., BÜLBÜL Ş. 2024. Low formaldehyde–emission particleboards with the addition of Scots pine wood waste derived activated carbon. Wood Material Science & Engineering, 1–11 (online first).

FERNANDEZ M. E., NUNELL G. V., BONELLI P. R., CUKIERMAN A. L. 2014. Activated carbon developed from orange peels: Batch and dynamic competitive adsorption of basic dyes. Industrial crops and products, 62: 437–445.

GONZÁLEZ–GARCÍA P. 2018. Activated carbon from lignocellulosics precursors: A review of the synthesis methods, characterization techniques and applications. Renewable and Sustainable Energy Reviews, 82: 1393–1414.

KHALED A., EL NEMR A., EL–SIKAILY A., ABDELWAHA, O. 2009. Treatment of artificial textile dye effluent containing Direct Yellow 12 by orange peel carbon. Desalination, 238, 1–3: 210–232.

KOYUNCU F. 2022. Endüstriyel İşlenmiş Kırmızıbiber Atıklarından Değişik Koşullarda Üretilen Nanogözenekli Karbonlu Materyallerin Sulu Fazdan Bazı Su Kirleticilerini Uzaklaştırma ve Süperkapasitör Performanslarının İncelenmesi. Doktora Tezi, Dicle Üniversitesi, Fen Bilimleri Enstitüsü, Diyarbakır.

KUMAR A., GUPTA A., SHARMA K. V., NASIR M., KHAN T. A. 2013. Influence of activated charcoal as filler on the properties of wood composites. International Journal of Adhesion and Adhesives, 46: 34–39.

LÓPEZ–GONZÁLEZ J. D. D., MARTINEZ–VILCHEZ F., & RODRIGUEZ–REINOSO F. 1980. Preparation and characterization of active carbons from olive stones. Carbon, 18, 6: 413–418.

MÉNDEZ A., GASCÓ G., FREITAS M. M. A., SIEBIELEC G., STUCZYNSKI T., FIGUEIREDO J. L. 2005. Preparation of carbon–based adsorbents from pyrolysis and air activation of sewage sludges. Chemical Engineering Journal, 108, 1–2: 169–177.

OWODUNNI A. A., LAMAMING J., HASHIM R., TAIWO O. F. A., HUSSIN M. H., MOHAMAD KASSIM M. H., HIZIROGLU S. 2020. Adhesive application on particleboard from natural fibers: A review. Polymer Composites, 41, 11: 4448–4460.

PANDIARAJAN A., KAMARAJ R., VASUDEVAN S., VASUDEVAN S. 2018. OPAC (orange peel activated carbon) derived from waste orange peel for the adsorption of chlorophenoxyacetic acid herbicides from water: adsorption isotherm, kinetic modelling and thermodynamic studies. Bioresource technology, 261: 329–341.

RONG H., RYU Z., ZHENG J., ZHANG Y. 2002. Effect of air oxidation of Rayon–based activated carbon fibers on the adsorption behavior for formaldehyde. Carbon, 40, 13: 2291–2300.

TASDEMIR H. M., SAHIN A., KARABULUT A. F., GURU M. 2019. Production of useful composite particleboard from waste orange peel. Cellulose Chemistry And Technology, 53: 517–526.

YANG T., LUA A. C. 2006. Textural and chemical properties of zinc chloride activated carbons prepared from pistachio–nut shells. Materials chemistry and physics, 100, 2–3: 438–444.

ZHANG F. S., NRIAGU J. O., ITOH H. 2005. Mercury removal from water using activated carbons derived from organic sewage sludge. Water research, 39, 2–3: 389–395.

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EFFECT OF AGING ON THE AESTHETIC AND DECORATIVE FEATURES OF THE INNOVATIVE SALIXDUO PRODUCT FINISHED WITH ACRYLIC AND POLYURETHANE LACQUERS

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ABSTRACT

An innovative research material called „Salixduo“ was developed and patented as part of an ongoing shrub willow wood rods project. With a view to the final use of this product, it was decided to conduct aging tests of the finished product.

Two acrylic and one polyurethane lacquer were selected for testing. Their application by pneumatic spray in the form of two coatings was carried out in the technology laboratory of a leading manufacturer of lacquer products. After 28 days of seasoning under laboratory conditions (temperature 20±5°C and relative humidity 65±5%), the parts were cut into samples for aging tests. The coatings were then exposed to UV radiation, UV+IR radiation, and varying humidity and temperature acc. to the AMK procedure as a function of time. The parameters evaluated were appearance, color, and gloss.

Gloss testing of lacquer coatings was performed by a photoelectric method using a TESTAN DT–G268 gloss meter according to PN–EN ISO 2813:2001. Measurements were made at three angles of incidence of light at ten randomly selected locations in the direction along and across each sample.

The color determination was determined with a DT–145 colorimeter, using a CIELab measurement system equipped with a daylight illuminator and 45º/0° directional measurement geometry. Ten measurements were taken on each sample before and after application of varnish. They were carried out always in the same places, thanks to the marked measuring areas.

Based on the results of the tests, the most significant effect on changes in color and degree of gloss was found after exposure to UV, followed by UV+IR.

Key words: Salixduo, acrylic and polyurethane lacquer, aging, colour.

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INTRODUCTION

In case of a shortage of wood on the market, alternative raw materials from, among others, fast–growing tree and shrub plantations are sought. One of the more popular species used for plantation crops is shrub willow (Boruszewski i in. 2021). This raw material is a valuable renewable energy source that corresponds to the sustainable development strategy. In addition to its ecological importance, it is used, among other things, for braiding and decorative purposes in landscaping, in producing wood–based panels (Waliszewska i in. 2013, Warmbier i in. 2013, Goliński i in. 2016, Sandak i in. 2017, Sobczyk i Sobczyk 2019, Boruszewski i in. 2021, Konatowska i in. 2021, Stankova i in. 2022). One of the more interesting possibilities for using willow is to create a composite as an alternative to wood products. In 2021, as part of the Ministry of Education and Science's Science for

Society programme entitled 'Science for Society for the 'Innovative shrub willow product for the wood industry, ' work began on using willows for furniture applications. A technology was developed as part of the ongoing work, and an innovative material made of consolidated Salix viminalis wood rods called „Salixduo" was patented. A unique appearance characterises the resulting product. Different visual effects can be achieved depending on the species, the age of the willow, and how they are prepared for the composite manufacturing process. This makes it a very original material for designers to create uncommon furnishing products. To preserve the beauty of this raw material, its surfaces should be protected with varnish products.

This study investigated the aesthetic and decorative properties of Salixduo treated with lacquers based on acrylic and polyurethane polymers as a function of accelerated ageing tests.

EXPERIMENTAL METHODS

MATERIALS

Salixduo from willow wood rods made by the Research and Development Centre of the Wood–Based Panels Industry in Czarna Woda were used for the tests. Before varnishing, the surfaces of the samples were treated by sanding using successively numbered abrasive paper: P100, P120 and P150. Two waterborne varnishes based on acrylic dispersions (AC2 and AC4), and a solvent–borne polyurethane varnish (PUR 2) were selected for the planned experiments. The products were applied in the Remmers Technical Centre (temp. 23±2ºC and RH 50±5%) by applying two layers to the substrate. In between, inter–layer sanding was carried out using P400 numbered abrasive paper. The samples were then air–conditioned for 28 days, after which the aesthetic and decorative characteristics were tested in terms of 3 accelerated ageing tests. Aging procedures:

– Cycles of changes temperatures and RH acc. to AMK–MB–005 (performing measurements for 3, 5 and 10 cycles):

- 0.5 h cooling to –20°C
- 1 h freeze–thaw at –20±2°C
- 0.5 h thawing to approx. 20°C
- 3 h storage at 20±2°C and RH 85±5%
- 0.5 h heating to 60°C
- 3 h heating at 60±2°C and RH 55±5%
- 0.5 h cooling to approx. 20°C.

– Simulated UV–IR in conditions acc. to PN–88/F–06100/08 standard, for 3, 5 and 10 hrs (quartz lamp type VT 800 with a power of 740 W).

– Simulated conditions in the SOLARBOX 1500 model 522 chamber, UV wavelength 280 nm, energy of radiation – 550 W/m^2, BST – 65°C, carried out measurements at every 3, 5 and 10 hrs.

The appearance of coatings was evaluated by PN–88/F–06100/01 standard guidelines.

Colour measurements were carried out with a colourimeter DT–145, recording the coordinates in the CIELab system. The ranges in Table 1 were used to interpret the colour difference between the samples (ΔE) before and after ageing.

Table 1: Range of ΔE values indicating colour change

Interval Variation	Colour difference
$0 < \Delta E < 1$	Invisible
$1 < \Delta E \leq 2$	Very small, recognizable only by an experienced observer
$2 < \Delta E \leq 3{,}5$	Medium, recognizable also by an inexperienced observer
$3{,}5 < \Delta E \leq 5$	Clear
$\Delta E > 5$	Large

Gloss was tested using the photoelectric method with apparatus DT–268 PN–88/F–06100/02 standard by performing measurements at various angles of light incidence along and across. The gloss degree in verbal form was determined according to a scale (Table 3).

Table 2: Classification of gloss levels at a light angle of 60° including verbal evaluation

Gloss degree	Verbal form
< 10	Mat
10 – 35	Semi–matte
35 – 60	Semi–gloss
60 – 80	Gloss
> 80	High gloss

RESULTS

Salixduo submitted for testing was characterised by its attractive and striking appearance. However, the willow rods did not always adhere perfectly to each other along the entire length of the Salixduo and voids (discontinuities) or areas filled with the bonding binder – occurred between them.

Evaluation of the surface of the samples immediately after application of the varnish products showed their beneficial effect on the appearance of the substrate. The varnishes applied enlivened the natural grain of the substrate. Despite the imperfections of the substrate, there were no defects on the coatings as a result of the application in the form of craters, blisters or streaks. This demonstrates that the application steps of the individual paint product layers were carried out correctly.

Colour changes of the tested finishes including the adhesive located in the discontinuities of the substrate were noted. In the case of the Solarbox test, a livening up of the systems with PUR2 coating was observed, while with AC2 a less saturated colour was noticed, which gave the impression of a slightly muted colour. The changes assessed visually were then confirmed using an instrumental method. The colour assessment was based on the parameter characterising the total colour difference (ΔE). Fig. 1 shows the values after 10 ageing cycles.

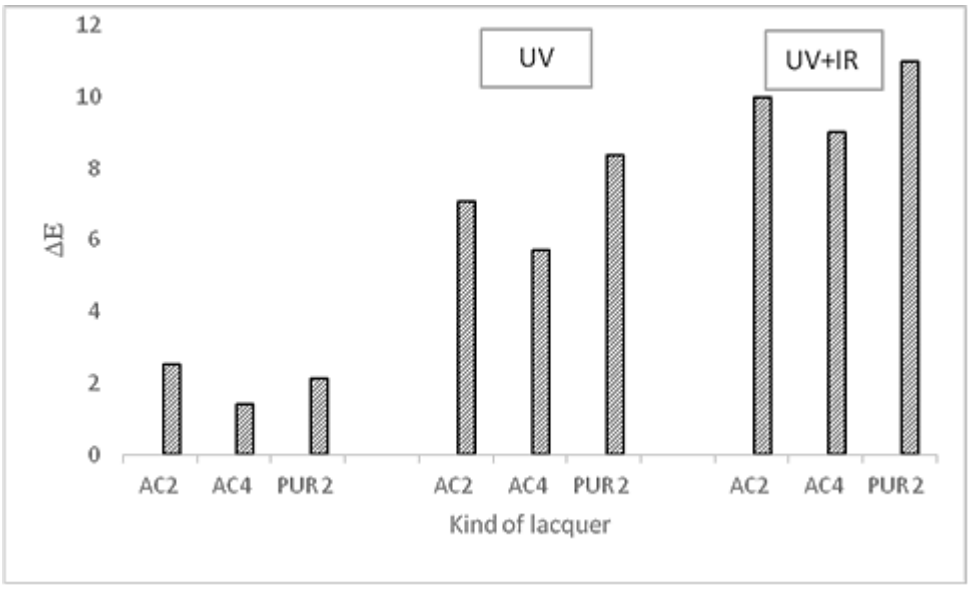


Figure 1: Development of the ΔE parameter after 10 ageing cycles

The criterion in Table 1 was used to discuss the results. In general, the final result of the colour perception of the tested samples was influenced not only by the used kind of lacquer, but also by the type of willow rods, the surface structure (roughness), the proportion of the adhesive used to form the tested composite, which was subject to pronounced discolouration. These relationships may have influenced the colour values recorded. The greatest changes were recorded after UV radiation tests, i.e. after Solarbox and UV+IR, as the radiation passed through transparent systems. It can be assumed that in the case of UV exposure, the resulting discolouration is the cause of photochemical degradation of both some substrate components and varnish products. In the experiment, after one ageing cycle, the values obtained indicated noticeable colour changes visible to an inexperienced observer. After further exposures, a further increase in the value of this indicator was recorded. The highest change tendency for this parameter was recorded for the PUR2 finish. In the case of the AMK test, the colour change process was slower and after two ageing cycles, a level noticeable only to an experienced person was achieved. Again, greater differences were registered for measurements on the PUR2 finish than on the acrylic varnishes. In the case of the AMK test, the colour change process was slower and after two ageing cycles, a level noticeable only to an experienced person was achieved. Again, greater differences were registered in the PUR2 coating than in the acrylic varnishes. At the end of the last aging cycle, the evaluated parameter exceeded the level of two units, making a noticeable difference for an inexperienced observer in the finish with PUR2 and AC2. In this case, PUR2 achieved a level 0.4 units lower than the coating with AC2. Overall, the coatings in terms of colour stability under the various ageing tests can be ranked as follows (from highest to lowest): AC4>AC2>PUR2.

The results of the gloss level tests for the finishes considered in the study after 10 ageing cycles are shown in Figures 2–3.

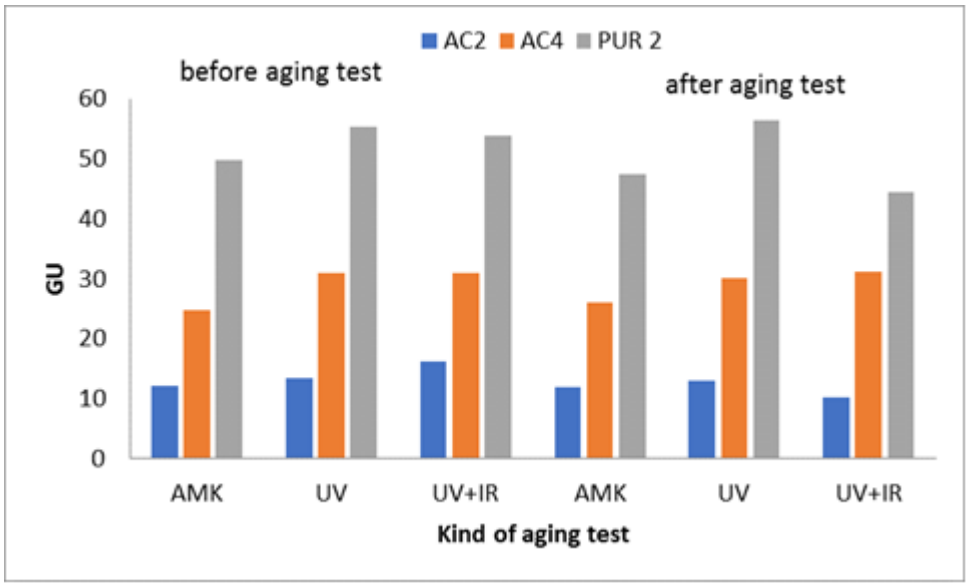


Figure 2: The course of the gloss degree along the sample at an angle of 60°

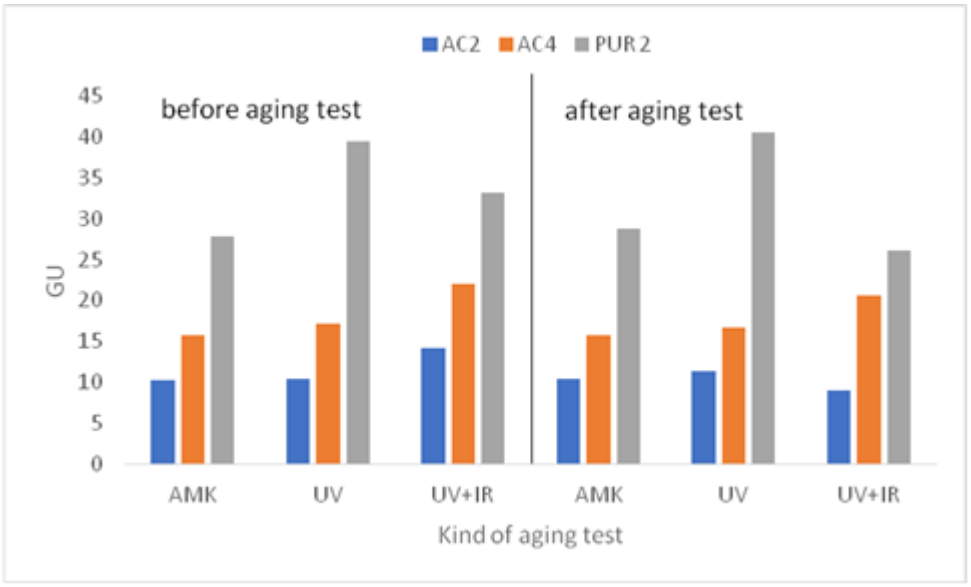


Figure 3: The course of the degree of gloss across the sample at an angle of 60°

The results obtained were characterised by a varied coefficient of variation v in the range of 3.0–44.4. A high value indicates large differences between the samples, indicating their heterogeneity. There was also a significant scatter of results for each sample tested. It should be mentioned that the degree of gloss is significantly influenced by the specific nature of the substrate surface, which causes additional scattering phenomena of the incident light. Undoubtedly, the results obtained were affected by voids in the substrate, areas filled with the binding agent – adhesive or changes in the smoothness of the surfaces protected after application. These factors may have led to changes in the scattering of incident light on the surface. Variations in the values obtained were also found during exposure to different ageing conditions.

In general, a higher gloss of the coatings was obtained by measuring along the fibres than across them. Analysing the average values according to the criterion in Table 1 obtained at an angle of 60° on the control coatings formed from AC2 and AC4, the parameter in question was assessed as semi–matt regardless of the direction of measurement. The exception was the AC4 sample exposed to

UV+IR for 3h for which the value slightly exceeded the range giving a semi–gloss. The PUR2 coating was classified as semi–gloss, while semi–matt/semi–gloss was recorded across the sample, which was reported to be due to differences in light scattering caused by the quality of the substrate. Variations in the recorded values were noted concerning the control samples during ageing. However, the same verbal evaluation was obtained in most cases. During ageing in the AMK and Solarbox test conditions, the systems with AC2 and AC4 remained stable. In the UV+IR test, after 10h of ageing, this parameter was slightly reduced in the measurements across the sample with AC 2 coating, classifying the surface to matt. In contrast, a value in the borderline was obtained along the fibres.

For PUR 2 varnish finishes, the ageing tests did not affect the development of this parameter in measurements along the sample, while across the length of the sample, it decreased to semi–matt regardless of the ageing time after the UV+IR test, after 5 and 10 cycles of the AMK test and after 3 and 5h after the Solarbox.

CONCLUSIONS

1. As a function of ageing, the greatest colour changes were observed after UV (Solarbox) and UV+IR tests. In the case of the AMK test, the colour change process was slower. In terms of colour stability under different ageing tests, the following can be ranked (from highest to lowest):

   AC4>AC2>PUR2

2. The gloss tests of the coatings showed a higher degree of gloss when measured lengthwise than crosswise. Coatings with AC2 and AC4 were rated semi–matt regardless of the measurement direction. PUR2 finishes, on the other hand, were classified as semi–gloss, while semi–gloss/semi–gloss was recorded transversely. Variations in the recorded values were noted during ageing. However, the same verbal rating was obtained in most cases.

REFERENCES

BORUSZEWSKI P, LASKOWSKA A, JANKOWSKA A, KLISZ M, MIONSKOWSKI M. 2021. Potential Areas in Poland for Forestry Plantation. Forests, 12 (10), 1360. https://doi.org/10.3390/f12101360.

GOLIŃSKI P., RUTKOWSKI P., WALISZEWSKA B., STOLARSKI M., CZAPIEWSKI G., SZENTNER K., GĄSECKA M., MAGDZIAK Z., MLECZEK M. 2016. Salix: Properties and Practical Purposes.

KONATOWSKA M., RUTKOWSKI P., WENDZONKA J. 2021. The Impact of Willow Flowering Time on Species Composition and the Number of Apoidea Pollinators. Journal of Biosciences and Medicines. 09. 89–100. 10.4236/jbm.2021.911009.

SANDAK A., SANDAK J., WALISZEWSKA B., ZBOROWSKA M., MLECZEK M. 2017. Selection of optimal conversion path for willow biomass assisted by near infrared spectroscopy. iForest 10: 506–514. – doi: 10.3832/ifor1987–010.

SOBCZYK W., SOBCZYK E. J. 2019. Economical and ecological effects of cultivation of basket willow Salix viminalis L. 2nd International Conference on the Sustainable Energy and Environmental Development IOP Publishing IOP Conf. Series: Earth and Environmental Science 214 (2019) 012002 doi:10.1088/1755–1315/214/1/012002.

STANKOVA T., GYULEVA V., TSVETKOV I., POPOV E., KALMUKOV K., DIMITROV D., ANDONOVA E., STEFANOVA P. 2022. Adaptive potential and productivity of two Salix viminalis L. clonal varieties grown in North Central Bulgaria. Dendrobiology. 88. 1–15. 10.12657/denbio.088.001.

WALISZEWSKA B., SZENTNER K., PRĄDZYŃSKI W., DUKIEWICZ H., SIERADZKA H., SPEK–DŹWIGAŁA A., RUTKOWSKI P. 2013. Variation in selected morphological traits of Cfr. Salix viminalis from different experimental plots. Annals of Warsaw University of Life Sciences – SGGW Forestry and Wood Technology № 84, 269–274.

WARMBIER, K., WILCZYŃSKI, A., DANECKI L. 2013. Properties of one–layer experimental particleboards from willow (Salix viminalis) and industrial wood particles. Eur. J. Wood Wood Prod., 71, 25–28.

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PROPERTIES OF CALCIUM CHLORIDE HEXAHYDRATE IMPREGNATED WOOD

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ABSTRACT

Calcium chloride hexahydrate impregnated wood is wood that has been treated with a solution of calcium chloride hexahydrate (CaCl2·6H2O) in order to improve its durability and resistance to decay. Spruce sapwood (Picea orientalis) was impregnated with different concentrations of calcium chloride hexahydrate (CCH) (10, 50 and 100%). The decay resistance of impregnated wood was evaluated by attacks of white rot fungus as Trametes versicolor (Trv), brown rot fungus as Poria placenta (Pop), Coniophera puteana (Cop) was used after leaching procedure. Changes in the surface morphology and chemistry of the decayed biocomposites were investigated by TGA (Thermogravimetric Analysis) and ATR–FTIR (Fourier Transform Infrared), respectively. The calcium chloride in the solution helps to reduce the amount of water that is absorbed by the wood, making it more resistant to decay caused by fungal growth. As a results of FTIR measurement, impregnated with the CCH showed significant changes at the 1643 cm^{-1} and 1053 cm^{-1} peaks. The process of impregnating wood with calcium chloride hexahydrate is more expensive than other methods of wood preservation. So the final treated wood is expected to be at a slightly higher price point compared to untreated wood. It's important to note that this treatment process doesn't make wood completely resistant to decay, but it can significantly extend the life of the wood in certain environments

Key words: Calcium chloride hexahydrate, Wood, Decay test, TGA.

INTRODUCTION

A increasing population, an expanding economy, and a growing demand for a higher standard of living are all contributing to the global energy consumption rates (Nazir *et al.* 2019) The primary source of energy consumption, accounting for 40% of the total yearly power usage, is the heating and cooling of residential and commercial structures. The global energy ecology will be negatively impacted by the growing energy demand due to the extensive use of fossil fuels and greenhouse gas emissions. For building technology applications, it is crucial to create sustainable, renewable, and eco–friendly energy generating and storage systems. A viable and effective method for storing energy for later use that can boost energy efficiency and reduce costs is to employ latent heat thermal energy storage systems (LHTESS) (Sikiru *et al*.2022). The exceptional thermophysical characteristics of phase change materials (PCMs), a noteworthy family of LHTESS, have piqued curiosity Kumar et al. 2019). These materials are employed in many different applications, such as heat exchangers (Kalapa and Devanurr, 2018), cooling (Zou et al. 2018), desalination Al–harahsheh et al. 2018), and construction (Li et al. 2017). PCMs are used in construction applications to reduce heat transmission between a building and its surroundings. PCMs can reduce heat transmission between a building and its surroundings because they store energy in both sensible and latent forms (Faraj *et al*. 2020).

A notable subset of PCMs that garnered a lot of attention were inorganic PCMs based on salt hydrates for latent heat thermal energy storage. These PCMs have a significant volumetric storage capacity, are nonflammable, have a high volumetric energy storage capacity, and are more affordable than other PCM classes like fatty acids, paraffin, and waxes (Hirschey *et al*. 2021). Pure salt hydrates, such as calcium chloride hexahydrate (CaCl2•6H2O, CCH) and sodium sulfate decahydrate (Na2SO4 •10H2O), may be able to meet the temperature and energy storage capacity requirements for building

applications, but they also have drawbacks because of supercooling, low thermal conductivity, phase separation, and incongruent melting (Li *et al*. 2016; Akamo *et al*. 2023).

Because of the difference in solubility, phase separation increases the probability of partial or anhydrous salt precipitating during the melting of salt hydrates. Following a series of heat cycles, the settling of the salt eventually causes a decrease in the PCM's ability to store energy (Akamo *et al*. 2023). Moreover, the supercooling phenomenon causes crystals to form at temperatures far below the freezing point because there are insufficient nucleation sites to initiate crystallization. This affects the heat that salt hydrates emit and results in a significant temperature difference between melting and freezing. Therefore, these basic problems need to be resolved if PCMs are to fulfill their potential for common TES applications.

The studies have investigated the thermal performance of different materials treated with CCH phase change material. However, in the literature review, no studies were identified where CCH was used to impregnate wood samples. This study aims to evaluate the performance of spruce wood samples impregnated with CCH through tests such as TGA, FTIR, and resistance to wood–decaying fungi.

EXPERIMENTAL METHODS

MATERIALS

Spruce (*Picea orientalis*), sapwood, dimensions 5 × 15 × 30 mm, six replicates for treatment and reference controls, were used for the decay test. Calcium chloride hexahydrate (CHH) as PCM was selected and studied. Calcium chloride hexahydrate with the formula CaCl2H12O6 (known also as calcium dichloride hexahydrate) and a purity ≥ 98.0% has a melting temperature range from 30°C, the molecular weight of 219.07 g/mol, and density of 1.71 g/mL at 25°C (lit.).

IMPREGNATION OF WOOD SAMPLES WITH PCM

The wood samples were conditioned for 2 weeks at 23°C and 65% relative humidity (RH) before impregnation. Wood samples were impregnated at three different concentrations (10%, 50% and 100%). To prepare a concentration of 10–50%, CHH was prepared by mixing with water at 35°C at a mixing speed of 500 rpm. The impregnation of CHH was carried out in a vacuum oven under a pressure of 850 mbar at 40°C for 1 h and left at atmospheric pressure for 3 hours. The weight percentage gain (WPG) for 10%, 50% and 100%, was 56%, 73% and 55%, respectively. After impregnation, the samples were conditioned in the climate chamber for 3 weeks, and the mass was recorded prior to a leaching test.

LEACHING AND DECAY TEST

A leaching test according to EN 84 standard was conducted on the half of the samples for 14 days prior to the decay test in order to evaluate any loss in the effectiveness of decay resistance. The decay test was performed according to the principles of EN 113 with some modifications to the sample dimensions, Kolle flasks, and the total test period. A brown rot fungus, namely Coniophora puteana (Mad–515) and a white rot fungus, namely Trametes versicolor (L.) Lloyd (Mad–697) was inoculated to a sterile malt extract agar medium in petri dishes. Samples were placed on the growing mycelium in each petri dish and then were incubated at 20°C and 70% relative humidity for 12 weeks. The weight loss was calculated on the basis of the oven–dry weight before and after the decay test.

CHARACTERIZATION

The FTIR spectra of weathered and unweathered samples were recorded between 400 and 4000 cm^{-1} wavelength and with a 4 cm^{-1} resolution using a Bruker ATR–FTIR spectrometer. The radial surface of wood was used for the measurement. The spectra were baseline corrected and smoothed using the OPUS software (Bruker Optics GmbH, Ettlingen, Germany).

The thermal stability of the samples was characterized using a thermogravimetric analyzer (Perkin Elmer Pyris™ 1 TGA) at a scanning rate of 10°C min^{-1} in the temperature range of 20–500°C under a nitrogen atmosphere.

RESULTS AND DISCUSSION

The FTIR graphs for the prepared chemicals are presented in Figure 1, while Figure 2 displays the FTIR graphs for the wood samples impregnated with these chemicals.

It represents the wave numbers at which calcium chloride hexahydrate shows absorbance in certain bands during FTIR analysis. The 3300 cm^{-1} band may indicate O–H groups, which generally indicate the presence of hydrogen bonds. This band may indicate the presence of water molecules or hydrate. On the other hand, the 1643 cm^{-1} band probably indicates the presence of a C=O ester bond.

The spectrum of spruce wood (Fig. 2) shows the same basic structure as wood samples 3342 cm^{-1} peaks show strong main OH stretching, 2800–3000 cm^{-1} shows C–H stretching in methyl and methylene groups. The other characteristics peak at 1735 cm^{-1}, acetyl groups in xylan and other non–conjugated carbonyls), C=O Stretch in xylan (hemicelluloses), the peak at 1508 cm^{-1} shows the aromatic skeletal vibration of lignin, 1427 cm^{-1} Aromatic skeletal vibration in lignin with C–H deformation 1369 and 897 cm^{-1}, carbohydrates.

The peak at 1265 cm^{-1} indicates C–O stretch lignin ring in G units and 1026 cm^{-1} C–O vibration in cellulose and hemicellulose. Significant changes are expected in the FTIR analysis of the wood sample impregnated with CCH. During this chemical impregnation process, new peaks and bands may appear in the FTIR spectrum of the wood sample. In particular, an increase in the peaks originating from O–H groups in the 3300 cm^{-1} region can be observed after impregnation. This may occur due to the wood interacting with water or other hydrated components during the impregnation process.

Additionally, changes can be observed in the peak in the 1653 cm^{-1} region. The peak in this region may indicate the presence of C=O ester bonds or other organic components depending on the impregnation process.

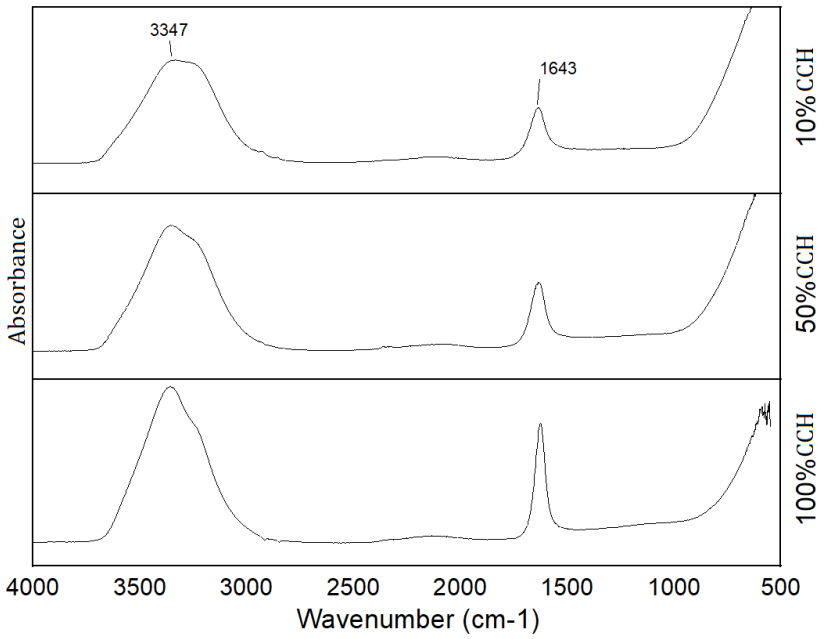


Figure 1: FTIR–ATR spectra of the different concentrations of CCH

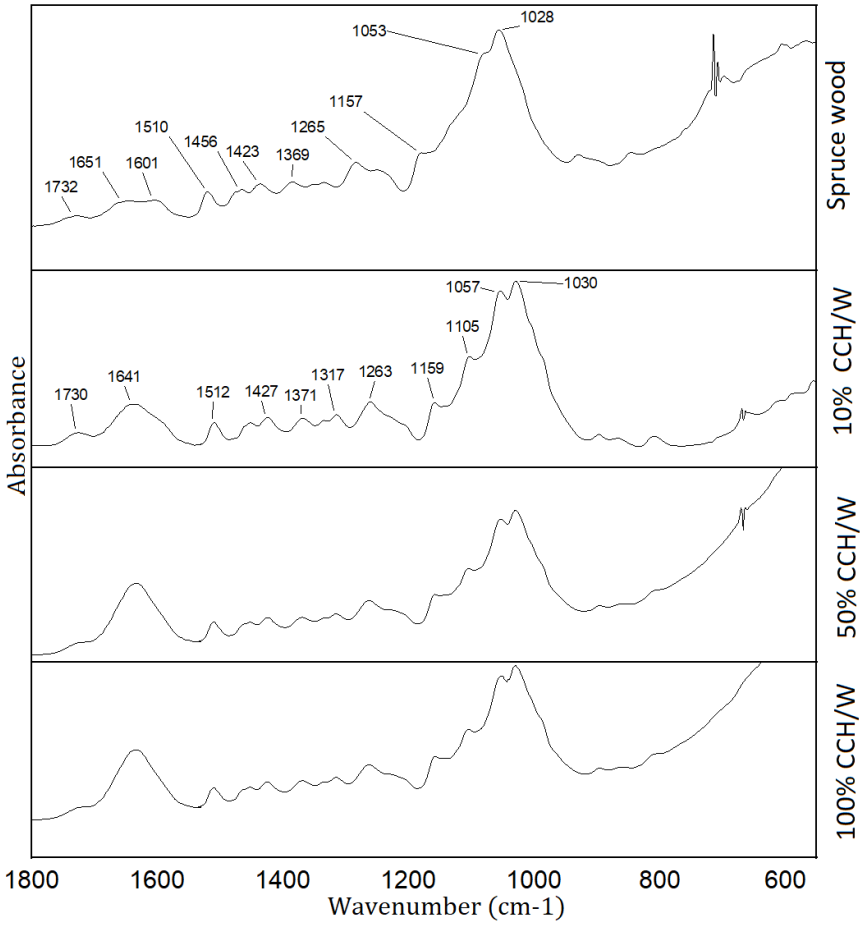


Figure 2: FTIR–ATR spectra of the different concentrations of CCH–modified wood (CCHW)

The TGA graphs for the prepared chemicals are presented in Figure 3–4, while Figure 5–6 displays the wood samples impregnated with these chemicals.

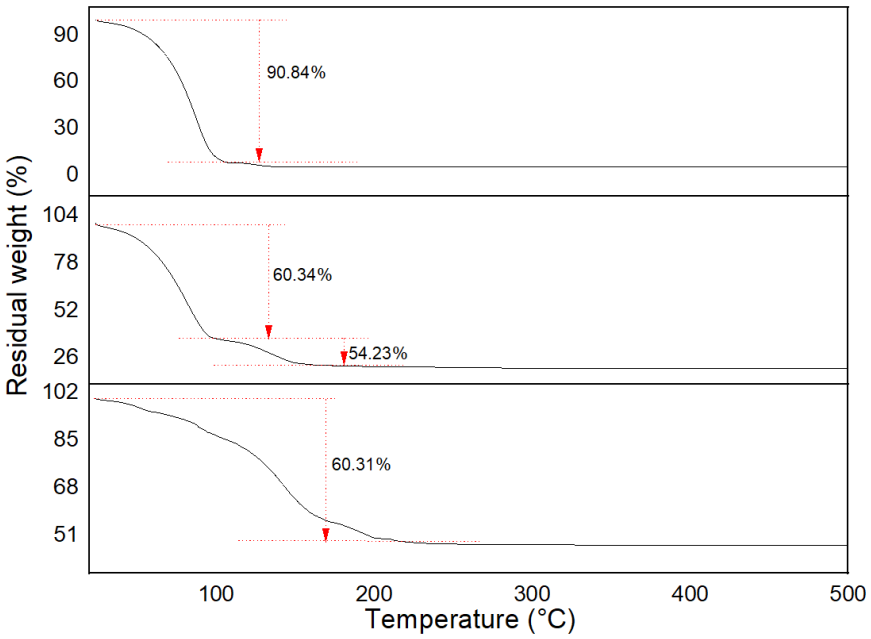


Figure 3: TGA curves of the different concentrations of CCH

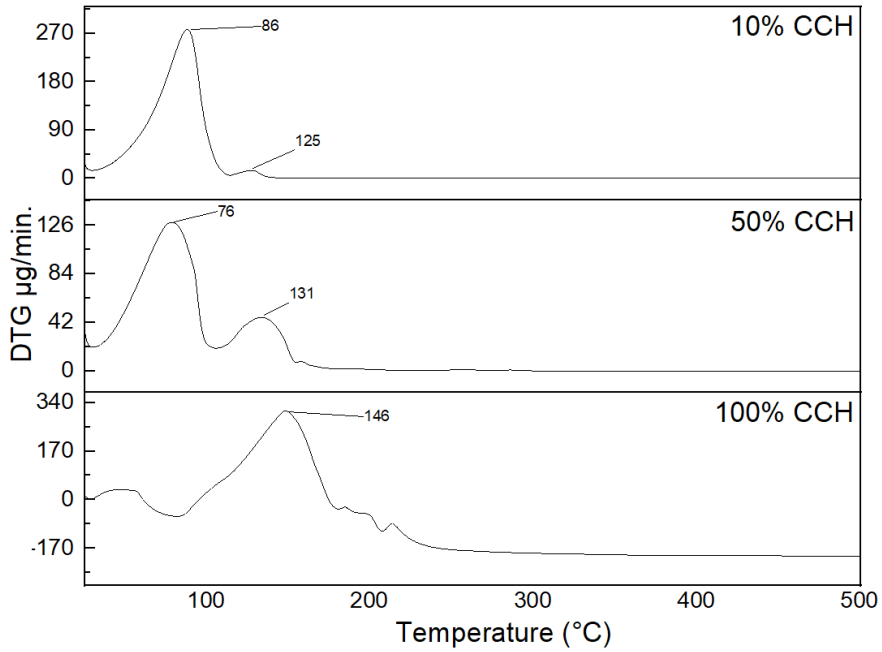


Figure 4: DTG curves of the different concentrations of CCH

In general, in the TGA analysis of calcium chlorite hexahydrate, water loss (first 100ºC) and thermal decomposition stages (146ºC) can be observed, especially in certain temperature ranges. These stages indicate loss of water content of calcium chlorite hexahydrate followed by thermal decomposition or decomposition reactions. These thermal properties of CCH provide information about the compound's uses and processing conditions. CCH decomposition at 100% concentration occurred at 146°C, and as the concentration rate decreased, thermal decomposition occurred at lower temperatures.

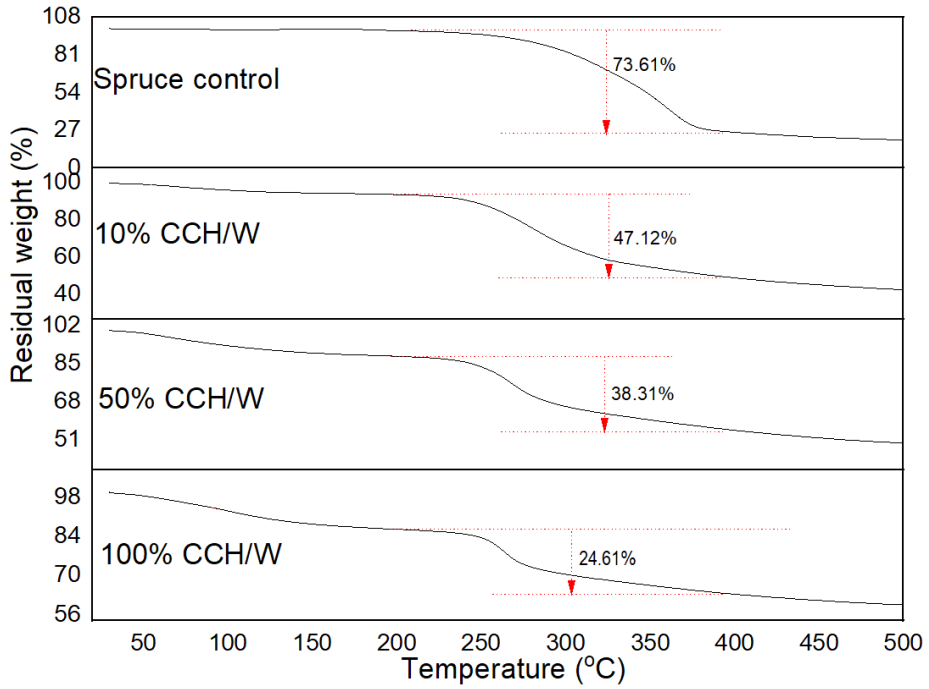


Figure 5: TGA curves of the different concentrations of CCH–modified wood (CCHW)

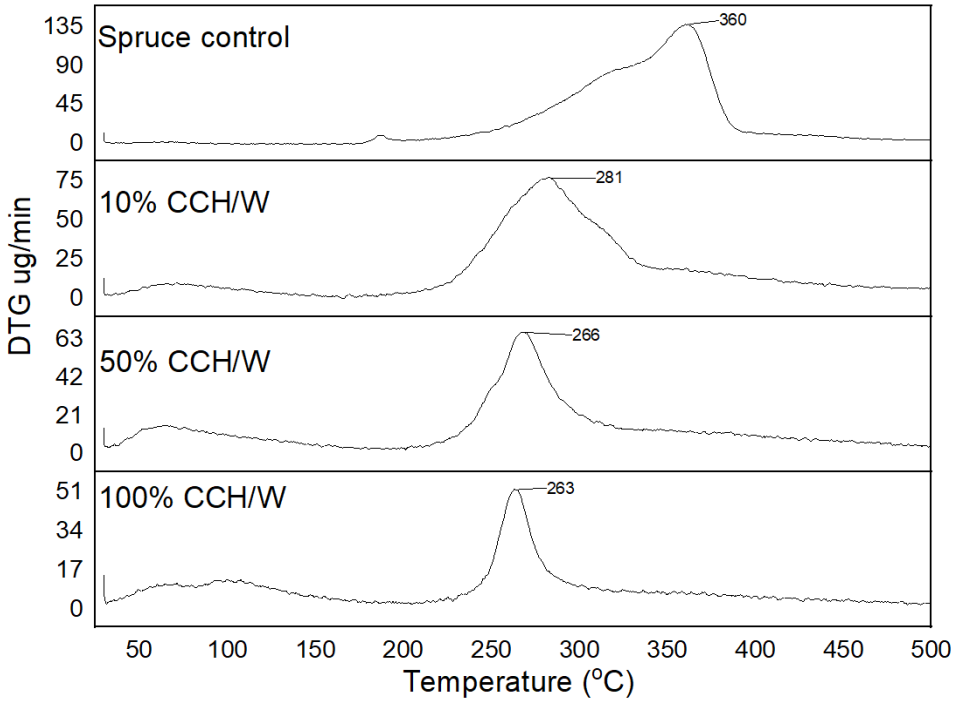


Figure 6: DTG curves of the different concentrations of CCH–modified wood (CCHW)

Since spruce wood is typically an organic material, two main stages of thermal decomposition are usually observed during TGA analysis. First, at low temperatures, the moisture content and slightly volatile components of wood can evaporate. This stage usually occurs between 100–200°C. At higher temperatures, organic polymers such as cellulose, hemicellulose and lignin, which are the main components of wood, may show thermal degradation. This stage usually occurs between 200–400°C. Since the CCH used in our study had low thermal stability, the thermal stability of the impregnated wood samples also decreased. While spruce wood underwent maximum degradation at 360ºC, CCH impregnated wood samples underwent maximum degradation at 263ºC.

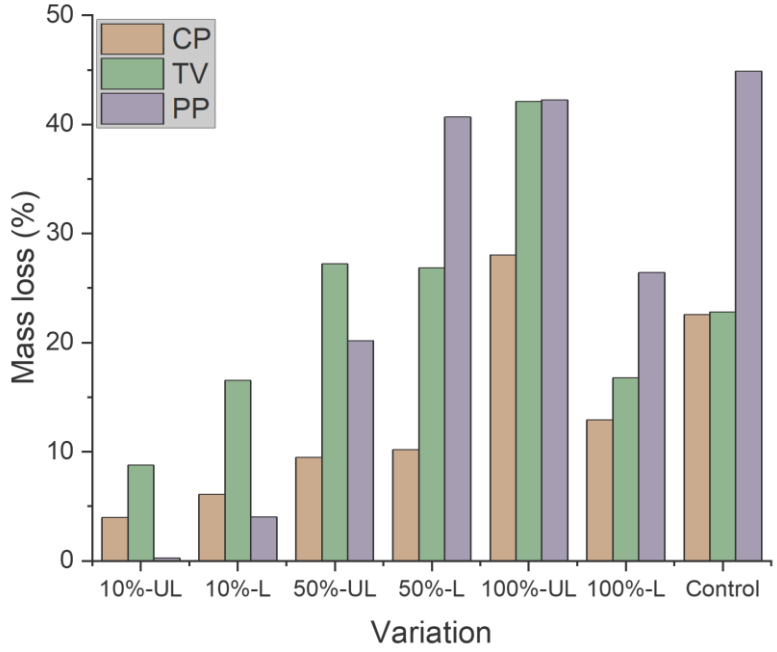


Figure 7: Weight loss after decay test

The results of the decay tests for both control and test samples are presented in Figure 7. The weight loss exceeding 20% in the control samples indicates the successful execution of the test. For wood samples exposed to CP and TV fungi, weight losses of up to 25% were observed, while samples exposed to PP fungi showed weight losses reaching up to 45%. In the test samples, an increase in concentration led to an increase in weight loss. This suggests the biodegradability of CCH to some extent, or the potential leaching of CCH from wood during the decay test. The liquidation and seepage of CCH from the wood are believed to be induced by the applied 25°C temperature during the test. Notably, wood samples impregnated at lower concentrations experienced weight losses below 5%, except for TV, indicating a possible correlation with the liquefaction of CCH and its influence on weight loss during the test.

CONCLUSIONS

In this study, the Fourier Transform Infrared (FTIR) and Thermogravimetric Analysis (TGA) of calcium chloride hexahydrate (CCH) and CCH–modified spruce wood (CCHW) were thoroughly investigated to understand their chemical and thermal properties. The FTIR spectra revealed significant absorption bands for CCH, particularly at 3300 cm^{-1} indicating O–H groups and at 1643 cm^{-1} indicating C=O ester bonds. The spruce wood samples showed characteristic peaks typical of lignocellulosic materials, including OH stretching, C–H stretching, and various vibrations associated with lignin, cellulose, and hemicellulose.

Upon impregnation with CCH, the FTIR spectra of the wood samples exhibited notable changes, such as increased peaks in the 3300 cm^{-1} region, suggesting interactions with hydrate components. Additionally, shifts in the 1653 cm^{-1} region indicated potential formation of new C=O ester bonds or other organic components due to the impregnation process.

The TGA results showed distinct thermal degradation stages for CCH, including water loss around 100 ºC and decomposition at 146 ºC. These stages were influenced by the concentration of CCH, with higher concentrations decomposing at higher temperatures. For CCH–modified wood, the thermal stability was reduced compared to untreated spruce wood, with maximum degradation

temperatures shifting from 360ºC for pure wood to 263ºC for CCHW samples, reflecting the impact of CCH impregnation.

Decay tests further demonstrated the biodegradability and potential leaching of CCH from the impregnated wood. Control samples exhibited significant weight loss, confirming the test's validity, while test samples showed varying degrees of weight loss depending on the concentration of CCH and the type of fungi. Notably, increased CCH concentration correlated with higher weight loss, suggesting that the compound can leach out under test conditions, particularly at 25°C.

REFERENCES

NAZIR H., BATOOL M., BOLIVAR OSORIO F.J., ISAZA–RUIZ M., XU X., VIGNAROOBAN K., PHELAN P., KANNAN A.M. 2019. Inamuddin, Recent developments in phase change materials for energy storage applications: a review. Int, J Heat Mass Transf. 129, 491–523.

SIKIRU S., OLADOSU T.L., AMOSA T.I., KOLAWOLE S.Y., SOLEIMANI H. 2022. Recent advances and impact of phase change materials on solar energy: a comprehensive review. J Energy Storage. 1 (Sep): 53.

KUMAR N., HIRSCHEY J., LACLAIR T.J., GLUESENKAMP K.R., GRAHAM S. 2019. Review of stability and thermal conductivity enhancements for salt hydrates. J Energy Storage. 24 (Aug): 100794.

LI X., ZHOU Y., NIAN H., ZHANG X., DONG O., REN X., ZENG J., HAI C., SHEN Y. 2017. Advanced nanocomposite phase change material based on calcium chloride hexahydrate with aluminum oxide nanoparticles for thermal energy storage. Energy and Fuels. 31 (6): 6560–6567.

ZOU T., FU W., LIANG X., WANG S., GAO X., ZHANG Z., FANG Y. 2018. Preparation and performance of modified calcium chloride hexahydrate composite phase change material for air–conditioning cold storage. Int. J. Refrig. 95: 175–181.

AL–HARAHSHEH M., ABU–ARABI M., MOUSA H., ALZGHOUL Z. 2018. Solar desalination using solar still enhanced by external solar collector and PCM. Appl. Therm. Eng. 128: 1030–1040.

KALAPALA L., DEVANURI J.K. 2018. Influence of operational and design parameters on the performance of a PCM based heat exchanger for thermal energy storage – a review. J Energy Storage. 20 (Dec 1): 497–519.

FARAJ K., KHALED M., FARAJ J., HACHEM F., CASTELAIN C. 2020. Phase change material thermal energy storage systems for cooling applications in buildings: a review. Renew. Sustain. Energy Rev. 119 (Mar 1).

HIRSCHEY J.R., KUMAR N., GLUESENKAMP K.R., GRAHAM S., HIRSCHEY J., ROBERT, KUMAR N., TURNAOGLU T., GLUESENKAMP K.R., SAMUEL G., TURNAOGLU T. 2021. Review of Low–Cost Organic and Inorganic Phase Change Materials with Phase Change Temperature between 0◦C and 65ºC. International High Performance Buildings Conference. 10.

LI X., ZHOU Y., NIAN H., REN X., DONG O., HAI C., SHEN Y., ZENG J. 2016. Phase change behavior of latent heat storage media based on calcium chloride hexahydrate composites containing strontium chloride hexahydrate and oxidation expandable graphite. Appl. Therm. Eng. 102: 38–44.

AKAMO D.O., KUMAR N., LI Y., PEKOL C., LI K., GOSWAMI M., HIRSCHEY J., LACLAIR T.J., KEFFER D.J., RIOS O., GLUESENKAMP K.R. 2023. Stabilization of low–cost phase change materials for thermal energy storage applications. iScience. 26 (7): 107175.

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SPECIFIC CUTTING ENERGY OF CO2 LASER BEAM INTERACTION WITH PLYWOOD

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ABSTRACT

In this paper, the results of the investigations for the determination of the specific energy in laser cutting of birch plywood using a ZnSe lens with focal length = 50.8 mm and focal position on and above the material surface are presented. The investigations were conducted at three levels of laser beam power and feed rate variation.

A comparison is made between the experimentally obtained results and the theoretically determined ones, and relevant conclusions and recommendations are formulated.

Key words: CO_2 laser, plywood, laser cutting, specific energy.

INTRODUCTION

In the woodworking and furniture industry, as well as in the souvenir industry in Bulgaria and worldwide, the CO_2 laser beam is increasingly used as a cutting and engraving tool.

A number of studies have been and are being conducted on the characteristics and effects of the laser beam in its interaction with different types of wood and wood–based materials (WBM) (Orech *et al*. 1987, Gochev *et al*. 1994, Gochev 1996, Gochev *et al*. 1996, Dinkov *et al*. 1996, Batov *et al*. 1997, Pagano *et al*. 2009, Kubovský *et al*. 2012 , Hernández–Castañeda *et al*. 2011, Eltawahni *et al*. 2013, Petutschnigg *et al*. 2013, Gurau *et al*. 2017, Martinez–Conde *et al*. 2017, Vidholdová *et al*. 2017, Jurek *et al*. 2021, Gochev *et al*. 2022, Gochev 2023, etc.).

When using classic tools for cutting wood and WBM, one of the quantities that characterizes the process is specific cutting work, i.e. the work required to convert 1 m^3 of wood into chips, with dimension J/m^3 (Gochev 2018).

When cutting wood and WBM with a CO_2 laser beam, analogous to the specific cutting work, the concept of specific laser cutting energy can be defined, i.e. the amount of laser beam energy that is required to remove a unit mass of wood, J/kg (Orech *et al*. 1987, Gochev 1996, Gochev *et al*. 1996, Kubovský *et al*. 2012, Gochev 2016).

The weight of material removed (vaporized) by the laser beam can be represented by the relation:

$$\Delta m = \frac{1}{E_s}.E_t \quad (1)$$

Where $\Delta m = m_1 - m_2$ is the weight of vapor from the laser beam, material, kg;

m_1 – weight of the material before its laser beam treatment, kg;

m_2 – the weight of the material after its treatment with a laser beam, kg.

E_s –the specific energy of laser cutting, J/kg;

E_t –the total amount of energy transmitted by the laser beam per unit area of the material surface per time *t*, J.

The formula for practical calculation of the specific energy of laser cutting can be represented by equality:

$$E_s = \frac{P.l}{v_f.\Delta m} \quad (2)$$

Where P is the laser beam power, W;

l – the slot length, m;

v_f – the feeding (scanning) speed of the laser beam, m/s;

ρ – the material density, kg/m^3.

Equation (1) expresses the linear relationship between Δm and E_t, and their relationship with Es can be represented as a linear equation of the form:

$$y(x) = b_0 + b_1.x \quad (3)$$

Using this equation, it is possible to determine the values of Δm and E_t and to calculate those of E_s for the material under study. In this way, experimentally obtained and theoretically calculated results for the specific laser cutting energy can be compared.

METHODOLOGY

The experimental studies were conducted using using a laser engraving and cutting machine of *FormaTec*, model *K40* (China) (Fig. 1), with the following parameters:

- operating mode – continuous;
- wavelength (λ) – 10.6 μm;
- laser beam power (P) – 8; 11 and 14 W;
- feed rate (scanning) of the laser beam (v_f) – 20, 30 and 40 mm/s;
- ZnSe focusing lens with focal distance (F) – 50.8 mm;
- focus position ΔF = 0 mm – on the surface of the material and ΔF = –4 mm – above the surface of the material.

For the purpose of the experiment was used plywood – common birch (Betula pendula Roth.) with a thickness of 3.5 mm – ρ = 650 kg/m^3; W = 6%.

The plywood density was determined by weight method and its moisture content by moisture meter, model Lignomat (*Ligno VersaTec* – USA).

To determine the specific energy of laser cutting, two series of 12 (twelve) specimens were made, from birch plywood, with the shape of a parallelepiped and dimensions: L = 200 mm; b = 25 mm; h = 3.5 mm. Their weights before and after laser beam exposure were measured with an electronic balance, model *RADWAG WLC 1/A2* (Poland), with an accuracy of 0.001 g (Fig. 2 A). The values of the laser beam parameters were chosen so that the condition of incomplete cutting of the examined material was fulfilled (Fig. 2 B).

Fig. 3 shows the position of the laser beam focus, at the material surface (ΔF = 0 mm) and at 4 mm above the material surface (ΔF = –4 mm).

The values of the variable factors – laser beam power (P, W) and laser beam scan (feed) speed (v_f, mm/s) in explicit and coded form are given in Table 1.

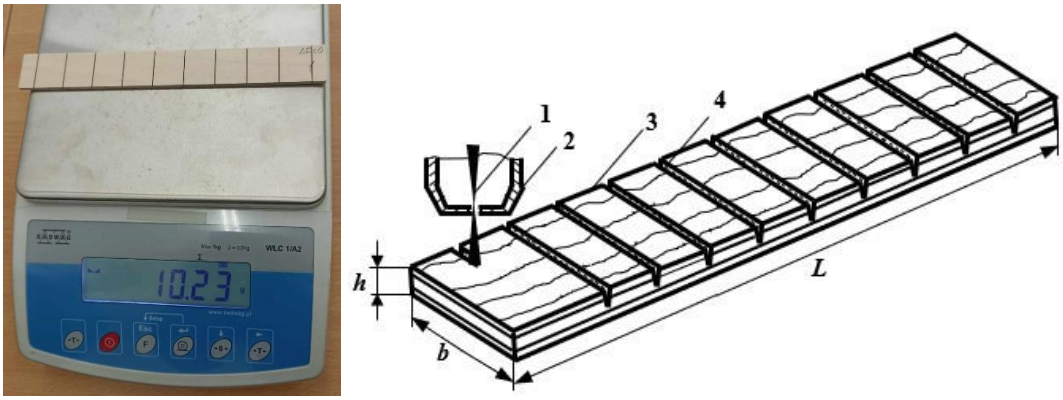
The matrix of the planned two-factor experiment is shown in Table 2.

Ten (10) slots were made on each sample of the two series of sampless, according to Table 2, at ΔF = 0 mm and ΔF = –4 mm (Fig. 4 A).

After the experiment, each of the sample bodies was weighed and the value of its lost weight was recorded (Fig. 2 A). Figure 4 B and C shows all the sample bodies, from both series, with the slots made.

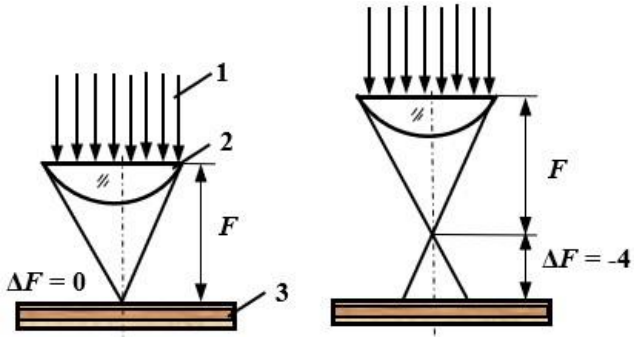


Figure 1: Experimental setup: laser engraving and cutting machine K 40 with PC control



A **B**

Figure 2: A – Electronic balance RADWAG WLC 1/A2 (Poland); B – General view of the experiment: 1 – laser beam, 2 – laser head, 3 – plywood, 4 – slot; *L* – length; *b* – width; *h* – thickness



A **B**

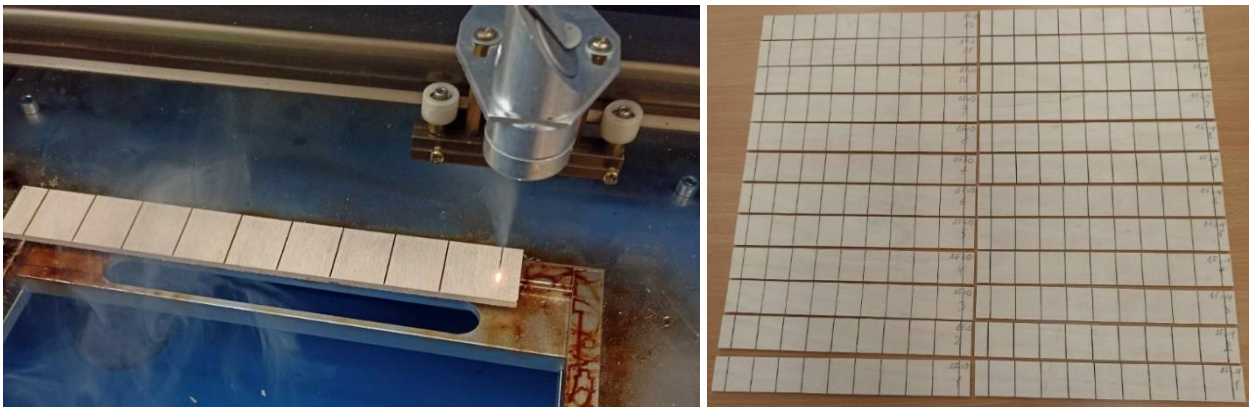
Figure 3: Focus position relative to the material surface: A – on the material surface (Δ*F* = 0 mm); B – above the material surface (Δ*F* = –4 mm); 1 – unfocused laser beam; 2 – focusing lens; 3 – material (plywood)

Table 1: Variable factor values

Variable factors	Minimum value		Average value		Maximum value	
	open form	coded form	open form	coded form	open form	coded form
$x_1 = P$, W	8	–1	11	0	14	+1
$x_2 = v_f$, mm/s	20	–1	30	0	40	+1

Table 2: Matrix of the planned two–factor experiment

№ of the experiment	Variable factors			
	$x_1 = P$, W		$x_2 = v_f$, mm/s	
1.	–1	8	–1	20
2.	+1	14	–1	20
3.	–1	8	+1	40
4.	+1	14	+1	40
5.	–1	8	0	30
6.	+1	14	0	30
7.	0	11	–1	20
8.	0	11	+1	40
9.	0	11	0	30
Experiments in the middle of the factor space				
10.	0	11	0	30
11.	0	11	0	30
12.	0	11	0	30



A **B** **C**

Figure 4: A – Processing of the specimens; B and C – General view of the specimens, from both series, after the slotting: A – at ΔF = 0 mm; B – at ΔF = –4 mm

The dispersion analysis methodology was used to evaluate the results of the conducted two–factor experiment (*Vuchkov at. al.* 1986). The regression equation for two factors of variation is of the form:

$$y_{pr.v.} = b_o + b_1 x_1 + b_2 x_2 + b_{11} x_1^2 + b_{22} x_2^2 + b_{12} x_1 x_2 \quad (4)$$

Where $y_{pr.v.}$ is the predicted value of the output quantity;

b_o – coefficient in front of the free term;

b_1 and b_2 – coefficients in front of the linear terms;

b_{11} and b_{22} – coefficients in front of the nonlinear terms of the equation.

RESULTS AND DISCUSSION

Tables 3 and 4 present the values for the weight of the material before and after laser beam treatment, as well as those for the weight of the material vaporized by the laser beam, at the focal position on the material surface (ΔF = 0 mm) and above the plywood surface (ΔF = –4 mm), according to the two–factor experiment matrix (Table 2).

Tables 5 and 6 show the values for E_s calculated from formula (2) at ΔF = 0 mm and ΔF = –4 mm, where l is the length of all ten slots for a given specimen.

Table 3: Material weight at focal position ΔF = 0 mm (at the material surface)

№	Variable factors		Initial and output values		
	$x_1 = P$, W	$x_2 = v_f$, mm/s	m_1, g	m_2, g	Δm, g
1.	8	20	10.28	10.23	0.05
2.	14	20	10.45	10.39	0.06
3.	8	40	10.31	10.29	0.02
4.	14	40	10.34	10.31	0.03
5.	8	30	10.71	10.69	0.02
6.	14	30	10.29	10.25	0.04
7.	11	20	10.20	10.14	0.06
8.	11	40	10.38	10.35	0.03
9.	11	30	10.40	10.36	0.05
Experiments in the middle of the factor space					
10.	11	30	10.41	10.39	0.04
11.	11	30	10.54	10.50	0.02
12.	11	30	10.54	10.53	0.04

On the basis of the conducted experimental studies and after mathematical processing of the data, using specialized software Q–StatLab, are deduced:

Table 4: Material weight at focus position ΔF = –4 mm (above material surface)

№	Variable factors		Initial and output values		
	$x_1 = P$, W	$x_2 = v_f$, mm/s	m_1, g	m_2, g	Δm, g
1.	8	20	10.30	10.23	0.07
2.	14	20	10.50	10.40	0.1
3.	8	40	10.35	10.32	0.03
4.	14	40	10.55	10.53	0.02
5.	8	30	10.48	10.46	0.02
6.	14	30	10.17	10.12	0.05
7.	11	20	10.14	10.09	0.05
8.	11	40	10.20	10.17	0.03
9.	11	30	10.10	10.04	0.06
Experiments in the middle of the factor space					
10.	11	30	10.16	10.13	0.03
11.	11	30	10.39	10.34	0.05
12.	11	30	19.33	10.25	0.08

Table 5: Specific cutting energy E_s at ΔF = 0 mm (at the material surface)

№	Variable factors		Initial and output values		
	$x_1 = P$, W	$x_2 = v_f$, mm/s	Δm, kg	l, mm	E_s, J/kg
1.	8	20	0.00005	257	2.06×10^6
2.	14	20	0.00006	256	2.99×10^6
3.	8	40	0.00002	256	2.56×10^6
4.	14	40	0.00003	254	2.96×10^6
5.	8	30	0.00002	255	3.40×10^6
6.	14	30	0.00004	256	2.99×10^6
7.	11	20	0.00006	255	2.34×10^6
8.	11	40	0.00003	255	2.34×10^6
9.	11	30	0.00005	255	1.87×10^6
Experiments in the middle of the factor space					
10.	11	30	0.00004	256	2.35×10^6
11.	11	30	0.00002	255	4.68×10^6
12.	11	30	0.00004	256	2.35×10^6

Table 6: Specific cutting energy E_s at ΔF = –4 mm (above material surface)

№	Variable factors		Initial and output values		
	$x_1 = P$, W	$x_2 = v_f$, mm/s	Δm, kg	l, mm	E_s, J/kg
1.	8	20	0.00007	255	1.46 x 10^6
2.	14	20	0.0001	255	1.79 x 10^6
3.	8	40	0.00003	255	1.70 x 10^6
4.	14	40	0.00002	256	4.48 x 10^6
5.	8	30	0.00002	255	3.40 x 10^6
6.	14	30	0.00005	256	2.39 x 10^6
7.	11	20	0.00005	256	2.82 x 10^6
8.	11	40	0.00003	256	2.35 x 10^6
9.	11	30	0.00006	255	1.56 x 10^6
Experiments in the middle of the factor space					
10.	11	30	0.00003	256	3.13 x 10^6
11.	11	30	0.00005	255	1.87 x 10^6
12.	11	30	0.00008	255	1.17 x 10^6

- Regression equation at ΔF = 0 mm

$$Y_1 = 2.83 + 0.85X_1 – 0.79X_2 + 0.34X_1^2 + 0.053X_2^2 – 0.249X_1X_2 \quad (5)$$

- Regression equation at ΔF = –4 mm

$$Y_1 = 2.13 + 0.64X_1 – 0.32X_2 + 0.36X_1^2 + 0.06X_2^2 – 0.293X_1X_2 \quad (6)$$

Where Y_1 is the expected variation of the specific cutting energy E_s in coded form at the corresponding focal length;

X_1 – the laser beam power (P) in coded form;

X_2 – feed rate (v_f) in coded form.

It can be seen from equations (5) and (6) that it is the coefficient in front of X_1 corresponding to the cutting power that will have the greatest influence, and to a greater extent than feed rate, on the specific cutting energy (E_s). The sign in front of the coefficient is „plus“, i.e. as P increases, so will E_s. The coefficient in front of X_2 has a negative sign, i.e. as the feed (scan) speed increases, the specific cutting energy will decrease. The sign in front of the coefficient b_{12} is negative, indicating the divergent influence of the laser beam power (P) and feed rate (v_f) on the specific cutting energy (E_s).

Figures 5 and 6 present the graphical relationships showing the variation of the specific cutting energy Es with laser beam power (P) at different feed rates (v_f) and at focal distance ΔF = 0 mm and ΔF = –4 mm.

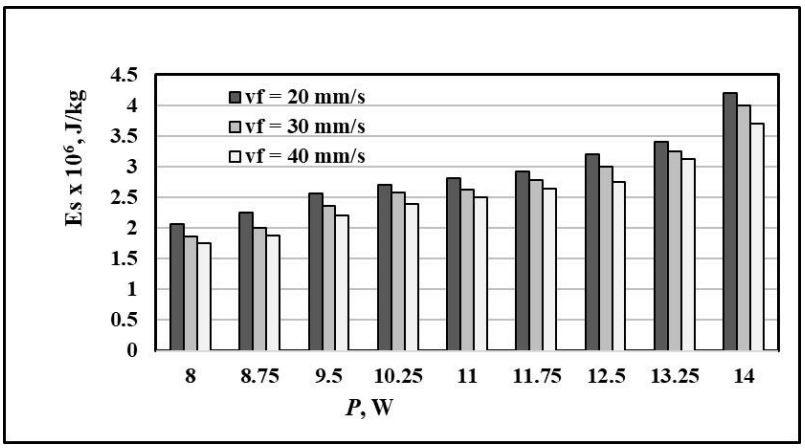


Figure 5: Variation of the specific cutting energy E_s with laser beam power (P) at different feed rates (v_f) and at focus position ΔF = 0 mm

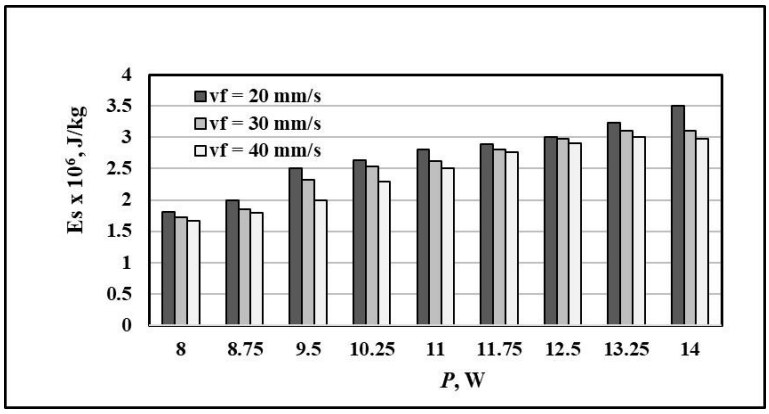


Figure 6: Variation of the specific cutting energy E_s with laser beam power (P) at different feed rates (v_f) and at focus position $\Delta F = -4$ mm

The linear relationship between Δm and E_t and their connection with E_s represented as a linear equation (3) was investigated using *MS Excel* and the *Data Analysis* module, which included a linear regression procedure.

Tables 7, 8 and 9 give the summary data, *ANOVA* analysis of variance and values of regression coefficients and other quantities for $\Delta F = 0$ mm and Tables 10, 11 and 12 for $\Delta F = -4$ mm.

Table 7: Summary results for $\Delta F = 0$ mm

Regression Statistics	
Multiple R	0,867845
R Square	0,753156
Adjusted R Square	0,717892
Standard Error	8,4E–06
Observations	9

Table 8: Dispersion analysis for $\Delta F = 0$ mm

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1,51E–09	1,51E–09	21,35795	0,002421946
Residual	7	4,94E–10	7,05E–11		
Total	8	2E–09			

Table 9: Values of regression coefficients, standard errors and other quantities for $\Delta F = 0$ mm

	Coefficients	*Standard Error*	*tStat*	*P–value*	*Lower 95,0%*	*Upper 95,0%*
Intercept	3,49977E–06	8,2279E–06	0,425354	0,679587	–1,48331E–05	2,1833E–05
E_t, J	3,49888E–07	7,851–8E–08	4,45656	0,001223	1,74955E–07	5,2482E–07

Table 10: Summary results for $\Delta F = -4$ mm

Regression Statistics	
Multiple R	0,808242
R Square	0,653255
Adjusted R Square	0,603719
Standard Error	1,66E–05
Observations	9

Table 11: Dispersion analysis for ΔF = –4 mm

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3,63E–09	3,63E–09	13,18772	0,008381
Residual	7	1,93E–09	2,75E–10		
Total	8	5,56E–09			

Table 12: Values of regression coefficients, standard errors and other quantities for ΔF = –4 mm

	Coefficients	*Standard Error*	*tStat*	*P–value*	*Lower 95,0%*	*Upper 95,0%*
Intercept	–6,6E–06	1,6E–05	–0,413	0,691963	–4,4E–05	3,11E–05
E_t, J	5,36E–07	1,48E–07	3,63149	,008381	1,87E–07	8,85E–07

The multiple correlation coefficient (*Multiple R*), which in this case is the coefficient of linear correlation between the dependent factor (Δm – the weight of material vaporized by the laser beam, kg) and the independent factor (E_t – the total amount of energy that is transmitted by the laser beam per unit area of the plywood surface, per time t, J) is 0.87 at ΔF = 0 mm and 0.81 at ΔF = –4 mm.

The coefficient of determination (*R Square*) has a value of 0.75 at ΔF = 0 mm and 0.65 at ΔF = –4 mm, indicating that approximately 75% (ΔF = 0 mm) and 65% (ΔF = –4 mm) of the variation in the dependent factor (Δm) is „explained“ by the regression.

In the examples considered, the *F*–ratio has a value of 21.36 (ΔF = 0 mm) and 13.19 (ΔF = –4 mm), which are significantly larger than the corresponding critical values in the F–distribution tables (*Significance F*). This leads to the conclusion that the fraction of the variance of the dependent factor (Δm) that is „explained“ by the regression is significantly larger than the residual variance (*Residual*) that is due to unobserved factors.

Tables 9 and 12 include the values of the regression coefficients, their standard errors, the corresponding *t*–statistics and *p*–values that determine the statistical significance of the regression coefficients, the upper and lower bounds of the confidence intervals for the regression coefficients at the chosen confidence level. In the first column of these tables are the names of the free term (*Intercept*) and the regression coefficients in front of the corresponding independent variables.

The results of the experimental and theoretical determination of the specific laser cutting energy at the interaction of the laser beam with common birch plywood (E_s) are presented in Table 13.

Table 13: Specific energy of the laser beam when interacting with birch plywood

Material	**Specific laser cutting energy (E_s)**			
	Experimental results	**Theoretically calculated results**		
		ΔF = 0 mm		
	E_s, J/kg	**E_s, J/kg**	**Equation (1; 3)**	***R***
Plywood – common birch	$2{,}74.10^6$	$2{,}54.10^6$	$\Delta m = 5{,}08.10^{-6} + 3{,}44.10^{-7}E_t$	0,87
		ΔF = –4 mm		
	$2{,}34.10^6$	$2{,}14.10^6$	$\Delta m = -6{,}6.10^{-6} + 5{,}36.10^{-7}E_t$	0,81

CONCLUSIONS

Based on the research conducted, the following more important conclusions and recommendations can be drawn:

1. From the summarized results presented in Table 13 it can be seen that the experimentally obtained and statistically calculated E_s values for the studied material – common birch

plywood are very close in value. The difference is of the order of7,3% (ΔF = 0 mm) to 8,5% (ΔF = –4 mm).

2. At the position of the focus above the material surface (ΔF = –4 mm), the loss of wood mass is greater than at the position of the laser beam focus on the plywood surface (ΔF = 0 mm). In the first case, the slot width is larger due to the larger diameter of the unfocused laser beam (Fig. 4. B) and the larger amount of material vaporized.
3. The difference in the laser cutting specific energy values at different focal positions, on the material surface (ΔF = 0 mm) and at 4 mm above the surface (ΔF = –4 mm) is of the order of 15%, with larger E_s values obtained at ΔF = 0 mm, since the laser beam spot diameter at its focus is the smallest and the power density is the largest.
4. As the feed (scan) speed of the laser beam increases, the specific energy of laser cutting decreases, which is logical given formula (2), but this is also confirmed by the smaller amount of material removed (Table 3 and 4).
5. Due to the small thickness of the birch plywood used – 3.5 mm, the influence of the position of the focus under the surface of the material was not investigated..
6. Based on experimental studies and statistical calculations, the specific energy of the laser beam when interacting with birch plywood can be considered as a constant quantity at a given focal position (ΔF) relative to the material surface. This can be used for further studies, for example in a model describing the kinetics of slot formation.

REFERENCES

BATOV I., ZH. GOTCHEV, B. DINKOV, Z. JANIC, 1997, Study on the head field and the structural changes during the interactions between CO_2 laser beam and wood material, The 3rd International Conference on the Development of Forestry and Wood Science/Technology, Volume II, Belgrade, pp. 560–568, ISBN 86–7299–048–x.

DINKOV., ZH. GOCHEV, V. BARNEKOV, 1996. Optimization of the Influence of the Main Notch Formation Factors in Laser Beam Interaction with Wood and Wood Materials, Proceedings of the International Scientific Conference „Mechanical Technology of Wood", 21–23 November 1996, Sofia, University of Forestry Publishing House, pp. 305–311 (in Bulgarian).

ELTAWAHNI H., N. ROSSINI, M. DASSISTI, K. ALRASHED, T. ALDAHAM, K. BENYOUNIS, A. OLABI, 2013. Evaluation and optimization of laser cutting parameters for plywood materials. Opt. Lasers Eng., 51(9):1029–1043, ISSN: 0143–8166.

GOTCHEV J., V. BARNEKOV, B. DINKOV, 1994. Modeling the Laser Cutting of Particleboard, 2nd International Conference on Automated Lumber Processing Systems and Laser Machining of Wood and Composites, Michigan State University, East Lansing, Michigan, USA, pp. 71–81.

GOCHEV ZH., 1996. Investigation of the process of laser cutting of furniture parts made of particle board, PhD Thesis, University of Forestry, Sofia, p. 200 (in Bulgarian).

GOCHEV ZH., B. DINKOV, 1996. Specific Cutting Energy at Laser Beam Interaction with Wood and Wood Materials, Proceedings of International Scientific Conference, University of Forestry, Section: Mechanical Technology of Wood, Sofia, pp. 298–304 (in Bulgarian).

GOCHEV ZH., 2016. Laser wood cutting and modification in its structure, IInd International Furniture Congress: proceedings of papers, 13–15 October, Muğla Sitki Koçman University Faculty of Technology Department of Wood Product Industrial Engineering, Turkey, pp. 210–215.

GOCHEV ZH., 2018. Wood cutting and cutting tools, Avangard Prima Publishing House, Sofia, c. 523, ISBN 978–619–239–047–1 (in Bulgarian).

GOCHEV ZH., P. Vichev, 2022. Color modifications in plywood by different mode of CO_2 laser engraving, Scientific journal Acta Facultatis Xylologiae, Zvolen, 64(2), DOI: 10.17423/afx.2022.64.2.08, pp. 77–86, ISSN 1336–3824.

GOCHEV ZH., 2023. Real Parametefrs of a Focused CO2 Laser Beam and its Determination when Using Lenses with Different Focal Lengths, 32nd International Conference on Wood Science and Technology – ICWST 2023, Unleashing the Potential of Wood–Based Materials, proceeding of papers, 7–8 December, Zagreb, pp. 67–74, ISBN 978–953–292–083–3.

GURAU L., A. PETRU, A. VARODI, M. TIMAR, 2017. The Influence of CO2 Laser Beam Power Output and Scanning Speed on Surface Roughness and Colour Changes of Beech (Fagus sylvatica), BioResources 12(4):7395–7412, ISSN: 1930–2126.

HERNÁNDEZ–CASTAÑEDA J., H. KURSAD, L. LI, 2011. The effect of moisture content in fibre laser cutting of pine wood. Opt. Lasers Eng., 49(9–10):1139–1152, ISSN: 0143–8166.

JUREK M., R. WAGNEROVÁ, 2021, Laser beam calibration for wood surface colour treatment, European Journal of Wood and Wood Products, 79(5):1097–1107, ISSN: 1436736X.

KUBOVSKÝ I., M. BABIAK, Š. CIPKA, 2012. A determination of specific wood mass removal energy in machining by CO2 laser, Acta Facultatis Xylologiae Zvolen, 54(2): 31−37, 2012, Zvolen, Technická univerzita vo Zvolene, ISSN: 13363824.

MARTINEZ–CONDE A., T. KRENKE, S. FRYBORT, U. MÜLLER, 2017. Review: Comparative analysis of CO_2 laser and conventional sawing for cutting of lumber and wood–based materials. Wood Sci. Technol., 51: 943–966, ISSN: 1432–5225.

ORECH, J., F. JŮZA, 1987. Měrná energie úběru a její určení při interakci laserového záření se dřevem. Drevársky výskum, Číslo 114, stránky 29–40, ISSN 0012–6136.

PAGANO N., S. GENNA, C. LEONE, V.LOPRESTO, 2009. Wood Laser machining using CO_2 30W laser in CW and pulse regime, In book: Innovative production machines and systems. LAPT, Napoli, pp. 145–150, ISBN–10:1849950067.

PETUTSCHNIGG A., M. STÖCKLER, F. STEINWENDNER, J. SCHNEPPS, H. GÜTLER, J. BLINZER, H. HOLZER, TH. SCHNABELL, 2013. Laser Treatment of Wood Surfaces for Ski Cores: An Experimental Parameter Study, Advances in Materials Science and Engineering, Volume 2013(11), , Article ID 123085, pp 1–7, ISSN: 1687–8434 (Print), ISSN: 1687–8442 (Online).

VUCHKOV I., S. STOYANOV, 1986. Mathematical modeling and optimization of technological objects, SPH Tehnika, Sofia, p. 341 (in Bulgarian).

VIDHOLDOVÁ Z., L. REINPRECHT, R. IGAZ, 2017. The Impact of Laser Surface Modification of Beech Wood on its Color and Occurrence of Molds, 12(2):7395–7412, ISSN: 1930–2126.

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ADVANTAGES AND APPLICATION OF RIBBED BELTS FOR DRIVING THE CUTTING MECHANISMS OF MILLING MACHINES

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ABSTRACT

The present work discusses the advantages of ribbed belts when using them to drive the cutting mechanisms of milling machines. The cases of driving the cutting mechanism using different belt gears are investigated. Emphasis is placed on the two widely used belts in contemporary machine building – classic V–belts and ribbed belt with profile PK. The cutting mechanism during its operation at idle is carefully examined. During the experiment, the vibration speed was measured at four points in the radial direction. Two of them are located in the upper bearing housing whereas the other two are located in the lower bearing housing. A universal milling machine with a lower position of the working shaft is used for the experiment. The measurements were performed at three different rotation frequencies 4000 min^{-1}, 6000 min^{-1} and 8000 min^{-1}. The specified rotation frequencies are often used in the various milling processes of wood and wood–based materials. The study is aimed at improving the reliability and efficiency of a wood shaper machine, as well as to ensure the accuracy and quality of products.

Key words: Wood shapers, cutting mechanism, ribbed belt, vibration.

INTRODUCTION

One of the most commonly used gears in general mechanical engineering are belt drives. This is based on their numerous advantages, some of which are their simple construction, low cost, easy service of the gear and others. Belt gears are widely used to drive the various types of mechanisms in woodworking machines. Classic V–belts are most often used. Narrow V–belts, ribbed belts are an increasingly common application to drive the various types of mechanisms in woodworking and furniture manufacturing machines. The variety of constructions is very large. The shapes, the constructions, the rubber compound from which the belts are made are constantly being improved. All this is done with the aim of improving the qualities of the belt, and hence improving the operation of mechanisms and machines. Manufacturers of belts and rubber products offer various systems, devices and software for calculating, designing and controlling the operation of belt drives (SOKOLOVSKI 2007, Dayco.com, Gates.com, Continental–industry.com, Optibelt.com). Universal milling machines are widely used in the woodworking and furniture industries. They allow working with high cutting speeds, which can reach up to 90 m/s (OBRESHKOV 1997). This inevitably is associated with the machinery resources to work at different rotational frequency. Wood shapers allow different devices to be attached to them. This increases their technological capabilities. High rotations frequencies are one of the reasons for the occurrence of intense vibrations at idle. Their reduction is essential for the operation of the cutting mechanism of the machine both at idle and in working mode (KMINIAK *et al.*2018, KORCOK *et al.*2018, SYDOR *et al.*2021, VITCHEV *et al.*2019).

The aim of the present work is to measure and analyze the vibration speed at idle on a universal wood shaper with bottom location of the working shaft. The cutting mechanism of the machine was driven by two different belt types: classical V–belts with Z section and ribbed belts with profile PK. The load in the two bearing supports is investigated. The analysis of the obtained results can be aimed at improving the drive of the cutting mechanisms of various woodworking machines and for reducing

the vibration levels both at idle and at working mode, improving the working environment around the machines, improving work safety and creating prerequisites for increasing the quality of the products.

MATERIAL AND METHODS

In the present paper, all experimental studies are made on a woodworking shaper with bottom position of the spindle Fig. 1. The design of the cutting mechanism consists of an asynchronous electric motor with power of 3 kW and a rotation frequency of 2880min^{-1}, a belt drive and a main shaft on which the cutting tools are put. The working frequencies of the machine are 4000 min^{-1}, 6000 min^{-1} and 8000 min^{-1}. They allow high technological results to be achieved for realizing different cutting speeds by using cutting tools with different diameters.

These rotation frequencies are realized with the help of specially made belt pulleys, which are mounted on the electric motor and the working shaft of the wood shaper Fig. 2.



Figure 1: Wood shaper with bottom position of the spindle



Figure 2: Electric motor with belt pulley

During the experiment, the cutting mechanism was driven by two classic V–belts with a Z section and one ribbed belt with PK profile. Classic V–belts are widely used to drive various types of machines, including woodworking machines. Realizing the gear is simple and quick (SOKOLOVSKI 2007). Ribbed belts are increasingly used in practice. In addition to the automotive industry, this type of belt is used to drive metalworking, woodworking and other types of machines. Compared to classic V–belts, they have higher pulling capacity and opportunity to work at higher speeds (SOKOLOVSKI 2007).

Fig. 3 shows classic V–belt size with a Z section.



Figure 3: Classic V–belt with a Z section

Fig. 4 shows ribbed belt with PK profile.

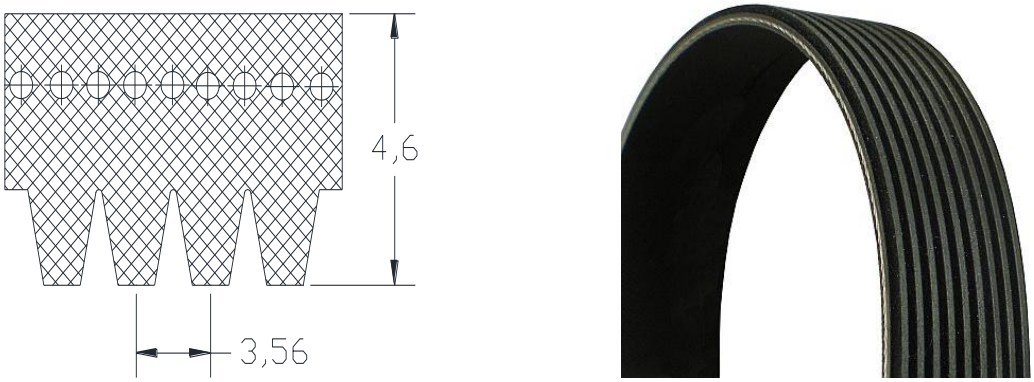


Figure 4: Ribbed belt with PK profile

The intensity of the vibrations is assessed on the basis of the root mean square value of the vibration speed (V mm/s (r.m.s.)).The measurements have been performed at four measuring points located on the bearing house. Two of them are located near the upper bearing next to the cutting tool. The other two are located near the lower bearing next to the belt pulley. The measurement points are located mutually perpendicular, radial to the main shaft of the machine fig.5 (BDS ISO 10816 – 2002).

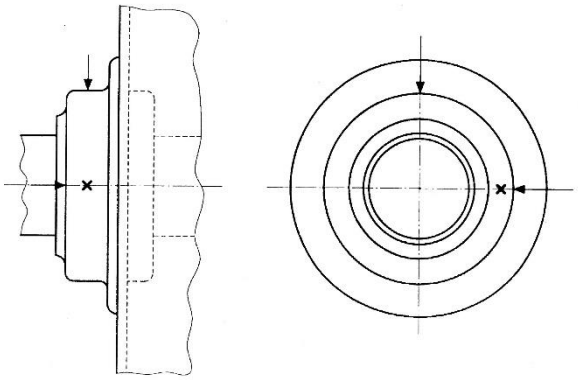


Figure 5: Measurement points

Root mean square value of vibration speed V mm/s (r.m.s.) is measured using a specialized device model Bruel&KjaerVibrotest 60 fig.6. The sensor which measures the intensity of the vibrations is attached to the bearing house with a magnet fig.7 (Bkvibro.com). The vibration speed

was measured while the machine was at idle. A groove cutter with diameter D = 140 mm is put on the machine.



Figure 6: Bruel&KjaerVibrotest 60



Figure 7: Measuring sensor

RESULTS AND DISCUSSION

All measurements were carried out at idle. In this way we tracked out which type of belt has a lower vibration speed. The measurement points near the upper bearing are respectively: A_x – radial direction parallel to the feed direction, A_y – radial direction perpendicular to the feed direction. The measurement points near the lower bearing are respectively: B_x – radial direction parallel to the feed direction, B_y – radial direction perpendicular to the feed direction.

Fig. 8 and Fig. 9 show the variation of the vibration speed measured at a rotation frequency 4000 min^{-1}. To drive the cutting mechanism two belts with section Z and ribbed belt with profile 3PK.

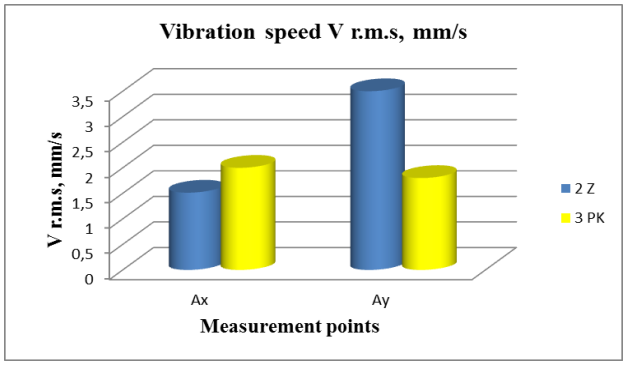


Figure 8: Variation of the vibration speed near the upper bearing, rotation frequency 4000 min^{-1}

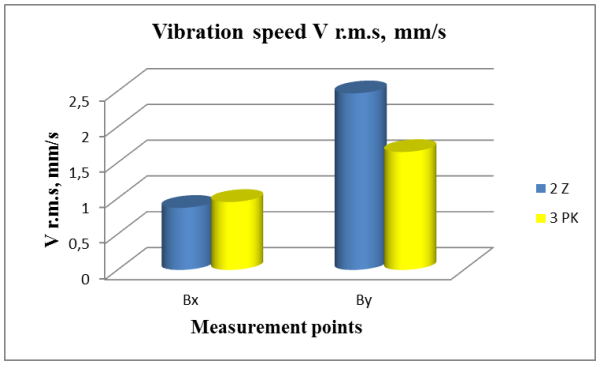


Figure 9: Variation of the vibration speed near the lower bearing, rotation frequency 4000 min^{-1}

From fig.8 it can be seen that at point A_x the vibration speed is 0.5 mm/s higher when the cutting mechanism is driven by a ribbed belt with a 3PK profile. This is small increase. At point A_y, the opposite trend is observed. Here, when the cutting mechanism is driven by a ribbed belt with a 3PK profile, the vibration speed is lower by 1.8 mm/s. The following fig.9 shows the values measured in the lower bearing. At point B_x, the measured vibration speed is almost equal regardless which belt is used. At point B_y, once more the vibration speed is lower by 0.8 mm/s when the cutting mechanism was driven by a ribbed belt.

Variation of the vibration speed at a rotation frequency of 6000 min^{-1} is shown in Fig. 10 and Fig. 11.

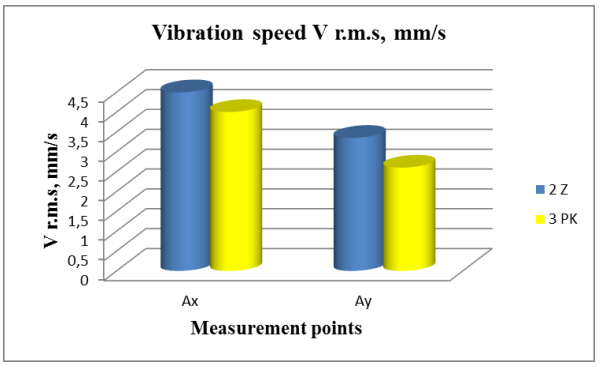


Figure 10: Variation of the vibration speed near the upper bearing, rotation frequency 6000 min^{-1}

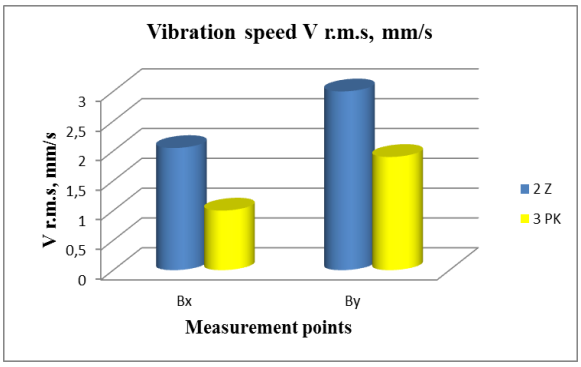


Figure 11: Variation of the vibration speed near the lower bearing, rotation frequency 6000 min^{-1}

From Fig. 10, we can see that at both measurement points near the upper bearing, the vibration speed is lower when the cutting mechanism is driven by a ribbed belt with profile 3PK. Fig. 9 shows the values measured in the lower bearing. Here again the vibration speed is lower when a ribbed belt is used. The vibration speed is lower by 1 mm/s. This applies to both measurement points.

Variation of the vibration speed at a rotation frequency of 8000 min^{-1} is shown in Fig. 12 and Fig. 13.

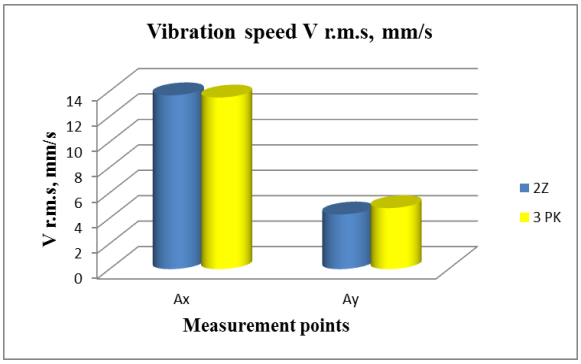


Figure 12: Variation of the vibration speed near the upper bearing, rotation frequency 8000 min^{-1}

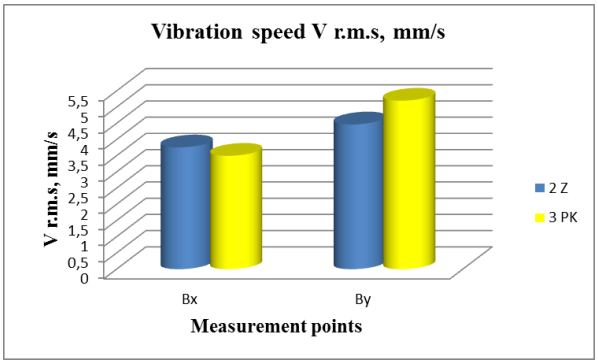


Figure 13: Variation of the vibration speed near the lower bearing, rotation frequency 8000 min^{-1}

Fig. 12 shows the measurements taken in the upper bearing of the machine. At point A_x we can see a sharp rise in the vibration speed to 13.5 – 13.6 mm/s regardless which belt drives the cutting mechanism. This result can be explained by an operating mode close to the resonance zone. At point A_y, the vibration speed levels are within normal limits. The results show 4.3 – 4.6 mm/s for both types of belts. Fig. 13 shows the values measured in the lower bearing. At point B_x, the measured vibration speed is almost equal. At point B_y, the vibration speed increases when the cutting mechanism is driven by a ribbed belt of 0.6 mm/s.

From the conducted experiments the following conclusions can be drawn:

- At a rotation frequency of 4000 min^{-1}, we can see from the graphs that at point A_x, the vibration speed increases when the cutting mechanism is driven by a ribbed belt. This is a small increase. At point B_x, the measured vibration speed is almost equal. In the other two points the vibration speed is lower when the machine is driven by a ribbed belt.
- At a rotation frequency of 6000 min^{-1}, the results show that ribbed belts work more smoothly than classic V–belts. In all four measurement points, the values of the vibration speed are lower, when ribbed belts are used for driving the cutting mechanism. This is a direct

prerequisite for a higher quality of the processed details (KOVATCHEV et al. 2022, KOVATCHEV et al. 2023).

- At the highest rotation frequency of 8000 min^{-1} in one of the measuring point A_x, the vibration speed levels were higher for both types of belts. This result can be explained by an operating mode close to the resonance zone. At the other measurement points, the values of the vibration speed are close to each other regardless of the used belt.

REFERENCES

KMINIAK, R., SIKLIENKA, M., SUSTEK, J. 2018. Influence of the thickness of removed layer on the quality of created surface when milling oak blanks on the CNC machining center. Chip and Chipless Woodworking Processes 11 (1): 79–86, Zvolen, ISSN 2453–904X (print), ISSN 1339–8350 (online).

KORCOK, M., VANCO, M., BARCIK, S., GOGLIA, V. 2018. Influence of tool angular geometry on surface quality after milling of thermally modified oak wood. Chip and Chipless Woodworking Processes 11 (1): 87–96, Zvolen, ISSN 2453–904X (print), ISSN 1339–8350 (online).

KOVATCHEV, G., V. ATANASOV, I. RADKOVA (2022), Influence of mechanical oscillations on the accuracy of making grooves in solid wood, 13th International Science Conference „Chip and Chipless Woodworking Processes", Tatranska Lomnica, TU–Zvolen, ISSN 2453–904X (print) ISSN 1339–8350 (online), pp. 65–71.

KOVATCHEV, G., V. ATANASOV, I. RADKOVA (2023), Influence of mechanical oscillations on the accuracy of making grooves in wood–based materials, Pro Ligno, Volume 19, Issue 3, pp. 3–9, Online ISSN 2069–7430, ISSN–L 1841–4737.

OBRESHKOV P. 1997. Woodworking Machines, Sofia. 182 p. (in Bulgarian)

SOKOLOVSKI, S. 2007. Machine elements, Sofia, ISBN 978–954–332–044–38, 318 p. (in Bulgarian)

SYDOR, M., R. MIRSKI, K. STUPER–SZABLEWSKA, T. ROGOZINSKI (2021), Efficiency of Machine Sanding of Wood, Applied Sciences, Volume 11 .– Issue 6 /2860/ March 2 2021, ISSN 2076–3417, https://doi.org/10.3390/app11062860

VITCHEV, P., ANGELSKI, D., MIHAILOV, V. 2019.Influence of the processed material on the sound pressure level generated by sliding table circular saw. Acta Facultatis Xylologiae Zvolen, 61(2): 73−80, 2019, DOI: 10.17423/afx.2019.6.

БДС ISO10816–1:2002, Evaluation Of Machine Vibration By Measurement On Non – Rotating Parts – Part 1: General Guidelines, 25 p.

Bruel & Kjaer Vibro – www.bkvibro.com

Continental Belts and Components the Product Range – www.continental–industry.com.

Dayco drive belts online catalog – www.dayco.com.

Gates industrial power transmission product catalog – www.gates.com.

Optibelt Power Transmission Compact Catalogue – www.optibelt.com.

PROCEEDINGS OF TWELFTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN – INNO 2024
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CHANGES IN THE LEVEL OF NOISE EMISSIONS, GENERATED BY CNC WOODWORKING CENTER, DEPENDING ON THE CUTTING MODE AND THE GEOMETRY OF THE CUTTING TOOL

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ABSTRACT

The current paper presents the results from experimental study, investigating the changes in the noise emissions level (L_{pA}), measured at the workplace of a CNC woodworking centre Rover A3.30, depending on the: (i) cutting tool rotation speed (n), feed speed (V_f) and radial depth of cut (h), and (ii) the geometry of the cutting tool. Scots pine (*Pinus sylvestris* L.) wood test specimens were processed, separately, with two end mills with the same linear and angular parameters. The first tool is a spiral cutter with positive rake angle (PS–1), and the second one is a spiral cutter with negative rake angle (NS–2). The results show the influence of the cutting mode parameters and cutting tool geometry, alike. The results determine the influence, both of the cutting mode parameters and cutting tool geometry on the changes of the noise emissions values.

Based on the regression models, derived under the conditions of this study, it was found that the greatest influence on the nose emissions level was exerted by the cutting tool rotation speed (n), followed by the feed speed (V_f) and the radial depth of cut (h).

Regarding the rake angle of the spiral cutter, in respect to the direction of rotation of the cutting tool at V_f = 3,5 m.min^{-1} and h = 2 mm, it was found that a spiral cutter with positive rake angle (PS–1) caused a higher noise emission level L_{pA} = 82,52 dB(A), which was about 3 dB(A) higher, when compared with the noise emission level, generated by the spiral cutter with negative rake angle (NS–2) – L_{pA} = 79,8 dB(A). Based on the carried–out experiments and the statistical analysis of the results, two regression models and their graphical dependences, representing the correlation between the change in the A–weighted sound pressure level and the studied factors have been derived. Despite the noise dynamics, depending on the investigated factors, the maximum noise emission level, measured at the control panel under the specific conditions of the experiments, was 83.3 dB(A), which is below the safe upper limit of 85 dB(A) regulated for eight hours of exposure per day.

Key words: noise emission level, sound pressure, Scots pine, cutting mode, rotation speed, feed speed, CNC centre.

INTRODUCTION

The working environment in the woodworking and furniture enterprises is traditionally qualified as one of the noisiest, given the complexity of heterogeneous technological operations and the pursuit of high productivity. The machines used in the woodworking and furniture industry differ in dimensions, shapes, number of technological operations etc. The technological characteristics of the woodworking machines, combined with the presence of aspiration systems at the workplace as well as with different technological factors, such as high feed speed and cutting speed, account for noise levels at workplace ranging from 90 dB(A) to 115 dB(A). These levels exceed significantly the set up by the EU Directive 2003/10/EC safe upper limit for workers of $L_{EX,\,8h}$ = 85 dB(A) for 8 working hours per day. To ensure safer working environment, the woodworking industry has put a lot of effort to reduce the noise levels at workplace, by developing and implementing specialized technological equipment and cutting tools.

A number of experimental studies, described in the scientific literature, have been performed to investigate how the noise emission levels, generated by woodworking machines can be influenced by

different factors, e.g. the type of the processed wood material, the type and characteristics of the cutting tool, the type of the technological factors etc. (Hesselbach et et al. 2010, Rudak et al. 2019, Vitchev 2020, Vitchev 2023). In one of their studies, Rudak & Grishkevich (2012) evaluated the influence of wood milling shank cutters construction on the noise levels. Wood of different breeds was processed with CNC machine, Rover B 4.35, using end milling cutters of two different constructions: with continuous and irregular channel taking off shaving from the area of cutting. Based on the results, the authors concluded that the noise emission levels generated when using the continuous channel for chip removal were significantly greater (by around 3 dB), compared to the noise generated by the irregular channels.

The objective of the current study was to investigate the noise emission levels, generated at the workplace of CNC woodworking machine Rover A3.30 when processing specimens from Scots pine wood (*Pinus sylvestris* L.) and how these levels were influenced by the following technological factors: rotation of the cutting tool (*n*), feed speed (V_f) and radial depth of cut (*h*). In addition, the influence of the geometrical characteristics of the cutting tool on the noise level was also evaluated.

STUDY DESIGN

The experiments were performed with CNC–machining center, model Rover A 3.30 (Biesse, Italy) with the following dimensions: length, width and height (*L* x *B* x *H)* = 4900 x 2700 x 2100 mm (Fig. 1). The machine has three interpolated control axes (*X*, *Y* and *Z*), with operational steps of *X* = 3060 mm; *Y* = 1260; mm; *Z* = 150 mm, allowing for continous regulation of the feed speed and adjustment of the cutting speed via changing the rotation speed of the cutting tool (*n*). the main electrospindel of the CNC machine is with a power of 7 *kW* (9.5 *HP*) with a chuck type *ISO* 30.



Figure 1: General appearance of CNC–machining center, model A 3.30 (Biesse, Italy)

The experiments were carried out at cutting mode of the machine, with the aspiration system turned off, to minimise the background noise. Test specimens from Scots pine wood (*Pinus sylvestris* L.) with the following characteristics: moisture contend *W* = 12%, density ρ = 630 kg/m^{3}and dimensions: length (*l)* = 600 mm and width (*b*) = 185 mm, were processed. For their processing, two spiral end mills (CMT, Italy) were used. The spiral end mills characterised with the same linear and angular parameters but differed in the orientation of the cutting bits against the rotation of the cutter. The first tool is a spiral cutter with positive rake angle (PS–1), and the second one is a spiral cutter with negative rake angle (NS–2) (Fig. 2).



Figure 2: Cutting tools a) end mill cutter with positive spiral (PS–1); b) end mill cutter with negative spiral (NS–2)

The technical characteristics of the cutting tools, presented in fig. 2 are summarised in table 1, where *D* is the cutting diameter; *S* – body diameter; *L* – overall length; *I* –cutting length; *z* – number of the spiral cutting edges; *n* – maximum rotation frequency.

Table 1: Characteristics of the cutting tools

Name	Direction of the spiral	*D* *mm*	*S* *mm*	*L* *mm*	*I* *mm*	*z* бр.	*n* min^{-1}
PS–1	Positive	12	12	83	35	3	18 000
NS–2	Negative	12	12	83	35	3	18 000

The levels of variation in the variable factors are presented in clear and in coded mode in Table 2.

Table 2: Level of changes in the variable factors *n*, V_f and *h*

Variable factors	Minimum value		Average value		Maximum value	
	Expl.	Coded	Expl.	Coded	Expl.	Coded
Rotation speed $n = X_1$, [min^{-1}]	12000	–1	15000	0	18000	1
Feed speed $V_f = X_2$, [$m.min^{-1}$]	2	–1	3,5	0	5	1
Radial depth of cut $h = X_3$, [mm]	1	–1	2	0	3	1

To evaluate the influence of the factors: rotation speed of cutting tool (*n*), feed speed (V_f) and radial depth of cut (*h*) on the noise emission level, the methodology of multifactorial planning followed by regression analysis was implemented (Vutchov et al. 1980).

The expected sound pressure level is expressed mathematically by a quadratic (second order) polynomial model. The adequacy of the model is checked according to the Fischer equation. The suitability of the derived regression model is evaluated by the coefficient of determination R^2, which varies in the interval from 0 to 1.

The data was statistically analysed by a specialized software Q–StatLab, which was also used to calculate the regression coefficient values of the model, the dispersion of errors and the coefficient of determination R^2.

The sound pressure level was measured with a digital sound level meter (CEL–620B1/K1 (CASELLA, UK) with built–in octave frequency filters with geometric mean frequencies from 63 Hz to 16,000 Hz and standard frequency correction characteristics *A*, *B*, *C*, according to accepted international standards which measures sound pressure levels from 20 Hz to 20 kHz. Prior to the measurements the device was calibrated by means of an acoustic calibrator of the same company with a constant sound pressure level of 114 dB, $p_0 = 2.10^{-5}$ N.m^2 at a frequency $f = 180$ Hz.



Figure 3: Digital sound level meter (CEL–620B1/K1 (CASELLA, UK)

The noise emission level, generated during the working mode of the CNC machine, was determined based on the *A*–weighted sound pressure level (L_{pA}) in dB(A).

The measuring point was at a distance of 1 m from the base parallelepiped, corresponding to the operator's position, and was 1.5 m above the sound–reflecting floor (Fig. 4). The workpieces were placed on the machine table in the area near the control panel (near the measuring point).

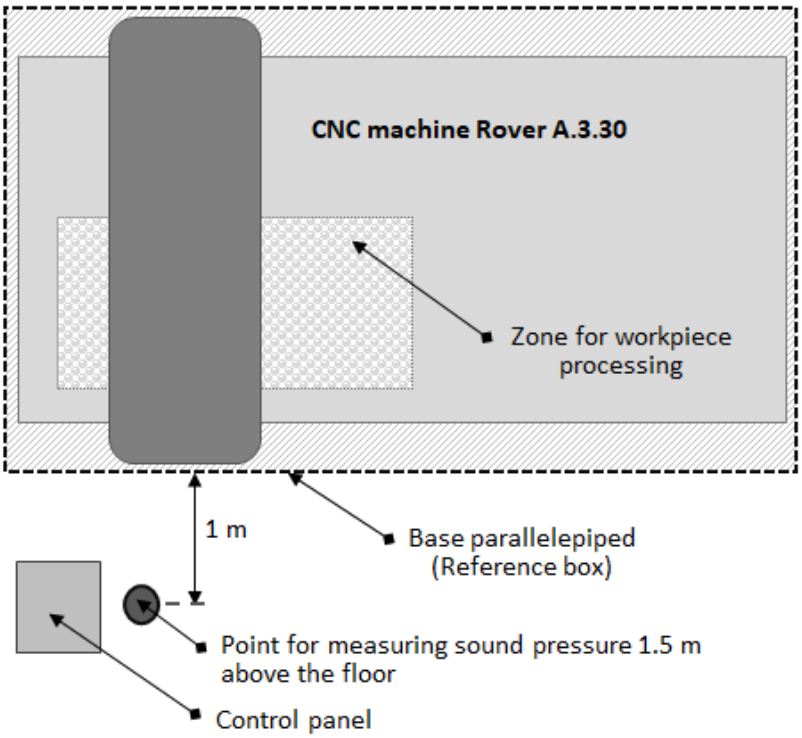


Figure 4: Diagram showing measuring point position and zone for workpiece processing

When determining the actual sound pressure level (L_{pA}), the influence of the background noise with the correction coefficient K_1 and the influence of the characteristics of the sound field with the correction coefficient K_2 were considered in the following way:

$$L_{pA} = L'_{pA} - K_1 - K_2 \quad (1)$$

where

L'_{pA} is the measured sound pressure level;

K_1 – the correction coefficient accounting for the influence of the background noise;

K_2 – the correction coefficient accounting for the characteristics of the sound field.

Background noise is the noise from all other internal and external sources, except the noise from the machine under study. To assess its influence, the difference (ΔL_p) between the sound pressure level from the sound source and the background noise level was calculated. In case of ΔL_p<6 dB, measurements are not recommended as the background noise will have a significant impact on the results. When $6 \leq \Delta L_p \leq 15$, it is necessary to calculate the correction coefficient K_1 which shows the influence of background noise which calculated using the formula (2):

$$K_1 = -10lg\left(1 - 10^{-0.1\Delta L_p}\right), dB \quad (2)$$

In case of ΔL_p>15 dB the background noise does not affect the measurements as the sound pressure it generates is masked by the sound emission of the sound source. In this case $K_1 = 0$.

The correction coefficient K_2 which shows the characteristics of the sound field, depends on the volume of the room in which the measurements are made, on the sound absorption capacity of its surfaces (walls, floor, ceiling) and on the area of the measuring surface. From a practical point of view, it is most often accepted that the calculation of the correction coefficient K_2 is based on the sound absorption capacity of the room and is calculated using the formula:

$$K_2 = 10lg\left[1 + 4\frac{S}{A}\right] \quad (3)$$

where:

A is the equivalent sound absorbing area of the room, m^2;

S – the area of the measuring surface, m^2.

When K_2>4 dB(A), the conditions for free or approximately free sound field are not fulfilled and the results of the measurements are not correct (BDS EN ISO 3744).

Under the experimental conditions of this study, the calculated value of K_2 = 2,6 dB.

The tests were performed according to the requirements of BDS EN ISO 3744 and BDS ISO 7960.

RESULTS AND DISCUSSION

Based on the methodology, explained above, two series of experiments were conducted. The first series aimed to investigate the change in the noise emission levels, generated by the CNC woodworking machine Rover A3.30, depending on the rotation speed of the cutting tool (n), the feed speed (V_f) and radial depth of cut (h). In the second series of experiments, the changes in the noise emission levels depending on the geometry of the cutting tool were evaluated.

The influence of the background noise and the characteristics of the sound field were also evaluated according to BDS EN ISO 3744 and BDS ISO 7960 and was concluded that the conditions in the room are suitable to perform acoustic measurements.

PROCESSING OF TEST SPECIMENS FROM SCOTS PINE WOOD WITH CUTTING TOOL PS–1

In the first series of measurement spiral, an end mill cutter with positive rake angle (PS–1) was used. After mathematical and statistical analysis of the results the following regression equation was derived (4):

$$y = 81{,}89 + 0{,}7X_1 + 0{,}27X_2 + 0{,}26X_3 - 0{,}073X_1^2 - 0{,}68X_2^2 - 0{,}77X_3^2 - 0{,}25X_1X_2 - 0{,}175X_2X_3 - 0{,}4X_1X_3 \quad (4)$$

where:

y – predicted sound pressure level in coded form;

X_1 – rotation speed of the cutting tool (n) in coded form;

X_2 – feed speed (V_f) in coded form;

X_3 – radial depth of cut (h) in coded form.

The obtained values for the dispersion ratio $F = 2.859$ and the tabulated coefficient (Fisher's test) $F_T = 5.303$ show that the condition for the adequacy of the model is met and gives the confidence to analyze the derived regression equation (3). The coefficient of determination of the derived regression model is $R^2 = 0{,}82677$, which makes the predictability of the model reliable.

Based on the analysis of equation (3) it was predicted that when processing specimens from Scots pine wood with a cutting tool PS–1, the greatest influence on the noise emission level would be exerted by the rotation speed of the cutting tool $n = X_1$. This is visible by the positive value of the regression coefficient $b_1 = 0{,}700$, i.e. the noise emission level increases with the increase of the rotation speed of the tool (see also fig. 5 and 6). The second most important of the investigated factors was the feed speed $V_f = X_2$, with a regression coefficient $b_2 = 0{,}270$. The noise emission level was the least influenced by the radial depth of cut $h = X_3$, with $b_3 = 0{,}260$.

Influence of the rotation speed of the cutting tool

The changes in the sound pressure level depending on the rotation speed of the cutting tool (n), measured at different speed feed (V_f) is graphically presented in Fig. 5. From the generated noise emission curves, it is visible that the highest noise emission level was generated at the highest feed speed $V_f = 5$ m.min^{-1}. A similar trend of increasing noise emission levels with increasing in the rotation speed of the tool was observed in the three noise curves. Based on the results, it could be concluded that the noise emission levels, measured at rotation speeds of the cutting tool 12 000 min^{-1} and18 000 min^{-1}and feed speed $V_f = 5$ m.min^{-1} change from 82,3 dB(A) на 83 dB(A), respectively. This accounts for about 30% difference in the sound level.

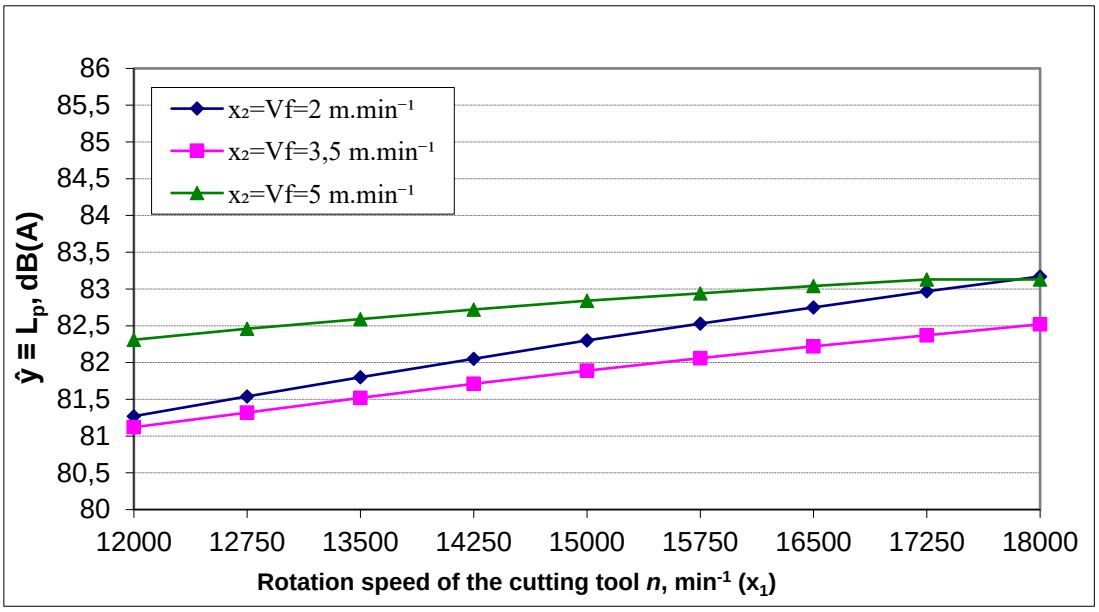


Figure 5: Influence of the rotation speed of the cutting tool PS– 1 (n) on the *A*–weighted sound pressure level, generated under milling of Scots pine wood specimens and measure at different feed speed (V_f)

The changes in the sound pressure level (L_p) depending on the rotation speed of the cutting tool (n), measured at different radial depth of cut (h) is graphically presented in Fig. 6. The results confirmed the predicted increase in the sound pressure level with the increase of the rotation speed of the cutting tool. It is worth noting that the noise emission level, measured at the lowest radial depth of cut (h = 1 mm) is lower, when compared to the radial depth of cut h = 2 and h = 3 mm. Its value changed from 78,6 dB(A) at rotation speed n = 12 000 min^{-1} to 81 dB(A) at n = 18 000 min^{-1}, i.e. the difference is 2,4 dB(A).

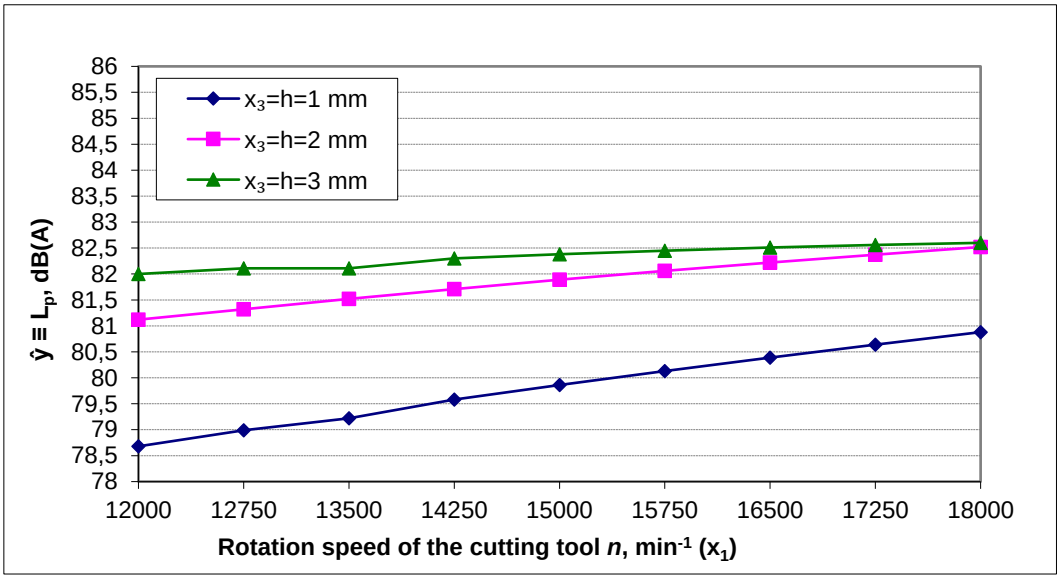


Figure 6: Influence of the rotation speed of the cutting tool PS– 1 (*n*) on the *A*–weighted sound pressure level, generated under milling of Scots pine wood specimens and measure at different radial depth of cut (*h*)

Influence of the feed speed and the radial depth of cut

It was predicted that the feed speed (V_f,) is the second important factor, influencing the levels of noise emissions, generated under certain conditions. Figure 7 depicts the changes in the sound pressure level, depending on the feed speed and the radial depth of cut. From the graph., it is visible

that the noise emission level changes from 80 dB(A) at V_f = 2 m.min^{-1} to 83,2 dB(A) at V_f = 5 m.min^{-1}. Even though the noise emission level in, it creased nearly twice, it did not exceed the safe upper limit of 85 dB(A) for 8 hours/day. Under the conditions of this experiment, the lowest noise emission levels were generated at V_f (3÷3,5 m.min^{-1}) and radial depth of cut h = 2 mm. These conditions are considered optimal.

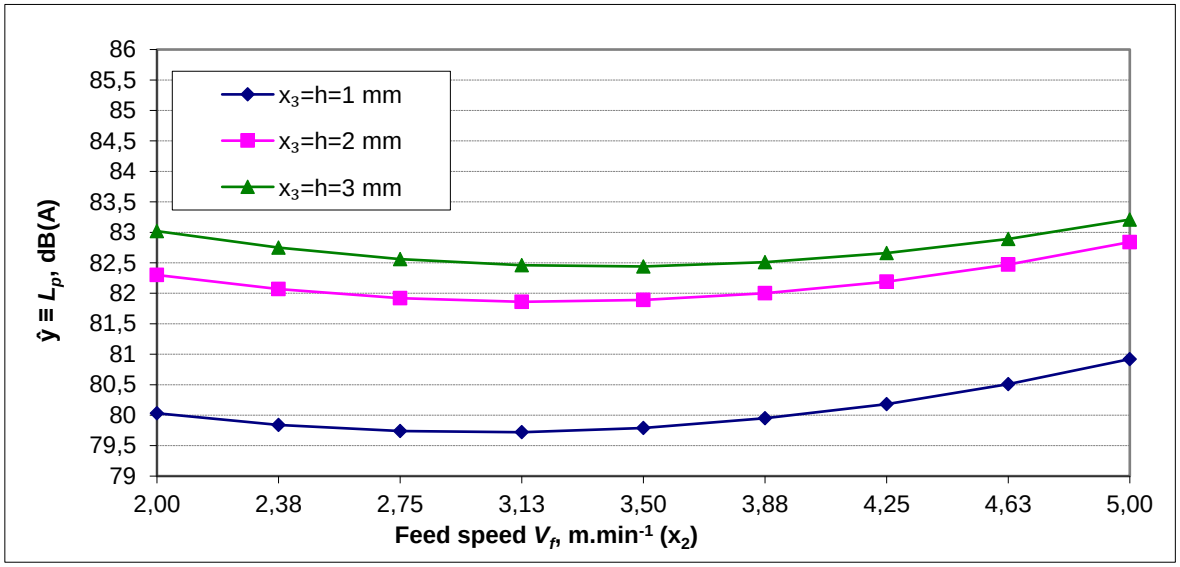


Figure 7: Influence of the feed speed on the *A*–weighted sound pressure level, generated under milling of Scots pine wood specimens with PS–1 cutter and measure at different radial depth of cut (*h*)

PROCESSING OF TEST SPECIMENS FROM SCOTS PINE WOOD WITH CUTTING TOOL NS–2

In the second series of measurements an end mill spiral cutter with negative rake angle (NS–2) was used. After mathematical and statistical analysis of the results the following regression equation was derived (5):

$$y = 79{,}25 + 0{,}87X_1 + 0{,}83X_2 - 0{,}68X_3 - 0{,}323X_1^2 - 1{,}523X_2^2 + 1{,}228X_3^2 - 1{,}325X_1X_2 + 0{,}075X_2X_3 + 0{,}275X_1X_3 \quad (5)$$

The obtained values for the dispersion ratio F = 2,022 and the tabulated coefficient (Fisher's test) F_T = 4,753 show that the condition for the adequacy of the model is met and gives the confidence to analyze the derived regression equation (5). The coefficient of determination of the derived regression model is R^2 = 0,64539, which makes the predictability of the model reliable.

Based on the analysis of equation (4) it could be concluded that, when processing of the test specimens with cutting tool, NS–2, similarly to the results for cutting tool PS–1, the greatest impact on the noise emission levels was had the rotation speed of the tool $n = X_1$, followed by the feed speed $V_f = X_2$, and the radial depth of cut $h = X_3$.

Influence of the rotation speed of the cutting tool

From the results presented in Fig. 8. it is confirmed that the lowest expected noise emission level is measured at the lowest values of the feed speed V_f = 2 m.min^{-1}and the rotation speed of the tool n = 12 000 min^{-1}. The highest noise emission of 79,9 dB(A), generated at V_f = 3,5 m.min^{-1} and n = 18 000 min^{-1} is 5,1 dB(A) which is well below the safe upper limit of 85 dB(A) for 8 hours/day. It is interesting to note the diverging noise level curves at feed speed (V_f) 3,5 m.min^{-1} and 5 m.min^{-1}. One of the potential explanations for this higher noise emission levels, generated at lower feed speed

(V_f = 3,5 m.min^{-1}) is the presence of anatomical irregularities on the surface of the processed specimens.

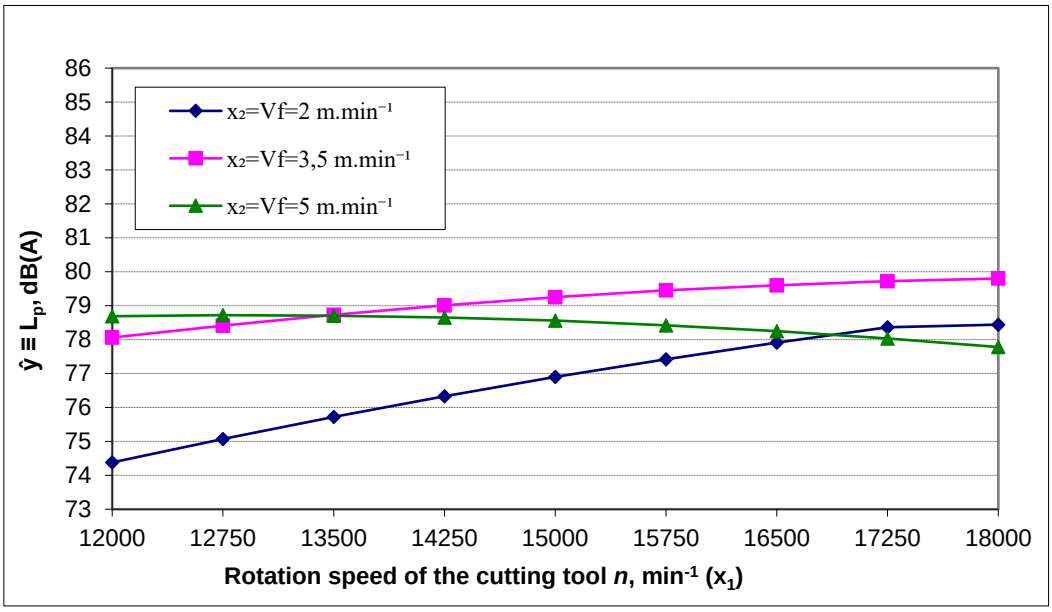


Figure 8: Influence of the rotation speed of the cutting tool NS– 2 (*n*) on the A–weighted sound pressure level, generated under milling of Scots pine wood specimens and measure at different feed speed (V_f)

An increase in the noise emissions were observed with an increase rotation speed of the tool, measured at three different values of the radial depth cut. The results are presented in Fig. 9. At the lowest radial depth of cut (h = 1 mm), the noise emission levels were determined to be higher, when compared to the noise emissions, generated at higher radial depth cut values (h = 2 mm and h = 3 mm). The changes in the noise emission were from 80,1 dB(A) to 81,5 dB(A), measured at rotation speeds n = 12 000 min^{-1} and n = 18 000 min^{-1}, respectively. The difference in the noise emission is 1,4 dB(A).

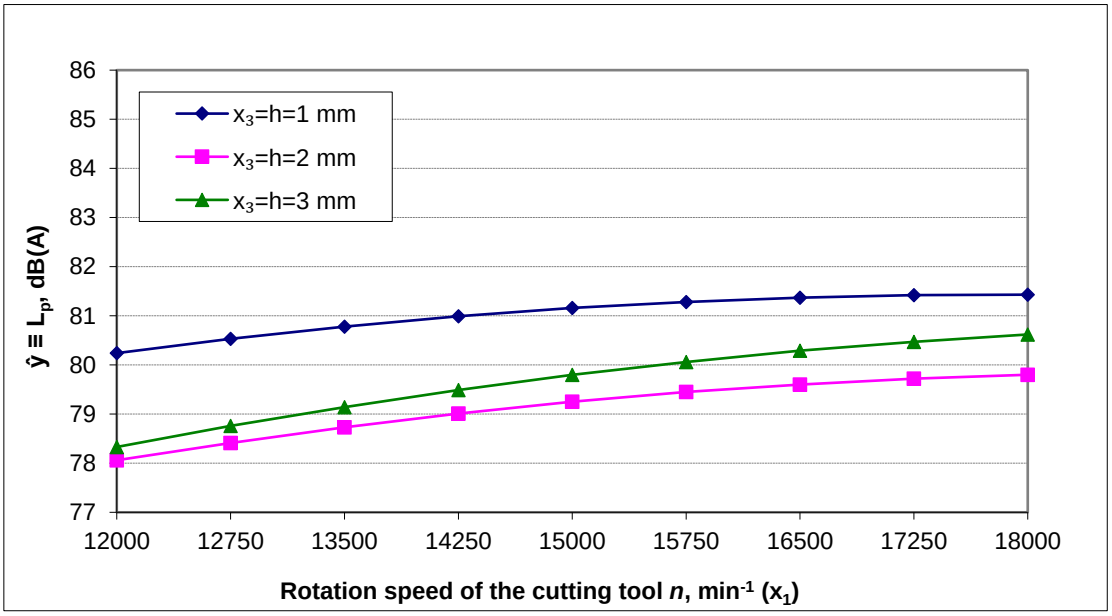


Figure 9: Influence of the rotation speed of the cutting tool NS– 2 (*n*) on the *A*–weighted sound pressure level, generated under milling of Scots pine wood specimens and measure at different radial depth of cut (*h*)

Influence of the feed speed and the radial depth of cut

It was predicted that the feed speed (V_f,) is the second important factor, influencing the levels of noise emissions, generated under certain conditions. Figure 7 depicts the changes in the sound pressure level, depending on the feed speed and the radial depth of cut. From the graph., it is visible that the noise emission level changes from 80 dB(A) at V_f = 2 m.min^{-1} to 83,2 dB(A) at V_f = 5 m.min^{-1}. Even though the noise emission level increased nearly twice, it did not exceed the safe upper limit of 85 dB(A) for 8 hours/day. Under the conditions of this experiment, the lowest noise emission levels were generated at V_f (3÷3,5 m.min^{-1}) and radial depth of cut h = 2 mm. These are recommended as optimal.

The peak levels of the noise emission were measured at feed speed $V_f \approx 4$ m.min^{-1} and for the three tested radial depth cuts, the noise levels are as follows: 81,3 dB(A) at h = 1 mm, 80 dB(A) at h = 3 mm and 79,5 dB(A) at h = 3 mm.

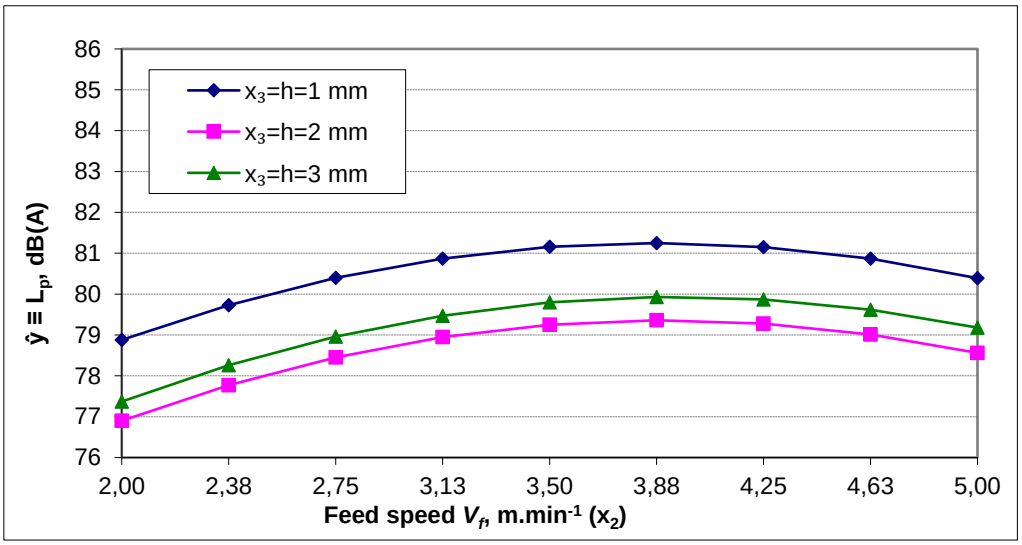


Figure 10: Influence of the feed speed (V_f) on the *A*–weighted sound pressure level, generated under milling of Scots pine wood specimens with NS–2 cutter and measure at different radial depth of cut *(h)*

From the results presented on Fig. 10 it is clearly visible that the changes in the noise emission levels, measured at the three tested radial depth cuts, follow the same pattern. The noise curves show that the noise emissions increased with an increase in the feed speed from 2 m.min^{-1} to 3,5 m.min^{-1}. However, the increase in the feed speed above 3,5 m.min^{-1} did not result in further increase in the noise emissions, even at V_f= 4,5 and V_f= 5 m.min^{-1}, a slight decrease in the noise levels was observed for the three radial depth cuts.

INFLUENCE OF THE GEOMETRY OF THE CUTTING TOOL ON THE NOISE EMISSION LEVEL

From the results, presented in Fig. 11 is visible that the noise emission levels, generated by the use of the end mill spiral cutter with negative rake angle (NS–2) were significantly lower, compared to those generated by the use of the end mill cutter with positive rake angle (PS–1). Similar influence of the cutting tool geometry on the noise levels was observed by Rudak & Grishkevich (2012) in their research. Under the conditions of our study, these results could be explained with the fact that the direction of the helix in PS–1 tool coincides with the direction of the rotation of the tool. This, consequently, leads to an increase in the level of aerodynamic noise due to the more intense swirling of the air flow.

From the noise curves on Fig. 11 is visible that the noise emission level L_{pA} = 82,52 dB(A), generated using cutting tool PS–, is nearly two times higher, around 2,7 dB(A) compared to the noise emission level generated using of cutting tool NS–2 – L_{pA} = 79,8 dB(A).

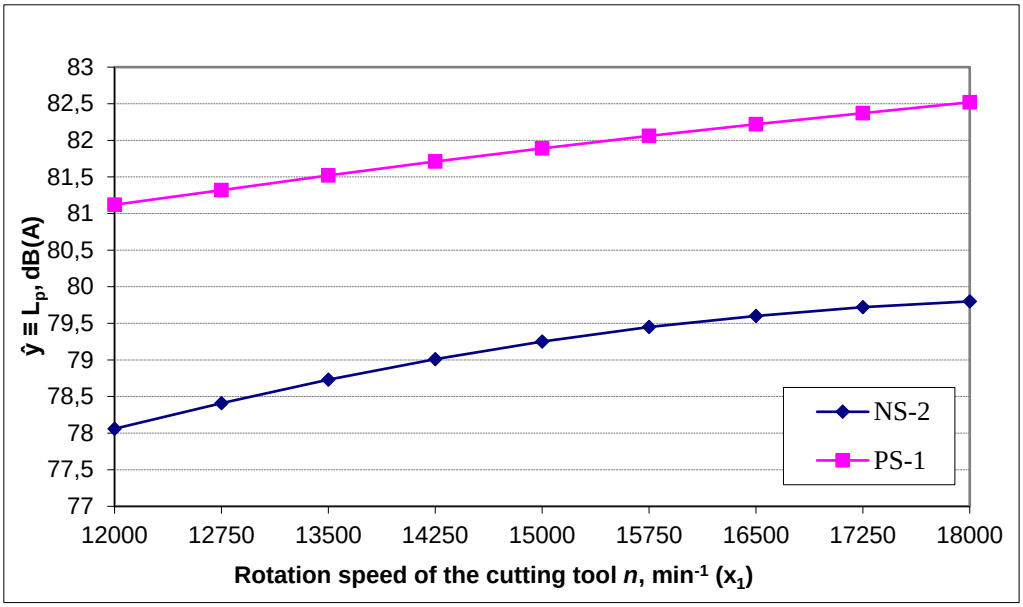


Figure 11: Influence of the rotation of the cutting tools PS–1 and NS–2 on the *A*–weighted noise emission levels, generated at feed speed V_f = 3,5 m.min^{-1}and radial depth of cut *h* = 2 mm

The noise curves unambiguously confirm that with an increase in the rotation speed of the cutting tool, the emission levels of the generated noise also increase. The lowest noise emission level of 78,06 dB(A). was measured with the use of cutting tool NS–2 at rotation speed n = 12 000 min^{-1}. The highest noise emission level of 82,52 dB(A) was generated with the use of the PS–1 cutter at rotation speed n = 18 000 min^{-1}. Even though the increase in the noise emission levels was nearly two times higher when PS–1 was used, it did not exceed the maximum permissible health and safety norm of 85 dB(A) for 8 hours/day.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results obtained under the different experimental conditions of this study, it could be concluded that the sound emission level does not exceed the maximum permissible health and safety norm of 85 dB(A) for 8 hours/day.

When processing test specimens from Scots pine wood (*Pinus sylvestris* L.) with an end mill cutters PS–1 (positive spiral) and NS–2 (negative spiral), the greatest influence on the level of noise emission level is exerted by the rotation speed of the tool ($n = X_1$), followed by the feed speed ($V_f = X_2$), and the radial depth of cut ($h = X_3$).

When investigating the influence of the geometry of the cutting tool on the noise emission level, it was noted that the use of end mill cutter with positive rake angle (PS–1) lead to an increase in the noise level by 2,7 dB(A), which is nearly two times higher when compared to the noise generated by the end mill spiral cutter with negative rake angle (NS–2).

To achieve lower levels of noise emission during milling of specimens from Scots pine wood (*Pinus sylvestris* L.) using end mill cutters with positive (PS–1) and negative (NS–2) rake angle, the following optimal values of the investigated factors can be recommended:

When end mill cutters PS–1 (positive spiral) is used:

- rotation speed of the cutting tool n = 12 000 min^{-1};

- feed speed (V_f) from 2 m.min^{-1} to 3,5 m.min^{-1};
- radial depth of cut h = 1 mm.

When end mill cutters NS–2 (negative spiral) is used:

- rotation speed of the cutting tool n =12 000 min^{-1};
- feed speed V_f = 2 m.min^{-1};
- radial depth of cut h = 2 mm.

REFERENCES

BIS ISO 7960. 2005. Airborne noise emitted by machine tools – Operating conditions for woodworking machines.

BIS EN ISO 3744 (2010). Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering methods for an essentially free field over a reflecting plane.

CHUNHUI, J., ZHANQIANG, L., LUNING, L. 2010. Simulation and analysis of aerodynamics for high speed face milling cutters. Sci China Tech Sci, 53(9):2575–2580.

DINKOV, B., CHESHMEDJIEV A., VITCHEV, P. 2016. Exercise manual, interior acoustics, Intel Entrans publishing house, Sofia, 188 pages, ISBN 978–954–2910–59–6.

FIDAN M., KOMUT O., YAŞAR S., YAŞAR M. 2020. A study on noise levels of machinery used in lumber industry enterprises. 65(5):785–796.

GOCHEV, ZH., VITCHEV, P. 2023. CNC machines and technologies, Avangard Prima publishing house, Sofia, 473 pages, ISBN 978–619–239–872–9.

GOCHEV, ZH., VITCHEV, P. 2023. CNC tools and processes, Avangard Prima publishing house, Sofia, 378 pages, ISBN 978–619–239–873–6.

HESSELBACH, J., HOFFMEISTER, H., SCHULLER, B. 2010. Development of an active clamping system for noise and vibration reduction. CIRP Annals – Manufacturing Technology, 59(1): 395–398.

JUNGA P., TRAVNICEK P., RUZBARSKY J., KOPECKY Z., SOLAR A. 2019. Noise emissions of older woodworking machines at parallel operation process. DOI: 10.17973/MMSJ.2019_03_201870.

RUDAK P.V., GRISHKEVICH A.A. 2012. Experimental studies results of influence of wood–milling shank cutters constructions on noise level. Proceedings of BSTU, 2: 143–145.

VITCHEV, P. 2020. Acoustic characteristics of woodworking machines for cutting, Avangard Prima publishing house, Sofia, 192 pages, ISBN 978–619–239–428–8.

VITCHEV, P. 2023. Dynamics of noise emission generated by CNC woodworking center. Innovation in woodworking industry and engineering design, 24(2): 78–85, ISSN 1314–6149, e–ISSN 2367–6663.

VUTCHKOV, I., STOYANOV, S. 1980. Mathematical modeling and optimization of technological objects, Tehnika publishing house, Sofia, 336 s., UDC 519.95:519.2:681.3.06.

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THE INFLUENCE OF STEAMING MODES ON THE ROUGHNESS OF THE MILLED SURFACE OF BEECH WOOD IN THE SAPWOOD AND FALSE HEARTWOOD ZONE

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ABSTRACT

The quality of the surface, expressed by its irregularities, is one of the important indicators in woodworking. In CNC milling, the size of the surface unevenness can be an indicator of incorrect setting of technological parameters. However, in the current trend of the wood industry, we are not only looking at the milling parameters of native types of wood, but also at the milling of thermally treated types of wood. In the processing of beech wood, steaming is also a type of thermal modification process, which significantly affects the quality of the surface after CNC milling. It has been proven that the parameters of the steaming process (especially the steaming temperature) can significantly contribute to the change in quality after milling. At the same time, beech wood is specific for its high share of the false heartwood zone, which shows a different size of surface irregularities compared to the sapwood zone. Measured data about the effect of the steaming process on the roughness of individual zones of beech wood help in the industry to better optimize the quality of the surface after milling. In the presented experiment, it will therefore be quantified how significantly the steaming mode in the sapwood zone and the false heartwood zone of beech wood contributes to the roughness of the surface after milling. Roughness will be expressed through areal surface roughness parameters and measured optically using a Keyence VHX–7000 digital microscope. Areal surface roughness has been considered an innovative method of quantifying surface irregularities.

Key words: CNC Milling, Areal Surface Roughness, Beech Wood, False Heartwood, Sapwood, Digital Microscope.

INTRODUCTION

Milling is one of the most important processes in woodworking. Achieving different profile shapes along the length of the machined part has become significantly easier in the last decade. The reason is the use of CNC machining centres with multiple axes (Ergin and Sofuoglu 2023; Jiang *et al.* 2022; Lungu *et al.* 2023) . The ability to vary a whole range of technological parameters, tools and movement trajectories made it possible to use CNC machining centres for milling very complex shapes of wood products and wood–based materials. However, the different density of wood species and their heterogeneous nature in three anatomical directions greatly complicates the optimization of the mentioned parameters in terms of the quality of the created surface. However, from a technological point of view, it makes sense to deal with the optimization of technological parameters with regard to the quality of the created surface. In case of their incorrect setting, not only the roughness or waviness of the surface deteriorates (which significantly increases the time of sanding as a follow–up operation), but also places with deep dales are created due to torn fibres. These often cannot be removed by further sanding and require complex repair with fillers, or they are a non–part that is completely excluded from production. Also for this reason, a lot of authors deals with the questions of how best to choose these parameters, with the achievement of targeted quality (Cota *et al.* 2017; Gurău *et al.* 2021; İşleyen and Karamanoğlu 2019; Pelit *et al.* 2021).

With the gradual modernization of the wood industry, there is also the use of newer materials or materials modified by hydrothermal or thermal processes. In this case, there are several properties that are changed by modification – improvement of dimensional stability (Damay *et al.* 2024),

reduction of surface hydrophobicity (Huang *et al.* 2023), reduction of thickness swelling, reduction of the equilibrium moisture content of the wood (Keržič *et al.* 2021), increasing rot resistance (Bi *et al.* 2024), improving overall biological durability (Anish *et al.* 2023) or intentional modification of wood colour (Dzurenda *et al.* 2023; Gaff *et al.* 2023). On the other hand, the modification process significantly reduces wood density, wood hardness and many other mechanical properties. This also significantly affects the quality of the created surface after milling. It follows from the work of some authors that during milling there is an improvement in quality, i.e. a reduction in surface roughness (Korkut *et al.* 2012; Shukla 2019). However, in the case of modified beech wood, it is necessary to deal not only with the influence of the thermal modification temperature on the surface roughness after milling, but also on the development of the surface roughness in the sapwood zone and the false heartwood zone. A false heartwood is a frequent defect of beech wood and can form a proportional part in the sawn timber. In terms of optimization, it is therefore necessary to find out what surface roughness is achieved in these two parts of beech wood.

In order to determine the average value of the roughness or waviness of the surface, however, with this type of measurement, it is necessary to take several profile traces. When measuring the irregularities of the wood, it is advisable to repeat this procedure in the direction perpendicular to the fibres (where greater irregularities of the surface is assumed) and also in the direction of the fibres. Another solution is the use of the areal surface texture parameters, which has become more and more prominent in recent years. This measurement represents a very fast and effective way of detecting the very complex effects of the anatomical structure of wood and the movement of the tool – cutter.

In this paper, surface roughness will be measured through the areal surface texture parameter Sa, which represents one of the more stable parameters. The aim of the article is to quantify the change in roughness after CNC milling in different modes of thermal treatment (steaming) and in two parts of beech wood – sapwood as the outer peripheral part and false heartwood as the central part.

EXPERIMENTAL METHODS

For the preparation of the samples, boards from Beech wood (*Fagus sylvatica* L.) were used with a moisture content ranging from 54.7% to 58.2%. The samples were subsequently divided into 5 groups and steamed under the conditions listed in Table 1.

Table 1: Temperatures and time of individual steaming modes

Groups	Conditions of steaming modes	
	Temperature [°C]	Duration [h]
Unmodified (UM)	–	
I.	95	
II.	115	6
III.	125	
IV.	135	

When steaming beech wood, saturated steam was used in a pressure autoclave APDZ 240 (Himmasch AD, Bulgaria). The process of thermal modification took place in industrial conditions in the company Sundermann s.r.o., Slovakia. After thermal modification, all boards were subsequently dried in a conventional SUZAR KC 1/50 hot air dryer (SUZAR s.r.o., Slovakia).

After drying, the boards were placed indoors, where the equilibrium moisture content was maintained in the range of 8 to 10 %. Samples with a size of 20 × 70 × 400 mm (thickness × width × length) were manipulated from the boards using a circular saw, jointer and a thicknessing milling

machine with a helical cutterhead with razors . For the purposes of this experiment, the samples were manipulated from the false heartwood and also the peripheral, sapwood part. The dimensions of the samples were chosen depending on the design of the mechanical clamps and the design of the CNC machining centre SCM Tech Z5 (Scm Group, Rimini, Italy). For each sample, two VCMC–S4 145x145x50 12–80 clamps (Schmalz GmbH, Glatten, Germany) were used for clamping. This procedure minimized the vibrations of the samples during CNC milling. A Klein T143 spiral finisher (Sistemi Srl, Pesaro, Italy) with a positive helix and solid tungsten carbide was used for edge milling. The cutter diameter was 20 mm, and the total number of teeth was 3. The tool was clamped in a GM 300 HSK 63F hydraulic chuck (Gühring KG, Albstadt, Germany). Milling of the edge was performed in two passes with a size of the thickness of the removed layer of 1 mm each. In the first step, the edge was cleaned of irregularities that arose during thickening, the resulting quality of the milled surface was then created in the second step. The tool speed was 18,000 rpm and the feed speed was 14 $m.min^{-1}$.

The measurement of surface roughness parameters was performed using a Keyence VHX–7000 digital microscope (Keyence, Japan) with a VH–Z100R objective. For the purposes of this experiment, the objective zoom was chosen to be 100×. On each sample, 10 locations were uniformly scanned along the length of the milled edge (scan image size was 3 × 18 mm) to capture surface irregularities due to tool movement. Depending on the standard EN ISO 25178–3 („EN ISO 25178–3. Geometrical product specifications (GPS) Surface texture: Areal Part 3: Specification operators“ 2012), the evaluation area was the S–L surface, i.e. a square with dimensions of 2.5 × 2.5 mm. The digital microscope then measures 1 value of the surface parameter on 1 evaluated surface. In order to avoid measurement extremes (high peaks or deep dales of the surface) and to express the milled surface by the average value of the surface parameter, 5 evaluation areas were measured for each scanned image. 5 values of the areal surface texture parameter are subsequently averaged by the digital microscope. For measuring the surface roughness, the S–filter value of 25 μm and the L–filter value of 2.5 mm were chosen. The evaluated areal surface texture parameter was Sa (Arithmetic mean height). The reason for choosing this parameter was its stability during measurement. The surface roughness was measured separately for part of the false heartwood and part of the sapwood, both for thermally unmodified beech wood and for all modes of thermal modification.

RESULTS AND DISCUSSION

The measured file was subsequently analysed using the statistical software STATISTICA 14 (TIBCO Software Inc., Palo Alto, California). In the first step, the extremes of the measurement were searched in the data sheet. These arose as a result of the incorrect setting of the surface scan before measuring the roughness. Subsequently, this setting caused a sharp increase in roughness values compared to the remaining part of the sample. These measurement extremes were removed, and the measurement was repeated. The set of measurements subsequently showed that the roughness of the surface of thermally unmodified beech wood in the sapwood zone is higher (Sa = 15.60 μm) than in the heartwood zone (Sa = 14.29). It follows that the quality of the milled surface in the peripheral part of sapwood is lower than in the central part with a false heartwood. The reason for these measured values may be the lower density of the sapwood and the resulting lower hardness (which was found in previous experiments). As a result of this decrease, sapwood after milling is characterized mainly by a higher rate of torn fibres at the same technological parameters. Similarly, at a lower density, protruding fibres often appear on the surface after processing, forming the characteristic hairiness of

the surface (Landry *et al.* 2013). In previous experiments, it was found that the amplitude parameters also showed higher values, i.e. greater irregularities in the sapwood zone.

In the aforementioned experiment, the surface roughness in the zone of false heartwood and sapwood was investigated. The second observed effect was the influence of steaming modes on the resulting roughness of the surface after CNC milling. A two–factor analysis of variance (ANOVA) was used to investigate mentioned two factors. The results of the variance analysis show that both mentioned effects have a statistically significant effect on surface roughness independently as well as in mutual interaction ($p < 0.000$).

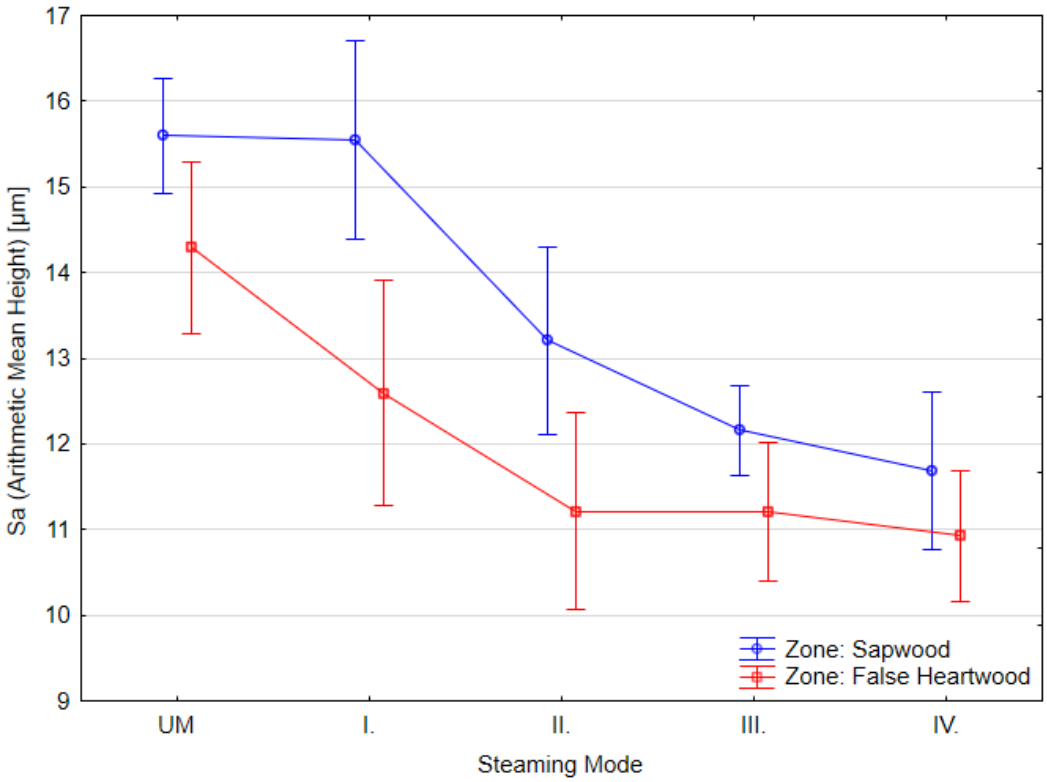


Figure 1: Effect of wood steaming mode on surface roughness parameter Sa in the zone of sapwood and false heartwood

From Fig. 1, it can be seen that the roughness of the surface after CNC milling decreases with the increasing temperature of the steaming modes. The statistical significance of these changes proves that the roughness of the milled surface can decrease even at lower modification temperatures than 160°C. Above this temperature, several authors also measured a statistically significant decrease in roughness with increasing modification temperature (Corleto *et al.* 2020; Kamboj *et al.* 2020). Also, from previous experiments dealing with milling of beech wood at a lower temperature of the steaming modes, it follows that the roughness of the surface decreases as the steaming temperature increases. The opposite trend occurs in the case of sanding thermally modified types of wood, where roughness usually increases with increasing temperature.

Fig. 1 also shows that the decrease in the zone of sapwood and false heartwood is slightly different. The roughness of the milled surface of the sapwood after the I. steaming mode remained almost unchanged, then with the II. in the steam mode with a higher temperature, it decreased statistically significantly ($p = 0.001$). At III. steaming mode, a lower roughness was again measured, but its change was not statistically significant. A significant change was achieved again only at IV. steaming mode, i.e. at a temperature of 135 °C. The same applies to the roughness of the milled

surface in the false heartwood zone, that the surface roughness decreased with increasing steaming temperature. A statistically significant difference (p = 0.013) was already measured in the first steaming mode. In the second mode of steaming, although the roughness after milling decreased, this change was not statistically significant. The roughness value remained unchanged even at a temperature of 125°C in III. steaming mode, it subsequently decreased slightly. Another statistically significant decrease in roughness was measured only at IV. steaming mode (p = 0.023). The decreasing roughness of the milled surface of beech wood at a temperature of 120 °C was also measured in a study (Ozcan *et al.* 2012). At higher temperatures (above 150 to 160 °C), the authors justify the decrease in roughness by the change of lignin to a thermoplastic state, which caused densification of the surface layers. However, according to (Varga and van der Zee 2008), even at lower wood steaming temperatures (92°C, 100°C, 108°C, 115°C and 122°C), the values of Janka hardness of wood decrease. The decrease in hardness is greater with increasing temperature and duration of wood steaming, which has been found in several studies. Despite this, the surface roughness of steamed wood decreases with increasing temperatures. Referring to the study (Laina *et al.* 2017) on the dependence of hardness and roughness, this phenomenon is a paradox, because with decreasing hardness, surface roughness should increase. However, according to (Kaygin *et al.* 2014), the wood steaming process causes plasticization of cell walls, which results in cell wall collapse. From several SEM analyses, it can be concluded that such cell wall collapse creates a dense layer without lumens and thus a layer with lower roughness. This may also be the reason why the surface roughness of the samples decreases with increasing temperature (Fig. 1).

From Fig. 1 it is also possible to see that in the case of thermally unmodified beech wood there are differences in surface roughness, however, according to Duncan's post–hoc test, these differences are not statistically significant (p = 0.0586). However, the average value of surface roughness is higher in the sapwood zone. Previous experiments showed that sapwood has a lower hardness. For this reason, it is more prone to dents from torn fibres during processing, as well as to the formation of surface hairiness. Research (Laina *et al.* 2017) shows that the higher the hardness of the wood, the lower the roughness of the machined surface and vice versa. This dependence also explains why the machined surface of the false heartwood is smoother than the surface of the sapwood. These differences between sapwood and false heartwood were greatest in the case of I. and II. mode of thermal modification, i.e. at temperatures of 95°C and 115°C. The measured differences are also statistically significant (at 95°C p = 0.000 and at 115°C p = 0.006). At temperatures of 125°C and 135°C, the difference in surface roughness between the sapwood and the false heartwood subsequently decreases again.

CONCLUSIONS

The measured results show that the thermal modification of beech wood by steaming partly contributes to improving the quality of the milled surface. However, a statistically significant decrease in surface roughness occurred only up to a certain temperature of the steaming mode. These changes differed depending on whether it was the roughness of the surface of the false heartwood or the sapwood. The reason for the decrease in roughness was probably the collapse of the cell walls, where without the lumens of the cell, a dense layer with a lower roughness is formed. Statistically significant differences in surface roughness were also measured between heartwood and sapwood. Through previous experiments, it was found that the sapwood part of beech wood is softer, which leads to a higher formation of dales after torn fibres. At the same time, the paper confirms the theory and proves

that statistically significant changes in roughness occur even at lower temperatures of thermal modification by steaming.

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REFERENCES

ANISH MC, GIRIDHAR BN, NAIR S., ANANTHA NS, AND PANDEY KK. 2023. Influences of extractives and thermal modification on the UV resistance of Albizia lebbeck wood. Wood Materials Science & Engineering, Taylor & Francis, 18, 2: 540–548. DOI: 10.1080/17480272.2022.2053586.

BI Z., ZHOU X., CHEN J., LEI Y., AND YAN L. 2024. Effects of extracts on color, dimensional stability, and decay resistance of thermally modified wood. European Journal of Wood and Wood Products, 82, 2: 387–401. DOI: 10.1007/s00107–023–02024–4.

CORLETO R., GAFF M., NIEMZ P., SETHY AK, TODARO L., DITOMMASO G., RAZAEI F., SIKORA A., KAPLAN L., DAS S., KAMBOJ G., GAŠPARÍK M., KAČÍK F. , AND MACKŮ J. 2020. Effect of thermal modification on properties and milling behavior of African padauk (Pterocarpus soyauxii Taub.) wood. Journal of Materials Research and Technology, 9, 4: 9315–9327. DOI: 10.1016/j.jmrt.2020.06.018.

COTA H., DRITAN A., AND BESNIK H. 2017. The influence of machining process on wood surface roughness. Agricultural Sciences, 16, 7: 277–283.

DAMAY J., BENDER T., MUNK C., JOUSSERAND M., CRETON M., FREDON E., RÉMOND R., MEAUSOONE PJ, PFRIEM A., AND GÉRARDIN P. 2024. Properties improvement of seven hardwood species by combination of thermal and chemical modifications. European Journal of Wood and Wood Products, 82, 1: 93–106. DOI: 10.1007/s00107–023–02000–y.

DZURENDA L., DUDIAK M., AND KUČEROVÁ V. 2023. Differences in Some Physical and Chemical Properties of Beechwood with False Heartwood, Mature Wood and Sapwood. Forests, 14, 1123. DOI: 10.3390/f14061123.

EN ISO 25178–3. Geometrical product specifications (GPS) Surface texture: Areal Part 3: Specification operators. 2012. Brussels.

ERGIN Ü., AND SOFUOGLU SD 2023. Determination of Machining Characteristics of Heat–Treated Siberian Pine (Pinus sibirica). Drvna industrija, 74, 2: 139–152. DOI: 10.5552/drvind.2023.0003.

GAFF M., KUBOVSKÝ I., SIKORA A., KAČÍKOVÁ D., LI H., KUBOVSKÝ M., AND KAČÍK F. 2023. Impact of thermal modification on color and chemical changes of African padauk, merbau, mahogany, and iroko wood species. Reviews on Advanced Materials Science, De Gruyter Open Access, 62, 1. DOI: 10.1515/rams–2022–0277.

GURĂU L., COŞEREANU C., AND PAIU I. 2021. Comparative Surface Quality of Larch (Larix decidua Mill.) Fretwork Patterns Cut through by CNC Routing and by Laser. Applied Sciences, Multidisciplinary Digital Publishing Institute, 11, 15: 6875. DOI: 10.3390/app11156875.

HUANG Y., YU Y., ZHANG C., WANG X., YANG Z., AND YANG Y. 2023. Investigation of the relationship between surface color, contact angle and chemical properties of heat–treated bamboo . Wood Materials Science & Engineering, Taylor & Francis, 18, 3: 783–791. DOI: 10.1080/17480272.2022.2070029.

İŞLEYEN Ü. K., AND KARAMANOĞLU M. 2019. The influence of machining parameters on surface roughness of MDF in milling operation. BioResources, 14, 2: 3266–3277. DOI: 10.15376/biores.14.2.3266–3277.

JIANG S., BUCK D., TANG Q., GUAN J., WU Z., GUO X., ZHU Z., AND WANG X. 2022. Cutting Force and Surface Roughness during Straight–Tooth Milling of Walnut Wood. Forests, Multidisciplinary Digital Publishing Institute, 13, 12: 2126. DOI: 10.3390/f13122126.

KAMBOJ G., GAŠPARÍK M., GAFF M., KAČÍK F., SETHY AK, CORLETO R., REZAEI F., DITOMMASO G., SIKORA A., KAPLAN L., KUBŠ J., DAS S., AND MACKŮ J 2020. Surface quality and cutting power requirement after edge milling of thermally modified meranti (*Shorea* spp.) wood. Journal of Building Engineering, 29, 101213. DOI: 10.1016/j.jobe.2020.101213.

KAYGIN B., KOC KH, AND HIZIROGLU S. 2014. Surface quality and hardness of eastern redcedar as a function of steaming. Journal of Wood Science, 60, 4: 243–248. DOI: 10.1007/s10086–014–1399–x.

KERŽIČ E., LESAR B., AND HUMAR M. 2021. Influence of weathering on surface roughness of thermally modified wood. BioResources, North Carolina State University, Raleigh, United States, 16, 3: 4675–4692. DOI: 10.15376/biores.16.3.4675–4692.

KORKUT S., KORKUT DS, KOCAEFE D., ELUSTONDO D., BAJRAKTARI A., AND ÇAKICIER N. 2012. Effect of thermal modification on the properties of narrow–leaved ash and chestnut. Industrial Crops and Products, 35, 1: 287–294. DOI: 10.1016/j.indcrop.2011.07.016.

LAINA R., SANZ–LOBERA A., VILLASANTE A., ESPÍ P., MARTÍNEZ ROJAS J., ALPUENTE J., MONTERO R., AND PEÑA S. 2017. Effect of the anatomical structure, wood properties and machining conditions on surface roughness of wood. Maderas. Science and technology. 19. DOI: 10.4067/S0718–221X2017005000018.

LANDRY V., BLANCHET P., AND CORMIER LM 2013. Water–Based and Solvent–Based Stains: Impact on the Grain Raising in Yellow Birch. BioResources, 8, 2: 1997–2009. DOI: 10.15376/biores.8.2.1997–2009

LUNGU A., GURĂU L., AND COȘREANU C. 2023. Evaluation of CNC routed surface quality of maple (Acer pseudoplatanus) and oak (Quercus robur L.) with different milling angles as a function of grain orientation. BioResources, 18, 3: 5334–5350. DOI: 10.15376/biores.18.3.5334–5350.

OZCAN S., OZCIFCI A., HIZIROGLU S., AND TOKER H. 2012. Effects of heat treatment and surface roughness on bonding strength. Construction and Building Materials, 33: 7–13. DOI: 10.1016/j.conbuildmat.2012.01.008.

PELIT H., KORKMAZ M., AND BUDAKÇI M. 2021. Surface roughness of thermally treated wood cut with different parameters in CNC router machine. BioResources, 16, 3: 5133–5147. DOI: 10.15376/biores.16.3.5133–5147.

SHUKLA SR 2019. Evaluation of dimensional stability, surface roughness, color, flexural properties and decay resistance of thermally modified Acacia auriculiformis. Maderas. Ciencia y tecnologia, Universidad del Bío–Bío, 21, 4: 433–446. DOI: 10.4067/S0718–221X2019005000401.

VARGA D., AND VAN DER ZEE M. 2008. Influence of steaming on selected wood properties of four hardwood species. Holz als Roh– und Werkstoff, 66: 11–18. DOI: 10.1007/s00107–007–0205–5.

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CONSUMPTION SATURATED WATER STEAM IN THE PROCESS OF UNIFICATION OF THE COLOR OF BEECH SAPWOOD AND FALSE HEARTWOOD THROUGH STEAMING

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ABSTRACT

In the contribution, the consumption of saturated water steam of the AZ 240 autoclave in the process of steaming beech sapwood and the false heartwood is balanced in order to remove the color differences of the wood. The heat source is the condensation heat of saturated water steam. For steaming V = 16 m^3 of lumber, or blanks with a thickness of h = 40 mm with moisture content w ≈ 60% for a period of τ = 13 h with saturated water steam temperature t = 120 ± 2.5 °C, (mode III with the largest consumption of saturated water steam) m_{H2O} = 3051.9 kg of saturated water steam is consumed.

The discontinuous process of steaming wood in an autoclave is characterized by an uneven consumption of saturated water steam, the largest consumption is at the beginning of the technological process during the heating of the steamed wood and the autoclave. In the heating phase, m_{H2O} = 856.4 kg/h^{-1} of steam is consumed. During the wood color modification process itself, the consumption of saturated water steam drops significantly to m_{H2O} = 6.1 $kg.h^{-1}$.

The above knowledge about the consumption of saturated water steam in the technological steaming process is also a source of information about the production of condensate contaminated with hydrolysis products and released extractive substances from steamed wood, which are treated at wastewater treatment plants.

Key words: beech wood, saturated water steam, wood color, wood steaming.

INTRODUCTION

The wood of *Fagus sylvatica* L. belongs to the scattered–porous, coreless woods with the possibility of forming a false heartwood. Some older trees have wood of a different color in the center of the trunk, referred to as false heartwood. The color of beech wood in the zone of sapwood and mature wood is light whitish–grey, or white pink Nečesaný (1959), Makovíny (2010), Dzurenda – Dudiak (2022) and in the zone false heartwood is brown–red color Nečesaný (1959), Dzurenda – Dudiak (2023). *Dzurenda (2023)* numerically documented the visual color differences between the color of beech sapwood and wood with false heartwood through the values on the coordinates of the color space CIE L*a*b* and the total color difference ΔE*. The wood color is white with lightness L* = 79.2 ± 2.4 and values on the chromatic coordinates a* = 8.3 ± 1.6, b* = 19.1 ± 1.8. The color of the false heartwood is described by the following values: L* = 65.8 ± 3.8, a* = 11.6 ± 1.9, b* = 19.5 ± 1.5. The color difference between the color of the wood of the false heartwood and the color of the sapwood, expressed through the total color difference, is ΔE* = 18.1. Within the categorization of color difference, the value total color difference ΔE* = 18.1 belongs to the category of significantly different colors. The difference in the color of the wood of the false heartwood from the color of the sapwood is the reason for the removal of sawmill assortments with a share of wood of the false heartwood from the production of bent furniture, sports tools and partly construction and carpentry products.

Steaming of wood is a technological process in which wet wood is heated by the action of heat in the form of saturated moist air or saturated water steam and changes its physical, mechanical and

chemical properties. Temporary physical–mechanical changes are used in the production of veneers, plywood, bent furniture, or pressed wood *Nikolov et al. 1980; Sergovskij – Rasev 1987; Lawnniczak 1995; Trebula 1996; Dzurenda – Deliiski (2019).* Permanent chemical changes manifested, among other things, by a change in color, change the color of the wood to more or less distinct shades *Deliiski (1991), Tolvaj et al. (2009), Dzurenda (2014), Milić et al. (2015), Geffert et al. (2017), Dzurenda – Dudiak (2022).*

The aim of this paper is to determine the required amount of saturated water steam for steaming beech wood for a discontinuous heat consumer (steaming autoclave) in order to eliminate the differences between the colors of the sapwood and the false heartwood.

MATERIALS AND METHODS

On the basis of experimental research aimed at analyzing the influence of temperature and length of steaming on the unification of the color of beech sapwood and wood of false heartwood presented in the work of Dzurenda – Dudiak (2024), 3 steaming modes of unification of the color of sapwood and false heartwood with different degrees of darkening of steamed beech wood were proposed wood in Fig. 1.

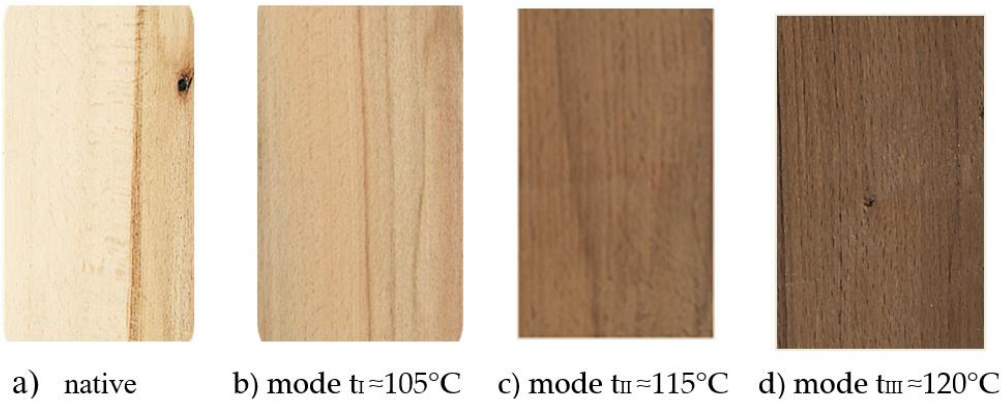


Figure 1: Wood color of unsteamed beech wood with false heartwood (native) and steamed beech sapwood with false heartwood by individual steaming modes after unification of color.

Due to the technological conditions of steaming, mode I. at the steaming temperature t_I ≈105 °C, beech wood acquires a pale brown color with values on the coordinates of the color space: L* = 63.4 ± 2.3, a* = 13.0 ± 1.4; b* = 19.1 ± 1.6. Mode II. at the steaming temperature t_{II} ≈115 °C, the color of the sapwood and the false heartwood becomes brown with the values on the coordinates: L* = 59.0 ± 2.1; a* = 12.9 ± 1.4; b* = 18.8 ± 1.7. Dark brown–gray color with values on the coordinates: L* = 57.5 ± 2.0; a* = 13.4 ± 1.2; b* = 18.8 ± 1.5 acquired by beech wood through the mode III. steaming process at the vaporization temperature t_{III} ≈120°C.

The modes of steaming beech wood with saturated water steam in order to eliminate the differences between the color of the sapwood and the color of the wood of the false heartwood are shown in Fig. 2.

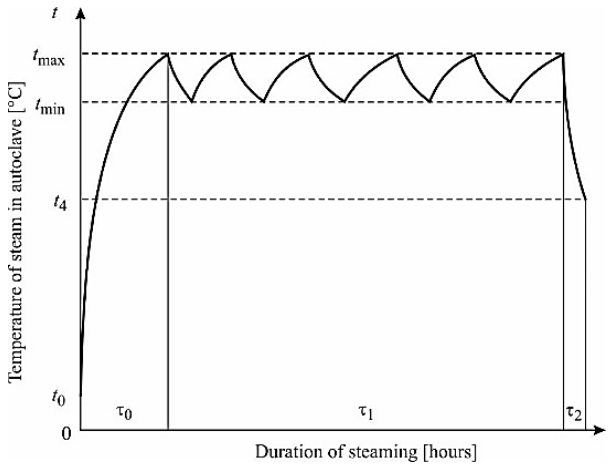


Figure 2: Mode of steaming beech wood with saturated water steam in order to eliminate the differences between the color of the sapwood and the false heartwood.

A breakdown of the technological conditions of steaming by individual modes of steaming beech wood in the form of h = 40 mm thick lumber to eliminate color differences between the color of sapwood and the color of wood with a false heartwood is presented in Table 1.

Table 1: Modes for steaming beech wood with saturated water steam

Modes	Saturated steam temperature [°C]			Steaming time [h]			
	t_{max}	t_{min}	t_4	τ_0 heating	τ_1 steaming	τ_3 cooling	Total time
Mode I	102.5	107.5	100	3.5	18.0	0.5	22.0
Mode II	112.5	117.5	100	3.5	15.0	0.5	19.0
Mode III	117.5	122.5	100	3.5	9.0	0.5	13.0

The source of heat for the implementation of the technological process is the condensation heat of saturated water steam. One of the alternatives for determining its consumption is the heat consumption balance of the technological process in the steam autoclave. The heat losses of the steaming autoclave and heat consumption balances, among others, are discussed in the following works: *Deliiski (2003), Dzurenda – Deliiski (2008), Dzurenda (2016), Dzurenda – Deliiski (2019).* The heat consumption balance of the steaming autoclave and the individual heat consumption items of the balance are described by the equations:

$$Q_{ha} = Q_{hw} + Q_{hf} + Q_{hil} + Q_{he} + Q_{hfv} + Q_{hcw} \text{ [kJ]} \quad (1)$$

Where: Q_{hw} – heat required for heating steamed wood, kJ;

Q_{hf} – heat required to heat the structural material of the autoclave, kJ;

Q_{hil} – heat required to heat the autoclave insulation, kJ;

Q_{he} – heat loss from the surface of the thermal insulation of the pressure autoclave to the atmosphere, kJ;

Q_{hfv} – heat loss of the pressure autoclave by the saturated water steam removed from the unfilled working space of the autoclave during its emptying, kJ;

Q_{hcw} – heat extracted by condensate from the pressure autoclave, kJ;

Individual heat consumption in the technological process of steaming wood is described by the equations:

Q_{hw} – heat required to heat steamed wood with moisture content w > 30%:

$$Q_{\text{hw}} = V_D \left[\rho_R \left(1 + \frac{w}{100}\right)\right] \frac{c_D}{10^3} (t_4 - t_D) \text{ [kJ]} \quad (2)$$

Where: V_D – volume of steamed wood in the pressure autoclave, m³;

ρ_R – reduced wood density, kg.m^{-3};

w – absolute moisture content of steamed wood,%;

c_D – mean value of specific heat capacity of steamed wood, kJ.kg^{-1}.K^{-1};

t_D – wood temperature at the beginning of the thermal process, ºC;

t_4 – temperature of saturated steam and autoclave body at the end of the technological process, °C.

Q_{hf} – Heat required to heat the structural material of the autoclave:

$$Q_{hf} = m_A c_A [t_4 - t_A] \text{ [kJ]} \quad (3)$$

Where: m_A – pressure autoclave body weight, kg;

c_A – specific heat capacity of the pressure autoclave material, kJ.kg^{-1}.K^{-1};

t_4 – temperature of saturated steam and autoclave body at the end of the technological process, °C;

t_A – temperature of the pressure autoclave material at the beginning of the technological process, °C;

Q_{hil} – Heat required to heat the autoclave insulation:

$$Q_{hil} = m_1 c_1 \left(\frac{(t_1 + t_2)}{2} - t_{Ai} \right) \text{ [kJ]} \quad (4)$$

Where: m_1 – mass of insulating material, kg

c_1 – average value of the specific heat capacity of the insulating material kJ.kg^{-1}.K^{-1};

t_1 – temperature of the body of the autoclave during the technological process, ºC;

t_2 – temperature on the outer surface of the autoclave insulation during technolog. process, ºC;

t_{Ai} – autoclave insulation temperature before heating, ºC.

Q_{he} – Heat loss from the surface of the thermal insulation of the pressure autoclave to the atmosphere:

$$Q_{\text{he}} = 3{,}6 \cdot \alpha_k . [\pi(D + 2 \cdot h_i)L + \pi(D + 2 \cdot h_i)^2] . (t_2 - t_0) . (\tau_C - \tau_1) \text{ [kJ]} \quad (5)$$

Where: α_k – heat transfer coefficient of the surface of the autoclave, W.m^2.K^{-1}

D – diameter of pressure autoclave without insulation, m;

h_1 – thickness of the insulating layer of the pressure autoclave body, m;

L – length of the cylindrical part of the pressure autoclave, m;

t_2 – temperature on the outer surface of the autoclave insulation during technolog. process, ºC;

t_0 – temperature of the pressure autoclave material at the beginning of the technological process,°C;

τ_0 – heating time, h;

τ_1 – time 1 of the technological process phase, h.

Q_{hfv} – Heat loss of the pressure autoclave by the saturated water steam removed from the unfilled working space of the autoclave during its emptying:

$$Q_{\text{hfv}} = \left[\frac{\pi \cdot D^2}{4} \cdot L - V_D\right] \cdot \frac{h''}{v''} \text{ [kJ]} \quad (6)$$

Where: D – pressure autoclave diameter without insulation, m;

L – length of the cylindrical part of the pressure autoclave, m;

V_D – volume of color–modified wood in the pressure autoclave, m³;

h“ – enthalpy of saturated steam in the autoclave at the end of the technological process, kJ.kg^{-1};

v“ – specific volume of saturated steam in the autoclave at the end of the technological process m^3.kg^{-1}.

Q_{hcw} – Heat loss of the pressure autoclave by the drained condensate at the end of the technological process:

$$Q_{\mathrm{hcw}} = m_K\left(h^{'} - h_{\mathrm{H2O}}\right) = \frac{Q_{\mathrm{hw}}+Q_{\mathrm{hf}}+Q_{\mathrm{hil}}+Q_{\mathrm{he}}}{r}\left(h^{'} - h_{\mathrm{H2O}}\right), \text{[kJ]} \quad (7)$$

Where: m_k – mass of condensed saturated steam during the technological process, kg;

h′ – condensate enthalpy at the end of the technological process, kJ.kg^{-1};

h_{H2O} – enthalpy of water used to produce saturated steam; kJ. kg^{-1}.

Q_{hw} – heat required for heating colored modified wood, kJ;

Q_{hfv} – heat required to heat the structural material of the autoclave;

Q_{hil} – heat required to heat the autoclave insulation, kJ;

Q_{hc} – heat required to cover heat losses from the surface of the pressure autoclave, kJ;

r – condensation heat of saturated steam used in the technological process; kJ. kg^{-1}.

The amount of saturated water steam consumed in the steaming process is quantified by a mathematical notation:

$$m_{H2O}^{“} = \frac{Q_{\mathrm{ha}}}{r} \text{ [kg]} \quad (8)$$

Where: Q_{ha} – total heat consumption wood steaming process, kJ;

r – heat of condensation of saturated water vapor used in the steaming process; kJ.kg^{-1}.

The steaming process of wood in a pressure autoclave is a typical discontinuous process characterized by uneven heat consumption. According to the work of *Dzurenda – Deliiski (2010)*, the largest heat consumption is at the beginning of the technological process during the heating time, when the heat of the condensing water steam is used to heat the steamed wood and heat the autoclave. Subsequently, during the technological process, the heat of the condensing saturated steam is used to cover the heat losses of the autoclave. The consumption of saturated steam during the heating of steamed wood and the autoclave τ_0 and the phase I. of the technological process τ_1 are described by equations (9) and (10):

$$m_{H_2O-\tau_0}^{''} = \frac{Q_{\mathrm{hw}}+Q_{\mathrm{hf}}+Q_{\mathrm{hil}}+Q_{\mathrm{hfv}}+Q_{\mathrm{hcw}}}{\left(h^{''} - h^{'}\right)\cdot\tau_0}, \text{[kg.h}^{-1}\text{]} \quad (9)$$

Where: Q_{hw} – heat required for heating steamed wood, kJ;

Q_{hf} – heat required to heat the structural material of the autoclave;

Q_{hil} – heat required to heat the autoclave insulation, kJ;

Q_{hc} – heat required to cover heat losses from the surface of the pressure autoclave, kJ;

Q_{hfv} – heat extracted by saturated steam after opening the autoclave, kJ;

h“ – enthalpy of saturated steam in the autoclave at the end of the technological process, kJ.kg^{-1};

h′ – condensate enthalpy at the end of the technological process, kJ.kg^{-1};

τ_0 – heating time, h.

$$m''_{H_2O-\tau_1} = \frac{Q_{he}}{\left(h'' - h'\right)\cdot\tau_1}, \text{[kg.h}^{-1}\text{]} \quad (10)$$

Where: Q_{hc} – heat required to cover heat losses from the surface of the pressure autoclave, kJ;

h“ – enthalpy of saturated steam in the autoclave at the end of the technological process, kJ.kg^{-1};

h´ – condensate enthalpy at the end of the technological process, kJ.kg^{-1};

τ_1 – time phase I of the technological process, h.

RESULTS AND DISCUSSION

Heat consumption for individual steaming modes in Table 2 are performed for steaming 16 m^3 of beech lumber with a moisture content of Wa ≈ 60%, saturated water steam in an AZ 240 autoclave with a weight of m_A = 12 500 kg.

Table 2: Heat consumption of the steaming process of beech sapwood and the false heartwood in the AZ 240 autoclave

Title of heat consumption item	Symbol	Mode I		Mode II		Mode III	
		[MJ]	[%]	[MJ]	[%]	[MJ]	[%]
Heat for heating thermally treated wood	Q_{hw}	4 026.48	68.1	4 490.98	68.8	4 726.20	70.4
Heat for heating the construction material of the autoclave	Q_{hf}	570.00	9.6	630.00	9.7	660.00	9.8
Heat for heating the autoclave insulation	Q_{hil}	82.62	1.4	91.32	1.4	95.66	1.4
Heat to cover the heat losses of the pressure autoclave	Q_{hc}	255.11	4.3	231.57	3.6	120.37	1.9
Heat loss of by the saturated water steam removed from the working space of the autoclave during its emptying	Q_{hfv}	54.94	0.9	54.94	0.8	54.94	0.8
Heat losses in the removed condensate at the end of the steaming process	Q_{hcw}	927.10	15.7	1 022.86	15.7	1 054.31	15.7
Total heat consumption for steaming wood in an autoclave	Q_{ha}	5 916.25	100.0	6 521.67	100.0	6 720.48	100.0

The individual items of heat consumption of the AZ 240 steaming autoclave in Table 2 quantify the heat consumption of the technological process for eliminating the color differences of beech sapwood and false heartwood. The largest heat consumption is the heat for heating with steamed wood Q_{hw} ≈ 69.2%. Heat consumption and heating of the structure of the steam autoclave and insulation is (Q_{hf} + Q_{hil}) ≈ 11% and Q_{hcw} ≈ 15.7% is consumed to cover the heat losses of the pressure autoclave in the form of drained condensate.

The fact that more than 2/3 of the supplied heat is directly used for the implementation of the technological process testifies to the high efficiency of heat use in the thermal process of color homogenization of wood in pressure autoclaves. The stated value is 3 times higher than the direct use of heat in wood steaming technologies implemented at atmospheric pressure in steam pits, chambers and bells *Lawnniczak (1995), Trebula (1996), Dzurenda – Deliiski (2019).*

A comparison of the heat consumption of individual steaming modes shows that steaming mode III. has the largest heat consumption. Steaming process by mode III. although it is shorter by $\Delta\tau$ = 9 h than mode I., but the increased temperature of saturated water steam from temperature t_I = 105°C to temperature t_{III} = 120°C, i.e. o Δt = 15°C is reflected in an increase in heat consumption in the process

of unifying the colors of sapwood and false heartwood from Q_{ha} = 5 916.25 MJ to Q_{ha} = 6 720.48 MJ i.e. by 13.6%.

Table 3 shows the consumption of saturated water steam for the steaming process based on heat consumption balances in the individual beech steaming modes with Table 2.

Table 3: Consumption of saturated water steam for steaming beech wood according to individual modes

Steam conditions		Mode I	Mode II	Mode III
Consumption of saturated steam	kg	2637.6	2942.9	3051.9

In Fig. 3 shows the consumption of saturated water steam during the process of steaming beech wood to a dark brown–gray color by mode III. for the heating phase and the unification phase of the wood colors by the steaming process according to equations (9) and (10).

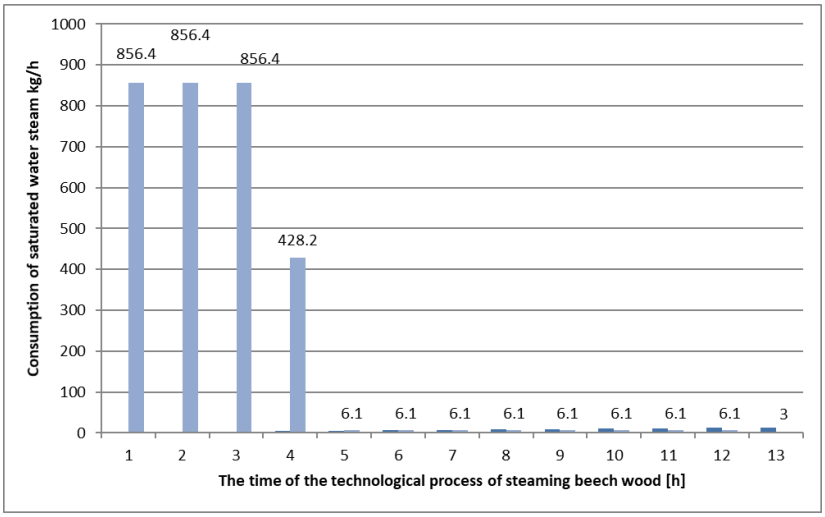


Figure 2: Dependence of the consumption of saturated water steam during the technological process steaming V = 16 m^3 of beech lumber in pressure autoclave AP 240 mode III.

The presented results of the consumption of saturated water steam of the steaming autoclave AZ 240 when unifying the colors of beech sapwood and false heartwood specify the requirements for the heat source. At the beginning of the technological process at the time of heating τ_0, the hourly consumption of saturated steam is m_{H2O} = 856.4 kg.h^{-1}. During the wood color modification process itself, the hourly consumption of saturated water steam drops to m_{H2O} = 6.1 kg.h^{-1}. Total water steam consumption for steaming beech wood to a dark brown–gray color using mode III. is m_{H2O} = 3051.9 kg of saturated water steam at temperature t = 120 ± 2.5 °C.

The specification of the consumption of saturated water steam during the steaming of wood in a steam autoclave is an important source of information for the planning of heat production in the thermal system of the plant.

Condensed water steam is contaminated during the technological process of wood steaming by products of hydrolysis and extraction from steamed wood *Samešova et al. (2018)*. After the end of the technological process, it is not sent to the heat producer's boiler room, but to the wastewater treatment plant. The condensate balance is also a specification of the capacity requirements for wastewater treatment at the wastewater treatment plant.

CONCLUSION

The article presents the consumption of heat and saturated water steam in the process of steaming 16 m^3 of beech lumber with a moisture content of Wa ≈ 60%, in order to eliminate the differences between the color of the sapwood and the wood of the false heartwood in the pressure autoclave AZ 240.

Due to the technological conditions of steaming, mode I. at the steaming temperature $t_I \approx 105°C$, beech wood acquires a pale brown color with values on the coordinates of the color space: L* = 63.4 ± 2.3, a* = 13.0 ± 1.4; b* = 19.1 ± 1.6. Mode II. at the steaming temperature $t_{II} \approx 115$ °C, the color of the sapwood and the false heartwood becomes brown with the values on the coordinates: L* = 59.0 ± 2.1; a* = 12.9 ± 1.4; b* = 18.8 ± 1.7. Dark brown–gray color with values on the coordinates: L* = 57.5 ± 2.0; a* = 13.4 ± 1.2; b* = 18.8 ± 1.5 at the vaporization temperature $t_{III} \approx 120°C$.

A comparison of the heat consumption of individual steaming modes shows that steaming mode III. has the largest heat consumption. Steaming process by mode III. although it is shorter by $\Delta\tau = 9$ h than mode I., but the increased temperature of saturated water steam from temperature $t_I = 105°C$ to temperature $t_{III} = 120°C$, i.e. o $\Delta t = 15°C$ is reflected in an increase in heat consumption in the process of unifying the colors of sapwood and false heartwood from Q_{ha} = 5 916.25 MJ to Q_{ha} = 6 720.48 MJ i.e. by 13.6%.

From the analyzes of the consumption of saturated water steam in the steaming process of 16 m^3 of beech wood in the pressure autoclave AZ 240, it follows that the autoclave consumes m_{H2O} = 3051.9 kg of saturated water steam at a temperature of $t_{III} = 120 \pm 2.5°C$ during the technological process. At the time of maximum consumption, at the beginning of the technological process during heating, the hourly consumption of saturated water steam is $m_{H2O} = 856.4$ kg.h^{-1}.

REFERENCES

NEČESANÝ, V. 1959. Beech heartwood, structure, origin and development. Publishing House of the Slovak Academy of Sciences, Bratislava, 256 p.

MAKOVÍNY, I. 2010: Useful properties and use of different types of wood. Zvolen: TU Zvolen, 104 p.

DELIISKI, N. 1991. The method extends the assessment of the degree of beech sawn timber during its drying process. Current problems and perspectives of beech lumber drying. 1991. ES–VŠLD in Zvolen (Slovakia), 37−44.

DELIISKI, N. 2003. Modeling and technologies for steaming wooden materials in autoclaves. Dissertation for Doctor of Science, LTU, Sofia.

DZURENDA, L., DELIISKI, N. 2008. Mathematical model for determining the norm of heat consumption for color homogenization of beech blanks in pressure coaches. In: Chip and chipless woodworking. 2008, pp. 307 – 314.

DELIISKI, N., DZURENDA, L. 2010. Modeling of thermal processes in wood processing technologies. Avangard Prima, Sofia. 299 pp. ISBN 978–954–323–719–7.

DZURENDA, L. 2014. Colouring of Beech Wood during Thermal Treatment using Saturated Water Steam. Acta Fac. Xylologiae Zvolen 2014, 56, 13–22.

DZURENDA, L. 2016. Numeric model of the normative consumption of heat for the colour homogenisation of wood in pressure autoclaves. In: AIP Conf Proc. 1745, 020008 (2016),

DZURENDA, L., DELIISKI, N. 2019. Thermal processes in wood processing technologies. Zvolen: Publishing TU Zvolen, 283s. ISBN 978–80–228–3159–5.

DZURENDA, L., DUDIAK, M. 2022. Modification of wood color with saturated steam. Zvolen: Publishing TU Zvolen, 120 p. ISBN 978–80–228–3318–9.

DZURENDA, L., DUDIAK, M. 2023. Color diversity of beech wood with a false heartwood in the color space CIE L*a*b*. In: Wood Research 68(4): 68(4): 792–801 pp.

DZURENDA, L., DUDIAK, M. 2024. Homogenization of the color of beech sapwood and false heartwood by the steaming process. In: Forests,15,1009. doi.org.10.3390/f15061009.

GEFFERT, A., VYBOHOVÁ, E., GEFFERTOVÁ, J. 2017. Characterization of the changes of colour and some wood components on the surface of steamed beech wood. Acta Facultatis Xylologiae Zvolen 59(1): 49−57.

LAWNICZAK, M. 1995. Outline of hydrothermal and plastic processing of wood. Part I. – Brewing and brewing wood. Poznan, 149 p.

MILIĆ, G.; TODOROVIĆ, N.; POPADIĆ, R. 2015. Influence of steaming on drying quality and colour of beech timber. Glas. Šumar. Fak. 2015, 112, 83–96.

NIKOLOV, S., RAJCHEV, A., DELIISKI, N. 1980. Steaming the wood. Sofia: Zemizdat, 174 p.

SAMEŠOVÁ, D., DZURENDA, L., JURKOVIČ, P. 2018. Contamination of condensate with products of hydrolysis and extraction from heat treatment of beech and maple wood during wood color modification. In: Chip and chipless woodworking 2018, p. 277 – 282.

SERGOVSKIJ, P. S., RASEV, A. I. 1987. Hydrothermal processing and conservation of wood. Lesnaja promyšlennost, Moskva, 360 p.

TOLVAJ, L.; NEMETH, R.; VARGA, D.; MOLNAR, S. 2009. Colour homogenisation of beech wood by steam treatment. Drewno 2009, 52, 5–17.

TREBULA, P. 1996. Drying and hydrothermal treatment of wood. Zvolen: TU Zvolen, 255 p.

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PROCEEDINGS OF TWELFTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN – INNO 2024
7 – 9 October, Hotel Imperial Plovdiv, a member of Radisson Individuals, Plovdiv, Bulgaria

EXPLORING THE PROCESS OF OBSERVATION, PERCEPTION AND INTERPRETATION IN STUDENT ASSIGNMENTS

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ABSTRACT

The paper clarifies the action of observation, perception and interpretation, as a part of the creative process. It is an immutable part of the design of products and interiors and, accordingly, of the training process of the students in the Engineering Design Program in University of Forestry, Sofia.

Information was collected and analysed from assignments (sketches and drawings) of 1st year students, in the Engineering Design Program, in the discipline of Artistic Methods and Techniques in Interior Design, with the aim of discovering the relationship between observation, perception and interpretation in the learners.

The main regularities between the individual parts of this process and the main difficulties that are characteristic of students' assignments are revealed. On the basis of multi–year analysis, the training model in the relevant discipline has been updated and enriched. This was accomplished through practical tasks aimed at increasing the effectiveness of the learning process (faster reception and better coping with assignments, applying the set criteria) and improving the observation, perception and interpretation process.

Key words: observation, perception, interpretation, design education, sketches, drawings.

INTRODUCTION

All designers, architects and visual artists have something in common – that is, they are visual thinkers. They actively use their visual perception, their imagination, and the ability to visualize their ideas to solve design problems and present them. A visual thinker skilfully uses observation, perception and interpretation during the design process – looking at the problem at hand from all possible angles (observing it), sometimes even sketching it (perceiving it and interpreting it on a medium); drawing solutions to it (interpreting the problem and interpreting their ideas on a medium). This cycle is possible to repeat several times during the design process. It provides the designer with multiple solutions to a given problem, placing visual images of the solutions in front of the designer. In this way, the visual thinker observes all solutions simultaneously and gets the opportunity to make visual analogies between them. „The use of analogies stimulates brain activity, triggers fantasy and imagination, and contributes to 'break' the stereotypical concepts dealing with psychological inertia of thinking, but its implementation requires training, rich imagination and ability to think abstractly“ (Angelova, 2013, p. 158).

According to Colin Ware (2008), in order for a visual comparison of two graphical objects to be as easy and effective as possible for the person analysing and comparing them, it is best for them to be in close proximity to each other (e.g.: on the same page). For this reason, often during ideation, all ideas, elements and drawings are displayed together. This method helps to compare shapes and proportions and sift out the better solutions to the given design problem.

In addition to the concept creation and display, where images of the ideas are compared for similarities and differences between them, when presenting a product (or furniture) design, several images are also used simultaneously – most often of the object in different views (technical, three–dimensional, or both) – to clarify the overall design concept more easily. As Lawson, 2005, says, „There is nothing wrong in producing beautiful presentations, so long as they continue to do their job

of revealing and communicating the design so it can be properly understood and thoroughly examined.“

For this reason, part of the brief of the experiment discussed in this paper is instructions on the composition of the presentation board, which includes having the original design present on it, along with the redesign of the furniture.

The experiment discussed in this paper aims to explore the complex relationship between observation, perception and interpretation in the context of design learning. Through this research, it aims to reveal how students, from the Engineering Design major at the University of Forestry, Sofia, perceive and synthesize information to complete their assignments. In relation to the set goal, the results achieved by the students of the 1st year of the course „Visual Art Methods and Techniques for Interior Design“ are examined. The work submitted by the students on the assignment „Chair Redesign“ from two academic years is examined and analysed. The experiment was conducted in an online environment, remotely. The assignment was completed completely independently by the students, based on the author's interpretation, basic guidelines were set to support the process of observation, perception and interpretation of the students.

The design process is also related to the visualization of ideas – whether technical drawings, sketches, models or computer three–dimensional models. For this reason, they are also an integral part of design education. To be able to visualise their ideas, students and designers in general must first be able to recreate objects from the subject environment, and from their imagination, on paper. For this, often, in the first year of industrial/product/interior design students' training, the study of drawing, perspective and methods of presenting ideas is present.

RESEARCH METHODS

In the experiment with the task „Chair Redesign“, a total of 71 submitted student assignments were analysed – 28 assignments in the academic year 2020/2021 and 43 assignments in the academic year 2021/2022.

Based on the predefined assignment criteria, the assignments of the first year Engineering Design students were grouped by category and analysed. They were compared for whether and how many of them met the various performance and execution criteria of the redesign itself.

How many of the students met these criterion – separately for the two academic years – and the percentage dependence to the total number of participants in the experiment are investigated. It is also examined whether there is a relationship between work gaps and the assigned chair.

On the basis of the analysed student assignments, basic guidelines to support the learning process and in particular the process of observation, perception and interpretation of students are derived.

STATEMENT

The 1st year students of the Engineering Design major at the Forestry University, Sofia, study the two–semester course „Visual Art Methods and Techniques for Interior Design“. It (the Discipline) helps students to develop skills to visualize ideas and to use design drawing as a basis in the creative process. It also develops their aesthetic taste for selection of means of expression and compositional relationship of drawing elements. The course develops these skills in students through weekly assignments directly related to the development of their mechanical skills (quick sketching, clear lines and shapes), their three–dimensional perception and visualization (from the basics of perspective to the perspective of an interior executed by hand), and their innovative skills (idea generation and visual presentation).

After a few weeks aimed at introducing students to the basics of sketching, perspective and rendering, they are given the assignment of „Redesigning a Chair“, which each student must complete independently. It aims to reveal the level of observation, perception and interpretation in all the students of the course, and also sets them the task of showing it visually.

On the one hand, the experiment enables students who are at the beginning of their design studies to observe, perceive and interpret three–dimensional objects, their structure and the different materials. And on the other hand, the Teacher gets clarity about the level of all participants, their strengths and weaknesses as well as learning needs. This information (about the level of knowledge of the students) is particularly important for a successful educational process, since at the beginning students have a different base of knowledge and skills (because of the different profiles they have studied in high school – there are those with language, mathematics, art and other profiles). This leads to variation in the speed and quality of their understanding and performance of the tasks given to them, as well as their learning of new material. In order to level the playing field between students and to make sure that the tasks are not too easy for some and/or too difficult for others, during the first year, especially the first few months of their studies, it is important to monitor through assignments how they perceive and visualize the visual.

The „Chair Redesign“ assignment was piloted during the 2020/2021 school year and 2021/2022 school year, during online training mandated due to the global COVID 19 epidemic.

Due to the format of the training in both academic years – namely the online environment, **the experiment was conducted in the following stages:**

- During the online class, all the terms of the assignment were presented to the students and any questions about it were clarified.
- Students have 1 week to complete the assignment – independently, at home.
- The assignment is handed in as an A3 sized whiteboard, photographed and uploaded to the online classroom.
- Exactly one week after the assignment (in the next class), each assignment is reviewed, presented verbally by the student in the presence of the rest of the course and the instructor
- The instructor gives feedback on the work completed to each student.
- After the experiment is completed, the results of the submitted work are analysed.

What is the assignment? „Chair redesign“ is an assignment that gives students the opportunity to make their first design, referring to already existing examples. They receive the assignment in the form of verbal and written instructions during the online class, and for their convenience, the assignment is structured in steps and in the form of images that they can rely on during execution.

The instruction they receive is: Redesign an existing chair by building a tubular structure from its silhouette and a seat and backrest from a material of their choice. Each student is given 1 of 5 options for a chair. The option they get is determined by the last digit of their student ID number. They are then given 1 of 5 options for a tubular structure, also assigned according to the last digit of their student ID number, but with a different combination of digits (Fig. 1).

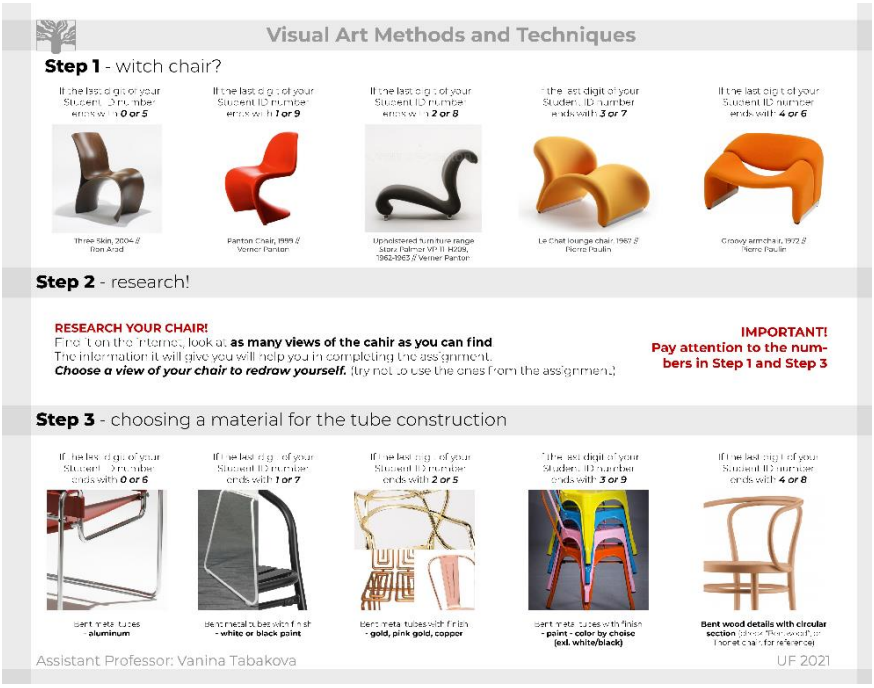


Figure 1: Instruction board for the first steps of the assignment

For the seating and reclining material of the new chair, they have a free choice. To make it easier for them to choose, they are given a list of possible materials (with the freedom, if they want one, which is not present in the examples, to use it). They can also use a combination of materials for this part of the task. Selecting material for the rest of the chair – at the student's CHOICE; Examples (also given in the student manual in text and visual form) (Fig. 2).

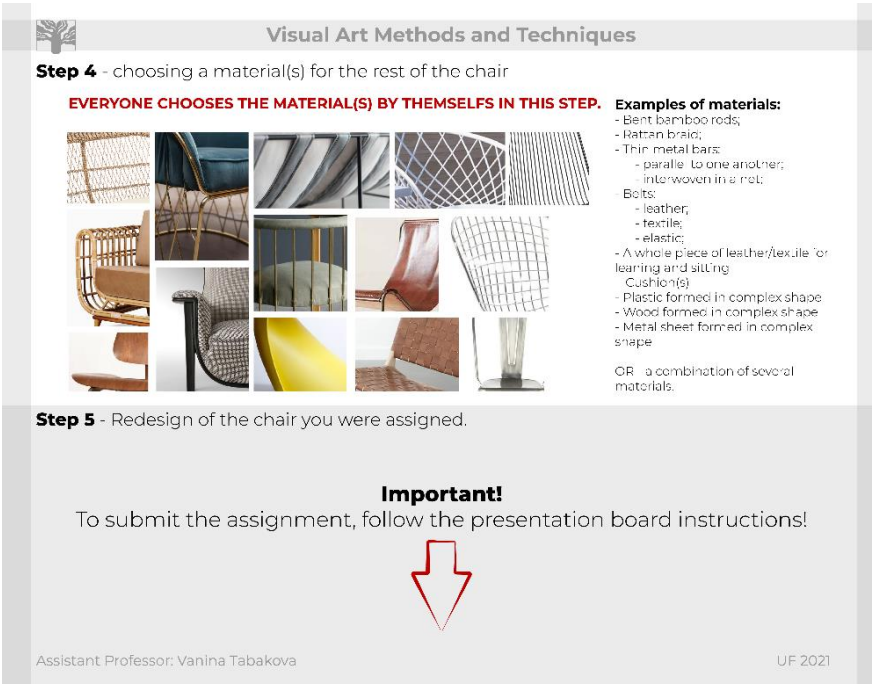


Figure 2: Instruction board with material examples for the redesign

In addition to redesign instructions, students receive instructions on how to render and present their solution. **Submission requirements:**

- The assignment is completed by hand.

- Coloring is done using one of the following techniques: alcohol markers, watercolor paint, watercolor pencils, or a combination of these (technique is student's choice).
- The assignment is completed within a standard A3 sheet (420 x 297 mm), horizontally oriented.

To complete the assignment on the piece of paper, the following elements must be present:

- Upper left corner – drawing of the chair that they were assigned;
- below it – an inscription with the name of the chair, the year of its design and its author;
- Lower left corner – description of the seat and back material(s) and other elements, if any;
- In the middle (with the largest size) – a drawing of the Chair Redesign, necessarily colored to clarify the chosen materials of the new design;
- below it an inscription: Redesign of ...(name of the chair), year (when the student did the redesign) and the name of the student;
- Lower right corner – sketch of only the tubular structure with „transparent“ tubes and visible sections;
- different colors indicate the different types of bends along the tube axis and different cross–sectional dimensions, if any;
- Upper right corner – description of the material of the tubular structure;
- A strip with inscriptions at the bottom of the sheet – Teacher: Assistant Professor Vanina Tabakova; UF, Visual Art Methods and Techniques and date. (Fig. 3)

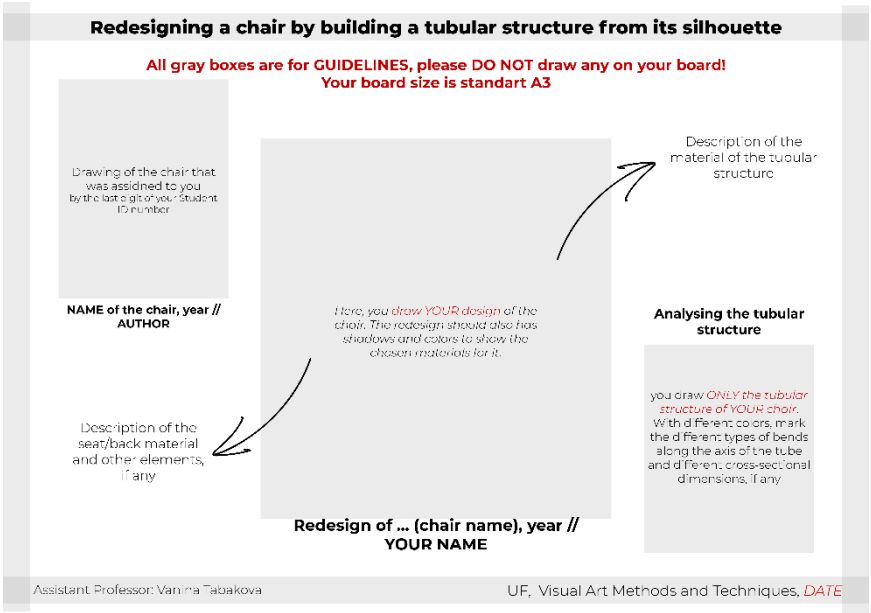


Figure 3: Instructions for the elements of the presentation board

The first goal of the assignment is to reveal the students' ability to observe an object and analyse it – the shape of the whole and its individual parts, how they are unified, the silhouette, proportions and perspective cuts from the images (photographs) they observe.

The second purpose of the assignment is to show students' visual interpretation resulting from their observation and perception. As the assignment gives the opportunity to show not only the interpreted object (the chair) but the interpretation of different materials and colors and how they are combined in the new piece of furniture.

RESULTS

The first analysis of the students' work is related to their success in completing the task (Conditions met by the participants). The following five criteria were used for this analysis:

- Criterion 1.1 – Everything is on the board – The conditions for the presentation board are fulfilled and there are no missing elements on it;
- Criterion 1.2 – Silhouette preserved – The silhouette of the assigned chair and the redesign are preserved, so it is clear that they are one and the same
- Criterion 1.3 – Clear materials – It is rendered in such a way that the materials of the new design are instantly clear
- Criterion 1.4 – Tubes clearly displayed – The analysis of tubes shows the degree of understanding of three–dimensional object and space
- Criterion 1.5 – The original chair is drawn – A drawing of the assigned chair is present

The proportion of student work in terms of their success in completing the assignment, by year and overall, for all participants in the experiment is displayed on Fig. 4. The highest score is for criterion 1.5 – where for both academic years all participants (100%) have a drawing of the original chair on the presentation board. This shows that each student, as a visual thinker, has the need to visually understand the assigned chair for the redesign. It can be seen that observation is easier and clearer for them when they have redrawn the observed object. The criterion with the lowest score (compared to the others) is 1.3. which tracks whether the materials depicted by the students become clear without the additional descriptions on the board. Considering the stage of design training they are in – the first weeks of their first year, it could be argued that even these results are very good.

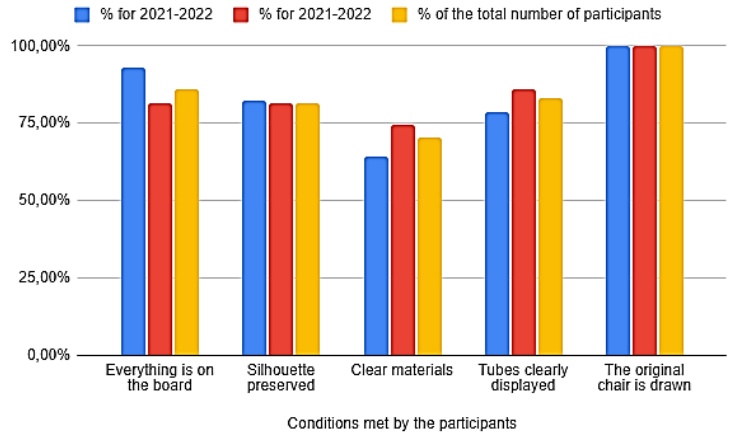


Figure 4: Diagram of the proportion of student work for criteria 1.1 to 1.5

Table 1 with examples of students' work on all 5 criteria from the first analysis (Conditions met by the participants)

Table 1: Examples of students' work on all 5 criteria from the second analysis (Presenting conditions NOT met by the participants)

Table 1	Conditions met by the participants	Example of student work
Criterion 1.1	Everything is on the board	
Criterion 1.2	Silhouette preserved	
Criterion 1.3	Clear materials	
Criterion 1.4	Tubes clearly displayed	
Criterion 1.5	The original chair is drawn	

The second analysis of the student work refers to the proportion of mistakes made by the participants in performing the presentation board (Presenting conditions NOT met by the participants). The following five criteria were used for this analysis:

- Criterion 2.1 – Missing authorship inscriptions – Authorship inscriptions on the original model and/or the redesign are missing
- Criterion 2.2 – There are no material descriptions
- Criterion 2.3 – Missing the visual analysis of tubes
- Criterion 2.4 – Failure to follow board layout
- Criterion 2.5 – A combination of the criteria listed is missing

Fig. 5. – the results and their correlations from this analysis. Firstly, it is noticeable that criteria 2.1. and 2.2. have the most deficiencies, which are related to the required lettering on the board. Often both criteria are not present on the board together, so criterion 2.5 has the same results. This indicates that some of the participants have focused entirely on the visual part of their redesign presentation. The lowest score was for criterion 2.3 – lack of analysis of the tubular structure. This reveals that only 5.63% (four) of all participants were unsure of what the tubular construction they used to create their redesign looked like.

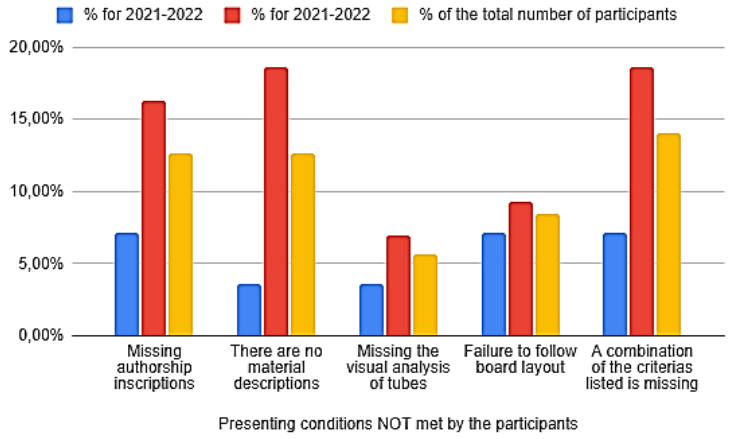
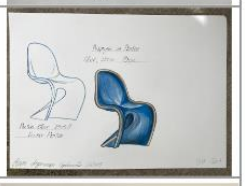


Figure 5: Diagram of the proportion of student work for criteria 2.1 to 2.5

Table 2: Examples of students' work on all 5 criteria from the second analysis (Presenting conditions NOT met by the participants).

Table 2	Presenting conditions NOT met by the participants	Example of student work
Criterion 2.1	Missing authorship inscriptions	
Criterion 2.2	There are no material descriptions	
Criterion 2.3	Missing the visual analysis of tubes	
Criterion 2.4	Failure to follow board layout	
Criterion 2.5	A combination of the criterias listed is missing	

The third analysis of the students' work refers to the shortcomings made by the participants when creating their redesign (Redesign conditions NOT met by the participants). The following criteria were used for this analysis:

- Criterion 3.1 – A very different silhouette of the redesign – the new design has added too many and/or differently shaped elements, losing the original silhouette of the model (the original design and the redesign are too far apart visually)

- Criterion 3.2 – Too few changes for the redesign – the design changes are small or even invisible – at first glance, or made by adding an element

Fig. 6 displays the correlation of these results. The interesting thing here is that both criteria reveal the same number of errors by the students. Compared to the total number of all participants, both are 18.31%, which means that the majority of students have successfully performed the chair redesign.

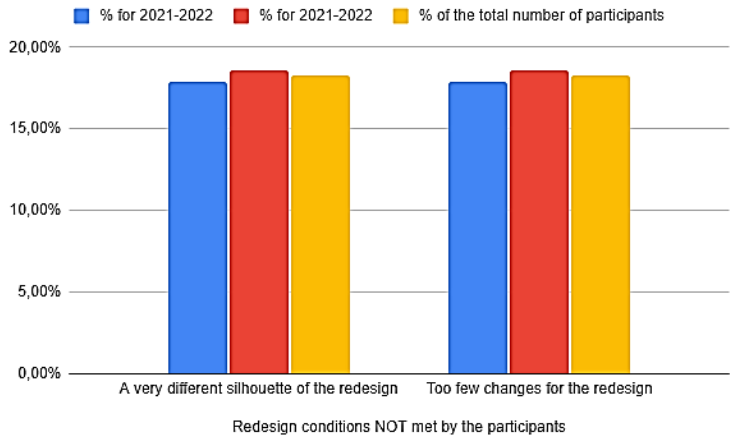
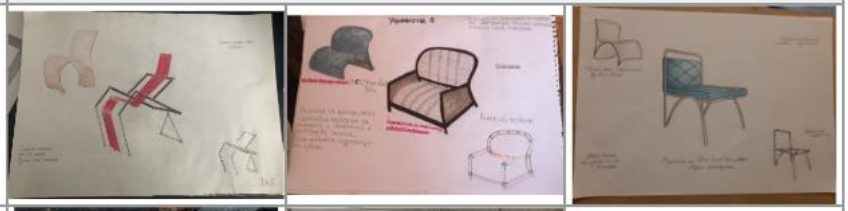


Figure 6: Diagram of the proportion of student work for criteria 3.1 and 3.2

Table 3: Examples of students' work on the criteria from the third analysis (Redesign conditions NOT met by the participants)

Table 3	Redesign conditions NOT met by the participants	Examples of student work
Criterion 3.1	A very different silhouette of the redesign	
Criterion 3.2	Too few changes for the redesign	

When analysing the student work, additional criteria were found on which they were deficient. Their percentages are shown in Fig. 7 (Other omissions in the work found after the experiment was conducted). The following two criteria were used for this analysis:

- Criterion 4.1 – A skewed perspective – the side that is further from the viewer (already hidden in the view of the original design) is unfinished, unclear and there are missing parts of it in the redesign and/or in the tube analysis
- Criterion 4.2 – Not respecting the proportions of the chair

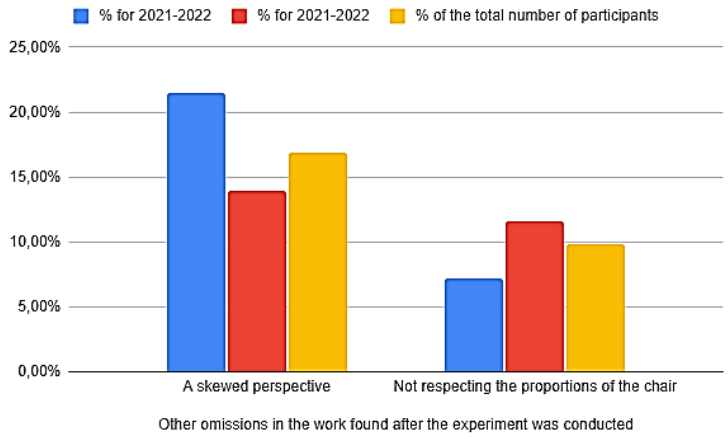


Figure 7: Diagram of the proportion of student work for criteria 4.1 and 4.2

Table 4: Examples of students' work on the criteria from the fourth analysis (Redesign conditions NOT met by the participants)

Table 4	Other omissions in the work found after the experiment was conducted	Examples of student work
Criterion 4.1	A skewed perspective	
Criterion 4.2	Not respecting the proportions of the chair	

Examining and identifying these gaps in the participants' work informs the instructor whether and how much emphasis should be placed on subsequent assignments aimed at improving the students' knowledge and skills. The percentage of mistakes made in the assignments did not exceed 17% (of the total number of participants), but still shows that it is important to address these gaps in order to level the students within the study of the discipline.

The last analysis examines whether there is a correlation between the errors made in the participants' work and the chair they were assigned (Correlation between the assigned chair and the omissions made by the participants) The analysis is shown in fig. 8 and has the following criteria:

- Criterion 5.1 – Two or more presenting conditions are missing from the presentation board
- Criterion 5.2 – A very different silhouette of the redesign
- Criterion 5.3 – Too few changes for the redesign
- Criterion 5.4 – A skewed perspective
- Criterion 5.5 – Not respecting the proportions of the chair

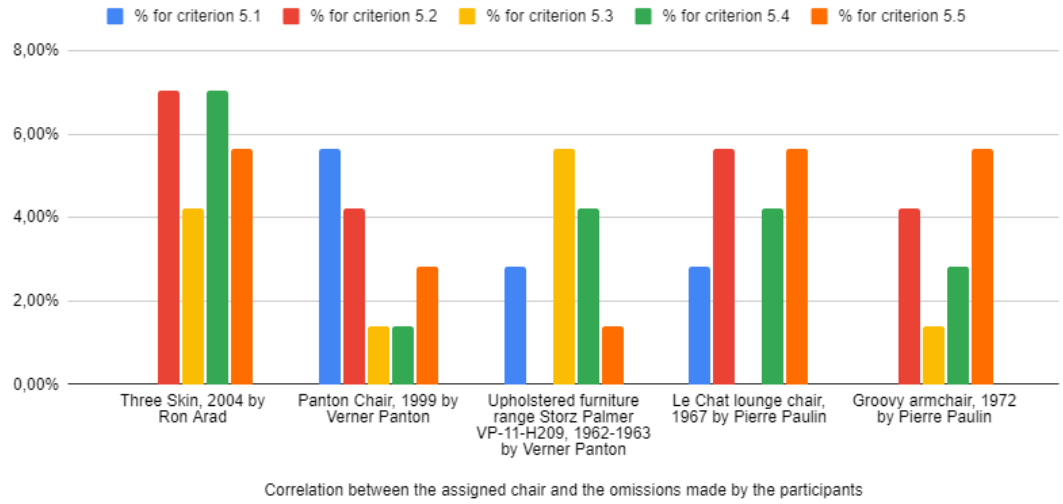


Figure 8: Diagram of the correlation between the assigned chair and the omissions made by the participants

Criterion 5.1 has the lowest scores overall, with chairs such as Three Skin by Ron Arad and Groovy armchair by Pierre Paulin having no open problems with „two or more presenting conditions missing from the presentation board“. This error occurs most frequently in Panton Chair by Verner Panton.

The highest number of omissions occurs in Three Skin by Ron Arad. As in criterion 5.2. „A very different silhouette of the redesign“ – there is a lack of understanding of the original silhouette by the students, resulting in the creation of a very different one for the redesign. Criterion 5.4. also has the highest score for this chair compared to the others. The misunderstanding of the silhouette and the distortion of perspective in the rendering and interpretation (redesign) are directly related to the complexity of the form and the understanding of the three–dimensional object (in itself and in space). This has led to the admission of more omissions in Three Skin by Ron Arad.

As can be seen in Fig. 8 – the errors for all five criteria and for all five chairs did not exceed 8% (relative to the total number of participants), because of which it can be argued that the experiment was successful.

FINDINGS

The Three Skin, 2004 by Ron Arad chair, is the only one of the five assigned chairs with more than two main curved details forming the silhouette. This complicates the form and leads to confusion among students. As a consequence, as seen in the results from fig. 8, the participants have more difficulties for a new design and correct perspective in rendering (the former probably a result of the latter). For this reason, the brief would benefit if the Three Skin chair is replaced with one of more uniform silhouettes, similar to the other 4 chairs.

A future study would provide more information on the development of these skills in the cold by asking twice. First at the beginning of the training (first weeks of the course) as in the experiment shown above and then in the last weeks of the school year. This would allow a comparison of the students' performance and what they were able to acquire as skills during their first year of study. This information would allow for refinement of instructional design to fit the needs of the students.

Although this type of analysis and three–dimensional thinking is a new concept for many, students are showing their innovation and understanding of the form – even at this early stage of their

training. The vast majority successfully tackled the task set to them, despite the errors found in their work.

The gaps are due to the students' little training in three–dimensional and perspective analysis, perception and representation. This assignment clarified each student's weaknesses regarding understanding and interpreting materials and three–dimensionality early in their training. This provides information to the instructor, for each of them, and the course as a whole, and allows future assignments during class to be geared to address these weaknesses in students.

CONCLUSION

Visual thinking, observing, perceiving, interpreting, and representing are complex systems of interrelated skills that continually influence one another. They are one of the most important strengths a designer possesses. For this reason, it is important to integrate these processes continuously in design education, through assignments and tasks. From the analysis of the students' results, it is clear that the experiment called „Chair Redesign“ is a good way to train and improve the creative process of observing, perceiving and interpreting for students studying Engineering Design.

REFERENCES

ANGELOVA, D. 2013. Analogy as a Basic Technique in the Process of Creating New Products. Science, Innovations in Woodworking Industry and Engineering Design, ISSN 1314–6149, 2/2013 (4): p. 151–156. DOI: 10.13140/2.1.3225.5686).

LAWSON, B. R. 2005. How Designers Think. The Design Process Demystified, Fourth edition. University of Sheffield.

MCKIM R. H. 1980. Thinking Visually a Strategy Manual for Problem Solving, Dale Seymour Publications, ISBN 0–86651–423–6.

WARE, C. 2008. Visual Thinking for Design, Morgan Kaufmann Series in Interactive Technologies, ISBN 9780123708960.

PROCEEDINGS OF TWELFTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN – INNO 2024
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OVERVIEW OF PICTORIAL TECHNIQUES FOR VISUALIZING IDEAS IN FURNITURE DESIGN

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ABSTRACT

In the contemporary design process, there are many digital techniques that aim to support the designers' work. In the context of the evolving artificial intelligence technology, many of them offer an increasingly faster and more realistic way to visualize ideas. This leads to the impression that the hand sketching process can be skipped as part of the creative search process and go straight to building 3D models and/or technical drawings.

From here arises the need to examine the stage of "creative search", its essence and the appropriate techniques that could be used in formulating and depicting good ideas in furniture design.

On the basis of a case study of the pictorial techniques used by established designers and architects during their work, a classification of them was made. Those visual techniques that are suitable for the "creative search" stage of the design process have been analysed and selected.

Key words: creative search, pictorial techniques, design process, furniture design, visualizing.

INTRODUCTION

In contemporary design, the integration of digital techniques is significantly changing the way designers approach their creative processes. With the rapid advancement of Artificial Intelligence (AI) technologies, there is now access to tools that facilitate faster and more realistic visualization of ideas. This shift begs the question: can the practice of manual sketching be skipped in favour of directly creating 3D models or technical drawings during the design process?

The use of digital design tools streamlines the design process allows for faster iterations and modifications. This transition to new techniques and technologies also requires a critical examination of the 'creative exploration' stage - an essential part of the design process where designers explore and refine their concepts before committing to a final design. The essence of this stage lies in its ability to foster creativity and innovation by allowing designers to generate, evaluate, select and combine multiple ideas before arriving at a solution that meets both the aesthetic and functional requirements of their given problem.

In the context of furniture design, understanding the creative search process is particularly important. Furniture design is not just about aesthetics; it involves a thorough understanding of materials, ergonomics and user needs. The techniques used during the creative search process can significantly affect the quality of the final product.

It is therefore particularly important to explore the different methods and approaches that designers can use to effectively formulate and portray their ideas. The aim of this review is to gain insight into the importance of the creative search stage in furniture design by looking at the different techniques involved in hand sketching and their role in generating ideas and innovation.

RESEARCH METHODS

The methodology for this review paper includes a review of existing literature on the topic. Selected publications were reviewed and analysed to identify key themes, findings and gaps in existing knowledge. The results are synthesized and organized in a way that provides a clear and concise overview of the current state of research on the topic.

STATEMENT

The design process is divided into multiple stages from problem definition to the final product. One of the initial and very crucial stages is the creative search stage. It involves generating ideas from the brief. This idea generation is most often done through brainstorming and/or ideation - in a short time, as many solutions to the problem as possible are presented.

As Eissen and Steur (2011) argue in their book Sketching the Basics, during brainstorming (individual or in a group), the flow of ideas and suggestions should take priority. The important thing at this point in the depiction is just that it happens quickly and that the form of the suggestions is clear. In order to keep the flow of ideas it should not be interrupted by refining perspective or shading. That is why one of the recommendations is to make this kind of conceptual sketches small - this ensures that they are created quickly. Also, it should be done on small sheets that can be easily rearranged and make it easier to create new connections between already formed ideas and shapes. Speed in the brainstorming and ideation stage is important for the designer to be able to create as many ideas as possible for the problem at hand. In the next stage of the design process ideas are screened and selected. The more generated ideas there are, the higher the chance that there will be good ones among them, which will eventually become concepts or proposals (solutions) for the design problem.

At the beginning of any project (design or art), every artist experiences fear of the blank paper. For this often designers need to overcome the initial hesitation of sitting down and starting to sketch freely. To make this happen, the designer has tricks, such as - creating loose sketches on plain paper and using a technique with material they are comfortable working with.

„Sketching is not a linear process. It is a journey that can have good and bad results. For that reason, sketching needs to be done with confidence and with a sense of freedom. Failing and succeeding in sketching go hand in hand, and just like anything else in life, sketching will get progressively better with practice. It is a skill that needs constant honing. The more we practice it, the better we become at it, but it requires time and dedication“ (Jorge Paricio, 2015).

„Sketching is a basic skill for a designer. It is a tool for communication. Often time, designers need to convey their ideas through visual presentations. Although there are various ways to achieve the goal, sketching is the most handy, effective and economical tool to quickly illustrate designers' brilliant ideas.“ (Carl Liu, 2013).

Eberhard Holder (2009) argues that it is not necessary to create perfect renderings with a computer or a marker in order to achieve product recognition in form and materiality. In view or perspective, shape and proportion can be depicted and represented graphically. The elements of each drawing, namely contrasts, reflections, shadows, textures suggest that they are derived from visible reality without imitating it directly. They are symbolic and are used to better understand the object in the sketch.

The visual images found in sketches - whether two-dimensional, three-dimensional or digital - consist of markings that form a diverse collection of images. This transformability makes them essential tools in architectural and design thinking, allowing the visualiser to modify and refine concepts, thus encouraging conceptual exploration and development. This "manipulation of sketches" requires reflection, and interpretation of ideas and concepts. Sketches serve as a means of translating the essence or visual characteristics of a concept into an understandable and functional format. By comparing the representational qualities of sketches, we can reveal all the key elements of the image or concept, making sketches essential to the design process (Kendra Schank Smith, 2008).

Often the ideas in a person's mind are abstract and do not always have a clear form. When a designer has a set problem whose solution they need to find, ideation and brainstorming are the best ways to discover as many as possible. Sketching helps to visualize these abstract ideas through multiple drawings on a medium. The visualized ideas appearing in the visual field of the designer through shapes and markings, in turn they lead to new ideas and concepts related to the design problem.

What can be the rendering techniques (in general)? Pictorial techniques can be divided into 2 main categories:

According to the medium on which it is drawn/sketched/visualized: paper (rice, thin, thick); canvas; collaging with paper and other materials; wood, metal sheet; digital drawing (using a device, stylus and drawing software); mixed (e.g. sketching on paper and coloring digitally) and others.

According to the material used for drawing (markings): graphite pencils; mechanical pencil; charcoal; ink; felt tip pens; gel pens; coloured/watercolour pencils; watercolour paints; markers (watercolour, alcohol, permanent); pastels (dry or oil); tempera paints; oil paints; acrylic paints; mixed (combination of 2 or more of the above) (Fig. 1).



Figure 1: Examples of different rendering materials

Analysis and Classification of Imaging Techniques Used During Creative Search – Factors for Classification: What defines a technique as appropriate for the creative stage of the design process?

- The rapid application of heuristic ideas onto a medium.
- Generation of as many ideas as possible in the shortest possible time.
- „Optimal legibility“ (clear conveyance of the idea with a minimum number of lines/signs/symbols).

Of the existing representational techniques, during the creative search phase, the most used by architects and designers are those that are most accessible to them. This includes materials that can be easily procured, that the designer usually has on hand, and that do not require layering, waiting, and/or drying. For this reason, these are most often plain paper in combination with: graphite pencil (regular or mechanical), and/or ink pen (gel or felt) and/or marker. Figures 2 to 6 show examples of sketches by well-known seating furniture designers created during the creative search phase.



Figure 2: Sketch by Ludwig Mies van der Rohe of 'Chair without Arms'

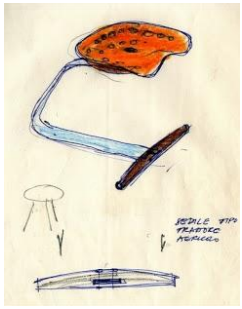


Figure 3: Sketch by Achille and Pier Giacomo Castiglioni of 'Mezzadro', 1957

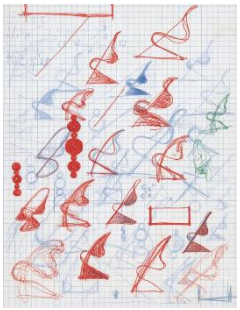


Figure 4: Sketch by Verner Panton of 'Panton chair', 1960

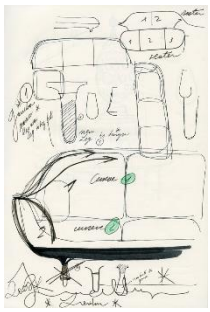


Figure 5: Sketch by Jaime Hayon of 'Favn sofa', 2009



Figure 6: Sketch by Frank Molina of 'Elvira chair', 2019

FINDINGS

When abstract ideas take form on a medium, they become more understandable and easier to iterate and refine, and subsequently select the best solutions to the design problem. Design sketches maintain a dialogue, (within the design team, between the designer and the client, and sometimes between the ideas and the designer) that enables them to create a good design solution.

For the process to be effective and for this dialogue to happen with ease, the designer is required to visualize their ideas quickly. This makes sketching an important part of the design process. It provides a clear and quick way to communicate ideas and concepts in the early stages of the design process, giving form to abstract concepts in the designer's mind with just a few sketches. The speed of sketching is one of the key elements. During the creative search, ideas appear instantaneously, and their rapid materialization allows them to be seen, realized and thought through. This speed is determined not only by the skill and confidence of the designer who is sketching, but also by: the drying time of the materials on the medium (not to smudge unless this effect is intended), how easily they are applied to the medium, how many tools are needed to do the sketching, and, of course, the accessibility of the materials. Other reason for choosing that kind of techniques is the need for sketches to be clear in form, not full in detail.

For these reasons, designers most often use techniques like - paper and graphite (regular pencils or mechanical), paper and ink (gel pens or felt tip pens), or paper and marker (alcohol).

CONCLUSION

Despite evolving digital technologies, the design process still needs sketching by hand. Abstract ideas in the initial design stage most easily and quickly take shape through sketches. The key to sketching during creative exploration is to make it quick and easy. It, of course, depends on the skills of the designer themself, but also on the techniques they use. This includes making the materials to

be easily accessible, not involving too many steps for making markings and familiar to the designer so that they can work confidently with them and visualise as many ideas as possible in a short time.

REFERENCES

EISSEN K., STEUR R. 2011. Sketching The Basics, BIS Publishers, ISBN 978-90-6369- 253-7.

HOLDER E. 2009. Sketch and Scrapbook Architektur und Design, Verlagsgruppe Random House, ISBN 978-3-421-03736-7.

LIU C. 2013. Innovative Product Design Practice, Design Book 2.

PARICIO J. 2015. Perspective sketching Freehand and Digital Drawing techniques for Artists & Designers, Rockport Publishers, ISBN 978-1-63159-032-0.

PEPER R. 2021. The Artists Manual the Definitive Art Sourcebook Media, Materials, Tools, and Techniques, A Penguin Random House Company, ISBN 978-0-2414-8385-5.

SMITH K. S. 2008. Architects' Sketches Dialogue and Design, Architectural Press Elsevier, ISBN: 978-0-7506-8226-8.

Fig. 1: *How is a drawing made?* (2020, May 1). The Metropolitan Museum of Art. https://www.metmuseum.org/about-the-met/collection-areas/drawings-and-prints/materials-and-techniques/drawing.

Fig. 2: *Ludwig Mies van der Rohe. Lounge Chair with Arms. Lounge Chair without Arms. Reclining Chair without Arms., Perspective and elevation sketches. 1926-46 | MoMA*. (n.d.). The Museum of Modern Art. https://www.moma.org/collection/works/87917.

Fig. 3: Db, F. (2018, October 6). *the achille castiglioni effect*. Designboom | Architecture & Design Magazine. https://www.designboom.com/design/the-achille-castiglioni-effect/.

Fig. 4: *Vitra | Marianne Panton*. (n.d.). https://www.vitra.com/en-us/magazine/details/please-have-a-seat.

Fig. 5: *Jaime Hayon*. (n.d.). Fritz Hansen https://www.fritzhansen.com/en/inspiration/designers/jaime-hayon.

Fig. 6: *Fran Molina Studio*. (n.d.). Fran Molina Studio https://franmolinastudio.com/elvirachair/.

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GOOD PRACTICES IN CREATING BRANDED INTERIORS FOR HOME FURNISHING RETAILERS

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ABSTRACT

The paper examines the interiors of international furniture chains in the territory of Europe in the 21st century. The focus is on the methods of creating visual identity for their interior design.

The aim of the study is to trace the factors and characteristics that influence the development of the interior. Selection of key examples, comparative analysis, and classification are used.

The expected results are in the fields of design theory and art, contemporary design and architecture.

Key words: brand, visual identity, retail spaces, European stores, home furnishing retail.

INTRODUCTION

With the advance of technology, the idea of shopping has changed, thanks to a new approach to sales - online commerce. There is no product that cannot be ordered through a website. Despite this easy and accessible way, some things still are missing. One of them is the direct contact - to feel by touch, as is the case when choosing a textile: it's important to interact with it, as is the case with the choice of a technological device, or to feel the aroma, as is the case with perfumes. Retail existing on place outlets contain a number of other advantages, and their construction is key to the successful sale of products.

In addition to the sensual shopping experience, they can evoke positive emotions in the buyer, and to create engaging and memorable event. This requires careful consideration of many different design components, including layout, lighting, colour, texture, zoning, technology, which are part of the interior design project and other components such as brand identity, accessibility, sustainability, art, sound, aroma, digital technology, experimental design, multi-sensory design, and personalization, which are part of the branding process and branding strategy. By considering all of these factors, an attractive, functional space can be created so that it leaves a lasting impression on customers and provides a unique and memorable experience.

This is especially important for furniture stores, for various reasons like:

- A high percentage of a family income goes to the purchase of home products
- There are also a lot of industrial, administrative buyers on various levels
- Furniture stores require large space for the exposition of goods

The purpose of this paper is to compare different retail sites and to analyse the amount of branding elements and techniques involved in the design of the commercial space.

LIMITATIONS OF RESEARCH METHODOLOGY

The brand plays an important role in the design of the interior, but it should be noted that it not only includes a visual layout consisting of the selection of shapes, fonts and colours, but also includes the company values, strategy and character.

Retail brands tend to be more multi-sensory than product brands and can offer an enhanced user experience. (Kusum L. Ailawadi & Kevin Lane Keller, 2004).

The history and connection with the craft foundation are of great importance for this type of brands, especially when related to the production of furniture. This aspect affects the emotional impact of the brand on the consumer.

If a consumer does not discover the added value of a product, then price and availability will be decisive in choosing a particular product.

Another important factor in a similar brand for furnishing goods is the presentation of the goods, the interaction of the customer with the products offered and the overall experience in the store.

Numerous factors have been studied that affect the overall image, such as the variety and quality of the products, services or brands sold, the appearance of the store, the façade of the store, the behaviour and quality of service by employees, the price range, etc. Lindquist (1974) and Mazursky and Jacoby (1986) categorized these attributes into a smaller set of location, merchandise, service, and store atmosphere related dimensions (Kusum L. Ailawadi, 2004).

Therefore, commercial branding is different from product branding: the focus falls on creating and managing the overall identity of the outlet or chain of stores, rather than a specific product or product line.

This study examines five large retail chains for home furnishings, which are located in Europe and are known in Bulgaria. The relationship between the brand and interior design is analysed. The comparison in the text is made on the basis of personal observations and publicly available information to date. Statistical significance is not the goal, as the focus is on examining the typology of interior design approaches rather than on a large sample of individual stores.

Tracing the good practices in the design of branded interiors of furniture chains the presence of the brand is followed on several levels:

- The values and emotional impact it brings;
- The relationship with products and consumers;
- And the vision achieved through the graphic design.

CASE STUDIES

1. CASE STUDY: IKEA

1.1. Profile

IKEA was founded as a small Swedish furniture store in 1943 by Ingvar Kamprad. IKEA has become a global retail company with a deep vision to improve the lives of various stakeholders. The name "IKEA" is an acronym derived from Kamprad's initials and the first letters of the farm and village where he grew up: Elmtarid and Agunarid. With an emphasis on consumer well-being, the company strives to offer high-quality products at affordable prices without compromising the interests of other stakeholders, including employees and suppliers. As of 2015, the company is the largest furniture retailer in the world with a net profit of $3.5 billion, from total sales of €31.9 billion euro. Today, IKEA remains a respected global retailer, with a presence in 47 countries, covering more than 365 stores.

Its success is due to its consistent marketing strategy and adherence to promises of accessibility and sustainability.

1.2. Brand Features



Figure 1: Image of IKEA store entrance.

A Swedish brand represented by the colours, shapes, fonts and overall graphic design of the brand.

Core values:

IKEA's core values include caring for people and the planet, following modern trends (modernity), cost awareness, simplicity, responsibility, developing and being an example. Each of these values is integrated into all aspects of the business, from product design to the way the company communicates with its customers. This consistency creates a deep emotional connection with consumers that supports the sustainable development of the brand.

Emotional impact

IKEA strives to create innovative products that are functional and environmentally friendly, while promoting a do-it-yourself culture. This concept connects to family values and offers a solution that is not just a product, but a way of life. The use of digital technologies such as AR (Augmented Reality) underscores the company's commitment to innovation and improves customer interaction, allowing them to visualize how IKEA products will look in their home before purchasing them.

It is these solutions that make the company so competitive with other similar brands and famous among consumers.

1.3. Types of products

IKEA offers a wide range of products suitable for all rooms in the home: furniture, decoration and textiles, kitchen appliances and accessories, lighting fixtures, children's and kid's goods and products for the garden and terrace.

1.4. Approach to the user:

IKEA's approach to customers is based on creating products that are easy to assemble and suitable for any interior. IKEA stores are organized in such a way that customers can see and feel how the furniture will look in a real environment, showing different interiors, furnished and decorated in the smallest detail.

Another successful approach is the strict arrangement and organization of products by name and catalogue number, which is beneficial for both employees and customers. Recently, IKEA has been striving to integrate the digital world into the physical world as much as possible with AR technology.

They also allow customers to design their own kitchen, bathroom or storage system, thanks to a 3D program that can be used from the official IKEA website.

1.5. Methods of organization

Presentation of the products: All the goods are sold in parallel online and in existing physical stores.

The organization of the store is structured in three main departments:

- A showroom recreating various living spaces, decorated and furnished in detail. This area is also home to the restaurant serving Swedish cuisine and the food market offering also Swedish delicacies and packaged foods for purchase.
- Market hall: this part houses mainly smaller items such as decoration, textiles and bathroom and toilet accessories.
- Self-service area for customers: large stands where items are displayed by codes and names.
- Additional areas: Småland: a supervised play area where parents can drop off their children while shopping.

1.6. Brand presence in the interior space

The presence of the IKEA brand in the interior is strongly expressed through the use of corporate colours and logos, which are present everywhere – from the entrance of the store to the labels of the products.

The use of corporate colours is used as a means of organization. The logo is present at the entrance, advertising materials and posters. Every product in Ikea is branded with its logo, including groceries. The branded materials are bags and other types of packaging, labels, signs, banners, posters, stickers, pencils, tape measures, employee clothing and catalogues. Cash register: the brand is clearly expressed there through the brand colours (the cash registers are in blue) and the signs suggesting where they are located.

The environment is clean: the furniture elements used to display the products for sale are white, and the directional symbols and signs are in brand colours.

2. CASE STUDY: JYSK

2.1. Profile

JYSK A/S is a Danish retail chain for household goods, furniture and interior decorations. JYSK is Denmark's largest retailer with an international presence.

In Danish, the word "JYSK" is used for people from Jutland (hence Lars Larsen) and is often associated with qualities such as modesty, consistency and honesty.

The company owns both physical stores and online stores, which are part of the family-owned company Lars Larsen Group. Founder Lars Larsen opened his first JYSK store in Aarhus, Denmark, in 1979. 28 countries are managed directly by JYSK, and the remaining 22 countries are part of the JYSK franchise concept. Although JYSK is a global business today, the company is run based on its Scandinavian roots. This is reflected in the company's culture and the way it does business.

2.2. Brand Features

The brand is characterized by a clean design with a Scandinavian influence, showing functionality and accessibility. The company's company values encompass both the professional attitude towards customers and the internal company culture.

The values associated with trade are propensity for service, cost-effective, reliable, purposeful and professional, and those related to employees: helpful service, mutual respect, flexibility, openness, honesty, straightforwardness and positivity.

Emotional impact:

The company strives to create an easier shopping process and promises versatility and accessibility at a good level.

2.3. Types of products

JYSK offers a wide range of furniture for all rooms in the home, as well as kitchen and bathroom accessories, lighting fixtures and garden and terrace products. The products are designed to meet mainstream trends in interior design while remaining accessible to a wide range of consumers.

2.4. Approach to the user:

JYSK's approach to consumers is focused on providing affordable goods that are in line with mainstream interior design trends. This includes products that are easy to assemble and use, as well as various online and offline shopping tools.

2.5. Methods of organization

Presentation of the products

JYSK products can be purchased in physical stores and online via the website. Distribution of in-store areas: JYSK stores are organized into categories and zones, making it easier for customers to find the products they need. Areas include, for example, garden furniture and accessories departments, with each area clearly marked and easily accessible.

2.6. Brand presence in the interior space



Figure 2: Image of JYSK cash registers.

The logo is present at the entrance and at the cash register.

The branded materials are bags and other types of packaging, labels, signs, banners, posters, stickers, employee clothing.

Cash register: the brand is clearly expressed through the brand colours and logo.

The interior space is designed with metal shelves and islands for displaying the goods.

3. CASE STUDY: VITRA

3.1. Profile

Vitra is a Swiss family-owned furniture company headquartered in Biersfelden, Switzerland. It is a manufacturer of the products of many furniture designers. The company is also known for the works of notable architects, which are located in its premises in Weil am Rhein, Germany, in particular in the Vitra Design Museum.

It was founded by Willie and Erica Felbaum, owners of a store equipment company - it entered the furniture market in 1957 with the licensed production of furniture from the Herman Miller collection for the European market - mainly designs by Charles and Ray Eames and George Nelson.

The Vitra product line consists of designer furniture for use in offices, homes and public spaces. In 2002, the company entered the field of domestic life.

3.2. Brand Features

The Vitra brand is known for its simple and clean vision, inspired by the principles of originality and sustainability. The company pursues an environmental, cultural and commercial mission, which is reflected in the quality and design of the products.

Emotional impact

The emotional impact is based on a long history and unique products that are quite famous and some of them carry collector's value.

3.3. Types of products



Figure 3: Image of Vitra’s UK showroom.

Vitra's product line includes home furniture, office furniture, lighting fixtures and accessories. The products are known for their minimalist style and the ability to customize and configure.

3.4. Approach to the user

Vitra focuses on offering minimalist and high-quality products created by renowned designers.

The company's original strategy includes offering modular systems that can be easily built by customers, thanks to the 3D configuration system.

3.5. Methods of organization

Presentation of the products

Products are presented primarily through a website, physically present through showroom, museum, and campus. Vitra has created a large catalogue of customisable products with modular products suitable for different spaces.

The distribution of areas in the store depends on whether it is a showroom, then it is by category, if it is a campus type then we observe an arrangement of the products of the "exhibits" type.

3.6. Brand presence in the interior space

The Vitra brand is clearly expressed through the logo at the entrance of commercial spaces and branded materials such as packaging, catalogues, signs, banners at showrooms and brochures. The environment varies depending on the type of commercial space – from arranged as exhibits in a museum to a more traditional presentation in showrooms.

4. CASE STUDY: BOCONCEPT

4.1. Profile

BoConcept is a Danish furniture retail chain.

The company was founded in 1952 by Jens Ærthøj and Tage Mölholm, Danish craftsmen and carpenters. The store was opened in Paris in 1993, but since 2006 all furniture has been sold through franchise stores. BoConcept specializes in modern furniture and accessories that can be customized and are designed by international designers. BoConcept collaborates with designers from Denmark and further afield, including Morten Georgsen, Karim Rashid and Henrik Pedersen. unlike others in our industry, today more than 90% of BoConcept's furniture is still produced in Denmark and other parts of Europe.

The company is headquartered in Herning, Denmark. Today, BoConcept is located in 337 locations around the world.

4.2. Brand Features

The BoConcept brand is distinguished by a luxurious and modern style that is suitable for different audiences. The company offers a personalized approach to customers, working with Danish and international designers to create unique products. BoConcept's franchise model is also a key element of the brand's success.

Emotional impact

BoConcept creates a sense of luxury and modernity, appealing to customers with a similar vision for their home. This strategy creates a deep emotional connection with customers who value individuality and comfort combined with a modern lifestyle.

4.3. Types of products

BoConcept's product range includes home, garden and office furniture, lighting fixtures and also offers interior design services.

4.4. Approach to the user

They offer goods in line with the mass trends in interior design, which are also affordable.

4.5. Methods of organization

Presentation of the products

Mostly through a website, physically present as shops and showrooms. Distribution of areas in the store: BoConcept's shops and showrooms are organized into zones recreating different living spaces. Next to the furniture are presented samples of textiles and materials.

5.6. Brand presence in the interior space

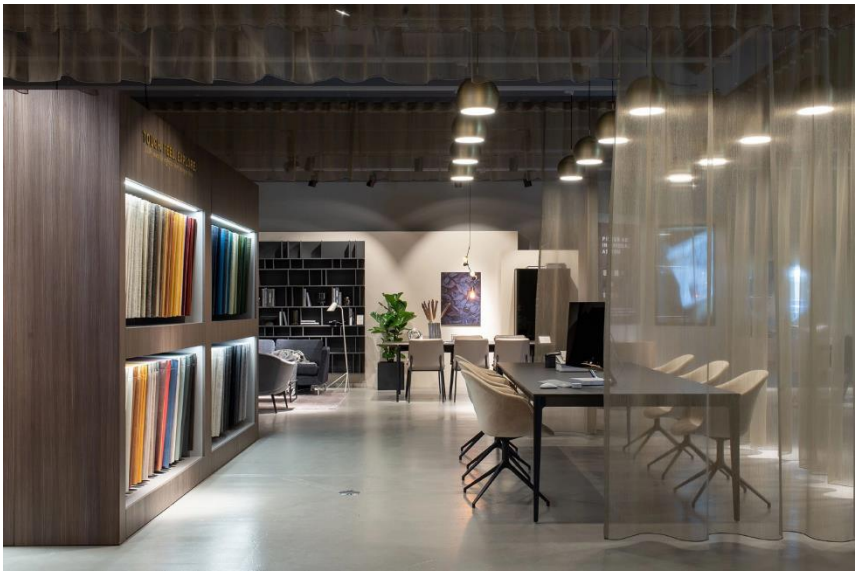


Figure 4: Image of the interior of a BoConcept store.

The presence of BoConcept in the interior of the stores is minimalistic, with a focus on furniture. to emphasize the stylish look of its products, while at the same time letting customers focus on the design and quality of the furniture on display.

The brand uses signs and posters and follows the simple design. The main focus falls on furniture.

5. CASE STUDY: KARE

5.1. Profile

KARE was founded in 1981 by Jürgen Reiter and Peter Schönhofen with its first store in Munich. Since then, the brand has been recognized as unique with its non-standard and artistic furniture. The SHOP-IN-SHOP concept of KARE is one of the key reasons for the success of the brand, which today operates in over 40 countries with over 150 stores around the world, including Bulgaria.

5.2. Brand Features

KARE is positioned as a brand for design enthusiasts and people looking for something different and eccentric for their home. The main elements of the brand include unique and bold designs that feature an artistic layout. It targets design enthusiasts and influencers. One of the company's brand strategies is the SHOP-IN-SHOP option, which offers partnerships with other brands.

Emotional impact

It is based on the eccentricity of the brand's vision and the products offered.

5.3. Types of products



Figure 5: Image of displayed KARE products.

The shop offers a wide selection of furniture, home accessories and lighting for every area of the home.

5.4. Approach to the user

KARE focuses on attracting customers looking for extravagant furniture and accessories by targeting design enthusiasts and influencers. The brand actively participates in various events for advertising purposes, which helps it maintain the interest of its audience.

5.5. Methods of organization

Presentation of the products

Mostly through a website, physically present as shops and showrooms. Distribution of in-store zones: KARE stores and showrooms are organized by styles and zones, making it easy for customers to find products according to their preferred design. Products are arranged on stands.

5.6. Brand presence in the interior space

The KARE logo is visible at the entrance and in various places in the showrooms. The brand uses signs, posters and brochures to present its products, with the checkout unit emphasizing the brand's colours, which contribute to the creation of an eccentric and colourful environment.

RESULTS AND COMPARISONS

Indeed, IKEA appears to be one of the most famous companies selling furniture and accessories for home, office and garden. The brand strategy is significantly more developed than other similar brands. In addition, the overall experience of shopping for home products takes longer because the products are arranged and presented in such a way that customers forget why they came to the store. This leads to additional impulsive purchases - the so-called. "The Gruen effect".

The Gruen effect was first identified by architect Victor Gruen, who designed many early shopping centres. He noticed that people tend to get disoriented and lose themselves in these large, open spaces. To counteract this, he designed malls with a central "anchor" store, usually a large department store, to act as a starting point. He also placed smaller stores around the mall's perimeter so that people would have to walk past them as they moved to the main store. (Prince Mukherjee, Medium, 2022).

The following approaches are observed in the construction of the interior space:

1. Maze layout: the space is designed to predispose customers to go around more and pay attention to products that are "off their shopping list". In this way, customers stay in the store longer. ("The Gruen effect" mentioned above).

For this purpose, the space occupied by an IKEA store is not small at all. Therefore, it is required to be located in a separate building built specifically for IKEA. Of course, there have recently been smaller IKEA stores, but they are an exception to the rule.

2. The presentation of furnished and well-decorated spaces: this generates the desire of buyers to buy the overall look and thus they acquire several items.

3. The right choice of colours and lighting: contributes to a positive customer experience in the IKEA store. The colours blue and yellow (from the brand) and bright red are skilfully proportioned. In-store lighting is also designed to make customers feel comfortable and products look more attractive.

Branded materials such as packaging, labels, signs, banners and posters, employee clothing, the logo present on each product are not only a means of reminding the brand, but also carry organizational and informative value.

After IKEA, JYSK also appears as a retail outlet with a more pronounced brand compared to other interior furnishing chains. It is distinguished by its quality service, simple and clean vision in order to turn shopping into an easy process for the customer. His brand includes both external values - customer-oriented, and internal - affecting company policy and attitude towards its employees (company values are mentioned above). Everything is structured and arranged - achieved through the correct arrangement of products by category and marked with signs. The branded materials are present, but not intrusive (e.g. the signs), a colour arrangement is created - the brand colours dark blue and white are present in the checkout unit, packaging, clothing of the employees, and as an accent that attracts attention, is the yellow used for the signs.

In terms of space occupied, JYSK falls among larger stores, but there is no condition set for occupying a separate building.

With the Vitra brand, the commercial space acquires a different concept - a type of museum, campus or the more common showroom format. What is characteristic of Vitra is the history of the company and the values clearly expressed in the design of the commercial spaces, presenting the furniture as exhibits. It should be noted that at the campus and the museum, the products are not exhibited for commercial purposes, but for educational and purely artistic purposes. At showrooms, products are sold.

The presence of branded materials in Vitra's retail spaces is significantly less than that of Ikea and JYSK. The same applies to the BoConcept.

BoConcept presents its products mainly in a showroom. The interior construction follows the style of the exhibited products - simple and minimalistic, and the furniture and accessories are arranged to represent a specific area of the home.

At the same time, the products are in a higher price class than more affordable brands such as IKEA and JYSK.

The KARE brand is distinguished by originality and even a slight touch of extravagance. The interior construction of the commercial space does not follow the model of the previously listed shops and showrooms. In the principle of arrangement of products, it is related to their style characteristics

and the possibilities for combination. Here we can meet the concept of SHOP-IN-SHOP. It offers partnerships with other brands, giving the opportunity to display items from other brands in the store.

CONCLUSIONS AND DISCUSSION

The successful design of the commercial space includes the implementation of the brand's core values such as: eco-friendliness, efficiency, quality, accessibility, functionality and artistic value. This palette of values enriches and attracts the consumer and makes the brand memorable.

The commercial spaces analysed in this paper are different from each other in style, standard, vision, character and approach to consumers, but all manage to reflect the overall presence of the brand in the interior.

In the examples considered and analysed, we can list as good practices:

1. A comprehensive interior design concept that aligns with the brand's overall aesthetic, including subtle brand integration (such as IKEA or KARE elements) as dictated by the brand's style guide.

2 Complete branding on the customer journey. From the entrance board with the logo, each branded sign to the cash register.

3. Branding consistency from graphics to interior design project. There is no fragmentation in terms of brand and interior design - they follow the same style.

In my opinion, the examined stores largely followed the principle formulated by the director of Mission, Karl Martin Sætren:

"The interior should be an extension of the visual identity in a physical environment. It should expand the understanding and perception of the brand — while generating internal pride." (Karl Martin Sætren, Mission).

REFERENCES

AILAWADI KL, KELLER KL. 2004. Understanding retail branding: conceptual insights and research priorities. Journal of Retailing 2004; 80: 331–42. doi:10.1016/j.jretai.2004.10.008.

ARUN R. IKEA Marketing Strategy 2024. A Case Study, Simplilearn.com. 2024. [https://www.simplilearn.com/tutorials/marketing-case-studies-tutorial/ikea-marketing-strategy-case-study].

BRAND IDENTITY | JYSK BLUE LINE [https://jyskblueline.com/brand-identity].

DANISH DESIGN since 1952 [Internet]. BoConcept. [https://www.boconcept.com/en-my/about-boconcept/the-history/].

DEEPA S, CHITRAMANI P. Brand building of retail stores. Journal of Contemporary Research in Management 2013; 8.

FURNITURE RETAILERS EUROPE | Retail-Index [https://www.retail-index.com/sectors/furnitureretailersineurope.aspx]

How IKEA invented the perfect marketing Strategy. Brand Vision [https://www.brandvm.com/post/ikea-marketing].

KIRAN KUMAR RANGANATHAN. 2019, Difference between Product Branding and Retail Branding.

MUKHERJEE P. How IKEA has mastered Gruen Effect - Bootcamp, Medium. [https://bootcamp.uxdesign.cc/how-ikea-has-mastered-gruen-effect-c51b0c3b6d80].

PRASANNAKUMAR V. IKEA – a case study, 2023 [https://www.linkedin.com/pulse/ikea-case-study-vivek-prasannakumar/].

VITRA | ABOUT VITRA [https://www.vitra.com/en-un/about-vitra].

WIKIPEDIA CONTRIBUTORS. 2024. BoConcept [https://en.wikipedia.org/wiki/BoConcept].

KARE.BG – Дизайнерски мебели, осветление и аксесоари. KARE.BG – Дизайнерски Мебели, Осветление И Аксесоари. [https://www.kare.bg/i/Shop-in-shop].

OTHOCHO JYSK | JYSK [https://jysk.bg/otnosno-jysk].

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CHANGES, CONSERVATION AND RECOVERY OF HEAT–TREATED WOOD HYDROPHOBICITY SUBMETED TO MOIST CONDITIONS EXPOSURE

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ABSTRACT

The Whilhelmy method of contact angle was used to define the hydrophobicity of beech and fir wood treated thermally in the range of 120 °C to 300 °C in nitrogen inert athmoshere. The hydrophobic character obtained by the heat treatment remains constant heat–treated, when samples are exposed to wet conditions during 1 week. The confered hydrophobic character of the heat treated wood shown by CP MAS 13C NMR and MALDI ToF mass spectrometry is mainly caused by furanic moieties produced from hemicelluloses thermal degradation. This is caused by the acid environment generated by the hydrolysis of the hemicelluloses acetyl groups. Furfural polymerizes to linear and branched oligomers and finally to water repellent, insoluble furanic resins. The water repellent, black colored, cross–linked polymerized furanic network is present throughout the heat–treated wood. Wood darkening as well as its water repellency due to increasing proportions of black colored furanic resins increase as a function of the increase with treating temperature, becoming particularly evident in the 200 to 300 °C treating temperature range.

Key words: heat treatment, hydrophobicity, MALDI ToF, wettability; Whilhelmy method, wood.

INTRODUCTION

The heat treatment upgrades wood's properties and makes possible outdoor applications. Heat–treated wood is dimensionally stable; resistant against fungal attack, and it becomes hydrophobic. These transformations are well known and allow for the industrialization and marketing of such a product (Pétrissans *et al.* 2003, Hakkou *et al.* 2005, Gérardin *et al.* 2007).

Very few studies exist in the literature to explain the wettability modification. Moreover, these rare studies only note the change in wetting, before and after heat treatment, without investigating treatment intensity and without offering any supporting explanation by chemical analysis for such an altered behavior. Finally, these studies use the sessile drop method, which is unsuitable for a porous and anisotropic support, such as wood, as the drop is absorbed during the measurement.

Recently, Endo *et al.* 2016 reported the instability of the heat–treated wood's conferred properties. The hygroscopicity of a wood heat–treated at 120 °C decreases.After exposure to a humid atmosphere for 1 week, this property is affected. Bekhta and Niemz, 2003 found that blackening is generally accelerated when the heat treatment temperature exceeds approximately 200 °C. Sivonen *et al.* 2002 also found that when the heat treatment temperature exceeds 200°C, the change in wood's chemical properties is more significant. Heat treatment of beech wood at different temperatures results in different changes in the chemical composition (Windeisen *et al.* 2009). This observation is important for the marketing of the product.

This investigation aims to study the evolution of the wettability (contact angle at the advance) according to the treatment intensity (temperature and duration) using the Wilhelmy method, based on a tensiometric force balance, which makes possible to measurement of the advance and at the retreat contact angle and characterize the wetting hysteresis. 13C NMR spectra and MALDI ToF spectra are applied to correlate the variation in wettability with the chemical modifications of wood at the molecular level. The interest was to try to link the variation of the contact angle either to the removing

of – OH groups due to the degradation of hemicelluloses or to other modifications of the wood constituents' network.

MATERIALS AND METHODS

^{13}C NMR and MALDI ToF spectrometry before and after treatment are applied in order to check wood constituents' modification.

WOOD HEAT TREATEMENT

A hardwood species (beech, Fagus Sylvatica) and a softwood species (fir, Abies alba) were studied. The wood boards were cut to the dimensions 140 x 60 x 20 mm^3 (LRT). Prior to the experiments, the boards were oven dried at 103°C until mass stabilization, anhydrous mass (M_1) is measured. The wood samples obtained under this condition were used as the control group and were called „untreated". Wood heat treatment was performed under different temperatures: 120, 140, 160, 180, 190, 200, 210, 220, 230, 240, 250, 275 and 300°C. The heat treatment was carried out in a reactor placed in a controlled oven under an inert nitrogen atmosphere from room temperature to the target temperature with a heating rate of 2°C/min. An isothermal plate is kept for 120 min and cooling to room temperature without control is made. Afterwards, the weight of heat–treated samples was measured (M_2), and the mass loss (ML) calculated according as $ML\% = (M_1–M_2)/M_1 \times 100$.

WOOD WET TREATEMENT

After the heat–treated wood was placed in an environment at room temperature for 24 h, it was sawed and cut into 24 × 20 × 1 mm^3 sample slices. A total of 16 sample slices were sawn from each treatment temperature. Wet treatment consists on placing wood samples in 95% humidity for 1 week. Potassium sulfate was used to prepare a suitable amount of saturated solution, placed in a closed desiccator (Figure 1). Contact angle is then measured.



Figure 1: Desiccator used for wood wetting (left). Wood samples are placed from low to high heat treatment temperature (right).

WOOD COLOUR

Colour change of the heat–treated samples was measured by a Chroma Meter CR–410 (KONICA MINOLTA, ZI Paris Nord 2, France) spectrophotometer, according to the CIELab system. Based on the L*, a*, b* colour coordinate system, L* represents the black–and–white axis; for black, L* = 0 and for white, L* = 100; a* represents red–green colour based on the positive and negative axes and b* represents yellow–blue colour (positive value to yellow, negative value to blue). There are two test pieces at each heat treatment temperature. The front and the back sides of the heat–treated samples of each collecting point were photographed. Therefore, the average value of 8 points (two points on each side of each sample) is taken as the final value.

CONTACT ANGLE

The advancing contact angles of beech and fir heat–treated at different temperatures were tested by the Wilhelmy method with a Force Tensiometer (KRÜSS France, Villebon–sur–Yvettes, France). Small samples (24 × 20 × 1 mm^3) were prepared along the grain from the large specimens (140 × 60 × 20 mm^3) before and after heat treatment for testing, and the specimens before and after being heat–treated at each temperature were tested 10 times. The length of each specimen was 24 mm length, 20 mm width, and 1 mm thickness. The immersion depth was 5 mm (in the direction of the width), and the immersion rate was 5 mm/min. The final contact angle (advancing and receding) values are the average of 10 valid tests. Due to heterogeneity and the anisotropic character, it is well known that the value of the receding contact angle with water is always equal to zero on the wood, the dewetting of water is never observed on the wood. In wood after the deposit of a drop of water, it is impossible to remove the water on the surface of the wood, there is no dewetting. This is the reason why, between water and wood, the receding contact angle is always equal to zero.

Figure 2 is a schematic diagram of the Wilhelmy method. Immersing a sample plate of wood into a probe liquid (water) and removing it allows for the determination of advancing and receding contact angles with the Wilhelmy method. In the figure, θ is the contact angle and h is the depth of the wood sample immersed in the liquid (water).

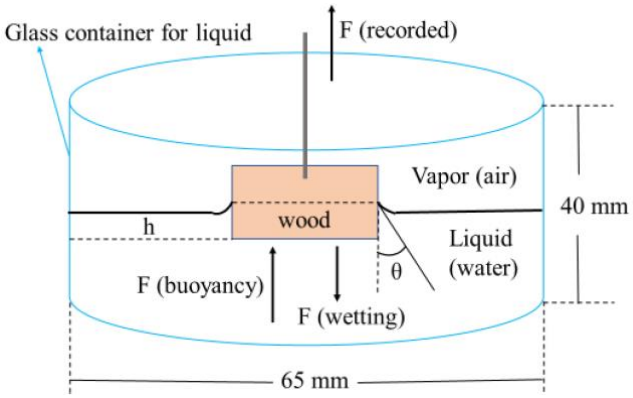


Figure 2: Schematic diagram of the Wilhelmy method.

Figure 3 shows the force recorded by tensiometer as a function of immersion depth. The force on the plate and the immersion depth are measured during the test cycle. The Wilhelmy force F_W has an effect only on the liquid surface. This force is constant during the whole immersion and pulling out procedure and is calculated according to equation: $F_W = \cos\theta \times б \times C$, where б is the liquid surface tension, C is the wetted circumvented length or perimeter, F_{W1} is the Wilhelmy force of receding, and F_{W2} is the Wilhelmy force of advancing.

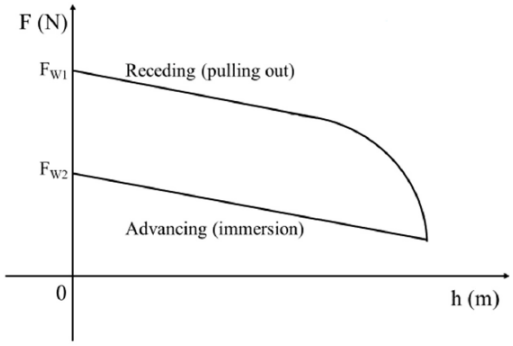


Figure 3: Force recorded by tensiometer as a function of immersion depth.

CP MAS ^{13}C NMR

Solid state Cross Polarization–Magic Angle Spinning CP MAS ^{13}C NMR was used to characterize the samples. The spectrometer used was an AVANCE II 400 MHz spectrometer (Brüker, Billerica, MA, USA). Furthermore, 100.6 MHz was the frequency used at a sample spin of 12 kHz, and the recycling delay was 1 s, depending on the 1H spin–lattice relaxation times (t1) estimated with the inversion–recovery pulse sequence and a contact time of 1 ms. The decoupling field was 78 kHz, with 15,000 being the number of transients. Tetramethyl silane (TMS) was used as the shift control. The spectra precision was ±1 ppm. Spinning sideband suppression was used. The sample chosen was one at 230 °C to be well in the 200–300 °C range where degradations and rearrangements clearly occur, but at a temperature not so high that oxidation phenomena and other may mask what occurs. The NMR results were interpreted according to established interpretation texts (Tian *et al.* 2021*)*.

MALDI TOF

Water/acetone (50/50 volume) was used to dissolve the most possible of the samples (4 mg/mL) and the solutions were added to the matrix solution of 10 mg/mL in acetone. 2,5–dihydroxy benzoic acid was used as the matrix to ease placing the sample on the sample–holder plate. Red phosphorus was used for instrument calibration (LaserBio Labs, Valbonne, France)). A concentrated solution of 10 mg/mL of sodium chloride (NaCl) in distilled water was mixed to the matrix to enhance ion formation. The sample was added into the matrix solutions and was divided into three parts of the matrix solution. Three parts of the sample solution and one part of NaCl solution were prepared; 0.5 to 1 μL was put on the MALDI target. The MALDI target was placed into the spectrometer after solvent evaporation. The peaks in the spectrum can present themselves at the actual molecular weight of the chemical species or increased by 23 Da, this being the molecular weight of the Na^+ linked to the molecule from the NaCl added to the matrix to facilitate the flight of heavier oligomers. Sometimes, both forms of the same species, with and without Na^+ can be present in the same spectrum. The MALDI–TOF spectra were recorded on an AXIMA Performance instrument (Shimadzu Scientific Instruments, Manchester, UK). The irradiation source was a pulsed nitrogen laser with intervals of 3 ns at a wavelength of 337 nm. The measurements were carried out using the following conditions: polarity: positive; flight path: linear; mass: high (20–kV accelerating voltage) and 100 to 150 pulses per spectrum. The delayed extraction technique was used to apply delay times of 200 to 800 ns, and the ion gate was set at 400 Da. The spectra are exact at ±1 Da.

RESULTS AND DISCUSSIONS

MASS LOSS OF FIR AND BEECH ACCORDING TO THE TREATEMENT TEMPERATURE

Figure 4 shows the mass loss trend of beech and fir at different temperatures. It can be seen from the figure that under the same conditions, when the heat treatment temperature increases, the mass loss of both wood species has an upward trend. Between 120–200°C, the mass loss does not change significantly. Between 200–300°C, the value of mass loss rises sharply. Compared to beech, the mass loss of fir is slightly lower.

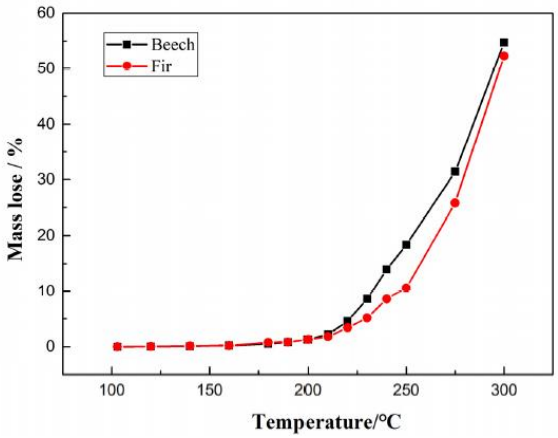


Figure 4: The mass loss of beech and fir at different temperatures.

WOOD COLOUR

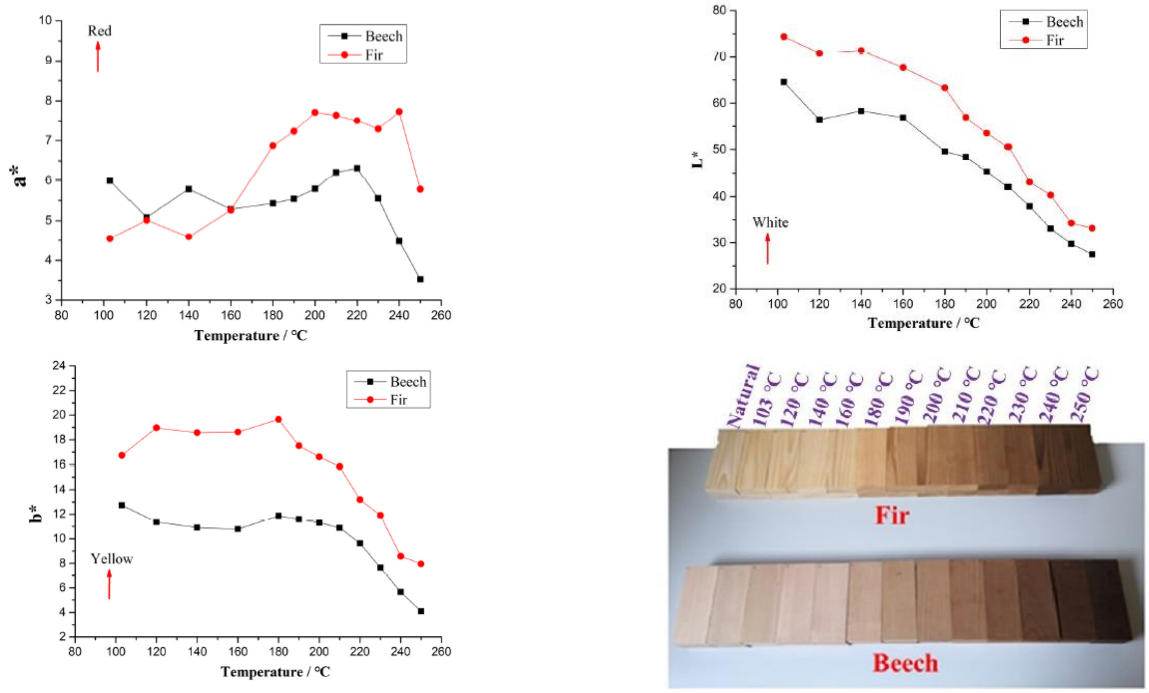


Figure 5: Changes of colour components a*, b* and L* as a function of treatment temperature and visual of colour change of beech and fir specimens under treatment temperatures.

Figure 5 shows the colour changes of beech and fir specimens at different mass loss values. It can be seen that as the heat treatment temperature continues to increase, the colour of the beech and fir specimens will become darker, beech being clearly darker than fir. This is an indication of chemical reactions occurring the reasons of which will become clearer by the chemical analysis. The colour of these two woods species before heat treatment is white or yellow. As the heat treatment temperature increases, the degree of white or yellow becomes lower. This change is more obvious in beech than in fir.

WETTABILITY AND CONTACT ANGLE

Figure 6 shows that the contact angle of beech and fir wood before and after heat treatment increased significantly after being placed in a 95% relative humidity environment for one week. When there is no degradation (before 200°C), there is no change in wettability. For temperatures higher than 200°C, the degradation of the hemicelluloses starts and the contact angle increases. There is then a

significant correlation between degradation temperature of the hemicelluloses and the contact angle. After a 1–week humidity treatment, all of the contact angle values for each temperature treated wood increased. This effect indicated a decrease in the wettability of the heat–treated wood, probably due to a chemical modification of the wood constituents, such as the degradation of hemicellulose. It means that even after permanence in a very moist environment the decrease in water repellence is rapidly recovered due to the modifications imparted by the heat treatment, contrary to a previous study .(Endo *et al.* 2016) Thus, after heat treatment and exposure to a wet atmosphere, the hydrophobic heat–treated timber remains hydrophobic rapidly higher than the original water repellence displayed after the heat treatment. The decrease of water resistance means that when the modified wood is in a humid environment or after raining, some water will enter, resulting in a short–term decrease in the water resistance of the modified wood. However, after the water evaporates (such as after being exposed to the sun), the water resistance will be restored or even improved. This study proves this phenomenon, which is also one of the innovative points of the study. The water wettability of wood is measured under the same conditions of roughness (identical wood machining), moisture content (anhydrous) and fresh surface to highlight the influence of chemical modification. The wetting was therefore tested before and after heat treatment, as well as before and after heat treatment and humid treatment.

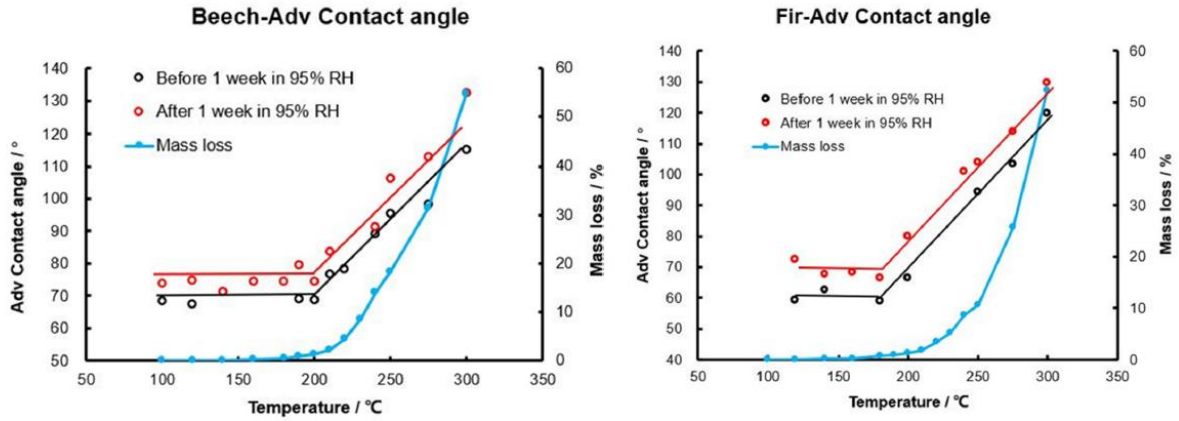
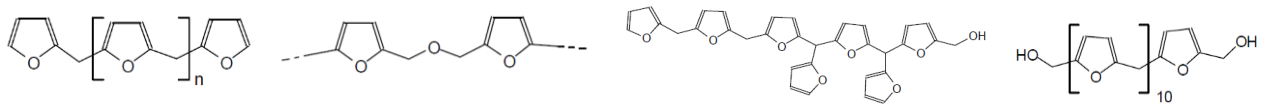


Figure 6: The advancing contact angles of beech (left) and fir (right) heat–treated at different heat treating temperatures after the humid test by being placed in a 95% relative humidity environment for 1 week.

CP MAS ^{13}C NMR

Of particular interest in the CP MAS 13C NMR of beech heat–treated at 230°C is the presence of pronounced peaks at 149 and at 148 ppm, which are absent or almost completely absent in an untreated beech wood control. Of these, the 149 ppm peak may corresponds to an aromatic carbon bonded to a non–aromatic carbon, thus ArC–C. This may be either a type of bond other than the normal bonds present in lignin or of the same type but in considerable excess than what is usually found, indicating rearrangements of lignin. However, it is also characteristic of furanic resins in which the C2 and C5 positions are substituted, thus of furanic resins where the furanic moieties are linked both by their C2 and their C5 to other furanic moieties in the middle of linear furanic resins with linkages of type I and II.



Type I Type II Type III Type IV

Figure 7: Type of linkages

This infers that a reaction introducing a substituent on the aromatic ring of lignin has occurred or that furanic resins have been formed. That this is the case is also shown by the greater number of peaks present in the crowded 147–165 ppm range in the heat–treated wood in relation to the beech control. However, the most interesting peak is at 148 ppm, which is characteristic of the carbons of a furanic ring, and in particular of the free C5 site of furfural (Pretsch *et al.* 1989). Furthermore the signals of furanic rings C2 and C5 linked by a methylene bridge should appear at 155 ppm indicating that furanic resins of some type have formed as well. Furfural, hydroxyl methyl furfural and other furanic materials are well known to be generated from wood carbohydrates (Chen *et al.* 2020), here quite likely being catalyzed from the acetic acid generated by the heat treatment induced hydrolysis of the acetyl groups on hemicelluloses, this being a well–known and studied reaction. The high temperatures between 200–300 °C used for the heat treatment, where other techniques have already shown reactions to occur (Figure 8), indicates that formation of furfural in the heat–treated wood may well occur and that this polymerizes to structures of the type.

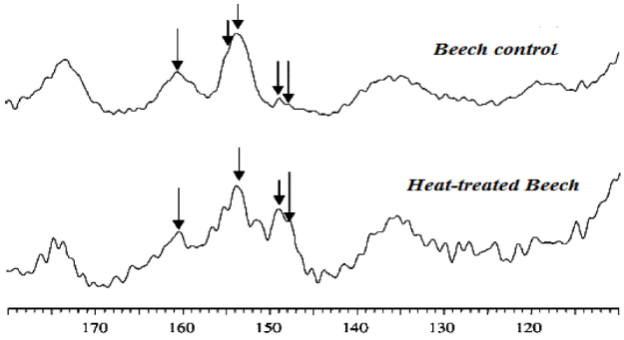


Figure 8: CP MAS ^{13}C NMR spectra of untreated beech wood and beech wood heat–treated at 230 °C in the 110–180 ppm.

This type of structures will also account for the 149 ppm peak, confirming the presence and formation of furanic resins. The presence of the smaller peaks at 152 ppm and 161–162 ppm also indicates that hydroxymethyl furfural has formed, although in lesser proportions. The fact is that the 148ppm peak is more marked in heat–treated wood samples; the higher treating temperature indicates that this is indeed the peak of the C5 of a furan ring. A peak of the same order of size should however appear in the 152–155 ppm range for the furan C2 (Pretsch *et al.* 1989), as indeed it does. A number of peaks fulfilling this requirement are indeed present although the most likely candidate peak is slightly more marked as it is likely to be a superposition of the furan C2 with another signal. The carboxylates band at 173 ppm decreases in heat–treated wood, indicating the heat induced hydrolysis of the acetyl groups on the hemicelluloses, the acetic acid so formed renders sufficiently acid the environment to catalyze the formation of furanic moieties (Chen *et al.* 2020). In all cases, all this indicates is an increase in cross–linking of the system either due to rearrangement of the lignin with itself or of the lignin with other wood constituents, namely, furanic resins generated from the carbohydrates, thus an increase in the water repellence of the heat–treated wood. The darkening of

the wood with the increasing treating temperature is due not only to oxidation reactions but mainly by the increase in the proportion of the black furanic resins generated by the degradation of the hemicelluloses.

MALDI TOF

The MALDI ToF spectra of the 300°C heat–treated beech wood (Figure 9a–e) show a great majority of furanics oligomers of higher molecular weight. One can notice in the first general spectrum (Figure 9a) at 300°C the predominance of the peak at 574 Da (Linkages of type III), thus a branched oligomer showing the start of cross–linking in relation instead to the predominance of the smaller molecular weight species at 200°C. It is interesting with the 907 Da peak being higher in the general spectrum at 200°C than at 300°C, that the predominant higher molecular weight oligomers at 200°C are linear and not branched as at 300°C. The same trend is valid at 103 °C but with the low molecular weight species greatly predominating and also some linear oligomers but no branched species thus with no cross–linking, but the linear oligomers present showing that polymerization already starts to occur at this lower temperature. The majority of the same water repellant furanic species are still present after the wet treatment explaining at the molecular level why the water repellence of the heat–treated timber is conserved and increased after a wet treatment. Branched species, thus the precursors of the start of the system cross–linking, such as those at 551 Da, 574 Da, 699 Da, 1037 Da, 1068 Da, 1151 Da and 1227 Da are present. Many lower molecular weight species as well as linear higher molecular weight oligomers are also present, such as the species at 324 Da, 361 Da, 853 Da, 882 Da, 897 Da, 904 Da, 937 Da (Linkages of type IV) and 942 Da.

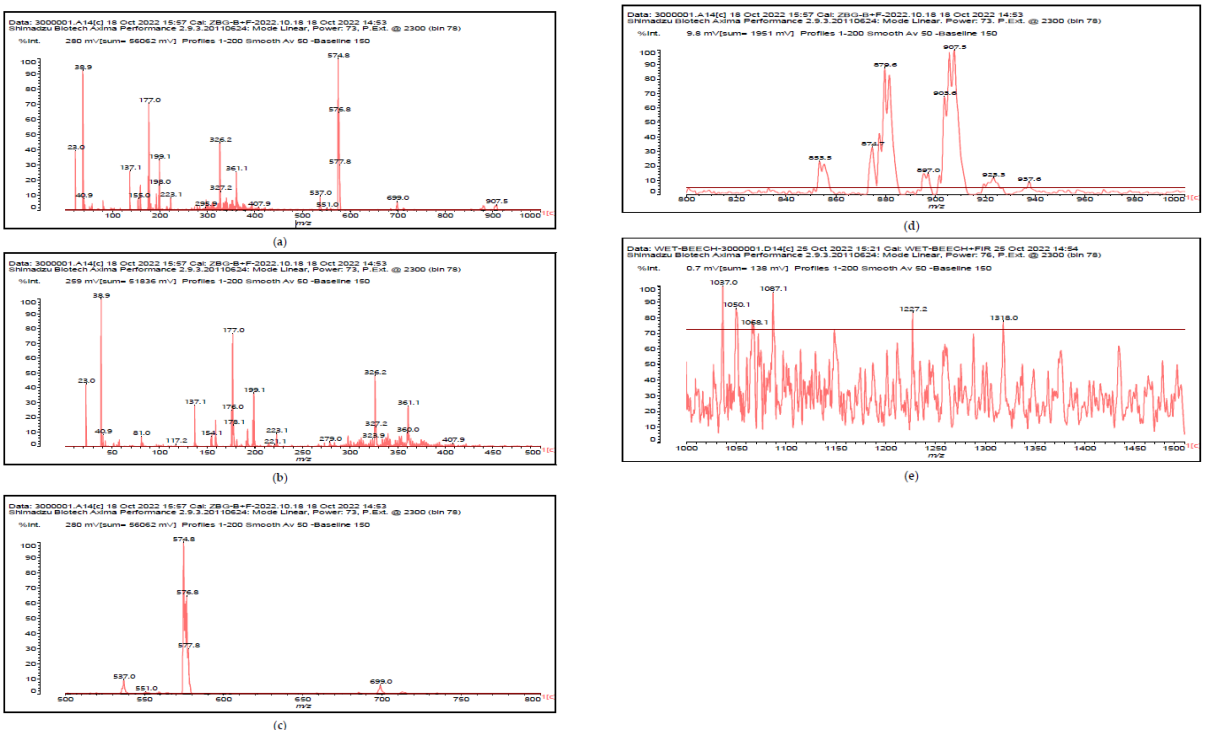


Figure 9: MALDI ToF spectra of heat–treated beech at 300 °C in the (a) 20–1000 Da range and details of the (b) 20–500 Da range, (c) 500–800 Da range, (d) 800–1000 Da range, (e) 1000–1500 Da range.

CONCLUSION

This work interests on hydrophobation of wood after heat treatment. Heat–treated timber remains hydrophobic rapidly. At 120 °C, wood polymers are not degraded, the temperature is too low to form furanics in any great amounts to show significant differences. The water wettability of wood is

measured under the same conditions of roughness (identical wood machining), moisture content (anhydrous) and fresh surface to highlight the influence of chemical modification. The wetting was tested before and after heat treatment. The wood becomes hydrophobic and this phenomenon is attributed to the chemical modification of the wood. The wood becomes hydrophobic with more thermal degradation and increases in the contact angle. After a wet treatment, the hydrophobicity generated by the thermodegradation was preserved. It is showed that after wet exposure, there is no notable modification of the contact angle. A slight increase of the contact angle is measured. This phenomenon is most likely due to aging (1 week) of the surface during wet processing. It can also be noted that exposure to the humid atmosphere does not change the wettability of heat–treated wood. Analysis by CP MAS ^{13}C NMR and MALDI ToF mass spectrometry has allowed for defining the reactions leading to wood hydrophobation. The indications obtained were that wood hydrophobation is caused by the formation of furanic compounds, mainly furfural, but also in minor proportions of hydroxymethyl furfural derived from the hemicelluloses degradation catalyzed by the acetic acid generated by the hydrolysis of their acetyl groups. The furanic compounds formed then both progressively polymerize to strongly water repellant, insoluble furanic resins finally forming a water repellant network throughout the heat–treated wood. The concomitant progressive darkening of the wood as a function of the increasing heat treatment temperature is not only due to some oxidation of wood constituents but mainly by the increasing proportions of the tri–dimensionally cross–linked black–colored, water repellant furanic resins network throughout the wood. It is by far and mainly an interpenetrating furanic network, although reaction with lignin moieties cannot be excluded. In fact, the furanic compounds that are generated from the hemicelluloses can react with lignin sites as well, but this is not possible to analyze as the experiments were carried out on solid wood samples, hence with lignin fixed in its wood network. This mechanism is particularly evident in the 200 to 300 °C temperature range. This study also proves that heat–treated wood will still have good water resistance after experiencing harsh environments, such as rain.

REFERENCES

BEKHTA, P., NIEMZ, P. 2003. Effect of high temperature on the change in color, dimensional stability and mechanical properties of spruce wood. Holzforschung 2003, 57, 539–546.

CHEN, X., GUIGO, N., PIZZI, A., SBIRRAZZUOLI, N., LI, B., FREDON, E., GERARDIN, C. 2020. Ambient Temperature Self–Blowing Tannin–Humins Biofoams. Polymers 2020, 12, 2732.

ENDO, K., OBATAYA, E., ZENIYA, N., MATSUO, M. 2016. Effects of heating humidity on the physical properties of hydrothermally treated spruce wood. Wood Sci. Technol. 2016, *50*, 1161–1179.

GÉRARDIN, P., PETRIČ, M., PETRISSANS, M., LAMBERT, J., EHRHRARDT, J.J. 2007. Evolution of wood surface free energy after heat treatment. Polym. Degrad. Stabil. 2007, 92, 653–657.

ENDO, K., OBATAYA, E., ZENIYA, N., MATSUO, M. 2016. Effects of heating humidity on the physical properties of hydrothermally treated spruce wood. Wood Sci. Technol. 2016, 50, 1161–1179.

HAKKOU, M., PÉTRISSANS, M., ZOULALIAN, A., GERARDIN, P. 2005. Investigation of wood wettability changes during heat treatment on the basis of chemical analysis. Polym. Degrad. Stabil. 2005, 89, 1–5.

PÉTRISSANS, M., GÉRARDIN, P., BAKALI, I.E., SERRAJI, M. 2003. Wettability of heat–treated wood. Holzforschung 2003, 57, 301–307.

PRETSCH, E., CLERC, T., SEIBL, J., SIMON, W. 1989. Tables of Spectral Data for Structure Determination of Organic Compounds: ^{13}C–NMR, 1H–NMR, IR, MS, UV/VIS, 2nd ed.; Springer–Verlag: Berlin, Germany.

SIVONEN, H., MAUNU, S.L., SUNDHOLM, F., JÄMSÄ, S., VIITANIEMI, P. 2002. Magnetic resonance studies of thermally modified wood. Holzforschung 2002, 56, 648–654.

TIAN, M., ZHANG, B., WU, Z., YU, L., LI, L., XI, X. 2021. Effects of Steam Heat–Treatment on Properties of Pinus massoniana Wood and Its Bonding Performance. J. Renew. Mater. 2021, 9, 789–801.

WINDEISEN, E., BÄCHLE, H., ZIMMER, B., WEGENER, G. 2009. Relations between chemical changes and mechanical properties of thermally treated wood 10th EWLP, Stockholm, Sweden, 25–28 August 2008. Holzforschung 2009, 63, 773–778.

PROCEEDINGS OF TWELFTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN – INNO 2024
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NUMERICAL MODELLING OF WAVE–FORM AUXETIC CORES FOR FURNITURE BOARDS

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ABSTRACT

The literature lacks a description of research on modeling wooden structures composed of corrugated sheets characterized by non–repeatability of length, height, and wave shape. This study aimed to model layered beams with a randomly generated corrugated core with auxetic properties. It was decided to determine the Poisson's ratio of the core, stiffness, strength and absorbed specific energy of layered beams. It was shown that corrugated cores formed from wood veneers are auxetic structures with negative Poisson coefficients. Numerical symplification of the cores can be based on replacing irregular waves with randomly generated sinusoids shifted in each core layer.

Key words: auxetics, wood, corrugated core, honeycomb, FEM.

INTRODUCTION

The mechanical properties of sandwich structures depend on the material properties of the surface layer and core and the surface strength at the surface layer–core interface. Natural fibers such as jute, fax, sisal, and hemp are also used in composite design due to their abundance, renewability, and biodegradability (Garmendia *et al.* 2011)(Alecci *et al.* 2017)(Ali et al. 2021)(Gioffré et al. 2021).

Cellular structures such as lattice structures are often used as the core of layered biocomposites (Smardzewski and Wojciechowski 2019) (Jin *et al.* 2015)(Zheng *et al.* 2020), pyramidal (Smardzewski and Wojciechowski 2019)(Li *et al.* 2022) and honeycombs (Mosallam 2016)(Fan et al. 2023)(Elephant *et al.* 2023). In the work of (Wang *et al.* 2020) prepared layered beams of cross, double–cross, and square construction, using spruce wood as outer cladding and jute composites as cores.

In wood–based composites, however, it is rare to find a wavy, periodic geometry, while this geometry is very common in advanced metal or plastic structures (Magnucka–Blandzi *et al.* 2015)(Bartolozzi *et al.* 2013)(Wang *et al.* 2024)(Pathirana and Qiao 2019). Wood–based corrugated core panels were characterized in the work of (Jiloul *et al.* 2023). Banerjee and Bhattacharyya (Banerjee and Bhattacharyya 2011) made a cell plate with a corrugated plywood core clad with two thin plywoods. They also studied single– and double–layer cellular boards with a corrugated plywood core made by subjecting them to three–point bending (Kavermann and Bhattacharyya 2019a). The work of (Labans *et al.* 2014) described the properties of sandwich panels with a top layer of plywood and a core of corrugated plywood or fiberglass–reinforced plastic. Subsequent bending tests of sandwich panels with thermoplastic fiberglass core, polypropylene facings and plywood have shown that these composites are an excellent alternative to solid wood panel materials (Labans *et al.* 2017). The manufacturing method and mechanical properties of panels made from corrugated–core plywood are also described in (Kavermann and Bhattacharyya 2019b). An interesting method of shaping plywood using heated rollers has also been proposed (Srinivasan *et al.* 2008), revealing a thermoforming technology (Srinivasan and Bhattacharyya, D. Jayaraman 2007). Also known are the

results of a study by Dykes et al. (Dykes *et al.* 2000), who developed veneer–rolling technology for the production of profiled wood–based panels.

The article (Smardzewski 2019) describes manufacturing wooden sandwich panels with a prismatic core. Uniaxial compression and 3–point bending tests of the panels are discussed, as well as a method for determining the amount of energy absorbed. It was shown that triple–core panels are more durable compared to single–core panels. In addition, these panels show higher energy absorption capacity. In contrast, in a paper (Smardzewski and Wojciechowski 2023) the main focus was determining the bending characteristics of wooden sandwich structures with a corrugated core, considering natural defects, random gaps and cracks in the veneer.

From the literature review presented above, it is clear that despite their great design attractiveness, wooden sandwich panels with corrugated cores have not yet been thoroughly studied and well understood.

This study aimed to model layered beams with a randomly generated corrugated core with auxetic properties (Fig. 1). It was decided to determine the Poisson's ratio of the core, stiffness, strength, and absorbed specific energy of layered beams.

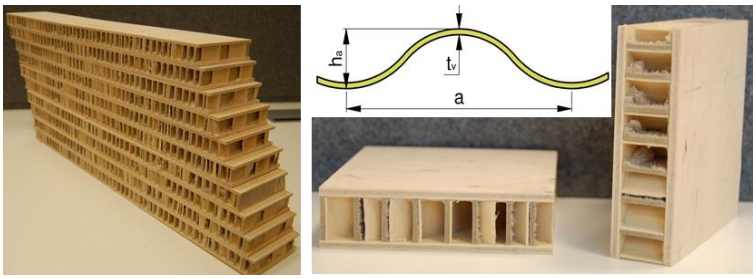


Figure 1: Honeycomb sandwich panels with a corrugated auxetic core

PANELS MANUFACTURING

Birch (*Betula* L.) wood was used for the study. The facings were birch plywood with a thickness of t_f = 3.7 mm, density ρ = 853 kg/m^3 and absolute moisture content MC = 4%. The corrugated cores were manufactured from veneer with a thickness of t_v = 1 mm, density ρ = 630 kg/m^3 and absolute humidity MC = 5%. Between the corrugated cores were used cardboard spacers of thickness t_a = 1.6 mm, density ρ = 532 kg/m^3 and absolute humidity MC = 8%. A machine for forming the corrugated web was designed and manufactured (Fig. 2). The veneer was obtained by slicing birch wood. After forming and cooling, the sheets assumed average dimensions h_a = from 29 to 30 mm, a = from 36 mm to 41 mm.



Figure 2: Method of forming corrugated core sheets

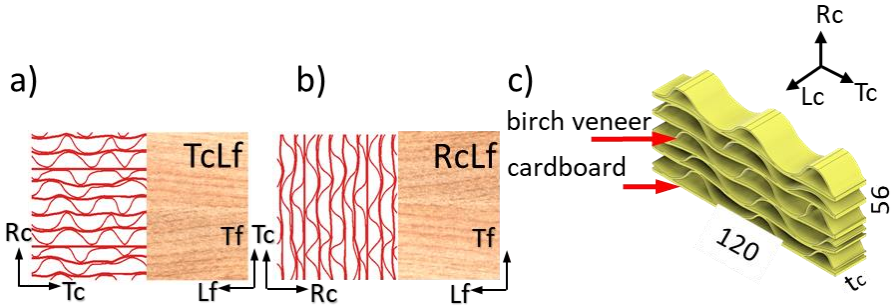


Figure 3: Test specimens: a) beam types T_cL_f, b) beam types R_cL_f, c) samples for compression

Rakoll Express 25 D adhesive (Fuller–Rakoll, Germany) was applied to the top surfaces of the corrugated sheets and to both surfaces of the cardboard (Fig.3a,b). The layers of cardboard and corrugated veneer were then stacked alternately. In this way, ten panels were made with a thickness of t_p = 28 mm, 650 mm wide, and 1250 mm long. Gluing the cores together caused the corrugated sheets obtained immediately after forming to change the dimensions and shape of the waves significantly. The waves were flattened and slightly elongated. The length of the waves a = varied from 36.5 mm to 43.7 mm, while the height of the waves h_a varied on average from 8.8 mm to 13.5 mm. Because of the perpendicular direction of the veneer wood fibers relative to the cladding surface, this direction of core orthotropy was denoted as L_c. The direction of T_c is related to the direction of alignment of the horizontal paperboard strips, while the direction of the R_c corresponds to the transverse direction relative to the T_c. In the case of orthotropic plywood cladding, the direction is assumed to be R_f is directed perpendicular to the surface of the cladding, the direction of the L_f directed is along the fibers on the cladding surface, while the direction of the T_f directed is perpendicular to the direction of the fibers on the cladding surface. Since paperboard is an orthotropic material, its orthotropic directions (machine MD and transverse to the machine CD) coincided with the following orthotropy directions of the core such that $CD = L_c$ and $MD = T_c$. The molded panels were cut, respectively, into beams of thickness t_p = 28 mm, width W_p = 100 mm, length L_p = 610 mm, intended for three–point bending. Samples were also made to determine Poisson's ratios in uniaxial compression testing. These specimens were given dimensions of 20 mm thick, 120 mm wide, and 56 mm high. Due to the varying mutual arrangement of the core and cladding, Table 1 and Fig. 3 summarize all variants of the specimens made.

Table 1: Dimensions, markings, and number of samples used for testing

Type of sample	Orientation		Symbol	m	ρ	L/L_s	W_p	t_p	t_c	t_f	Number of samples
	Core	Facing		[kg]	[kg/m]^3			[mm]			
Bending	T_c	L_f	T_cL_f	0.560	332	610/ 500	100	27.4	20	3.7	10
	R_c	L_f	R_cL_f	0.553	332						10
Compression	R_c	–	R_c	–		120	56	27.4	20	3.7	5
	T_c	–	T_c	–							5

THEORETICAL BACKGROUND

Auxetics are materials, metamaterials, or structures that, in uniaxial tension, expand laterally in at least one cross–sectional plane, i.e. have a negative Poisson's ratio. In 1987 Lakes (Lakes 1987) announced a new foam structure that exhibits a negative Poisson's ratio. Wojciechowski in 1989 showed that a two–dimensional (2D) lattice model of hexagonal particles in a triangular lattice

exhibits an anomalous (negative) Poisson's ratio at high densities when the anisotropy (non–convexity) of the particles is significant (Wojciechowski 1989). Contemporary work focuses on theoretical, numerical, and experimental methods for modeling the mechanical properties of auxetics (Mondal and R. 2024) (Wu *et al.* 2024) (Hassani *et al.* 2024) (Ebert *et al.* 2024) (McHale et al. 2024) (Di Brizzi *et al.* 2024) (Narojczyk *et al.* 2023). Current methods of measuring the Poisson's ratio are described in the works of (Cózar *et al.* 2024)(Fu et al. 2024).

In this work, digital image analysis (DIC) and finite element numerical (FEM) calculations were used to study the Poisson's ratio of corrugated core samples, with the shape and dimensions as in Fig. 3c. During uniaxial compression in the direction of respectively R_c, and then T_c, the deformations of the specimen in the direction in line with and transverse to the direction of loading were measured. The Poisson coefficients of the core ν_{cyx}, ν_{cxy} were calculated from the equations:

$$\nu_{cyx} = \frac{\varepsilon_x l_y}{\varepsilon_y l_x}, \text{ for load direction } y = R_c, \tag{1}$$

$$\nu_{cxy} = \frac{\varepsilon_y l_x}{\varepsilon_x l_y}, \text{ for load direction } x = T_c, \tag{2}$$

where: $\varepsilon_{x,y}$ strain in the direction of x i y , $l_{x,y}$ length of the measurement range in the x and y directions respectively. In addition, for each direction of orthotropy, the linear elastic moduli of the core E_{cy} , E_{cx} were determined based on the equations:

$$E_{cy} = \frac{F_y \cdot l_y}{t_c \cdot l_x \cdot \varepsilon_y}, \text{ for load direction } y = R_c, \tag{3}$$

$$E_{cx} = \frac{F_x \cdot l_x}{t_c \cdot l_y \cdot \varepsilon_x}, \text{ for load direction } x = T_c, \tag{4}$$

where: $F_{x,y}$ core load in the axis direction respectively x i y, t_c thickness of the core.

In the present study, the linear elastic moduli were also determined $E_{x,y}$ and crushing strength $MOR_{x,y}$ for each of the fabricated beams in accordance with EN 310 (1993):

$$MOE_{x,y} = E_{x,y} = \frac{(F_{0.4} - F_{0.1})}{4(\delta_{0.4} - \delta_{0.1})} \frac{L_s^3}{W_p t_p^3} \tag{5}$$

$$MOR_{x,y} = R_{mx,y} = \frac{3F_{max}L_s}{2W_p t_p^2} \tag{6}$$

where: F_{max} – maximal force, $F_{0.4}$, $F_{0.1}$– force equal $0.4F_{max}$, and $0.1F_{max}$ respectively, $\delta_{0.4}$, $\delta_{0.1}$ – deflection corresponding to $F_{0.4}$, $F_{0.1}$ respectively. The specific absorption energy (SEA), which expresses the amount of energy absorbed by a unit mass of material, was also calculated (LU, Guoxing; YU 2003):

$$SEA = \frac{EA}{m} = \frac{\int_0^{\delta} F(x)dx}{m} \tag{7}$$

where:

EA (J) is the total energy absorbed by the panel due to the force $F(x)$ under the bending, δ is the deflection, and m is the structure's mass.

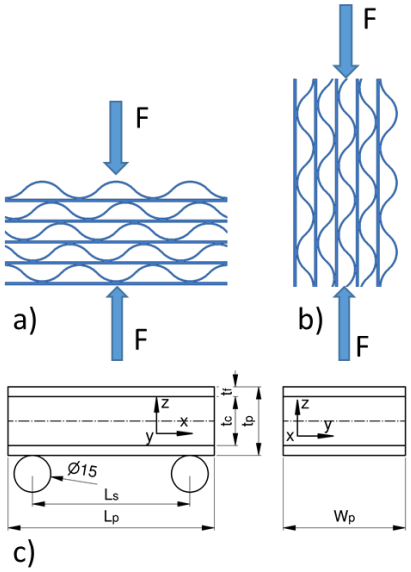


Figure 4: Experimental studies: a) measurement of Poisson's ratio in the direction of the R_c , b) T_c, c) three–point bending

COMPRESSION AND BENDING TESTS

Uniaxial compression tests were conducted on a Zwick 1445 universal testing machine (Zwick GmbH, Ulm, Germany). A digital camera (Dantec DIC System Q–400, Skovlunde, Denmark) was used to record the deformation of the specimens. It can be seen from Table 2 that the corrugated core with geometric imperfections has a negative Poisson's ratio. In the direction of loading $y = R_c$ the value of the coefficient ν_{cyx} is equal to –0.027 and is 37% lower compared to the coefficient of ν_{cxy} = –0.043. This part of the study clearly indicates that wavy cores made of wood and characterized by inhomogeneities in the shape of individual waves exhibit auxetic properties in two directions.

Table 2: Properties of the core

Parameter	Directions	Unit	Mean	Std. deviation
Relative density			**0.237**	–
F_y	R_c	N	14.96	1.75
F_x	T_c		181.78	6.63
ν_{cyx}	R_cT_c	–	–0.027	–0.001
ν_{cxy}	T_cR_c		–0.043	–0.002

Three–point bending tests were carried out on a Zwick 1445 universal testing machine (Zwick GmbH, Ulm, Germany), with a constant loading rate of 2 mm/min, according to the scheme as in Fig. 4c.

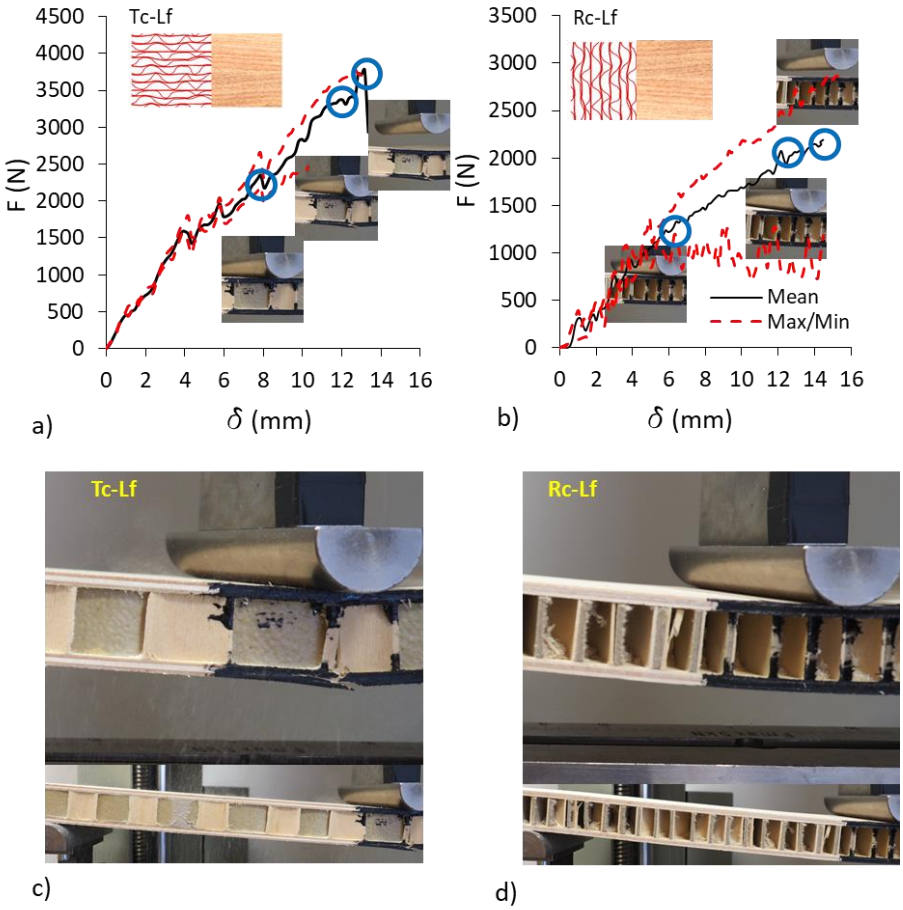


Figure 5: Force–deflection relationship for beams of type T_cL_f (a), for beams of type R_cL_f (b) and the characteristic failure mode of (c, d), respectively

Figure 5a shows that the beam type T_cL_f fails at a maximum force F equal to 3780 N. At this load, the bottom cladding was damaged. The crack occurred along the wood fibers. As a result of this damage, a further crack occurred along the fibers of the wooden core, directly under the thrust (Fig. 5c). The beam type R_cL_f is characterized by the transverse alignment of the core with respect to the direction of the fibers in the cladding. This design change resulted in the maximum destructive force of the beam F = 2192 N is 42% lower than the destructive force of the type beam T_cL_f (Fig.5b, d). Due to the lower value of the destructive force, no damage to the cladding was observed in this case. On the other hand, as in the previous beam, irregular, abrupt changes in the force–deflection relationship were observed. This means the damage occurs in the core and/or the adhesive bond between the cladding and the core.

FEM ANALYSIS

Since geometric imperfections are very time–consuming in numerical modeling and absorb enormous computer power during calculations, therefore, beam models with simplifications of these geometries were prepared for finite element method (FEM) calculations. For the simplification, it was assumed that a = 40 mm while the waves h_a = 11 mm. A model labeled „R“ and „Rnd“ with randomly shifted core waves, was made. The waves were shifted by the value $Rnd \cdot a$ where $Rnd \in \leq 0; 1 \geq$ (Fig. 6). Due to the random arrangement of core cells, three core models were made to ensure the correctness of the results, and the results from these calculations were averaged.

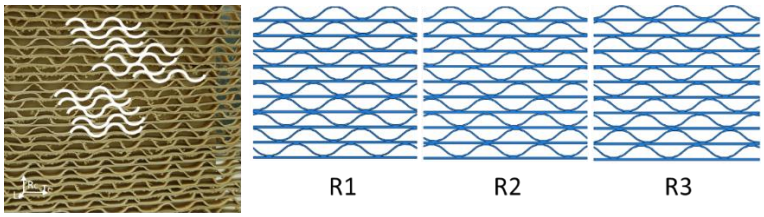


Figure 6: Randomized core models

Cladding, corrugated core, and cardboard strips were assigned the orthotropic properties summarized in Table 3, considering the ductile damage model. The cohesion zone model (CZM) was applied to the adhesive bond. The constitutive laws associated with CZM models are called traction separation laws. The study used the CZM model, which is available in the finite element code of Abaqus (2011). To preserve the adhesive bond between the cladding and the core, the dominant failure mode of the adhesive bond is in–plane shear. This leads to the inclusion of only the displacement value in the separation vector δ_s. The constitutive law can then be written in the form:

$$\tau_s = (1 - D)K\delta_s \tag{8}$$

where: K parameter which corresponds to the initial shear stiffness of the weld, and parameter D is a scalar damage variable, which can be written as follows:

$$D = \frac{\delta_s^f}{\delta_s}\frac{\delta_s - \delta_s^o}{\delta_s^f - \delta_s^o} \tag{9}$$

The values of individual displacements correspond to those given in Fig. 7, which shows the result of the shear test of the Rakoll Express 25 D adhesive used in the tests. All determinations of the mechanical properties of the materials used were made in our own laboratory in accordance with standards EN ISO 527.

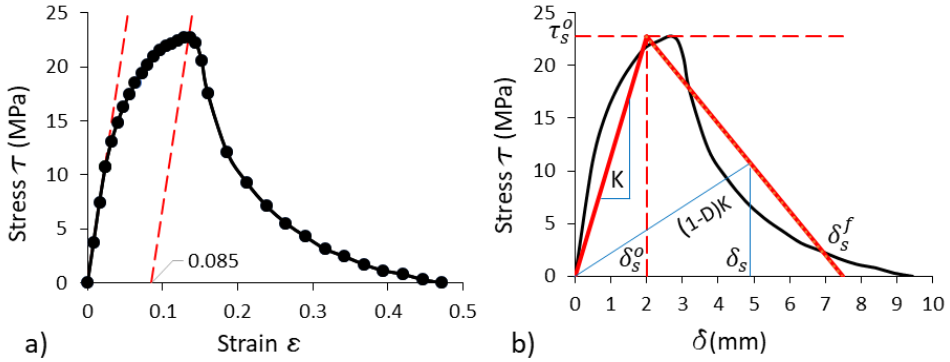


Figure 7: Bond–slip curve for the Rakoll Express 25 D adhesive (a), bi–linear traction separation model (b)

The indenter and supports were made as R3D4 (4–node 3–D bilinear rigid quadrilateral) solids. The corrugated core and cladding were made using C3D8R (8–node linear brick, reduced integration, hourglass control) elements. The cladding layers adjacent to the core contained thin adhesive joints 0.1 mm thick (Fig.8). These layers were made by splitting the cladding and using COH3D8 (8–node three–dimensional cohesive element) type elements. A tie type was used between the corrugated core's contacting surfaces and the adhesive bond's surfaces. On the other hand, a tie joint, commonly used in such cases, was used to connect corrugated cores and flat strips of cardboard (Labans *et al.* 2017)(Smardzewski and Wojciechowski 2023)(Xu *et al.* 2016). The global hard contact interaction was assumed for normal behavior for the remaining surfaces, not in direct contact. A friction

coefficient of 0.1 was assumed for tangential behavior (Smardzewski and Wojciechowski 2023)(Ingrole *et al.* 2017)(Li *et al.* 2018).

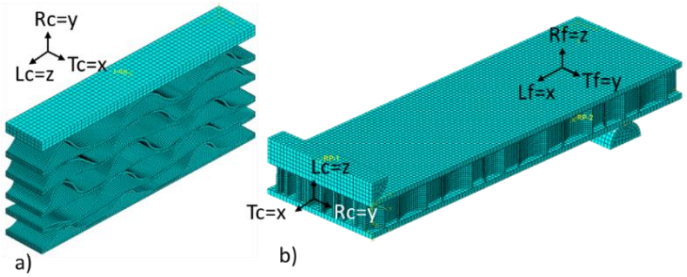


Figure 8: FEM models: cores (a), beams (b)

Table 3: Mechanical properties of materials. Standard deviations in brackets, (*) data base on (Kollmann and Cote 1968)(Cai and Ross 2010)(Green *et al.* 1999)

Properties	Units	Birch playwood	Birch wood	Cardboard	Glue Rakoll
E	MPa	–	–	–	460
E_x		9764 (672)	14455 (*)	2123 (24.2)	–
E_y		1914 (113)	1142 (*)	1316 (17.6)	–
E_z		1914	735 (*)	1316	–
G_{xy}		1509	1081 (*)	816	–
G_{xz}		957	990 (*)	505	–
G_{yz}		957	244 (*)	400	–
R_m		–	–	–	22.72 (4.31)
$R_{m(x)}$		95.6 (12.4)	144 (*)	12.1 (1.72)	–
$R_{m(y)}$		27.4	–	8.17 (0.95)	–
EF	N/mm	–	–		85.22
v	–	–	–	–	0.3 (–)
v_{xy}		0.482 (0.032)	0.426 (*)	0.337 (0.041)	–
v_{xz}		0.142	0.451 (*)	0.171 (0.012)	–
v_{yz}		0.142	0.697 (*)	0.171	–
η		0.333	0.333	0.333	0.333
$\varepsilon_{f,x}$		0.0015	0.0061	0.0021	0.085
$\varepsilon_{f,y}$		0.0040	–	0.0170	–
E/Enn		–	–	–	48
$G1/Ess$		–	–	–	16
$G2/Ett$		–	–	–	16
ρ	kg/m^3	966 (75)	630 (59)	1240 (86)	1300 (–)
MC	%	4.6 (0.24)	7.2 (0.61)	–	

It can be seen from Figure 9a that all core models after symplification are characterized by negative Poisson's coefficients in the plane in the two perpendicular directions. Larger values of the coefficients were observed in the direction R_c. For the R1, R2, R3 models, successive wave shifts in the individual core layers resulted in similar Poisson's coefficient values from –0.032 to –0.034. The reliability of these calculations is confirmed by the fact that the calculated Poisson's coefficient value for the experimental model is very close (Exp, –0.027). In contrast, it can be observed from Fig. 9b that in the compression direction the T_c cores showed smaller values of Poisson's coefficients for the individual models R1, R2, R3, –0.055, –0.048, –0.54, respectively. On the other hand, the calculated value of Poisson's coefficient for the reference model Exp (–0.43) is only slightly higher than the numerical simulation results.

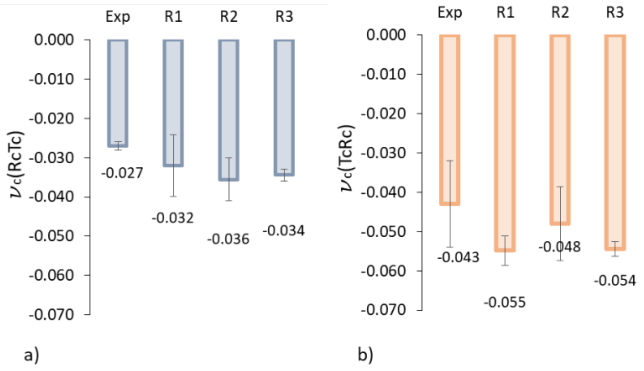


Figure 9: Poisson's coefficients of the core for load directions a) R_c, b) T_c.

To verify the quality of the results of the numerical calculations, the experimental values of three–point bending and the results of FEM calculations for the geometrically same models are summarized in Fig. 10. The waveforms of the numerically calculated force–deflection characteristics correspond well with the experimental characteristics, which allowed for a further course of analysis of the obtained numerical data. From Fig. 10a of this figure, it can be seen that structures of the type T_cL_f are distinguished by higher stiffness compared to structures of the type R_cL_f. In addition, the highest specific absorption energy is characterized by a beam of type T_cL_f 53.4 J/kg. The beams of type R_cL_f, show values lower by 32.8 J/kg, respectively. At the same time, the numerical models $R-T_cL_f$ and $R-R_cL_f$ provided results equal to 43.7 J/kg and 29.2 J/kg, respectively.

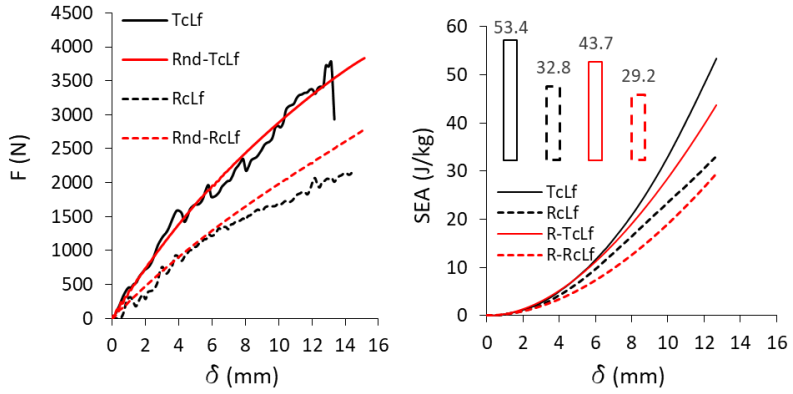


Figure 10: Beam stiffness characteristics (a), specific absorbed energy (b)

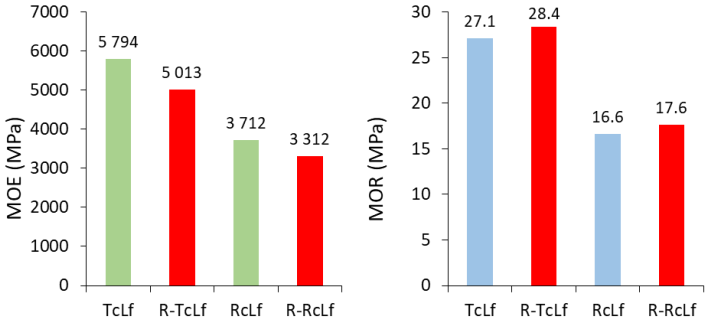


Figure 11: MOE (a) and MOR (b) for beams

Fig. 11a, on the other hand, shows the values MOE for the tested beams. It shows that structures of the type T_cL_f are distinguished by the highest stiffness MOE 5794 MPa. In the case of type

structures R_cL_f MOE is equal to 3712 MPa. In contrast, the calculated numerical values for these beams are respectively $R-T_cL_f$ 5013 MPa and $R-R_cL_f$ 3312 MPa. The flexural strengths of the tested beams are also arranged in similar relations. Fig. 11b shows that structures of the type T_cL_f are distinguished by the highest strength MOR 27.1 MPa. In the case of type structures R_cL_f MOR is equal to 16.6 MPa. In contrast, the calculated numerical values for these beams are respectively $R-T_cL_f$ 28.4 MPa and $R-R_cL_f$ 17.6 MPa.

The results of numerical calculations confirm that in the bottom cladding of the beams $R-T_cL_f$ (Fig.12) stresses reach 132.3 MPa and exceed the 113 MPa tensile strength of the cladding. Numerical calculations also showed core damage at the interface with the top cladding. This is due to the fact that the stresses at this point of the core exceeded the value of 133.7 MPa, while the permissible core failure stress should be equal to 82 MPa. It should also be noted that in the lower layers of the core, the stresses reach a value of 48.6 MPa and are greater than the adhesive bond strength of 22.7 MPa.

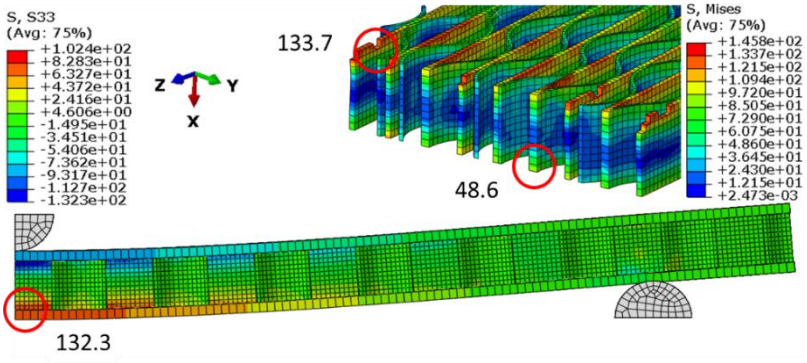


Figure 12: Stress distribution in cladding and core of beam type $R-T_cL_f$.

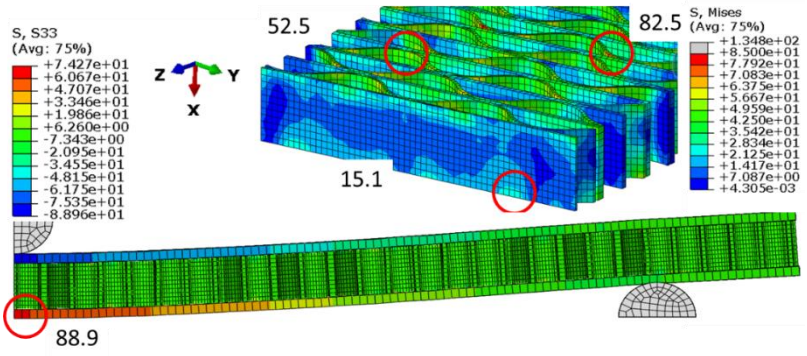


Figure 13: Stress distribution in the cladding (a) and core (b) of a beam type $R-R_cL_f$.

Experimental studies of beams of the type R_cL_f indicated only the possibility of core and glue weld failures. The results of numerical calculations confirm that in the bottom cladding of the beams $R-R_cL_f$ (Fig.13) the stresses reach a value of no more than 88.9 MPa. However, the numerical calculations showed the possibility of core failure at the interface with the top and bottom cladding. The stresses in these areas of the core exceeded the value of 52.5 MPa and 15.1 MPa, respectively. Meanwhile, the allowable core failure stresses should be equal to 46.9 MPa.

CONCLUSIONS

Wavy cores formed from wood veneers, even though they are characterized by significant and variable parameters of wave geometry, are auxetic structures with negative Poisson's ratios ν_{RcTc} = –

0.027; ν_{TcRc} = –0.043. The most advantageous way to simplify corrugated cores with shape irregularities is by randomly shifting the waves in individual core layers. This solution ensures the best agreement of the results obtained for numerical and real models. The most effective design solution is a beam with longitudinal alignment of the core waves and longitudinal alignment of the fibers in the outer cladding $T_c\ L_f$. In this case, the maximum contact force was equal to 3780 N. The highest specific absorption energy was characterized by a beam type of T_cL_f 53.4 J/kg. Beams of the type R_cL_f show values lower by 27.5%. The numerical models with randomized corrugated cores were well–defined and can be used to model analogous structures made of orthotropic materials.

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REFERENCES

ALECCI V., DE STEFANO M., FOCACCI F., *et al.* 2017. Strengthening Masonry Arches with Lime–Based Mortar Composite. Buildings 7.

ALI S., THAMBIRATNAM D., FAWZIA S., *et al.* 2021. Structural performance evaluation of innovative composite pedestrian arch bridge. Struct Infrastruct Eng, 17:74–85. doi: 10.1080/15732479.2020.1730411.

BANERJEE S., BHATTACHARYYA D. 2011. optimal design of sandwich panels made of wood veneer hollow cores. Compos Sci Technol, 71:425–432. doi: 10.1016/j.compscitech.2010.12.011.

BARTOLOZZI G., PIERINI M., ORRENIUS U., BALDANZINI N. 2013. an equivalent material formulation for sinusoidal corrugated cores of structural sandwich panels. Compos Struct, 100:173–185. doi: 10.1016/J.COMPSTRUCT.2012.12.042.

CAI Z., ROSS RJ. 2010. mechanical properties of wood–based composite materials. Gen. Tech. Rep. FPL ; GTR–190. madison, WI U.S. Dept. Agric. For. Serv. For. Prod. lab.

CÓZAR IR., ARBELÁEZ–TORO JJ., MAIMÍ P., *et al.* 2024. A novel methodology to measure the transverse Poisson's ratio in the elastic and plastic regions for composite materials. Compos Part B Eng, 272:111098. doi: 10.1016/j.compositesb.2023.111098.

DI BRIZZI D., GRAZIOSI S., BONDIN W., *et al.* 2024. On the behavior of auxetic inserts: a numerical analysis to derive design guidelines. Smart Mater Struct, 33:75018. doi: 10.1088/1361–665X/ad4e7e.

DYKES RJ., MANDER SJ., BHATTACHARYYA D. 2000. roll forming continuous fiber–reinforced thermoplastic sheets: experimental analysis. Compos Part A Appl Sci Manuf, 31:1395–1407. doi: 10.1016/S1359–835X. 00.00076–2.

EBERT M., ADHIKARI R., HASAN MK., *et al.* 2024. ABC–Auxetics: An Implicit Design Approach for Negative Poisson's Ratio Materials. Adv Eng Mater, 26:2301359. doi: 10.1002/adem.202301359.

FAN Z., YE G., LI S., *et al.* 2023. Compression performance and failure mechanism of honeycomb structures fabricated with reinforced wood. Structures, 48:1868–1882. doi: 10.1016/J.ISTRUC.2023.01.087.

FU T., WANG X., RABCZUK T. 2024. Broadband low–frequency sound insulation of stiffened sandwich PFGM doubly–curved shells with positive., negative and zero Poisson's ratio cellular cores. Aerosp Sci Technol, 147:109049. doi: 10.1016/j.ast.2024.109049.

GARMENDIA L., SAN–JOSÉ JT., GARCÍA D., LARRINAGA P. 2011. rehabilitation of masonry arches with compatible advanced composite material. Constr Build Mater, 25:4374–4385. doi: 10.1016/j.conbuildmat.2011.03.065.

GIOFFRÉ M., VINCENZINI A., CAVALAGLI N., *et al.* 2021. A novel hemp–fiber bio–composite material for strengthening of arched structures: Experimental investigation. Constr Build Mater, 308:124969. doi: 10.1016/j.conbuildmat.2021.124969.

GREEN DW., WINANDY JE., KRETSCHMANN DE. 1999. wood handbook: wood as an engineering material. USDA Forest Service, Forest Products Laboratory. General technical report FPL ; GTR–113:., Madison, WI.

HASSANI F., JAVANBAKHT Z., MALEK S. 2024. Large deformation behavior and energy absorption of rotating square auxetics. Compos Part B Eng, 283:111596. doi: 10.1016/j.compositesb.2024.111596.

INGROLE A., HAO A., LIANG R. 2017. Design and modeling of auxetic and hybrid honeycomb structures for in–plane property enhancement. Mater Des, 117:72–83. doi: 10.1016/j.matdes.2016.12.067.

JILOUL A., BLANCHET P., BOUDAUD C. 2023. mechanical characterization of corrugated wood–based panels and potential structural applications in a building. Constr Build Mater, 391:131896. doi: 10.1016/J.CONBUILDMAT.2023.131896.

JIN M., HU Y., WANG B. 2015. compressive and bending behaviors of wood–based two–dimensional lattice truss core sandwich structures. Compos Struct, 124:337–344. doi: 10.1016/j.compstruct.2015.01.033.

KAVERMANN SW., BHATTACHARYYA D. 2019a. Experimental investigation of the static behavior of a corrugated plywood sandwich core. Compos Struct, 207:836–844. doi: 10.1016/J.COMPSTRUCT.2018.09.094.

KAVERMANN SW., BHATTACHARYYA D. 2019b. Experimental investigation of the static behavior of a corrugated plywood sandwich core. Compos Struct, 207:836–844. doi: 10.1016/j.compstruct.2018.09.094.

KOLLMANN FFP., COTE WA. 1968. Principles of wood science and technology I – Solid wood. Springer Verlag., Berlin; Heidelberg; New York.

LABANS E., KALNINS K., ZUDRAGS K. 2014. Stiffness analysis of sandwich panels with corrugated plywood and GFRP core. In: Pietraszkiewicz W., Gorski J. eds. Shell Structures: Theory and Applications., 1st Ed. Taylor & Francis Group., London., pp 539–542.

LABANS E., ZUDRAGS K., KALNINS K. 2017 Structural Performance of Wood Based Sandwich Panels in Four Point Bending. Procedia Eng, 172:628–633. doi: 10.1016/j.proeng.2017.02.073.

LAKES R. 1987 Foam Structures with a Negative Poisson's Ratio. Science. 80–, 235:1038–1040. doi: 10.1126/science.235.4792.1038.

LI X., LU Z., YANG Z., *et al.* 2018 Yield surfaces of periodic honeycombs with tunable Poisson's ratio. Int J Mech Sci, 141:290–302. doi: 10.1016/J.IJMECSCI.2018.04.005.

LI Z., YE G., BI H., HU Y. 2022. compression and energy absorption of wood–based two–dimensional dowel lattice structures. Eur J Mech – A/Solids, 96:104729. doi: 10.1016/j.euromechsol.2022.104729.

LU., GUOXING; YU TX. 2003. energy absorption of structures and materials. Elsevier.

Magnucka–Blandzi E., Magnucki K., Wittenbeck L. 2015. Mathematical modeling of shearing effect for sandwich beams with sinusoidal corrugated cores. Appl Math Model, 39:2796–2808. doi: 10.1016/J.APM.2014.10.069.

MCHALE G., ALDERSON A., ARMSTRONG S., *et al.* 2024. Transforming Auxetic Metamaterials into Superhydrophobic Surfaces. Small Struct, 5:2300458. doi: 10.1002/sstr.202300458.

MONDAL P., R. J. 2024. Theoretical and Numerical Investigation of Mechanical Properties of Auxetic S–structure under Transverse Load. Preprints.

MOSALLAM AS. 2016. structural evaluation and design procedure for wood beams repaired and retrofitted with FRP laminates and honeycomb sandwich panels. Compos Part B Eng, 87:196–213. doi: 10.1016/j.compositesb.2015.09.053.

NAROJCZYK JW., TRETIAKOV K V., SMARDZEWSKI J., WOJCIECHOWSKI KW. 2023. hardening of fcc hard–sphere crystals by introducing nanochannels: Auxetic aspects. Phys Rev E, 108:45003. doi: 10.1103/PhysRevE.108.045003.

PATHIRANA S., QIAO P. 2019. Local buckling analysis of periodic sinusoidal corrugated composite panels under uniaxial compression. Compos Struct, 220:148–157. doi: 10.1016/j.compstruct.2019.03.050.

SLONINA M., DZIURKA D., SMARDZEWSKI J. 2023. Failure mechanism map for bending wood–based honeycomb sandwich beams with starch–impregnated core. Compos Struct, 116749. doi: 10.1016/j.compstruct.2023.116749.

SMARDZEWSKI J. 2019 Wooden sandwich panels with prismatic core – Energy absorbing capabilities. Compos Struct, 230:. doi: 10.1016/j.compstruct.2019.111535.

SMARDZEWSKI J., WOJCIECHOWSKI KW. 2023. study on the bending and failure behavior of wooden sandwich panels with corrugated core., randomized gaps., and wood defects. Constr Build Mater, 409:133924. doi: 10.1016/J.CONBUILDMAT.2023.133924.

SMARDZEWSKI J., WOJCIECHOWSKI WK. 2019. response of wood–based sandwich beams with three–dimensional lattice core. Compos Struct, 216:340–349. doi: 10.1016/j.compstruct.2019.03.009.

SRINIVASAN N., BHATTACHARYYA., D. JAYARAMAN K. 2007. Thermoforming of wood veneer composite sheets. Holzforschung, 61:558–562. doi: 10.1515/HF.2007.105.

SRINIVASAN N., JAYARAMAN K., BHATTACHARYYA D. 2008. profile production in multi–veneer sheets by continuous roll forming. Holzforschung, 62:453–460. doi: 10.1515/HF.2008.064.

WANG S., LI S., ZHAI Z., *et al.* 2024. Bending performance and failure modes of sinusoidal corrugated sandwich panels fabricated using stereolithography technology: Effects of geometric parameters. Eng Fail Anal, 158:107987. doi: 10.1016/J.ENGFAILANAL.2024.107987.

WANG X., SHI X LONG., MENG Q KAI., *et al.* 2020. Bending behaviors of three grid sandwich structures with wood facing and jute fabrics/epoxy composites cores. Compos Struct, 252:112666. doi: 10.1016/J.COMPSTRUCT.2020.112666.

WOJCIECHOWSKI KW. 1989. two–dimensional isotropic system with a negative Poisson ratio. Phys Lett A, 137:60–64. doi: 10.1016/0375–9601.89.90971–7.

WU K., ZHU X., BIFANO TG., *et al.* 2024. Computational–Design Enabled Wearable and Tunable Metamaterials via Freeform Auxetics for Magnetic Resonance Imaging. Adv Sci, 11:2400261. doi: 10.1002/advs.202400261.

XU G., YANG F., ZENG T., *et al.* 2016. Bending behavior of graded corrugated truss core composite sandwich beams. Compos Struct, 138:342–351. doi: 10.1016/j.compstruct.2015.11.057.

ZHENG T., YAN H., LI S., *et al.* 2020. Compressive behavior and failure modes of the wood–based double X–type lattice sandwich structure. J Build Eng, 30:101176. doi: 10.1016/J.JOBE.2020.101176.

EN 310:1993 Wood–based panels – Determination of modulus of elasticity in bending and of bending strength.

ABAQUS 6.1 Analysis User's Manual. Simulia.

EN ISO 527 Plastics – Determination of tensile properties.

EN ISO 1924–2: 2010 Paper and board – Determination of tensile properties – Part 2: Constant rate of elongation method (20 mm/min).

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THE IPORTANCE OF ENVIRONMENTAL PROTECTION IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

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ABSTRACT

Environmental protection refers to: the rational management of resources, avoiding imbalances through nature conservation, avoiding environmental pollution and ecological reconstruction of the environment.

Sustainable development represents the needs of the present, without compromising the possibility of future generations to satisfy theirs.

The planetary abiotic environment under the influence of vegetation and other organisms is transformed, acquiring its own distinctive characters. It becomes a biotope and finds itself in a continuous interaction both with the macro environment from which it emerged and from which it is not sharply separated, being a sequence of it, and with the biocenosis that it supports and with which it forms a special type unit called ecosystem.

The biocenosis and its living environment (biotope) form the ecosystem, within which they are closely correlated and dialectically interconnected, so that the biocenosis can be defined as the population of the biotope, and the biotope as the place, or environment, occupied by the biocenosis.

Unlike other types, the forest environment presents the biggest differences compared to the macro–environment and is the most uniform, more homogeneous from the point of view of the regime of ecological factors.

Key words: biocenosis, sustainable development, forest, air, wood, ecosystem.

INTRODUCTION

The forest, due to its significant vertical development, influences and modifies not only the underground environment but also the above–ground environment, occupying a large volume of atmosphere above the soil (at the base of the troposphere).

In the forest microclimate, the greatest screening of solar radiation occurs, the thermal regime is more moderated, air circulation is significantly slowed, and the distribution and circuit of water (rain, snow) follow their own patterns, which are more economical and favourable for living beings and the soil (Diederichs 2015).

According to the researcher C. Chiriță, the biotope has a dual functional significance:

- physical–geographical unit: a practically homogeneous area, with its own physical–geographical characters, by which it is distinguished and delimited from the landscape (geographical landscape unit);
- ecological unit, having in its content a unitary, characteristic way of being of ecological values and factors or, more concisely, a specific ecological character.

The forest is the structural and functional prototype of natural ecosystems. Moreover, the forest acts as a protective factor for the environment and maintains ecological balance by performing functions that protect water, land, soil, the atmosphere, and biodiversity.

The role of the forest regarding the climate change was recognized by the Kyoto Protocol, part of the Framework Convention on Climate Change from 1997, and in the proceedings of the Buenos Aires Conference in November 1998.

The Kyoto Protocol mandates reductions in greenhouse gas emissions in industrialized countries.

Light is a particularly important factor for the development of the forest. In the forest, vegetation is layered in such a way that they receive varying amounts of light. In coniferous forests, light is significantly diminished but qualitatively less modified, whereas in deciduous species, it is absorbed selectively (Doniță 2007).

Table 1 presents the light intensity in a 75–year–old spruce forest.

Table 1: Light intensity in a spruce forest

Relative height of measurement location (m)	Average light intensity (%) from open area light (upper light)	Average light intensity (%) from open area light (Lateral light)	Lateral light (%) from upper light
0.8	34.4	13.1	38
0.7	13.6	5.2	37
0.6	7.8	2.7	34
0.5	6.9	2.1	30
0.4	5.6	1.4	25
0.3	6.8	1.8	27
0.2	8.7	2.5	29
0.1	2.9	0.8	18

Table 2 shows the share of light intensity in the plant mass of a forest.

Table 2: Share of light intensity in plant mass of a forest

Area / Floor	Percentage of light in incident radiation (%)
Upper (1/3 upper of the canopy)	80–100
Middle (below 1/3 upper of the canopy)	50–80
Base of the canopy	15–60
Upper part of the shrub payer	5–40
Herbaceous layer	2–30
Moss and litter layer	0.5

Air temperature is a particularly important climatic factor.

The thermal balance within a forest is influenced by: the degree of insolation, the air currents, the landforms and the humidity of the air.

In natural forests, the temperature is always lower, and thus the variation limits are reduced compared to areas without woody vegetation. These differences between the outside and inside of the forest can be over 10°C at midday (Duțu 2003).

The specific air quality index, or „specific index", is coding system for concentrations recorded for each of the monitored pollutants:

a) Sulphur dioxide (SO2)
b) Nitrogen dioxide (NO2)
c) Ozone (O3)
d) Suspended particles < 2.5 μm (PM2.5)
e) Suspended particles < 10 μm (PM10)

The general index is established for each of the automatic stations within the National Air Quality Monitoring Network, as the highest of the specific indices corresponding to the monitored pollutants.

The general index and specific indices are represented by whole numbers ranging from 1 to 6, each corresponding to a colour.

The specific indices and the general index of the station are updated hourly.

Table 3 shows the concentration ranges for sulphur dioxide (SO2).

Table 3: Concentration ranges for sulphur dioxide (SO_2)

Concentration range for sulphur dioxide (µg/m^3)	Specific index
0–100	1
100–200	2
200–350	3
350–500	4
500–750	5
750–1250	6

Table 4 shows the concentration ranges for nitrogen dioxide (NO_2).

Table 4: Concentration ranges for nitrogen dioxide (NO_2)

Concentration range for nitrogen dioxide (µg/m^3)	Specific index
0–40	1
40–90	2
90–120	3
120–230	4
230–340	5
340–1000	6

Nitrogen oxides are a group of highly reactive gases, which contain nitrogen and oxygen in varying amounts. Most nitrogen oxides are gases without colour or odour. Nitrogen dioxide in combination with particles in the air can form a reddish–brown layer.

In the presence of sunlight, nitrogen oxides can also react with hydrocarbons forming photochemical oxidants (Marin 2008).

Nitrogen oxides are responsible for acid rain that affects the land surface. Nitrogen dioxide is known to be a highly toxic gas for both humans and animals (the degree of toxicity of nitrogen dioxide is 4 times higher than that of nitrogen monoxide). Exposure to this pollutant causes serious harm to vegetation by blanching or death of plant tissues, reducing their growth rate.

Nitrogen oxides contribute to the formation of acid rain and promote the accumulation of nitrates at ground level that can cause alteration of the environmental ecological balance. They can also cause fabric deterioration, paint discoloration, and metal degradation.

Table 5 shows the concentration ranges for ozone (O3).

Table 5: Concentration ranges for ozone (O_3)

Ozone concentration range (µg/m^3)	Specific index
0–50	1
50–100	2
100–130	3
130–240	4
240–380	5
380–800	6

Ozone is a highly oxidizing, highly reactive gas with a choking odour. It concentrates in the stratosphere and provides protection against life–damaging UV radiation. The concentration of ozone at ground level causes irritation of the respiratory tract and eye irritation 9 (Ionescu 1989). High concentrations of ozone can cause reduced respiratory function. It is responsible for damage to vegetation by atrophying some tree species in urban areas.

Table 6 shows the concentration ranges for PM 2.5.

Table 6: Concentration ranges for PM 2.5

Concentration range for particles in suspension PM 2.5 (µg/m³)	Specific index
0–10	1
10–20	2
20–25	3
25–50	4
50–75	5
75–800	6

Table 7 shows the concentration ranges for PM 10.

Table 7: Concentration ranges for PM 10

Concentration range for particles in suspension PM 10 (µg/m³)	Specific index
0–20	1
20–40	2
40–50	3
50–100	4
100–150	5
150–1200	6

AIR QUALITY MONITORING

The following graphs show visible differences in air quality indices placed in different areas of our country, from stations within the National Air Quality Monitoring Network (RNMCA).

Figure 1 shows the PM 10 values for the three analysed stations.

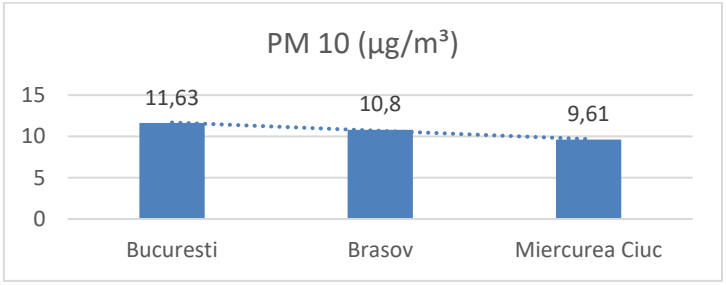


Figure 1: PM 10 values, for the 3 stations analysed

Figure 2 shows the values for NO2 for the 3 analysed stations.

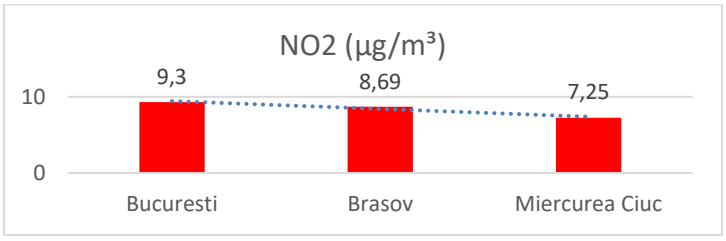


Figure 2: Nitrogen dioxide values for the 3 analysed stations

Figure 3 shows the values for O3, for the 3 analysed stations.

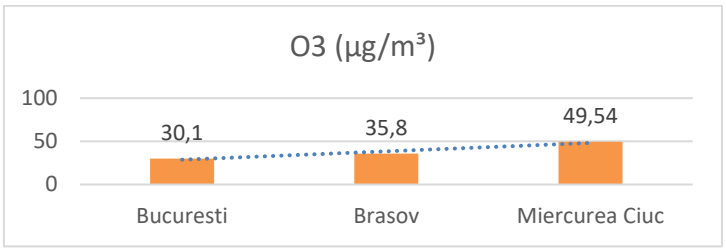


Figure 3: Ozone values for the 3 analysed stations

Figure 4 shows the air quality measurement station in Bucharest.



Figure 4: Bucharest air quality measurement station

CONCLUSIONS

Sustainable development seeks to establish a stable theoretical framework for decision–making in any situation involving the man–environment relationship, whether it concerns the natural environment, the economic environment, or the social environment.

Sustainability is based on the idea that human activities are dependent on the environment and resources. Health, social security, and economic stability are essential in defining the quality of life.

The main reasons for protecting the environment are:

- protecting the ecosystem. It is time to stop endangering forests, oceans, animals, and all living beings on this planet.
- protecting humanity. The global population continues to grow, but future generations will live on a planet very different from the one we grew up on. Present changes will improve the lives of future people.
- moral obligation: As intelligent beings, we are aware of the planet's problems and have access to numerous solutions to protect it. Therefore, humans are responsible for taking care of the environment.

REFERENCES

DIEDERICHS, S.K. 2015. Monitoring energy efficiency and environmental impact of the woodworking industry in Germany , Revista European Journal of Wood and Wood Products vol.73, Nr.5.

DONIȚĂ, N. 2007. Ecologie forestieră cu elemente de ecologie generală, Ed. Ceres, Bucureşti.

DUȚU, M. 2003. Dreptul mediului (vol. I, vol. II), Ed. Economică Bucureşti.

GODEANU, S. 2008. Biotehnologii ecologice şi ingineria mediului, Ed.Bucura Mond, Bucureşti.

IONESCU, A. s.a. 1989. Protecția mediului înconjurător şi educația ecologică, Ed. Ceres, Bucureşti.
MARIN, P., TEODORESCU, A. 2008. Biotehnologia Protecției mediului 1, Ed. CD Press, Colecția verde.
https://marathonepr.ro/blog/protejarea–mediului–ce–putem–face–pentru–a–ajuta–planeta/.
https://ro.wikipedia.org/wiki/Dezvoltare_durabilă.
https://www.calitateaer.ro/public/home–page/?__locale=ro.

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COMPETENCE NEEDS IN THE WOOD–BASED CONSTRUCTION INDUSTRY IN NORWAY

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ABSTRACT

The wood-based building material industry can be a significant source for the reduction of climate gas emissions. This desired contribution can be halted by that the industry currently has difficulties in recruiting both technical and environmental competencies.

This paper investigates what kind of competence the industry is asking for and how the needs will change, the research question is:

What changed competence needs do we observe in the wood–based construction industry in Norway?

Focusing on production at the expense of product innovation can limit the opportunity that lies in new environmentally friendly products.

The recruiting process has been forced to be broader and more general when it comes to asking for competence.

Instead of specific sustainable competence, the recruiters are asking for candidates with environmentally friendly attitudes and values, to later be given the necessary competence. Together with the need for training of currently employed personnel, newly employed people,

– or more people to come, will need extensive training and supply of competence.

There is an untapped opportunity in recruiting young candidates who want the possibility to develop professionally and personally through their work.

Key words: Wood-industries, competence, transition, green-economy.

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INTRODUCTION

The construction industry represents around one–third of global CO2 emissions (United Nations Environment Programme [UNEP], 2022) and there is great potential in cutting emissions in this industry. Transitioning towards a more environmentally and climate– sustainable construction industry can be achieved through a combination of reduced use of fossil fuels (e.g. emission–free construction sites), reduced transport needs, more reuse of materials, cutting down on resource use, by introducing a higher share of low–emission materials, as well as new models for cooperation on the decarbonization of building materials (United Nations Environment Programme [UNEP], 2023). Increased use of wood in construction can contribute to several of these areas of transition (REF).

The transition in sectors such as energy, construction, and manufacturing leads to the need for certain competencies (Cedefop, 2019). More specifically, the lack of skills is considered a bottleneck for the growth of a low–carbon building sector (United Nations Environment Programme [UNEP], 2023), and the need to reduce emissions in the construction industry introduces new competence needs in this industry (REF). These include competencies in climate adaptation and limiting damages from moisture, flooding, landslides, and drought. Digital competencies to improve productivity and reduce resource use, competencies related to life–cycle assessments (LCA), and a range of competencies related to maintenance will also be required.

More specifically, we can expect that the introduction of increased use of wood as a construction material also changes the competence needs in the construction industry.

The objective of this study is to understand how a transition to a more wood–based construction industry leads to changing competence needs in the industry. Our research questions are therefore: What changed competence needs do we observe in the wood–based construction industry.

THEORIES

COMPETENCES

Relevant and sufficient competencies are critical for any industry transformation. This has also been recognised in studies of the construction industry. Recent surveys of the members of the Federation of the Norwegian Construction Industries show that construction firms anticipate that a green transition will alter their needs for competencies in a substantial way (Håkon Endresen Normann et al., 2023a; Rørstad, Børing, & Solberg, 2023).

The OECD og Cedefop (2014) suggest that a sustainability transition more broadly will lead to changes in competencies in three ways. First, competencies will change through incremental efforts to adjust the competencies in an industry or a firm. This can be done by developing competencies amongst those already employed in an industry or firm. Thus, the relationship between a transition and changes in the labor market can be observed as the demands of workers within the same job change over time (Bianchi, 2020). Such changes are generally considered minor. Second, there will be a need to complement existing competencies by adding new competencies. This can be done e.g. as educational institutions and other training providers offer new skills for existing or new professions that are required in a green economy. This supply of new competencies can also occur through international recruitment. Finally, workers in industries that decline as a result of a sustainability transition will need to find work elsewhere and will often, as a consequence, require retraining (Håkon E. Normann & Tellmann, 2021).

There is limited empirical research on what the transition to a green economy will mean for the competencies needs in different parts of the labor market. However, different studies and reports point to different types of competencies relevant to a green transition.

We can expect that a transition will lead to a demand for a variety of competencies, including generic skills such as critical thinking, adaptability, and agility; technical competencies at all levels; interdisciplinary and cross–sectoral competencies; and certain leadership and management competencies (NOU, 2020:2). Other studies have shown that a transition will lead to increased demand for workers with higher education, and conversely reduced demand for workers with little or no education (Consoli, Marin, Marzucchi, & Vona, 2016).

There will be several different ways in which these competencies can be acquired. However, the two main arenas for developing the relevant competencies for a transition are considered to be the education system and on–the–job learning. The education system is particularly important for developing formal competencies, whereas learning on the job is important for informal competencies. Both learning arenas will be important for ensuring that industries and firms have the competencies needed for a transition (Consoli et al., 2016).

SUSTAINABILITY COMPETENCES

There is in the literature no established definition of green competencies or sustainability competencies. The International Labor Organisation (ILO) defines green jobs as „those that contribute to improving energy and material efficiency, limit greenhouse gas emissions, minimize

waste and pollution, protect ecosystems, and support climate adaptation" (ILO, 2016). Sustainability competencies may also be those required in industries or firms associated with a sustainability transition, such as battery technology, renewable energy, or waste management. Sustainability competencies can also be defined based on the contents and tasks of different job categories (Consoli et al., 2016).

Based on a review of the literature on green jobs and green competencies (Klitkou, Fossum, & Normann, 2022; Håkon Endresen Normann et al., 2023a), we distinguish between three types of competencies. First, technical competencies are in many studies found to be important for successful transition processes (Dvorak, Martinat, Van der Horst, Frantal, & Tureckova, 2017; Nikmehr, Hosseini, Martek, Zavadskas, & Antucheviciene, 2021). Technical competencies can include formal competencies such as within engineering, energy, and ICT, but also informal competencies associated with increased digitalization across sectors and firms. Second, generic or general competencies can include interdisciplinarity, system thinking, strategic thinking, anticipatory competencies, and relational competencies (Bianchi, Pisiotis, & Cabrera Giraldez, 2022). Third, some competencies are generic for sustainability, meaning that they are relevant across sectors and firms, but are specifically related to sustainability (Cedefop, 2019; ILO, 2019). These include basic competencies on climate change and environmental protection; climate reporting, calculations, and valuations; and norms, values, and motivation to work on climate and environmental issues.

SUMMING UP THE ANALYTICAL FRAMEWORK AND KEY CONSEPTS

To analyse how a transition towards increased use of wood in a construction industry affects the demand for competencies in wood–based firms, we draw on the literature above. We distinguish between technical competencies, generic competencies, and environmental and climate competencies. Yet, because exactly what characterizes these competencies is unclear in existing studies, we remain open as to how these competencies should be defined.

DESCRIPION OF CASE, DATA AND METHODS

DESCRIBTION OF CASE

This study builds on two primary data sources: job advertisements and focus group interviews. Job advertisement data underwent a process of content analysis, while focus group interviews provided qualitative data that informed our reflective analysis, ultimately leading to a comprehensive understanding that addresses the research questions. The relationship between competencies and a green transition to meet the objective of this study, we have mapped competence needs in parts of the wood– based construction industry in Norway.

In total, the construction sector in Norway employs 235,000 people (ssb.no). The sector consists of building and construction, specialized construction activities, real estate development and the production of construction materials. Manufacturing of building materials in Norway employs 5,190 people with an annual turnover of 21 billion NOK. The part of the industry based on wood and wood fibre, employs 3,600 persons. (byggevareindustrien.no, treindustrien.no).

The employer's association Treindustrien claims to represent 90% of Norwegian production. The number of member companies is 115, in addition a few wood based material production units are represented in the association Byggevareindustrien. („Nøkkeltall om treindustrien,"2016).

Moelven Industirier ASA og Hunton Fiber AS are typical representatives of dominant actors. Both companies utilize wood and chips as raw materials and distribute a broad spectrum of building

products both through building merchants for end users and directly to industrial customers. They both mainly operate in the Scandinavian market. https://www.moelven.com/ https://forestia.com/ .

The Norwegian Forest industry is a significant contributor to the country's economy. The sector includes the collection of timber from the forestry (forest covers one–third of the land area), primer wood processing, and the production of various wood products. The authorities recognize wood as a crucial element in addressing the climate crisis.

DESCRIPTION OF DATA AND METHODS

In order to gain a comprehensive understanding of the competency requirements within the wood–based building industry, this study employed job advertisement analysis as a means for data collection. Job advertisements serve as relevant indicators of the practical skills and knowledge sought by employers during recruitment processes, and will thus represent the need for skills and knowledge in the industry. (Barth, Dale–Olsen, Schøne, & Ostbakken, 2021).

Sources for getting relevant job advertisements were selected after screening the journals and magazines related to the wood building sector, company websites, the Norwegian Labour and Welfare Administration (NAV), and the commercial web–based marketplaces for publishing job advertisement finn.no. This Marketplace for job advertisements categorizes the advertisements in relation to industry. We sorted out advertisements from construction, industry and production. In addition, we used the keywords:

Wood, lumber, timber, wood, wood construction, wood industries, wood products and forest products, wood production, building materials in wood, sawmill.

The journals and the companies were selected strategically. From the journals Teknisk ukeblad (TU), Norsk Skogbruk, Magasinet Treindustri, Tre & Profil, finn.no, and NAV, we ended with a total of 497 job advertisements expected to be related to the wood–based building sector.

To compare development over time, we collected job advertisements for the years 2012 and 2022. Because the the digital archives did not include historical data going sufficiently far back, we had to collect job advertisements for 2012 using alternative methods. This was done by contacting a few main actors to get the desired number of ads for 2012 since this period was lacking in the digital archives.

We used a qualitative data analysis software, NVivo 14 for the analysis. All 497 job ads were allocated to different sectors of the wood building value chain. One sector, we found was exclusively linked to the use of wood. The sawmilling of logs and the processing of wood fiber for boards and insulation is the basic manufacturing for the increased use of wood in the building sector. To varying extents the actors in the wood industry are further processing the timber into building components and building systems, some are also directly involved in design and housing development. This implies a wide variety of processes and tasks to be performed within the organizations, with a corresponding need for competence.

Attributes for occupational classification were done according to the Standard for Occupational Classification (STYRK–08) which is the Norwegian standard for classifying occupations. It is based on the International Standard Classification of Occupations (ISCO– 08).

Table 1: Distribution by professions in the job ads

Profession (STYRK 08)	*Job ads: 2012 and older*	*Job ads: 2022 and later*	*Number of positions*
Managers	17	7	**24**
Professionals	4	3	7
Technicians and associate professionals	8	7	**15**
Clerical support workers	2	0	2
Service and sales workers	9	15	**24**
Skilled agricultural, forestry and fishery workers	0	0	0
Craft and related trades workers	0	1	1
Plant and machine operators, and assemblers	7	10	**17**
Elementary occupations	0	6	6
Armed forces and unspecified	0	0	0
Total (selection wood industries)	47	49	96

The codes that represent competencies are being developed contemporary as the data were collected and the analysis was prepared. Some of the concepts are retrieved from literature as a stepwise deductive inductive process (Fodor, Szabó, & Ternai, 2021) (Ahsan, Ho, & Khan, 2013).

Our initial coding process involved testing a comprehensive list of codes against a sample of job advertisements through inductive coding. We subsequently removed codes that did not correspond to any matching text within the advertisements, thereby streamlining the code list. Our initial assumption was that the advertisements would primarily demand detailed and industry–specific technical competencies. Examples of removed codes *include „woodworking skills," „timber technology," „wood properties," „grading," and „timber engineering."*

We subsequently expanded the code list to incorporate company–related codes, such as *„environmental commitment"* and *„sustainable raw materials and resources".*

To facilitate cross–analysis, we classified each advertisement with a set of attributes. These attributes initially included: Year of Publication (2012 or 2022), Educational Qualification, profession, industry segment.

After conducting an initial coding test on a subset of the 497 advertisements, we concluded that we could not reliably associate job advertisements with the forestry and wood sector. Consequently, we focused on only analysing advertisements with the attribute *„Wood Industries Employee."*

Consequently, the data source comprised 96 job advertisements with an even distribution between the years 2012 and 2022.

To further understand the concept of „sustainability competence“ within the wood industry, a supplemental web search was conducted. This analysis cantered on how the wood industry describes its emphasis on sustainability in its policies and marketing materials targeted towards potential applicants *(„Working with us“ sections).* Additionally, recent job advertisements (Q3 2023) from the wood industry relevant to sustainability competence were incorporated into the supplementary analysis.

Table 2: Final list of competence–nodes for coding of the job postings.

Technical competences	Innovation and product development	Come up with new ideas, concepts, or methods and then turn these into innovative products, services, or improvements in existing solutions
	Performance skills	Skills that are necessary to perform specific tasks or achieve specific results
	Planning skills	Ability to plan, organize, and structure activities and resources
Generic competencies	Communications skills	Ability to communicate internally and/or externally
	Digital competence	The ability to use digital tools and technologies effectively and efficiently
	Flexibility	Ability to readjust and adapt to new requirements or circumstances
	Improvement	The process of making something better or developing over time
	Teamwork	Ability to collaborate effectively with colleagues and external parties
	Work under pressure	Ability to maintain productivity and efficiency while working in demanding or stressful situations
	Writing and Speaking skills	When the word writing skills or ability to speak is used in the advertisement
Environmental and climate competences	Environmental awareness	Understanding the environment around us, and complying with sustainable practices
	Environmental commitment (company level)	Organization's commitment to protect and preserve the environment
	Sustainability knowledge	The knowledge of principles and practices related to sustainable development and conservation of the environment
	Sustainable raw materials and resources (company level)	Resources that can be renewed or utilized in a way that maintains the balance in nature

Present demands of competence and skills would also be a base for getting an understanding of what kind of competence is important for the industry to position them for the years to come. To better understand the changing competence needs over time, we compared competence demands in job postings in the year 2012 with postings in 2022. Based on this comparison we analysed if the need for specific competencies (see table 1) has decreased or increased and if the demand for new competencies was appearing.

A focus group interview was conducted in collaboration with an innovation cluster comprised of members from the wood–based building materials industry.

Our findings from the advertisements analysis would be a base for the interview with participants representing the human resource discipline. By first analysing the job advertisements and then doing the interview, our analyse of supplementary data would be a process leading us to a better

understanding of the competence needs in the industry and how this competence was going to be provided.

Our assumptions and questions derived from the job advertisement analysis were presented to the focus group of HR leaders. The objective was to foster a discussion that would refine and clarify these elements, ultimately leading to an enhanced understanding of competence needs and associated recruitment or development strategies.

The ten human resource professionals, representing a diverse range of actors within the sector, participated in the interview session. Following introductions, participants were asked to reflect on and discuss competence needs within the industry, along with their recruitment strategies for addressing these needs. The two–hour session was audio–recorded, transcribed, and analysed using the qualitative data analysis software NVivo. Thematic coding focused on identifying industry competence needs. Additionally, the interview data was coded and analysed to gain deeper insights into the ongoing changes observed through the job advertisement analysis.

RESULTS

INSIGHTS FROM ANALYZING JOB ADS Key Findings from the job ads:

- Technical Skills Remain Essential: Technical skills were the most demanded competence in both periods (2012 & 2022).
- Shifting Priorities: Demand for expertise in cost–efficiency and raw material utilization has grown, while the use of the term „LEAN“ has declined.
- Communication & Teamwork: Demand for communication skills doubled, often linked to personal characteristics like a positive attitude. Teamwork also showed an increase.
- Declining Demands: Innovation and product development expertise, along with sustainability knowledge, showed a decrease from 2012 to 2022.
- Increased Demands: „Digital competence“ and „environmental awareness“ showed an increase, potentially reflecting trends in sustainability and green transition.
- Job Advertisement Changes: The average number of listed competencies and the size of the „about the company“ section both increased significantly between 2012 and 2022.

Results from analysis of job advertisements

Initially we wanted to look at the job announcements by using standardized attributes to analyse job categories and requirements for formal education. When analysing the job postings for demands of formal education, we found no context linking the competence needs to a specific standard education (EQF), the dominant inquiries for education were „not specified” or a broader listing of education.

When we classified the positions to be recruited for, we found four dominant occupational groups: managers, technicians, service & sales workers, and plant & machine operators.

Competence with high demand

Technical competence is highly demanded. The competence performance skill/technical skills were found in two–thirds of the ads in both the periods that are analysed. The need for expertise for improvements in terms of cost efficiency and raw material tilization has increased and is also in high demand, but the use of the competence term „LEAN” has decreased.

From the group of generic competencies, the demand for „Writing and speaking skills” had doubled over the period. The ability to communicate more broadly was highly demanded in both

periods. The communication ability was often linked to more personal characteristics such as a „positive outlook on people" and an „outgoing and social personality".

Competence with low and/or decreasing demand.

We find little demand for „Innovation and product development" expertise, and the demand has declined from 2012 to 2022.

When it comes to „Sustainable knowledge", – the professional competence to be able to work with progress against sustainability, we found nearly no demand in our primary data. Only in 2022, we found one job ad asking for „Sustainable knowledge".

Competence with an increasing demand

The demand for „Digital competence" and „Teamwork" has increased and we interpret this by findings in the literature on competence needs for sustainability and green transition of the society (Håkon Endresen Normann et al., 2023b).

Demands for new competences

„Environmental awareness" has increased as a demand in our data, this competence will be knowledge and attitudes of a more personal nature, which in turn can mean that you live a sustainable way of life, are aware of your own choices, and are engaged in environmental issues. We found only one ad in 2010 asking for this but more than half of the ads were asking for this competence in 2022.

Competence for a green transition

We were also screening the text in the ads for words linked to a green transition. The use of sustainability, climate, green, renewable, and circular shows an increased focus on sustainability and green transition, this coincides with the development in general (Kompetansebehovsutvalget, 2023).

Our supplementary web search, utilizing current data, revealed that a subset of wood industries emphasizes environmental awareness and the capacity to address sustainability concerns. This includes expertise in Life Cycle Assessment (LCA) and Environmental Product Declaration (EPD) methodologies. Additionally, these industries seek candidates familiar with the digitalization of sustainability data and product documentation, along with relevant sustainability standards. Furthermore, the ability to contribute to the development and ongoing updates of environmental strategies is sought after.

We also found that the job ads in general had tripled their size and the listed demand for competence had gone from ten to fifteen on average. In 2012 the section „about the company", if present at all, was only a listing of a few facts such as turnover and the number of employees. The section had increased in the 2022 selection to a broader description of the company and the products to be produced and marketed. Several industries specify that the raw materials in the form of chips and timber come from certified forests (PEFC/FSC).

Table 3: Competence needs in job advertisements (no. of codes)

	Selection wood industries employee (96)		
	Year = 2012 and older (47)	Year = 2022 and later (49)	Trend
Working skills	39	43	High demand (But even)
Technical skills	24	23	
Writing and speaking skills	10	22	
Communication skills	17	17	
Planning skills	12	9	Low/decreasing demand
Marketing	8	7	
Analytical abilities	5	5	
Agility	0	4	
Logistics	2	4	
Problem solving	4	4	
Strategy	3	3	
Innovation and product development	4	2	
Cost management	7	2	
Sustainability knowledge	0	1	
Customer service	0	0	
Procurement	6	0	
Stakeholder management	0	0	
Performance skills	30	44	Increasing demand
Teamwork	26	39	
Improvement	17	27	
Digital competence	16	28	
Work under pressure	10	15	
Health and Safety	8	15	
Environmental awareness	0	25	New demands
Environmental commitment	1	23	
Flexibility	3	16	
Sustainable raw materials and resources	1	14	

INSIGHTS FROM FOCUS GROUP INTERVIEW

- HR personnel expressed concern about attracting candidates with vocational diplomas.
- A competitive job market led to a softening of formal competence requirements in job postings.
- The industry's focus on production efficiency explained the lack of demand for market innovation and product development skills.
- Companies preferred candidates with an interest in environmental issues, believing the necessary skills could be acquired later.

In the focus interview group consisting of human–resource officers, there was an agreed opinion that they,– the recruiters were concerned about the possibility of gaining access to professional expertise, represented by holders of a vocational diploma.

„Everyone is concerned about the vocational certificates, they (the industries) are worried that there are few young people who choose it."

While technical competence serves as the foundation for building organizational competence, a shift has emerged over time regarding its explicit mention in job advertisements. Recruiters navigate a job market characterized by high demand for individuals possessing specific skillsets. This

competitive landscape creates pressure to secure applicants, leading to a softening of formal competence requirements within job postings.

„...we just had to generalize much more in the texts in our ads".

The broadening of recruitment efforts can also partially explain the observed increased number of words in job advertisement in 2022. This expansion manifests as more extensive company descriptions, which function as a tool for recruiters to achieve a positive employer image for potential applicants. „..and when the demand is so big, we become more creative.."

The wood–based industry was in the interview session described as production–orientated and focused on process innovation to reduce production costs. This was the main explanation for the lack of demand for competence in market innovation and product development. *„...there is little room to work innovatively, you are very much caught up in production, – is it an industry where it is difficult to make room for innovation? (Product–innovations)"*

Knowledge about sustainability specifically about product documentation and declaration of environmental impact (EPD) was described as a professional language that when used in job ads could give a risk of scaring off applicants.

The companies were conscious of attracting applicants with the right attitudes. They specifically wanted applicants with an interest in environmental issues. If they succeeded in recruiting candidates with the right attitudes and values, the candidates could later acquire the necessary skills.

This was a good match with what the companies experienced that younger job seekers were looking for.

„Younger employees are more interested in opportunities for development and to acquire new skills"

To further attract young applicants, several companies have developed their own training and introduction programs. These programs are highly prioritized, and the entire organization contributes to training and knowledge transfer.

„Our managing director personally participates as a lecturer and mentor in our introduction and training program."

DISCUSSIONS

The wood industries will ensure technical competence by hiring candidates with vocational certificates. A competitive job market causes companies to deviate from the desire for vocational certificates when recruiting, even though they are concerned about access to formal technical expertise. The recruitment strategy shifts from demanding specific expertise to companies recruiting more broadly, this may lead to vacant positions not appealing to candidates with a strong focus on job content (Feldman et al., 2006). The wood industries may, therefore, miss out on valuable and necessary expertise.

To ensure technical competence, companies aim to elevate the skills of new hires to the equivalent of a vocational certificate through internal training programs. These programs will also facilitate and ensure change competence and a culture of incremental development and innovation. The training programs were not exclusively offered to new employees; the courses were also intended to provide continuing education for the existing workforce. This concurrent need for basic training of newly hired generalists and the need for continuing education in the existing workforce could slow down the process toward a sustainability/green transition.

But internal training programs also presents an opportunity to cultivate a culture and skillset for incremental improvement grounded in vocational competence further emphasized in a 2021 Fafo report. Vocational workers can play a crucial role in driving improvements and innovation within companies, particularly in the context of incremental development.

One case study featured in the report involves the wood industry company Moelven Limtre. The company seeks to maintain its capacity for continuous process and product improvement. The Lean philosophy has been partially replaced by company–tailored internal competence and development projects (Hilsen, I. , 2021).

New or increased demands for *„digital competence", „teamwork"* and *„flexibility",* indicates that the industry is getting ready for a green transition. Demands for „sustainable knowledge", – a more formal competence in the form of detailed knowledge of LCA and EPD is sought by some companies in advertisements we found in the additional analysis we conducted in late 2023 and early 2024.

This assumed change in the demand for competence can also be interpreted because of a shift in business strategy. Companies must adapt to new requirement from the market for product EPDs.

The job ad size has increased from 2012 to 2024, the section „About the company" often includes descriptions of how companies approach environmental issues, particularly how raw material procurement is subject to sustainability standards. This adaption in the design of job ads also corresponds with the literature (Feldman, Bearden, & Hardesty, 2006).

At a meta–level, we interpret this as supporting a desire for job candidates with the right attitudes and values who will feel at home in the company through these shared values.

Companies are looking for applicants with environmentally friendly attitudes and a lifestyle in line with sustainability, this reinforces the need for both the provision of formal expertise and on–the–job training in various fields. This is also seen as an opportunity since younger job seekers are looking for job opportunities with development possibilities and lifelong learning.

A recent article in the Harvard Business Review summarizes the authors' research on the labor market and the role of HR. A tighter labor market has led to a change in recruitment policies. Companies must offer more than before to attract the right candidates. These candidates may not necessarily have all the skills they need, but they are perceived as talent and are offered competence– and development programs within the companies. (Capeelli, P, 2024)

We found in our study that Norwegian HR leaders are adapting their efforts to secure talent and resources for their companies, in line with the international trend. In addition to demanding talent, they want to attract individuals who can connect personal commitment and lifestyle with the companies' values and strategies for green transition and sustainable material production.

CONCLUSIONS

There is a high demand for technical competencies, especially professional qualifications. Although technical competencies are crucial, the competition for labour has forced the companies not to request concrete/specific competence. This can result in missing out on candidates with a high focus on job content and thereby losing valuable candidates with in– demand competencies.

There is a high demand for competence in improvements leading to cost efficiency, but little demand for the competence for product innovation. This could slow down the development of new environmentally friendly wood–based products.

Generic competencies such as digital competence and teamwork have increased. This corresponds with the competencies needed for a green transition. The demand for the competence

for the ability to communicate has been high over time. Communication is often linked to personal characteristics and attitudes.

Positive attitudes towards the environment and sustainable living are something new. Specific sustainable knowledge was not requested, but there are traces of a change in data collected in the additional analysis. This indicates future demands for knowledge on how to provide, soon to be, mandatory product documentation and in an standardized way calculate and document environmental impact of products and building systems.

There is an opportunity to recruit by responding to the fact that younger job seekers are increasingly requesting opportunities for development and further education combined with their work.

Both technical and environmental competencies are difficult to recruit. The adapted strategy is to hire people with the right attitude and to educate and train them after they are employed. This recruiting policy together with the need to retrain existing employees will result in an extensive need for adapted training and supply of formal competence in the future.

Human Resource personnel have adapted their work on recruitment and competence development to a tighter labour market, in line with the international trend. In addition to recruiting talented applicants who can develop from on–the–job training, they want to hire individuals with attitudes and values that align with the companies' goals of sustainable wood based material production.

REFERENCES

AHSAN, K., HO, M., & KHAN, S. 2013. Recruiting Project Managers: A Comparative Analysis of Competencies and Recruitment Signals from Job Advertisements. Project Management Journal, 44(5), 36–54. doi:10.1002/pmj.21366.

BARTH, E., DALE–OLSEN, H., SCHØNE, P. & OSTBAKKEN, K. 2021. Chutes and ladders? Job opportunities for generation COVID. IZA Discussion paper series.

BIANCHI, G. 2020. Sustainability competences. Publications Office of the European Union. BIANCHI, G., PISIOTIS, U. & CABRERA GIRALDEZ, M. 2022. GreenComp The European sustainability competence framework.

CAPPELLI, P., NEHMEH, R. 2024. HR`s New Role. Harvard Business Review, May–June 2024, 97–103.

CEDEFOP 2019. Skills for green jobs: 2018 update. European synthesis report.

CONSOLI, D., MARIN, G., MARZUCCHI, A. & VONA, F. 2016. Do green jobs differ from non–green jobs in terms of skills and human capital? Research Policy, 45, 1046–1060.

DVORAK, P., MARTINAT, S., VAN DER HORST, D., FRANTAL, B. & TURECKOVA, K. 2017. Renewable energy investment and job creation; a cross–sectoral assessment for the Czech Republic concerning EU benchmarks. Renewable & Sustainable Energy Reviews, 69, 360–368.

FELDMAN, D. C., BEARDEN, W. O., & HARDESTY, D. M. 2006. VARYING THE CONTENT OF JOB ADVERTISEMENTS: The Effects of Message Specificity. Journal of Advertising, 35(1), 123–141. doi:10.2753/JOA0091–3367350108.

FODOR, S., SZABÓ, I., & TERNAI, K. 2021. Competence–Oriented, Data–Driven Approach for Sustainable Development in University–Level Education. Sustainability, 13(17). doi:10.3390/su13179977.

HILSEN, A. I., NYEN, T., & JOHAN RØED STEEN, A. H. T. 2021. Fagarbeiderens bidrag til innovasjon i norsk arbeidsliv. Retrieved from https://www.fafo.no/images/pub/2021/20797.pdf:

ILO. 2016. What is a green job? [Online]. ILO.

ILO 2019. Skills for a Greener future – a global view.

KLITKOU, A., FOSSUM, L. W. & NORMANN, H. E. 2022. Kunnskapsoppsummering kompetansebehov og grønn omstilling. NIFU Working Papers.

Kompetansebehovsutvalget. 2023. Utfordringer for grønn omstilling i arbeidslivet. Retrieved from Oslo:

NIKMEHR, B., HOSSEINI, M. R., MARTEK, I., ZAVADSKAS, E. K. & ANTUCHEVICIENE, J. 2021. Digitalization as a Strategic Means of Achieving Sustainable Efficiencies in Construction Management: A Critical Review. Sustainability, 13, 12.

NORMANN, H. E., STEEN, M., MÄKITIE, T., KLITKOU, A., BØRING, P., SOLBERG, E., LUND, H. B., WARDEBERG, M. & FOSSUM, L. W. 2023. Kompetanse for grønn omstilling: En gjennomgang av forskningslitteratur og arbeidslivets kompetansebehov knyttet til miljø– og klimautfordringer. NIFU rapport. NIFU Nordic Institute for Studies of innovation, research and education.

NORMANN, H. E. & TELLMANN, S. M. 2021. Trade unions' interpretation of a just transition in a fossil fuel economy. Environmental Innovation and Societal Transitions, 40, 421–434.

NOU 2020:2. Fremtidige kompetansebehov III – Læring og kompetanse i alle ledd. Kunnskapsdepartementet.

Nøkkeltall om treindustrien. (2016, mai 14). www.treindustrien.no

OECD OG CEDEFOP 2014. Greener Skills and Jobs. OECD Green Growth Studies.

RØRSTAD, K., BØRING, P. & SOLBERG, E. 2023. NHOs kompetansebarometer 2022. En kartlegging av NHOs medlemsbedrifters kompetansebehov i 2022. NIFU rapport 2023:1. NIFU.

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MICROLEARNING: AN INNOVATIVE APPROACH TO TEACHING FOR THE BENEFIT OF INTERIOR DESIGN PROGRAME IN THE BULGARIAN UNIVERSITIES

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ABSTRACT

The suggested report explores the innovative application of microlearning as a pedagogical tool in Interior Design education within higher education institutions. Microlearning, characterized by its delivery of compact, highly focused learning units, offers a novel approach to enhancing the educational experience, particularly in fields requiring a blend of theoretical knowledge and practical skills. The paper begins by delineating the principles of microlearning, emphasizing its potential to provide flexible, learner–centered experiences that cater to the diverse needs of students in Interior Design programs.

Drawing on existing research, the study examines the integration of microlearning strategies into the curriculum of Interior Design courses. It highlights the adaptation of microlearning modules for teaching complex design concepts, technical skills, and the application of theory to practice. The research findings suggest that microlearning not only facilitates better retention of knowledge but also encourages active learning and creativity, critical components in the education of future interior designers.

The paper explores the curriculums in the field of 3D modeling and computer visualizations in higher education institutions in Bulgaria and does comparison between them to find common points and to suggest areas where short, targeted learning activities can be used to supplement traditional teaching methods, provide immediate feedback, and support personalized learning pathways.

Discussed are the implications of microlearning for curriculum development in Interior Design education, including the potential challenges and opportunities for educators. It advocates for a thoughtful integration of microlearning techniques to enhance student engagement, learning outcomes, and readiness for the professional world of Interior Design. Through this exploration, the paper contributes to the broader discourse on innovative teaching strategies in higher education, proposing microlearning as a valuable approach to enriching Interior Design education.

Key words: microlearning, Interior Design education, education experience enhancement.

ANALYSIS OF THE NEED FOR MICROLEARNING IN ENGINEERING DESIGN EDUCATION AND ITS EFFECTIVE APPLICATION

The concept of using microlearning to support education in engineering design has great potential for development. Microlearning, characterized by short and focused learning materials and the ability to be practically applied just–in–time, fits well with the dynamic and creative nature of Engineering Design education. The field of Interior Design is constantly evolving, with new technologies, materials, and styles emerging at the forefront. This necessitates the use of educational strategies that can adapt to the integration of new technologies and disciplines and teaching methods into the curriculum. Such strategies would help students adapt more quickly to changes in their future profession.

CURRENT STATE OF ENGINEERING DESIGN EDUCATION

Higher education in Engineering Design in Bulgaria has rich traditions and is taught at several universities, with the focus of the specialty varying depending on the institution. There are common principles and fundamental knowledge that unify the different specialties. Below are described the

specialties in state and private universities where the specialty Engineering Design or similar specialties Industrial Design and Interior Design are studied. An analysis is based on freely available online information about the number of hours and disciplines focused on studying specialized CAD/CAM and 3D software.

University of Forestry, Sofia: Engineering Design (Interior and Furniture Design) Program encompasses a wide range of disciplines, focusing on the theoretical and practical aspects of interior design and furniture design. The program includes training in over 40 disciplines, aiming to provide students with comprehensive knowledge and skills necessary for developing functional and aesthetic solutions for residential and public spaces. The course aims to prepare specialists capable of meeting the demands of modern interior and furniture design, including proficiency in various styles and methodologies. The educational program is developed considering contemporary design trends and the need for specialists who can integrate technical knowledge with aesthetic principles, especially in the context of sustainability, functionality, and visual appeal. An important aspect of the training is preparing students to handle professional challenges that require innovative thinking and adaptability to dynamic market conditions. Regarding the curriculum's specialized software training for CAD/CAM systems, 3D modelling, and computer visualization, the courses include discipline Computer–Aided Design Systems, with 60 classroom hours in the fourth semester, and discipline Computer–Aided Furniture Design, also with 60 classroom hours during the fifth semester. The curriculum analysis reveals no allocated hours for 3D modelling using specialized software or for computer visualization, despite their necessity in modern design practice. This leaves room for future improvements in the curriculum.

Another Program at the University of Forestry – Computer Technologies in the Furniture Industry, focuses on training personnel to integrate information technologies into the furniture industry. The program emphasizes developing skills for using computer–aided design (CAD) and manufacturing (CAM), as well as other digital technologies for optimizing production processes. The program also provides practical application of theoretical knowledge through participation in project tasks, internships, and industry collaborations, facilitating students' integration into the professional environment and the development of professional contacts. In the context of rapid technological development, the program underscores the importance of constantly updating knowledge and skills to meet the dynamic requirements of the furniture industry. In this regard, the discipline Computer Animation and Virtual Reality lays the foundation for knowledge and skills in working with 3D modelling and visualization software, including contemporary techniques for creating animations and 360–degree images necessary for virtual reality hardware. The training is conducted in the third semester within 45 classroom hours. Besides this discipline, the curriculum includes discipline Fundamentals of CAD Design in the first and second semesters, within 105 classroom hours, discipline Computer–Aided Furniture Design in the fifth semester, within 60 classroom hours, as well as discipline CAD/CAM/CAE Systems in Furniture Production within 105 classroom hours during the sixth and seventh semesters. Given the specialty's focus, the number of hours dedicated to studying specialized software is not surprising, as it helps lay the foundation for the students' future profession.

Technical University – Sofia: The design education at the Technical University – Sofia is structured to combine rigorous engineering practice with artistic, creative, and artistic aspects. The Engineering Design Program at the university is designed to achieve a successful symbiosis between technical skills and creative capabilities. Within this program, students acquire specialized knowledge

in design and develop skills to design aesthetically pleasing products for various purposes – from household needs to industrial production and advertising products. This preparation includes the development of creative thinking, as well as gaining knowledge in leading creative teams and marketing. Students learn how to realize their projects by working in teams and developing specialized skills in their chosen engineering–design direction. The curriculum of the specialty includes several subjects related to computer design and visualization. Among the mandatory disciplines, there are Computer 3D Design, taught in the fifth semester, with a total of 60 classroom hours, and Computer Modeling in Design with 45 classroom hours in the seventh semester. Among the mandatory elective disciplines in the eighth semester, students can choose Interior Visualization with 60 classroom hours. Through these three disciplines, students in the specialty receive training totalling up to 165 classroom hours. With good planning of the content of the individual courses so that they build on each other, this would provide a solid foundation for further development of students' skills in 3D software.

Technical University – Ruse: The design education at the Technical University – Ruse is unique with its specialization in Industrial Design. This program, established in 1991, is the first of its kind in Bulgaria, offering training and preparation in the field of design. The program focuses on broad–based interdisciplinary training aimed at developing creative individuals with high adaptability and competitiveness in the professional market. Students specializing in Design at the Technical University – Ruse have the opportunity to study in various areas such as visual communications, spatial/architectural design, information design, and industrial/product design. They acquire fundamental knowledge and skills at the bachelor's level, with the program also offering opportunities to continue towards a master's degree and doctorate. The curriculum includes courses related to CAD systems and 3D software such as Digital Design and CAD Systems, with 60 classroom hours during the fourth semester, Computer 3D Modeling and Animation in the sixth semester for 60 classroom hours, and Game Design and Virtual Reality, with 40 classroom hours in the eighth semester. The curriculum features a broad range of specific technologies studied across different disciplines, although the insufficient number of classroom hours raises concerns about the depth of knowledge acquired during these sessions.

Technical University – Varna: The design education at the Technical University – Varna focuses on the Industrial Design Program. This program offers students comprehensive training in various fields of design, including industrial and design engineering, techniques and technologies in applied arts, artistic design, fundamentals of marketing and advertising, computer modelling of industrial forms, automation of drafting and graphic activities, computer animation, and other related disciplines.

Students have the opportunity to choose from a variety of disciplines such as Household Appliance Design, Urban Environment Design, Industrial Product Design, Artistic Metal Casting, Ergonomic and Design Evaluation, Corporate Management, and more. The training in CAD systems and 3D software is conducted through the following courses: Fundamentals of Computer–Aided Design in the third semester, with 75 classroom hours; Computer 3D Design in the fourth semester, with 60 classroom hours, and ComputerAnimation in the fifth semester, with 60 classroom hours. Among the elective courses in the sixth semester, students can choose between Three–Dimensional Digitization and Computer–Aided Design, each with 60 classroom hours. Here, there is a broader range of study disciplines and slightly more classroom hours, which would contribute to better and more thorough mastery of the study material.

National Academy of Arts: The design education at the National Academy of Arts (NAA) in Sofia is highly diverse, covering various aspects of design. The academy offers specialized programs that prepare students for a wide range of professional fields in design and applied arts. NAA brings together instructors and courses in various specializations, including general education disciplines, drawing, and different areas of design. Students can study disciplines such as Graphic Design, which examines the aesthetic and semantic aspects of communication, as well as other specializations in Industrial Design, Interior Design, and more. Training in CAD/CAM systems and 3D software at NAA is conducted across several specialties. In the Industrial Design Program, students study discipline Computer–Aided Design for a total of 180 classroom hours, distributed across the second, third, fifth, seventh, and eighth semesters. Students in the Advertising Design Program also study discipline Computer–Aided Design but with a total of 195 classroom hours conducted throughout all semesters of their education. The discipline Computer–Aided Design is also part of the curriculum in the Porcelain and Glass Design Program (180 classroom hours), Child Environment Design Program (120 classroom hours as an elective and 60 hours as a mandatory course). In the master's Computer Games Program there is a course on Three–Dimensional Modelling, which includes 360 classroom hours. The Academy of Arts is one of the universities where 3D software is strongly emphasized, with the necessary number of classroom hours. In the bachelor's programs, it is a mandatory part of the curriculum for several semesters.

New Bulgarian University: The design education at New Bulgarian University (NBU) in Sofia is diverse and innovative, offering students the opportunity to develop their skills in various areas of design. NBU provides educational programs that cover different aspects of design, including Interior Design, Web Design, Graphic Advertising, Fashion, and Spatial Design. These programs are available for both undergraduate and graduate students. In this analysis of the curricula, we will focus on the Interior Design Program. In this program, the study of CAD systems and 3D software is covered by the following courses: Two–Dimensional Computer–Aided Design with 30 classroom hours in the fifth semester, Computer–Aided Design of Three–Dimensional Objects with 30 classroom hours in the sixth semester, and Computer–Aided Design of Three–Dimensional Spaces during the seventh and eighth semesters with 60 classroom hours. The curriculum includes a relatively small number of courses focusing on specialized software, and the relatively small number of classroom hours may not be sufficient to acquire the deep knowledge necessary for the successful presentation of design projects.

Considering the Current State of Engineering Design education in Bulgaria, the following points can be proposed for future development of training in CAD Systems, 3D Software, and Computer Visualization:

Development of Software Skills: The analysis of design program curricula shows an insufficient focus on modern, high–tech skills in CAD systems and computer modelling and visualization, favouring more outdated disciplines. This, on one hand, does not allow students to gain the necessary in–depth knowledge and, on the other hand, reduces their competitiveness. It is important to note that graduates from universities will increasingly enter the international labour market, where high–level preparation is essential.

Improving the Connection Between Education and Business: Strengthening ties with the design industry through joint projects and internship opportunities can provide students with real–world experience and industry insights.

Promoting Research Activities and Development of Academic Staff: Encouraging research in various aspects of 3D and CAD/CAM software would attract better specialists to join universities as researchers or lecturers.

APPLICATION AREAS OF MICROLEARNING IN ENGINEERING DESIGN EDUCATION

Microlearning in the context of Interior Design education in higher education institutions can be an innovative and effective teaching approach. Below are some application areas where microlearning can be particularly useful:

Reinforcement of Core Concepts and Principles in Interior Design: In comprehensive design education, fundamental concepts and parts of various disciplines, such as Color Theory, Composition Theory, or Form Development, can be broken down into smaller, easily understandable learning units. An example could be a short learning module focused on the use of colors in small spaces, utilizing practical examples and interactive tests to reinforce students' knowledge. This would aid in the assimilation of material and its practical application. Although there are no studies specifically focused on engineering design education, some authors discuss microlearning in the general context of education and professional development. De Gagne explores microlearning in health professions education, highlighting the positive impact of microlearning on students' knowledge and confidence in various medical disciplines (De Gagne 2019). Gill discusses the potential of microlearning in product design education post–COVID–19. While his article focuses on product design, it provides valuable insights for integrating microlearning into interior design education (Gill, 2020).

Development of Technological Skills: Working with various software products is part of the modern practice of designers. Creating project documentation, photorealistic models and visualizations, and software for controlling high–tech manufacturing machines are highly suitable for microlearning, as the modules can be used not only during initial training but also in subsequent practice when the designer needs information on a specific functionality at the right moment (just–in–time). (Cupita 2016)

Studying the Historical and Cultural Context of Interior Design: Courses that introduce students to the historical development of art and design would greatly benefit from the diverse content formats typical of microlearning. For example, material on Interior Styles can be enriched with infographics showing the main characteristic elements of a particular style. This can work in two ways: it helps students recognize different styles in practice and aids in creating projects in a specific style.

Introduction to Technologies and Materials in Furniture Design and Production: This encompasses a large group of courses that can leverage microlearning principles to help students more easily absorb the material and retain what they've learned for longer periods.

Project Management and Development of Communication and Teamwork Skills (Soft Skills): This group covers key topics such as project and team management, communication with clients and subcontractors, and teamwork. Microlearning can be used to break down these broader concepts into small, easily understandable modules. For example, creating training videos with examples of successful communication between a designer and a client or communication with subcontractors. Additionally, an interesting audio format could be used to create interviews with successful designers who share their practical experiences and advice with students.

MICROLEARNING IN SUPPORT OF THE LEARNING PROCESS IN COMPUTER VISUALIZATION

Computer Visualization is a complex discipline that encompasses various aspects of working with 3D software, such as modeling, camera composition, lighting, material creation, rendering, and animation. The combination of these complex topics, which students need to master, makes the use of microlearning methods particularly suitable for this discipline. The main advantages of this method can be effectively used to break down the material into small, comprehensible parts with a clear focus. This would help students overcome the challenges they face more easily while retaining the acquired knowledge for a longer period.

ISSUES AND CHALLENGES IN COMPUTER VISUALIZATION EDUCATION

Computer Visualization, as a rapidly evolving field, is an essential part of many industries, including gaming, film production, architecture, and design. Although technological innovations offer new opportunities, they also create a number of challenges and problems in the educational process of computer visualization:

Technological Changes and Rapid Curriculum Updates: One of the biggest challenges in computer visualization education is the need to continuously update curricula to keep pace with rapidly changing technologies. Technological innovations in computer visualization are developing at a fast pace, with each new software version or emerging technology potentially transforming industry practices and methods. Adapting curricula to the latest technological changes is a complex process that requires time and resources. Educators must constantly monitor industry trends and effectively integrate new knowledge into their courses in a timely manner. This requires ongoing professional development and frequent training for the instructors themselves. New technologies, such as Virtual and Augmented Reality (VR and AR), Machine Learning (ML) and Artificial Intelligence (AI), and Advanced Rendering Techniques, are changing how computer visualization is taught and practiced. Curricula must incorporate these innovations to prepare students for the real job market. To respond to these dynamic changes, curricula need to be flexible. This means shifting from traditional, strictly structured courses to more adaptive and modular programs that can be easily updated or modified in response to new developments in the field. Collaboration with companies and professionals in the field of computer visualization can help educational institutions adapt more quickly to technological changes. Partnerships can include guest lecturers from the industry, internship programs, and projects that provide students with practical experience with the latest technologies and practices.

Practical Skills vs. Theoretical Knowledge: One of the main issues in computer visualization education is finding the right balance between providing theoretical knowledge and developing practical skills. This field requires both a deep understanding of theoretical concepts and the ability to apply them in real projects. Theoretical knowledge is foundational for understanding the principles of computer visualization. This includes studying color theory, design principles, basics of 3D modeling, and even aspects of physics such as lighting and texturing. These insights are critical for developing critical thinking abilities and solving complex problems in the field. Equally important is that students have the opportunity to apply their theoretical knowledge in practical situations. This means working with different software platforms for computer visualization, undertaking real projects, and participating in workshops where they can experiment and learn from their mistakes. Practical skills are particularly important in this field, as they enable students to translate their theoretical knowledge into creative and technical solutions. Integrating theory and practice in the

curriculum is key. This can include courses that combine lectures with laboratory exercises and projects that require students to apply their theoretical knowledge to real–world scenarios. Ideally, these projects would be related to real industrial applications, thereby providing students with both academic knowledge and practical experience. Integrating theory and practice in the curriculum is key. This can include courses that combine lectures with laboratory exercises and projects that require students to apply their theoretical knowledge to real–world scenarios. Ideally, these projects would be related to real industrial applications, thereby providing students with both academic knowledge and practical experience.

Access to Resources and Equipment: One of the key challenges in computer visualization education is ensuring adequate resources and equipment, which are essential for effective learning and skill development in this field. Computer visualization requires high–performance computer systems, specialized software, and often expensive equipment such as graphic tablets and VR devices. This equipment is necessary for performing complex tasks like 3D modeling, animation, and rendering. Updating and maintaining these resources can be financially burdensome for educational institutions, especially given the fast pace of technological change. Students often face the challenge of limited access to the necessary resources outside of the educational institution. This can include financial constraints in purchasing needed software and equipment, as well as a lack of access to specialized labs outside lecture times. This situation can limit opportunities for practice and skill development for students. To overcome these challenges, educational institutions can seek alternative strategies to reduce costs. This may include partnerships with software companies to provide licenses at student prices or even for free. Additionally, schools can invest in shared resources and equipment that are accessible to all students. The use of virtual labs and cloud technologies also presents a potential solution. These can offer students access to high–performance computing resources and specialized software without the need for investment in expensive equipment. This can be especially beneficial for educational institutions with limited financial resources.

Maintaining Motivation and Engagement: Maintaining student motivation and engagement is critical for success in the field of computer visualization, which is highly dynamic and requires continuous learning and skill enhancement. Diversity in teaching methods can significantly impact student motivation. Personalized learning plans that consider individual interests and strengths can improve engagement and stimulate interest. This includes providing opportunities for course selection, specialized modules, or project tasks that align with students' specific interests and career goals.

Including project–based exercises and real–world case studies in the curriculum can significantly increase student engagement. Working on real projects with practical applications helps students understand how theoretical knowledge can be applied in the real world. It also allows them to develop valuable skills in teamwork, time management, and problem–solving. Active learning methods such as group discussions, workshops, and interactive lectures can increase student engagement. These approaches allow students to be active participants in the learning process, thereby stimulating interest and participation. Interactive technologies such as virtual reality and gamification can also be incorporated into the curriculum to enhance engagement. Regular and constructive feedback from instructors is essential for maintaining student motivation. The ability to receive personalized feedback and guidance helps students understand their strengths and weaknesses and work towards improvement. Additionally, the presence of support systems such as mentoring programs and student clubs can encourage collaboration and provide additional motivation and support.

INTEGRATING MICROLEARNING INTO COMPUTER VISUALIZATION EDUCATION

Integrating microlearning into computer visualization education can contribute to a more dynamic and engaging learning experience that promotes self–directed learning, critical thinking, and creativity. By utilizing various formats and platforms, microlearning offers an adaptive and flexible approach to education that can be easily integrated into different educational contexts and programs. This allows educators to provide updated and relevant content that reflects the latest trends and developments in the field of computer visualization.

Content Formats and Techniques in Microlearning for Computer Visualization

The diversity of content formats in microlearning provides a rich set of tools for education in computer visualization. This approach not only facilitates the acquisition of complex technical skills and theoretical knowledge but also offers flexibility and adaptability, which are crucial in modern education and professional development (Torgerson 2022).

Video tutorials are one of the most popular formats in microlearning, especially in the field of computer visualization. They provide visually rich content that can include software demonstrations, modeling techniques, and animation.

Process Demonstrations: Video tutorials that show the detailed creation of 3D models, step–by–step animation processes, or demonstrate complex rendering techniques. For example, a short video explaining the use of different types of light sources in 3ds Max and V–ray.

Tips and Tricks from Professionals: Short videos where professionals share their unique techniques and industry secrets, such as how to create realistic textures or optimize lighting in a scene. The highly popular vertical video format, prevalent on modern social networks, can be used here. This could potentially allow the educational material to be uploaded to these platforms, attracting a wider audience and increasing the popularity of computer visualization.

Interactive Modules in E–Learning Systems include educational materials that require active participation from students, such as interactive tasks, simulations, and tests. This usually involves using e–learning platforms that can provide the additional functionality needed to create interactive modules.

Virtual Simulations: Interactive simulations that allow students to experiment with different aspects of 3D modeling and visualization, such as changing lighting and textures in real–time.

Gamified Learning Platforms: Using gamified platforms where students face challenges and tasks related to computer visualization, such as creating a specific animation effect within a time limit or integrating a test at the end of the module to monitor students' knowledge, allowing them to compete based on their results.

Infographics are particularly useful for presenting theoretical principles, algorithms, or visualization processes, thereby supporting visual learning.

Schematic Process Representation: Infographics that visualize the process of 3D modeling or the step–by–step development of an animation project. For example, a schematic representation of the workflow in computer animation.

Educational Posters: Visually attractive posters that summarize key concepts or show different visualization and design styles.

Short Articles and Blog Posts are ideal for explaining theoretical aspects, the history of technologies, and the latest trends in the computer visualization industry.

Short Articles: These can cover new trends in computer visualization, such as the use of artificial intelligence to create visual content.

Blog Posts from Experts: Posts by leading professionals in the field who share their opinions and experiences on the development of computer visualization, career advice, or reviews of new software tools.

Podcasts and Audio Lectures – although computer visualization is highly visually oriented, audio formats such as podcasts and audio lectures are convenient for learning on the go and offer an alternative way to absorb information.

Interviews with Professionals: Podcasts where leading experts in computer visualization share their experiences and views on the future of the industry.

Discussion Panels: Audio recordings of discussions and panels that cover current topics in computer visualization, such as new technological breakthroughs or ethical aspects in digital art.

Application of Microlearning in Computer Visualization Educational Programs

Integration into Course Programs

Microlearning can be integrated into course programs in various ways to enrich and complement traditional teaching methods:

As a Supplement to Lectures: Microlearning modules can serve as pre–lecture or post–lecture training for students, preparing them for new topics or reinforcing what has been learned in class. For example, a short video explaining the basics of texturing can be presented before a practical lesson on the same topic. Esin (2019) examines the effectiveness of using training lectures in mathematics e–courses, suggesting approaches to integrating microlearning into course programs to enhance students' grasp of theoretical material.

For Self–Directed Learning: Providing microlearning resources as part of the course's online platform allows students to expand their knowledge and skills at their convenience and at a pace that suits their individual needs. Draxler's (2022) study is interesting in this context, exploring ways to increase learner engagement through smart reminders synchronized with their daily tasks.

Maintaining Engagement and Motivation

Gamification in Learning: Incorporating gamification and game elements into microlearning can significantly enhance student engagement and motivation. Organizing design or animation competitions where students can win prizes or receive recognition for their skills stimulates their participation and encourages their creativity.

Personalized Learning: Microlearning allows for easy personalization of the learning process. Students can choose specific learning modules that match their interests and areas for improvement. This enables more targeted and effective learning.

Development of Specialized Skills

Focus on Key Techniques and Technologies: Microlearning modules can focus on specific techniques and technologies important for computer visualization, such as advanced use of 3D modeling software or techniques for realistic rendering. This allows students to develop specialized skills valuable in the job market.

Project–Based Learning: Integrating microlearning modules within larger project tasks allows students to apply what they have learned in practice. This helps them develop a comprehensive understanding of processes in computer visualization and hone their skills through real projects.

CONCLUSION

Engineering Design is a field that constantly evolves with new technologies and methods. Microlearning enables the rapid updating and delivery of educational content that reflects the latest changes in the industry, helping students and professionals stay current. Microlearning is particularly effective for acquiring specific skills or knowledge in the field of engineering design. Short and focused sessions can concentrate on specific tools, software, or techniques, thereby enhancing the learning process and knowledge retention. The interactive nature and variety of microlearning formats can significantly boost student engagement and motivation. Using videos, quizzes, and interactive exercises makes learning more enjoyable and engaging, which is critical for the effective assimilation of complex engineering concepts.

REFERENCES

DILLON, JD. 2018. Microlearning: The Ultimate guide [Онлайн] Достъпно на: https://axonify.com/en–uk/microlearning/#definition [Прегледано на 3 декември 2023г.].

DRAXLER, F. 2022. Agenda– and Activity–Based Triggers for Microlearning. 27th International Conference on Intelligent User Interfaces. https://doi.org/10.1145/3490099.3511133.

FITRIA, T. 2022. Microlearning in Teaching and Learning Process: A Review, CENDEKIA: Jurnal Ilmu Sosial, Bahasa dan Pendidikan, 2(4), pp. 114–135. doi: 10.55606/cendikia.v2i4.473.

HAMZAH, A. 2021. Determinant Factors and Adaptation Features of Mobile Personalized Learning System Journal of Physics: Conference Series DOI:10.1088/1742–6596/1858/1/012008.

HUG, T. 2006. Microlearning: A New Pedagogical Challenge. 7–11. Достъпен онлайн на: https://www.researchgate.net/publication/272178142_Microlearning_A_New_Pedagogical_Challenge [Прегледано на 28 ноември 2023г.].

KAPP, K., R. DEFELICE. 2019. Microlearning: Short and Sweet, Alexandria, Virginia: Association for Talent Development.

KOVACHEV, D., Y. CAO, R. KLAMMA, M. JARKE. 2011. Learn–as–you–go: New Ways of Cloud–Base Micro–learning for the Mobile Web Information Systems and Databases, RWTH Aachen University, Ahornstr. 55, 52056 Aachen, Germany.

REDONDO, R., M. RODRIGUEZ, J. ESCOBAR. 2020. Integrating micro–learning content in traditional e–learning platforms Multimedia Tools and Applications https://doi.org/10.1007/s11042–020–09523–z.

SHATTE, A., & TEAGUE, S. 2020. Microlearning for improved student outcomes in higher education: A scoping review. https://doi.org/10.31219/osf.io/fhu8n.

TROTSENKO, L. 2019. Using video materials in electronic learning courses. OPEN EDUCATIONAL E–ENVIRONMENT OF MODERN UNIVERSITY. https://doi.org/10.28925/2414–0325.2019s34.

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OPPORTUNITIES FOR INTEGRATING MICROLEARNING INTO MODERN EDUCATION TO INCREASE THE EFFECTIVENESS OF THE LEARNING PROCESS

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ABSTRACT

The report explores the transformative potential of integrating microlearning into contemporary education as a strategy to amplify the effectiveness of the learning process. Microlearning, defined by its delivery of concise, targeted learning experiences designed to achieve specific objectives, aligns well with the dynamic and digitally oriented landscape of modern education. This paper outlines the theoretical underpinnings of microlearning, emphasizing its role in facilitating enhanced engagement, improved retention rates, and personalized learning pathways.

The study presents empirical evidence supporting the efficacy of microlearning in diverse educational contexts, ranging from higher education to professional training. It showcases innovative case studies where microlearning modules have been successfully integrated into traditional and digital learning environments, resulting in notable improvements in student performance and satisfaction. The investigation also highlights the critical role of technology in microlearning, including mobile apps, online platforms, and multimedia resources, which enable flexible, on–demand learning experiences. The report also focuses on the ways that microlearning can be combined with other innovative education concepts, like Project Oriented Learning, Gamification, Flipped Classroom etc. to enhance the learning experience and yield a better outcome.

However, the paper addresses directly the challenges associated with microlearning's implementation, such as potential content oversimplification and the necessity of a robust instructional design to ensure comprehensive coverage of complex topics.

By providing a balanced perspective on microlearning's opportunities and challenges, this paper contributes valuable insights to the ongoing discourse on educational innovation, proposing microlearning as a viable tool for enhancing learning effectiveness in the 21st century.

Key words: Microlearning, Project Oriented Learning, Gamification, Flipped Classroom, Blended Learning.

INTRODUCTION

Microlearning, also known as „micro teaching“ or „micro educational units,“ is a learning process that breaks down information into small, specific, and easily digestible units (Hug, 2006). This approach to learning focuses on providing short, concentrated information aimed at achieving a specific learning outcome. With the increase in information flow and the advent of digital technologies, users seek more effective and flexible learning methods. In this context, microlearning offers an ideal solution by focusing on short and specific learning units that can be consumed at a convenient time for the learner. Microlearning differs from traditional methods not only in length but also in approach. It focuses on a specific topic or skill, providing information in a way that is immediately applicable. Tipton (2017) makes an important clarification that by breaking down information into smaller parts for easier absorption, we do not aim to make the learning superficial just to fit the shorter format. On the contrary, we strive to achieve deeper understanding and retention of information.

Microlearning is effective because:

Facilitates Information Absorption: Microlearning can help students by delivering educational content in smaller, easier–to–absorb segments, typically lasting from 2 to 15 minutes. This quality of microlearning makes it effective for maintaining engagement, especially in the context of online and remote learning, as it addresses the challenge of keeping students focused and attentive.

Improves Learning Ability: One research concludes that microlearning methods led to an 18% improvement in learning compared to traditional methods, and students displayed a high level of motivation and interest in the microlearning tools used (Sirwan Mohammed, 2018).

Enhances Retention of Acquired Knowledge: Microlearning helps improve the retention of acquired knowledge by leveraging psychological principles related to memory and learning. Ebbinghaus's 1880 „forgetting curve“ theory posits that memory retention declines over time (Ebbinghaus, 1885). This suggests that new information is forgotten over time unless efforts are made to retain it. The process of reviewing material creates stronger neural network connections in the brain and transfers memory from short–term to long–term. By repeatedly using the modules from the microlearning system, the retention level can reach early levels or at least plateau (avoiding a downward curve).

Microlearning Reduces Mental Fatigue: Microlearning engages learners by using smaller and specific learning objectives. The brief duration of microlearning content reduces the mental fatigue caused by longer lessons. Students can quickly experiment, grasp the key concept, and take a break.

The ability of microlearning systems to adapt can be utilised to enhance the modern teaching methods, especially in the field of higher education. The goal of this paper is to explore the possibilities of this blend and find the potential benefits for both students and teachers.

MODERN TEACHING METHODS AND THEIR COMBINATION WITH MICRO–LEARNING TO INCREASE THE EFFECTIVENESS OF THE LEARNING PROCESS.

An effective curriculum relies on a variety of methodologies and approaches to meet the different learning styles and needs of students. Modern teaching methods have evolved significantly in recent years, adapting to the dynamic needs of learners across all age groups. These methods combine traditional pedagogical techniques with innovations in technology and psychology to enhance the educational process. The potential of each method can be expanded by combining it with the principles of microlearning to achieve greater efficiency in the learning process.

BLENDED LEARNING

Blended Learning is an approach that combines traditional classroom instruction with online educational materials and opportunities for interactive online activities. This method allows students to have some control over the pace, time, and place of their learning. It is particularly effective as it caters to different learning styles and paces, offering a more personalized education.

The main advantages of blended learning are:

Flexibility – Blended learning allows for a flexible approach to education by integrating both in–person and online components, giving students the opportunity to engage with learning activities at their own pace (Deschacht, 2015; Garrison, 2004).

Improved Student Performance – Research shows improved exam results and positive outcomes due to the introduction of blended learning, with some studies reporting better test scores and potential for increased learning efficiency (Deschacht, 2015).

Resource Optimization – Blended learning facilitates the efficient use of educational resources, leading to a higher rate of course completion, better student attitudes toward the subject, and increased satisfaction with the learning method (Deschacht, 2015; Garrison, 2004).

Adaptive Learning Environments – Blended learning environments are adaptive and can meet various learning requirements, such as in–person meetings and community building at the beginning of a course, followed by asynchronous online discussions toward the end of the course (Afacan, 2016).

The main disadvantages of blended learning can be identified as:

Inconsistent Learner Performance – Some studies indicate a negative impact on learner performance when using online and blended learning methods.

Higher Dropout Rates – According to Deschacht (Deschacht, 2015), the dropout rate for students is higher in blended learning compared to traditionally conducted courses.

Technological Challenges – The use of various online platforms requires both teachers and students to have the necessary skills to work with them (Afacan, 2016).

Need to Revise Existing Curricula – The hybrid nature of blended learning necessitates the revision of existing curricula to adapt to both in–person and remote learning sessions.

Benefits of Combining Blended Learning and Microlearning:

Flexible Learning Program – Blended learning easily incorporates microlearning methods to enrich the program and adapt it to the individual needs of learners (Kovachev, 2011). The concept of a flexible learning program is part of learner–centered education principles, aiming to provide personalized learning that meets the unique needs of students. These flexible programs can adapt to different learning styles, cultural backgrounds, and prior knowledge, supporting a more inclusive and adaptable approach to education.

On–Demand Learning – Integrating microlearning elements in a blended learning environment allows students to access learning materials „on–demand“ – they are always available online and can be reviewed when needed, with the materials being short and focused on specific parts of the content. This way, the learning program can be tailored to the individual needs of students (Redondo, 2020). Additionally, on–demand learning is typically accessible via various devices such as mobile phones, tablets, and laptops, enabling students to have immediate access to information whenever needed, regardless of location – for example, during practical training (Lee, 2021).

Engagement and Information Retention – In her article, Cupita (2016) emphasizes the importance of engagement in the learning process, focusing on the interest, enjoyment, and enthusiasm of learners towards educational activities. She highlights how investing time in expanding knowledge can promote engagement before and during lessons, ultimately facilitating the learning process. These insights can be applied to microlearning strategies to improve learner engagement. Additionally, the previous topic in this paper discussed the benefits of microlearning on learners' ability to retain information, which would make learning more effective.

FLIPPED CLASSROOM

The flipped classroom model is characterized by swapping activities traditionally conducted during class time with those typically associated with homework. This approach is more interactive and allows for the acquisition of practical knowledge, with the role of teachers being more supportive and facilitative. In his book „Flip Your Classroom“, Jonathan Bergmann describes the model as reversing the learning process— theoretical material is presented before class, often in the form of pre–recorded video lessons or online resources, while class time is used for practical exercises,

discussions, and personalized teacher–student interactions (Bergmann, 2012). With this method, part of the theoretical knowledge is taken out of the time slots, normally allocated for it during the lectures and seminars, which allows the students to focus on more teacher assisted practice and can compencate for potentialy low number of lectures and seminars in the curriculum.

The main advantages of the flipped classroom method are:

Improved Student Engagement – The flipped classroom stimulates increased motivation and engagement among students, as reported in a study where students preferred this method over traditional strategies (Gilboy, 2014).

Enhanced Academic Performance – A study by González–Gómez (2016) found that students taught using the flipped classroom method demonstrated better academic performance compared to those in traditional settings.

Increased Interaction and Personalized Learning – The flipped learning model promotes more interaction between teachers and students and allows for personalized learning experiences (Evans, 2018).

Flexibility in Learning – Students have the flexibility to engage with lecture material at their own pace, which can be particularly beneficial and support diverse learning styles (Hwang, 2015).

The disadvantages of the method are:

Technological Challenges – The requirement for students to have access to technology and the internet can be a barrier to the successful integration of the method.

Increased Preparation Time for Learning Materials – Teachers may need to invest a significant amount of time in preparing and recording lectures and integrating them into classroom activities (Bergmann, 2012).

Potential Reduction in Classroom Interaction – Some studies indicate a potential decrease in student–teacher interaction, especially outside the classroom, which can impact the learning process (Taşpolat, 2021).

Issues with Student Discipline – There is a risk that students may not prepare before class, which can undermine the effectiveness of in–class activities (Moran, 2015).

Benefits of Combining the Flipped Classroom Method and Microlearning:

Integrating Microlearning into the Flipped Classroom model can enhance its effectiveness in various ways. Microlearning involves breaking down information into small, manageable parts, which can be especially beneficial in a flipped classroom environment. Here’s how this integration can be advantageous:

Facilitates Self–Preparation – A study on the Flip2Learn language learning system highlights that such integration not only better prepares students for flipped classrooms but also promotes academic achievement by enhancing self–regulation skills (Shyr, 2018).

Increases Engagement and Improves Student Performance – Using microlearning elements, such as multimedia lectures with embedded questions, in a flipped classroom has been shown to improve student outcomes and engagement, as demonstrated in a large–scale study of a principles of microeconomics course (Vazquez, 2015; Hong–li, 2015).

Improves Quality – The integration of microlearning and flipped classroom methods has been proposed as a means to enhance the quality of the educational process. Zhang provides an example with college–level English teaching. This approach involves effective time management before and during the lesson, as well as increased interaction inside and outside the classroom (Zhang, 2017).

PROJECT BASED LEARNING (PBL)

The dynamic approach characteristic of project–based learning (PBL) allows university students to work on projects similar to those in real–world practice. Typically, students work on one large project over an extended period, aiming to develop critical thinking skills and deeper knowledge in a specific area. This method of learning is effective in maintaining high student motivation and engagement. Here are the main characteristics and advantages of PBL as described in various studies:

Teacher–Student Interaction – PBL places significant emphasis on the interaction between students and teachers. Instead of imposing their authority, teachers respect students' opinions and primarily guide them in their projects and research endeavours (Angelova et al., 2019).

Improved Learning Outcomes – It has been found that PBL is significantly more effective in science education compared to traditional teaching approaches, with high effectiveness in improving academic achievements across various subjects (Angelova et al., 2019; Balemen, 2018).

Improvement of Critical Thinking Skills – PBL is considered effective in enhancing critical thinking skills. This includes cognitive processes such as analysis, problem evaluation, and problem–solving (Billah, 2019; Raycheva et al., 2016;).

Facilitation of Group Learning – PBL classes often involve team–based activities, emphasizing the importance of cooperative learning. Teams that perform better in PBL exhibit certain characteristics such as communication skills, which are critical for successful collaborative learning (Hayama, 2014).

Development of Practical Skills – PBL is particularly effective in vocational and technical education as it focuses on practical skills and real–world applications (Angelova et al., 2019; Raycheva et al., 2016).

Enhancement of Self–Improvement – PBL has shown a positive impact on students' self–improvement, especially in engineering education. Students in a PBL system demonstrate a higher level of efficacy in engineering design (Chen, 2015).

Support of Learning Through Technology – Technology can play a supportive role in PBL, helping to maintain motivation and thought processes. It can support students and teachers while working on projects, allowing for a diversification of learning materials and improvement of the learning process (Blumenfeld, 1991).

The main disadvantages of PBL can be identified as:

Limited Effectiveness in Certain Disciplines – In disciplines that require precision, such as statistics, mechanics, or structural analysis, PBL may fail to convey the fundamental knowledge necessary for students to understand the material (Patnaikuni, 2016). This makes the method more suitable for subjects where practical training is part of the learning process, such as education in computer visualization.

Requires Significant Investment of Time and Resources – PBL requires considerable investment of time from both students and teachers. Additionally, the operational costs to maintain this teaching method can be quite high, which is problematic for educational institutions suffering from a lack of funding. This fact may limit the cost–effectiveness of implementing the PBL method (Noviansyah, 2020).

Ensuring Teamwork – Rodriguez–Sanchez points out in his research that simply implementing PBL does not guarantee successful teamwork. The proposed solution to this problem is to familiarize students with best practices for teamwork from real life to improve dynamics in study teams. This

way, students can become familiar with real–world requirements, making teamwork in education more effective and meaningful (Rodríguez–Sánchez, 2016).

Dependence on Student Motivation – The success of PBL is highly dependent on student motivation and autonomy. Maintaining high motivation to work on project–based tasks is challenging, especially in fully remote learning. This dependence on personal motivation can lead to uneven performance and results among different student groups (Raycheva et al., 2016; Wahyuni, 2022).

Challenges of Integrating Content into Online Platforms – Transitioning PBL–based systems, such as during the Covid–19 pandemic, poses numerous challenges for students and teachers. This includes difficulties with practical tasks and student engagement in a virtual environment (Hidayah, 2021).

Risk of Inadequate Knowledge Acquisition – In some technically oriented disciplines, where both practical knowledge and fundamental theoretical preparation are necessary, it is important that the program is balanced to meet both requirements. This ensures that the education students receive is comprehensive (Milentijevic, 2007).

Combining microlearning with PBL can lead to the following benefits:

Improved Acquisition of New Skills – The microlearning system developed by Skalka (2017) in the field of programming shows how microlearning can enhance skill development in PBL. This system integrates a web–based learning environment with microlearning, leveraging the benefits of instant feedback that the environment allows for acquiring new skills. The study also focuses on creating an online student community and gamification elements (which will be discussed in the next section of this paper), which are effective in increasing engagement, especially for younger students. Microlearning also helps keep students motivated, which, as discussed above, is crucial for the success of PBL.

Enhances Knowledge Transfer – Beste's (2021) study on the role of microlearning in PBL examines its cost–effectiveness. The research shows that microlearning makes knowledge transfer more systematic by providing a shared knowledge base for all project teams. It indicates that microlearning can be used to share knowledge on various PBL topics, demonstrating its potential for broad application. This approach to learning ensures that all team members have access to the same information, which is critical for the collaborative and integrative nature of PBL.

Supports Different Learning Styles – Fitria (2022) explores the flexibility of microlearning in accommodating different learning styles and its ability to personalize. The study highlights how microlearning can be tailored to meet the individual needs of learners in PBL. Breaking content into smaller parts makes it easier for students to choose learning materials that are appropriate and desired at that moment, thereby increasing engagement and retention of knowledge. This adaptability is particularly useful in PBL, where learners may need to explore different aspects of a project based on their roles and interests.

An example of PBL integrated into the curriculum of the Engineering Design (Interior and Furniture Design) Program at the University of Forestry is the so–called Project Week Module, in which students work in teams on a problem set by a mentor (a company sponsoring the module) that requires a design solution. As the module's title suggests, it lasts for a week, during which students go through all the steps of developing and designing a concept. Its short duration and the focused work on a single problem align this project with the principles of microlearning (Raycheva, 2020). The analysyss of the group dynamics and the outcomes of this PBL implementation are extensivly

discussed in the article *Project–based learning in engineering design in Bulgaria: expectations, experiments and results* (Raycheva et al., 2016) and show the positive feedback, received from students.

GAMIFICATION

Gamification involves the strategic application of game principles and mechanics in a non–game environment with the goal of improving the learning process, engagement, and motivation. It can include point systems, levels, rewards, and other game mechanisms that encourage learners to progress (Deterding, 2011). Gamification in the context of higher education should not be viewed so much as a method of teaching the material, but rather as a set of techniques for applying the engaging aspects of games – such as challenges, competitions, rewards, and interaction – to educational activities. This approach aims to make learning more appealing, increase motivation, and improve retention and understanding of the educational material.

We can identify the following key elements of gamification, which can be combined in various ways depending on the desired outcome:

Point Systems – Points are awarded for completing tasks or achieving certain results, serving as a quantitative measure of progress or success. This can motivate students to continue participating in the learning process, similar to accumulating points in a game, which encourages continued play.

Levels and Progress – By structuring tasks or learning modules into levels, students can visually see their progress. Each level typically represents a more advanced stage of understanding or skill, providing a clear path for progress and achievement.

Badges and Rewards – These are tools for visually representing achievements and milestones. Badges can be displayed in students' profiles within learning management systems, serving both as a reward and a visible symbol of accomplishment.

Challenges and Tasks – Incorporating these elements adds an aspect of adventure and problem–solving to the learning process. Challenges can be individual or group activities that require critical thinking, application of knowledge, or creative solutions.

Leaderboards – They encourage healthy competition by displaying rankings based on points or achievements. Leaderboards can motivate students to strive for higher scores, but they should be used wisely to avoid discouraging less competitive or lower–performing students.

Immediate Feedback – Providing quick feedback on tasks and tests can maintain student engagement and help them understand their learning progress. Immediate feedback mechanisms are essential for sustaining learning momentum and motivation.

Storytelling – Using elements of storytelling can help students engage better with the material. Stories can provide context for learning materials, making them more memorable and enjoyable.

Freedom to Make Mistakes – Gamification allows students to experiment and learn from their mistakes without serious consequences. This encourages exploration and innovation in learning.

Social Engagement – Encouraging interaction among students through discussion forums, group challenges, and peer assessments can enhance the learning process. Social elements can create a sense of community and collaborative learning.

Several studies outline several key benefits of integrating gamification into the learning process:

Increased Student Engagement and Motivation – Gamification is effective in boosting student engagement and motivation, particularly in business courses. It transforms traditional learning material into something more interactive and enjoyable, which can lead to better attendance and more active participation in learning activities. The use of game elements, such as points, badges, and

leaderboards, can make learning more connected and engaging for students, creating a more dynamic learning environment. However, it is important that these elements are adapted to the educational content to ensure that they enhance rather than distract from the learning objectives (Pham, 2021).

Improved Learning Efficiency – The application of gamification, for instance through platforms like Kahoot!, has shown a positive impact on student motivation and learning efficiency. This approach can help with better retention of information and facilitate a deeper understanding of complex subjects. Gamified learning sessions are often more memorable and can encourage students to engage more deeply with the material. However, the effectiveness of gamification can vary depending on how well it is integrated into the curriculum and whether it aligns with the students' learning styles and preferences (Pham, 2021).

Development of Practical Competencies – Gamification can encourage the development of practical competencies in students. By incorporating game elements into assessments, students may find the learning process more engaging and less intimidating. This can lead to a better understanding of the real–world applications of their knowledge and skills. However, it is essential to ensure that these gamified assessments accurately measure the intended learning outcomes and maintain academic rigor (Spathopoulou, 2018).

Alongside the presented advantages, there are several key disadvantages of gamification and its implementation in education:

Decreased Motivation Over Time – Although initial engagement with gamified elements can be high, evidence suggests that this motivation can decrease over time. This indicates that the novelty of gamification may wear off, and students might respond more negatively to these elements as the course progresses. It is important for educational professionals to adapt their gamification strategies to maintain student interest and motivation throughout the entire course duration (Furdu, 2017).

Challenges in Implementation – The successful integration of gamification in education faces several challenges, including resource limitations, student apathy, and the proper incorporation of gamification into the curriculum. Educators may require additional training and resources to effectively implement gamified learning strategies. Additionally, there is a risk that gamification could be perceived as trivializing the learning material if it is not carefully designed and aligned with educational goals (Sánchez–Mena, 2017).

Insufficient Evidence for Long–Term Benefits – The long–term benefits of gamification in the educational context remain uncertain, with limited empirical evidence supporting sustained academic improvement. Research in this area is still evolving, and more rigorous, long–term studies are needed to determine the effectiveness of gamification in improving learning outcomes over time. It is important for educators to critically assess the impact of gamification and understand its potential limitations within the context of higher education (Dichev & Dicheva, 2017).

CONCLUSION

Microlearning is a powerful and flexible educational tool that meets the needs of modern learners and working professionals. Microlearning can be integrated into various educational environments – from traditional classrooms to online platforms and mobile applications. It supports personalized learning, allows for rapid updates of educational content, and facilitates continuous learning in the workplace. Microlearning can take various formats, including short videos, interactive exercises, infographics, quizzes, and e-books. The choice of format depends on the target audience and specific learning objectives. It offers an effective means of overcoming challenges related to information overload and decreased concentration, which are common with the intensive use of smartphones and

social networks. When applied correctly, microlearning can significantly improve the quality of education and support the development of skills and knowledge in various fields.

REFERENCES

ANGELOVA D., R. RAYCHEVA, R. CHIPEV. 2019. Student Workshop: Creativity in Progress. Proceedings of International Conference „Wood Science and Engineering in the Third Millennium"– ICWSE 2019, 7–9, November 2019, Transylvania University, Brasov, Romania, Volume 2, ISSN 1843–2689, pp. 549–557.

AFACAN, Y. 2016. Exploring the effectiveness of blended learning in interior design education, Innovations in Education and Teaching International, DOI:10.1080/14703297.2015.1015595.

BALEMEN, N., M. KESKIN. 2018. The effectiveness of Project–Based Learning on science education: A meta–analysis search. International Online Journal of Education and Teaching (IOJET), 5(4), 849–865. http://iojet.org/index.php/IOJET/article/view/452/297.

BERGMANN, J., A. SAMS. 2012. Flip your classroom: reach every student in every class every day. International Society for Technology in Education ISBN 978–1–56484–315–9.

BESTE, T. 2023. Knowledge Transfer in a Project–Based Organization Through Microlearning on Cost–Efficiency, The Journal of Applied Behavioral Science2023, Vol. 59(2) 288–313 DOI: 10.1177/00218863211033096.

BILLAH, A., U. KHASANAH, S. WIDORETNO. 2019. Empowering higher–order thinking through project–based learning: A conceptual framework. The 2nd International Conference on Science, Mathematics, Environment, and Education AIP Conf. Proc. 2194, 020011–1–020011–7; https://doi.org/10.1063/1.5139743.

BLUMENFELD, P., E. SOLOWAY, R. MARX. 1991. Motivating Project–Based Learning: Sustaining the Doing, Supporting the Learning, Educational Psychologist, 26:3–4, 369–398, DOI: 10.1080/00461520.1991.9653139.

CHEN, P., A. HERNANDEZ, J. DONG. 2015. Impact of collaborative project–based learning on selfefficacy of urban minority students in engineering. Journal of Urban Learning Teaching and Research, 2015 Vol.11, pp. 26–39.

CUPITA, L. 2016. Just in Time Teaching: A Strategy to Encourage Students' Engagement HOW Vol. 23, No. 2, July/December 2016, ISSN 0120–5927.

DESCHACHT, N., K. GOEMAN. 2015. The effect of blended learning on course persistence and performance of adult learners: A difference–in–differences analysis, Computers & Education, Volume 87, Pages 83–89, ISSN 0360–1315, https://doi.org/10.1016/j.compedu.2015.03.020.

DETERDING, S., D. DIXON. 2011. From game design elements to gamefulness: defining „gamification". Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments. https://doi.org/10.1145/2181037.2181040.

DICHEV, C., D. DICHEVA. 2017. Gamifying education: what is known, what is believed and what remains uncertain: a critical review. International Journal of Educational Technology in Higher Education, 14, 1–36. https://doi.org/10.1186/s41239–017–0042–5.

EBBINGHAUS, H. 1885. Memory: A Contribution to Experimental Psychology. Teachers College, Columbia University, New York.

EVANS, L., M. BOSCH, S. HARRINGTON. 2018. Flipping the Classroom in Health Care Higher Education, Nurse Educator, Vol. 44, No. 2, pp. 74–78, DOI:10.1097/NNE.0000000000000554.

FITRIA, T. 2022. Microlearning in Teaching and Learning Process: A Review, CENDEKIA: Jurnal Ilmu Sosial, Bahasa dan Pendidikan, 2(4), pp. 114–135. doi:10.55606/cendikia.v2i4.473.

FURDU, I., C. TOMOZEI. 2017. Pros and cons gamification and gaming in classroom. ArXiv, abs/1708.09337.

GARRISON, D. R., & KANUKA, H. (2004). *Blended learning: Uncovering its transformative potential in higher education.* The internet and higher education, 7(2), 95–105.

GILBOY, M., S. HEINERICHS, G. PAZZAGLIA. 2014. *En*hancing Student Engagement Using the Flipped Classroom. Journal of Nutrition Education and Behavior http://dx.doi.org/10.1016/j.jneb.2014.08.008.

GONZÁLEZ–GÓMEZ, D., D. RODRÍGUEZ. 2016. Performance and Perception in the Flipped Learning Model: An Initial Approach to Evaluate the Effectiveness of a New Teaching Methodology in a General Science Classroom. J Sci Educ Technol DOI 10.1007/s10956–016–9605–9.

HAYAMA, T. 2014. Analysis of Team Characteristics of Project–Based Learning based on Performance Factors of Collaborative Learning. 2014 IIAI 3rd International Conference on Advanced Applied Informatics DOI 10.1109/IIAI–AAI.2014.64.

HIDAYAH, N., A. ARUM. 2021. Project–Based Learning (PjBL): Advantages, Disadvantages, and Solutions to Vocational Education (in Pandemic Era), ICLSSE 2021, September 09, Singaraja, Indonesia 2021 EAI DOI 10.4108/eai.9–9–2021.2313669.

HUG, T. 2006. Microlearning: A New Pedagogical Challenge. 7–11. [Online] https://www.researchgate.net/publication/272178142_Microlearning_A_New_Pedagogical_Challenge [Accessed on 28th November 2023].

HWANG, G., C. LAI1, S. WANG. 2015. Seamless flipped learning: a mobile technology enhanced flipped classroom with effective learning strategies. J. Comput. Educ. DOI 10.1007/s40692–015–0043–0.

KOVACHEV, D., Y. CAO, R. KLAMMA, M. JARKE. 2011. Learn–as–you–go: New Ways of Cloud–Base Micro–learning for the Mobile Web. Information Systems and Databases, RWTH Aachen University, Ahornstr. 55, 52056 Aachen, Germany.

LEE, Y. 2021. Digital Skills of Mobile Journalists: Exploring Learning Needs and Learner Experiences of Just–in–Time Learning with Smartphones. Journalism and Mass Communication Educator 10.1177/10776958211001692.

MILENTIJEVIC, I., V. CIRIC P. 2007. Project–based learning environment for special purpose dsp architectures. 9th International Symposium on Signal Processing and Its Applications. doi:10.1109/isspa.2007.4555499.

MORAN, K., A. MILSOM. 2015. The Flipped Classroom in Counselor Education. Counselor Education & Supervision, March 2015, Volume 54 DOI: 10.1002/j.1556–6978.2015.00068.x.

MURRE, JM., J. DROS. 2015. Replication and analysis of Ebbinghaus' forgetting curve. PLoS One. Available at: 10:e0120644. 10.1371/journal.pone.0120644.

NOVIANSYAH, W., P. SUDIRA. 2020. The praxis of project–based learning at PIKA Vocational Secondary School Semarang. Jurnal Pendidikan Vokasi, 10(1), 103–113. doi:https://doi.org/10.21831/jpv.v10i1.29032.

PATNAIKUNI, I., H. MYADARABOINA. 2016. Is project based learning the way to go? Integrated Solutions for Infrastructure Development ISBN: 978–0–9960437–3–1.

PHAM, A., L, NGUYEN, L. 2021. Students' Perceptions of Gamification: A Case Study in Business Courses at an Institution of Higher Education. 2021 3rd International Conference on Modern Educational Technology. https://doi.org/10.1145/3468978.3468998.

PHAM, A., HO, N., & NGUYEN, L. 2021. An Investigation into Students' Motivation and Learning Effectiveness in Gamified Learning Experiences via Kahoot! at a Higher Education Institution in Vietnam. Proceedings of the 5th International Conference on Education and Multimedia Technology. https://doi.org/10.1145/3481056.3481066.

RAYCHEVA R, V. JIVKOV, D. ANGELOVA, P. VODENOVA. 2016. Study Module „Project Week“: Through the Eyes of Students, Science Journal: Innovations in Woodworking Industry and Engineering Design, Vol.5, Sofia 1/2016, ISSN 1314–6149, pp. 46–53.

RAYCHEVA, R, D. ANGELOVA, P. VODENOVA. 2016. Project–based learning in engineering design in Bulgaria: expectations, experiments and results. European Journal of Engineering Education, Taylor & Francis Online, October 2016, Pages 1–18, ISSN: 1469–5898 (online), DOI: 10.1080/03043797.2016.1235140 available at: http://www.tandfonline.com/doi/full/10.1080/03043797.2016.1235140 (Web of Science).

RAYCHEVA, R. 2020. 25 years of the engineering design program: challenges and successes. Innovation in Woodworking Industry and Engineering Design, 2/2020 (18): 45–54.

RODRÍGUEZ–SÁNCHEZ, A., T. DEVLOO. 2017. What Makes Creative Teams Tick? Cohesion, Engagement, and Performance Across Creativity Tasks: A Three–Wave Study. Group & Organization Management 2017, Vol. 42(4) 521–547 DOI: 10.1177/1059601116636476.

SÁNCHEZ–MENA, A., J. MARTÍ–PARREÑO. 2017. Drivers and Barriers to Adopting Gamification: Teachers’ Perspectives, The Electronic Journal of e–Learning Volume 15 Issue 5 2017, pp. 434–443.

SHYR, W., C. CHEN. 2017. Designing a technology-enhanced flipped learning system to facilitate students' self-regulation and performance. Journal of Computer Assisted Learning https://doi.org/10.1111/jcal.12213.

SIRWAN MOHAMMED, G., K. WAKIL, M. NAWROLY. 2018. The Effectiveness of Microlearning to Improve Students' Learning Ability. International Journal of Educational Research Review. 3 (3): 35. doi:10.24331/ijere.415824.

SKALKA, J., & DRLÍK, M. 2018. Conceptual Framework of Microlearning–Based Training Mobile Application for Improving Programming Skills. Interactive Mobile Communication Technologies and Learning, 213–224. doi:10.1007/978–3–319–75175–7_22.

SPATHOPOULOU, F. 2018. Can Gamified Assessment Replace Traditional Tests. Humanities and social sciences, 6, 10–15. https://doi.org/10.18488/JOURNAL.73.2018.61.10.15.

TAŞPOLAT, A., F. ÖZDAMLI1, E. SOYKAN. 2021. Programming Language Training with the Flipped Classroom Model. SAGE Open April–June 2021: 1–17 DOI: 10.1177/21582440211021403.

TORGERSON, C., S. IANNONE. 2020. Designing Microlearning (What Works in Talent Development), Alexandria, Virginia: Association for Talent Development.

VAZQUEZ, J., E. CHIANG. 2015. Flipping Out! A Case Study on How to Flip the Principles of Economics Classroom, Int Adv Econ Res 21:379–390 DOI 10.1007/s11294–015–9549–5.

WAHYUNI, N. 2022. Project–Based Learning during Covid–19 Pandemic, Journal of educational study. Volume 2 Issue 1 2022 ISSN 2798–0650 DOI: 10.36663/joes.v2i1.253.

ZHANG, F. 2017. Quality–Improving Strategies of College English Teaching Based on Microlesson and Flipped Classroom. English Language Teaching; Vol. 10, No. 5; 2017 ISSN 1916–4742 E–ISSN 1916–4750.

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APPROACH FOR VIRTUAL PROTOTYPING OF FURNITURE FACTORIES WITH CAD

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ABSTRACT

The use of digital technologies in the context of Industry 4.0 and virtual engineering, related to European trends in the field of higher education, is increasingly used in furniture manufacturing technology training. An innovative approach for virtual 3D prototyping of production lines and furniture factories with modern CAD software was considered, which will be used in the educational process of students at the Faculty of Forestry, University of Forestry, majoring in „Computer technologies in the furniture industry“ and „Furniture industry 4.0“, Master degree. The approach includes rapid 2D and 3D prototyping of a cabinet furniture production line, as well as analysis of the material flow in the production line – the costs of transportation between machines and for processing the parts, the percentage of machine utilization for the individual operations. It was found that with the help of this analysis, unnecessary flows can be eliminated and the total costs of the internal production material flow can be minimized. Mastering this knowledge, students will be prepared for the increased requirements of furniture manufacturers in the context of Industry 4.0.

Key words: digital prototyping, furniture factory, CAD, innovative learning.

ПОДХОД ЗА ВИРТУАЛНО ПРОТОТИПИРАНЕ НА МЕБЕЛНИ ФАБРИКИ С CAD

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РЕЗЮМЕ

Използването на дигиталните технологии в контекста на „Индустрия 4.0” и виртуалното инженерство, свързано с европейските тенденции в областта на висшето образование, намира все по–голямо приложение в обучението по технолигии за производство на мебели. Разгледан е иновативен подход за виртуално 3D прототипиране на производствени линии и мебелни фабрики със съвременен CAD софтуер, който ще бъде използван в образователния процес на студентите във факултет „Горска промишленост“, ЛТУ, от специалностите „Компютърни технологии в мебелната индустрия“ и „Мебелна индустрия 4.0“, ОКС „Магистър“. Подходът включва бързо създаване на 2D и 3D прототип на линия за производство на корпусни мебели, както и анализ на материалния поток в производственото помещение – разходите за транспорт между машините, разходите за обработване на детайлите и процента на натоварване на машините за отделните операции. Установено е, че с помощта на този анализ ненужните потоци могат да бъдат елиминирани и общите разходи за вътрешнопроизводствения материален поток могат да бъдат сведени до минимум. Овладявайки тези знания, студентите ще бъдат подготвени за повишените изисквания на производителите на мебели в контекста на „Индустрия 4.0”.

Ключови думи: дигитално прототипиране, мебелна фабрика, CAD, иновативно обучение.

УВОД

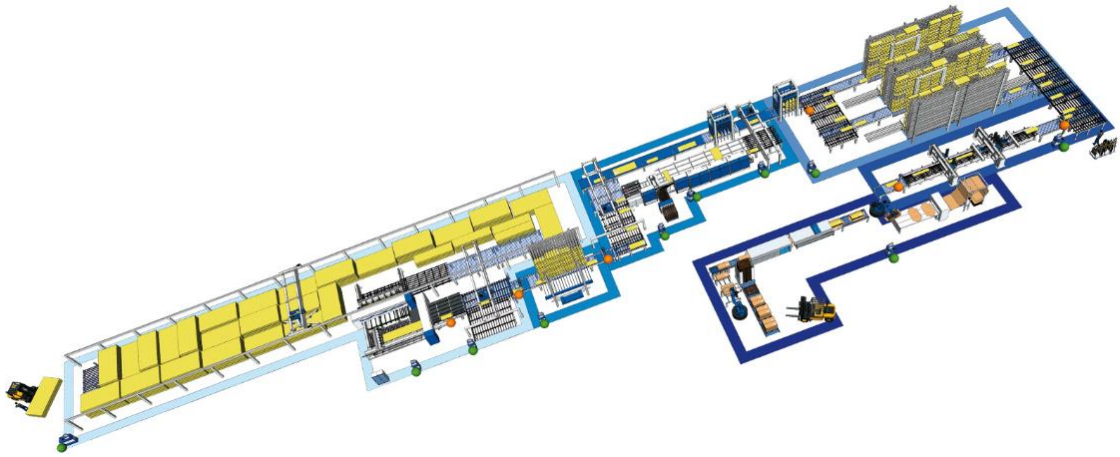
Планирането и разположението на машините и съоръженията за реализиране на производствения процес в дадена фабрика или завод е предпоставка за постигането на ефективен продуктов поток. Изчислено е, че между 20%–50% от общите разходи в производството са свързани с вътрешнопроизводствения материален поток. Тези разходи могат да бъдат намалени с близо 70% чрез ефективно планиране на съоръженията и така да се подобри производителността, като например намаляване на процента на тесните места, минимизиране разходите за обработка, намаляване на времето на престой и повишаване на използването на труд, оборудване и пространство (Savsar M. and Aldehaim A., 2020).

Много изследвания са проведени, за да се определи рационалното разположение на съоръженията от дадена производствена линия, като в последните години все повече се използва подхода на дигиталните симулации с различни софтуерни продукти – (Das A. 2024a, b, Hosseini–Nasab et al. 2018, Kadane, S. M. and Bhatwadekar, S. 2011, Sardar et al. 2016, Savsar M. and Aldehaim A. 2020, Zhang Z. et al.,).

Софтуерът за симулация на производствени процеси функционира за улесняване на проектантите, инженерите, мениджърите и инвеститорите, за да вземат по–информирани решения въз основа на визуализация на операциите или производството. Някои софтуери за симулация са разработени от лидерите в тази индустрия – Siemens, Dassault и Applied Mate rials, Autodesk са разработили софтуери за симулация на фабрики (напр. Siemens Tecnomatix Plant Simulation, Dassault CATIA V6, AutoMod, Facroty Design Utilities®), предоставайки различни пакети на производителите.

Оптимизацията и анализа на данни чрез „*Индустрия 4.0*“ навлиза все повече в мебелната промишленост, както на световно равнище, така и в България. Много фирми, производители на мебели, изразяват вече амбициозни планове за напредък в дигитализацията и автоматизацията на производството, поради което и производителите на мишини за производство на мебели като *Homag Group®, Exitech CNC Technology®, iGoldenCNC®, Blue Elephant®* и др. предлагат на клиентите дигитални 3D решения, както на отделни модули /станции/ за интелигентно производство на мебелни детайли, така и комбинирани в умни – интелигентни фабрики (smart factory) за производство на мебели от плочести материали (Фиг. 1 – Фиг. 6).

Водещата немска фирма *HOMAG Group®* е отличена на Allianz Industry 4.0 Award 2023 в категорията „Пионер в индустрията и изследванията“ за цялостното си решение „Приложения и дигитални асистенти за дървообработването“ предлагайки различни дигитални 3D прототипи на умни фабрики за производство на мебели – Фиг. 1.



Фигура 1: Дигитален 3D прототип за интелигентно производство с капацитет до 1200 детайла от мебелни плочи на *Homag Grup*®. (https://www.homag.com/en/topics/furniture–production).

За съгласуване на концепцията за мебелна фабрика с клиента се създават 3D дигитални прототипи и видеоклипове, които визуализират всички производствени секции. Моделите подлежат в последствие на модифициране и оптимизиране. Използва се методологията „бързо прототипиране“, по подобие на методологията „SCRUM“ при разработка на софтуер, и на практика идеите се прилагат по–бързо. Същевременно се изследва информационния поток на данни между различните машини и станции, за да могат да комюникират със софтуерните системи. (L. Mannl, 2021).

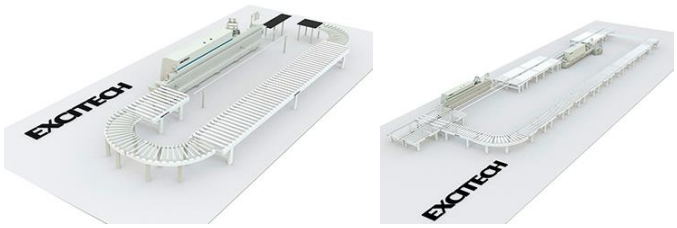
На Фиг.2 са представени части от дигитален 3D прототип на мебелна фабрика за производство на офис мебели в Китай, като цялостната концепция е разработена от Schuler Consulting Asia® от *Homag Group*®, в изпълнение на инициативата „Произведено в Китай 2025“, по пътя на Китай от „работна маса на света“ към глобален производствен и технологичен лидер до 2035 г. Визуализациите на 3D дигиталните прототипи са създадени с iVP – интелигентна 3D виртуална софтуерна платформа, която позволява на компаниите да планират и представят фабрични системи, машини и логистични процеси в 2D, 3D и VR. (https://www.i–vp.dev/de)



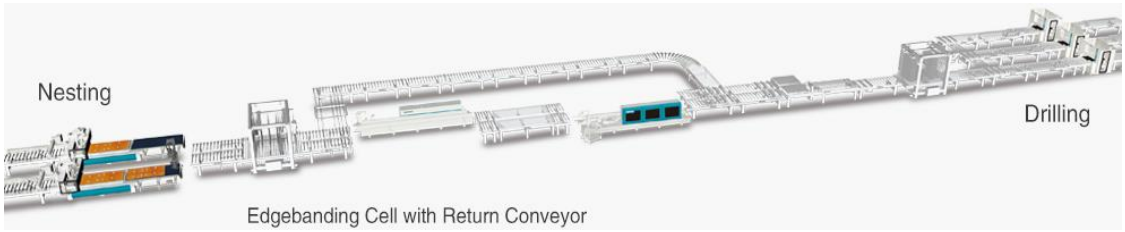
Фигура 2: Дигитален 3D прототип на умна фабрика за производство на офис мебели от *Homag Grup*®. (https://www.homag.com/en/company/news/case–studies/detail/paradigm–shift–in–furniture–manufacturing–in–the–middle–kingdom).

Като първи китайски производител, успешно внедрил Smart Factory Project, *Excitech CNC Technology*® помага на поризводителите на мебели да преодоляват проблемите с ефективността на производството. В предложените индивидуални решения за отделни

работни станции (Фиг.3) и особено тези за Smart Factory (Фиг.4), ефективността на производството се увеличава с поне 25%.



Фигура 3: Варианти на дигитални 3D прототипи на станции за кантиране от *Excitech CNC Technology*®. (https://www.excitech–sh.com/smart–factory–for–panel–furniture–production–line.html).



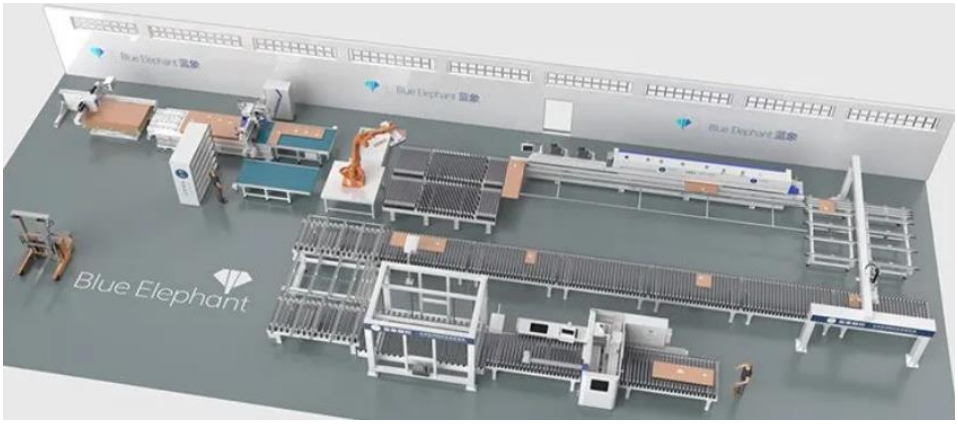
Фигура 4: Дигитален 3D прототип на линия за производство на корпусни мебели от *Excitech CNC Technology*®. (https://www.excitech–sh.com/smart–factory–for–panel–furniture–production–line.html).

Друга китайска фирма – *iGolden CNC Technology Co.*®, Ltd., също предлага на клиентите си дигитални 3D прототипи за Smart Production lines и Smart Factory – Фиг. 5. *iGoldenCNC Customized Furniture Industry 4.0* се основава на безпилотни фабрики, които интегрират процесите за производство на корпусна мебел без персонал – Фиг. 5.



Фигура 5: Дигитален 3D прототип на линия за производство на мебели с автоматично подаване от *iGolden CNC Technology Co.*®. (https://www.igoldencnc.com/cnc–furniture–production–line.html).

Китайска фирма *Blue Elephant*®, също предлага интелигентно решение за линия за производство на мебели от плочести материали – Фиг.6. Линията може да повиши максималната производствена ефективност с поне 25% и да намали степента на увреждане на плочите със 75%. Значително увеличава процента на инвестиции в производствени площи, машини и оборудване.



Фигура 6: Дигитален 3D прототип на умна фабрика за производство на корпусни мебели от *Blue Elephant*®. (https://www.elephant–cnc.com/smart–factory/intelligent–factory–furniture–production–line–solution/).

Всичко това налага и промени в обучението на кадрите, за да могат да отговорят на повишените изисквания в областта на производството на мебели.

Обучението във факултет „Горска промишленост“ на Лесотехнически университет понастоящем също е насочено към изучаване на съвременни автоматизирани и дигитализирани подходи за производство на мебели. В резултат на проведен анализ за самооценка, факултетът, е доразвил стратегията си за дигитализация в контекста на Стратегията за развитие на висшето образование в Република България за периода 2021 – 2030 година, подчинена на Европейските тенденции, подобрил е връзките с бизнеса, набелязал е ключови компетентности, приоритетни за бъдещото развитие на студентите, свързани с тяхната реализация. (Милчев и др. 2022). Обновени са учебните програми по дисциплините, като голяма част от тях са с възможност за дигитализирано ползване на ресурси. Преди 4 години в резултат от усилията и вижданията за развитие на образованието във факултета в контекста на концепцията „*Индустрия 4.0“* е създадена нова специалност „Компютърни технологии в мебелната индустрия“, ОКС „Бакалавър“, а от две години се провежда обучение в друга нова специалност „Мебелна индустрия 4.0“, ОКС „Магистър“, и двете в професионално направление 5.13 – „Общо инженерство“. От настоящата учебна 2024–2025 година стартира и обучение в ОКС „Магистър“ на специалност „Компютърни технологии в мебелната индустрия“.

ПОДХОД ЗА СЪЗДАВАНЕ НА ДИГИТАЛЕН ПРОТОТИП НА МЕБЕЛНА ФАБРИКА

Един от най–достъпните софтуери за 3D дигитално прототипиране на фабрики е Facroty Design Utilities®, създаден от Autodesk®. Софтуерът Facroty Design Utilities® е част от Product Design & Manufacturing Collection® на AutoDesk® и е налична в следните Autodesk® продукти: AutoCAD® Architecture, AutoCAD® Mechanical, AutoCAD® MEP, Inventor® Professional, Navisworks® Manage и Autodesk Vault®. Софтуерът Factory Design Utilities® има следните възможности (https://cadpoints.com/ factory–design–utilities):

- богата библиотека от 2D и 3D компоненти за фабрики;
- автоматично конвертиране на 2D чертежи в 3D модели и обратно, графици;
- анализ и оптимизиране на материалните потоци;
- вмъкване на файлове от различни CAD формати;

- вмъкване на 3D сканирани обекти;
- проверка за пресичане с 3D сканирани данни и данни от различни CAD формати;
- 4D Симулиране – построяване на фабрика и времеви графици;
- обединяване на файлове от различни CAD формати;
- интерактивна 3D разходка във фабриката;
- изграждане на сграда за фабриката, водопроводни, въздуховодни и транспортни системи.

С *Inventor® Professional Factory* се създава 3D прототип на фабрика, склад или офис. Размерът и сложността могат да варират от производствена станция до цяла фабрика. Моделът може да включва строителни елементи като стени, колони и инженерни съоръжения. Има възможност за проверка за колизии и планиране на свързването на отделни части от оборудването към захранване, данни, сгъстен въздух или други ресурси. Библиотеката Factory Assets съдържа модели на стандартни фабрични компоненти като машини, конвейери, тръбопроводи, стени и др. Възможно е да се използват файлове от *Inventor®* или импортирани модели.

AutoCAD® Mechanical Factory предоставя инструменти за проектиране на оптимизирана среда за конструиране на фабрики. Позволява да се отварят вече създадени 2D производствени планове и да се генерира алгоритмична рационализация за Factory Design. След това чертежите на Factory Design могат да бъдат отворени в 3D средата на Inventor и обратно. В *AutoCAD® Mechanical Factory* може да се направи анализ на материалните потоци в производствените помещения, да се оптимизират транспортните разходи и натоварването на машините чрез реорганизация на производствените станции.

Navisworks® Manage Factory обединява производствената линия със сградата, вентилационните, въздуховодните и транспортните системи. Предоставя времеви графици, възможност за виртуална разходка във фабриката, проверки за колизии.

Софтуерът за съвместна работа по проекти *Vault® Factory* помага на архитекти, инженери и изпълнители лесно да управляват проектни данни и ревизии. Позволява използването на компоненти за фабрики, съхранени в *Vault®* в различни проекти и лесно проследява къде те се използват. (https://help.autodesk.com/view/FDU/2025/).

С помощта на Autodesk Facroty Design Utilities® е симулиран технологичен процес за серийно производство на корпусни мебели. За производството им е предвидено да се използват ламинирани плочи от дървесни частици с дебелина 16–19 mm, а за гърбове – едностранно ламинирани плочи от дървесни влакна с дебелина от 2.7 до 3.5 mm. Поради големите обеми е избрана безмонтажна форма на производство. Обковът се комплектова и опакова самосоятелно, в специализирано складово помещение, което не е включено в симулацията. Избрана е поточна прекъсната организация на производството съгласно представената на фигура 7 блок схема.



Фигура 7: Структура на технологичен процес „производство на корпусни мебели”.

За реализиране на технологичния процес са избрани следните машини:

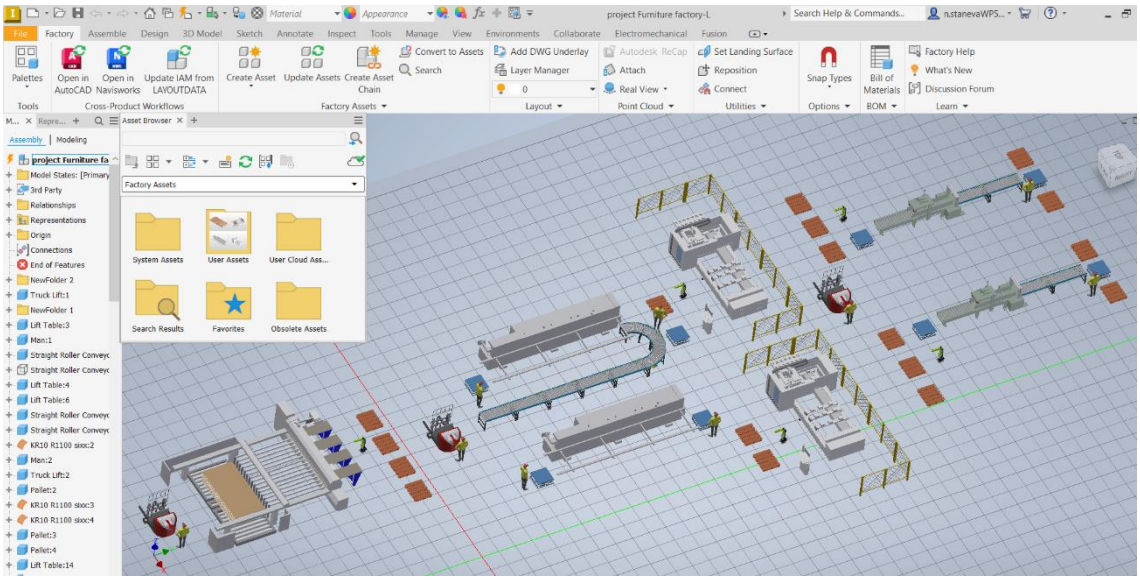
Пакетно–разкрояващ циркуляр HOMAG модел SAWTEQ S–210/32/22 със задна повдигаща маса за автоматично зареждане, скорост на каретката с дискови триони до 80 [m/min], мощност на основния двигател 7.5 kW и на двигателя на подрезвача 1.1 kW;

Едностранно праволинейно кантираща машина HOMAG EDGETEQ S–380 модел 1650E с регулируема скорост на подаване 8 – 20 m/min, мощност 5 kW;

CNC дървообработващ център HOMAG модел CENTATEQ P–210/31 с 3–/4– и 5–осна шпинделна технология и мощност на шпиндела 10 kW;

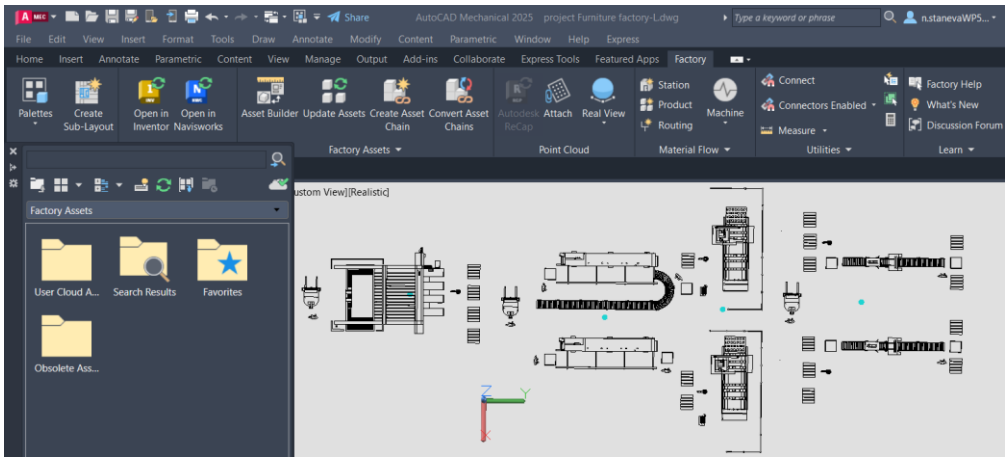
Автоматична опаковаща машина HOMAG PAQTEQ S–200 със скорост на подаване и опаковане в картонени кутии 35 m/min и мощност 1 kW.

В участъка за кантиране движението на детайлите е реализирано чрез управляеми подемни платформи и ролкови конвейери. Поради прекъснатия процес на производство и наличието на буферни складове, линията е комбинирана с електрокари, транспортиращи детайлите на палети, индустриални роботи и 9 работника – Фиг. 8.



Фигура 8: Дигитален 3D прототип на линия за производство на корпусна мебел с *Inventor® Professional Factory*.

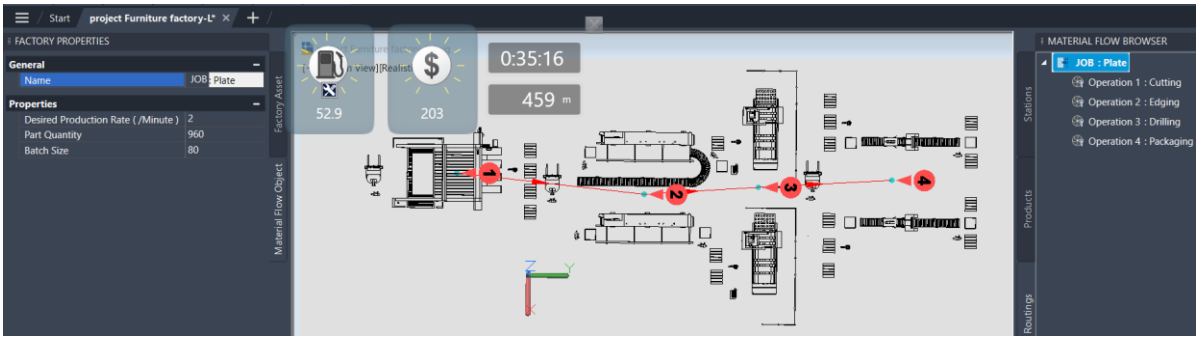
Първоначано е създаден дигитален 3D прототип на производствената линия (Фиг. 8) с *Inventor® Professional Factory*. Използвани са компоненти (Assets) от библиотеката на програмата, като 3D моделите на машините за разкрояване, кантиране и пробиване на отвори са импортвани допълнително в библиотеката. След като са уточнени всички компоненти в производствената линия, 3D прототипа автоматично се конвертира в *AutoCAD® Mechanical Factory* в 2D изображение (Фиг. 9).



Фигура 9: 2D план на линия за производство на корпусна мебел с *AutoCAD® Mechanical Factory*.

В AutoCAD® Mechanical Factory е направен анализ на материалния поток в производственото помещение относно разходите за транспорт между производствените станции (Фиг. 10) и за натоварването на машините (Фиг. 11).

За целта, предварително, в създадения 2D план са дефинирани производствени станции, продукт и маршрут (1–2–3–4), които съответстват на производствения процес и производствената програма – Фиг. 10. Обособени са 4 производствени станции, в съответствие с операциите, които извършват (разкрояване – Cutting, кантиране – Edging, пробиване – Drilling, пакетиране – Packaging). Зададени са характеристиките на машините в обособените станции – разходи за настройка и обработка, потребление на енергия, процент на времето за използване.



Фигура 10: Резултати от анализа с *AutoCAD® Mechanical Factory* на материалния поток относно разходите за транспорт между станциите и производство.

Зададена е и производствената програма – вид и количество на продукта, който се произвежда в проектирания технологичен процес. По принцип продуктът може да бъде мебел, агрегат, компонент или възел. В случая като краен продукт е зададен корпусна мебел /Case Furniture/ – гардероб, който се състои от 16 детайла. За една смяна от 8 часа са предвидени да се произведат 960 детайла за 60 броя крайни продукта, като една партида се състои от 80 детайла – Фиг. 10. Зададена е и желана производствена скорост – 2 детайла за минута.

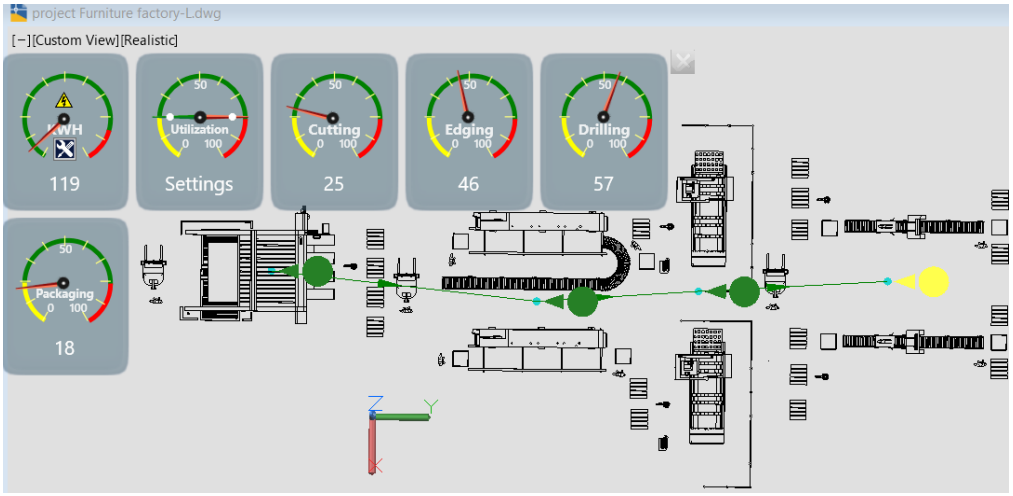
Зададени са също вида на транспорта между производствените станции – електрокари и промишлени роботи, както и характеристиките им – скорост на движение, цена за единица време, време за натоварване и разтоварване. Транспортният поток е дискретен и еднопосочен.

Материалният поток показва траекторията на движение, обема и концентрацията на материалите в производственото помещение. Крайният продукт на маршрута е „Job node“ /Case furniture/ със списък на производствените станции, използвани за производство. Редът

на станциите трябва правилно да дефинира маршрута на материалния поток в производствените помещения. Ако станциите не са избрани в рационален ред, е възможно да се пренаредят и така да се оптимизира процеса.

В браузъра на материалните потоци (Фиг. 10) маршрутите се появяват като задачи, съставени от една или няколко операции. Всяка операция е свързана с производствена станция. Например „Cutting“ се идентифицира като операция „разкрояване“. Зададени са времената за настройка и обработка за всяка операция.

Програмата дава възможност фабричните данни и параметри да бъдат импортирани или експортирани под формата на файлове с електронни таблици, което позволява тяхното модифициране или споделяне.



Фигура 11: Резултати от анализа с *AutoCAD® Mechanical Factory* на материалния поток относно натоварването на машините за производство.

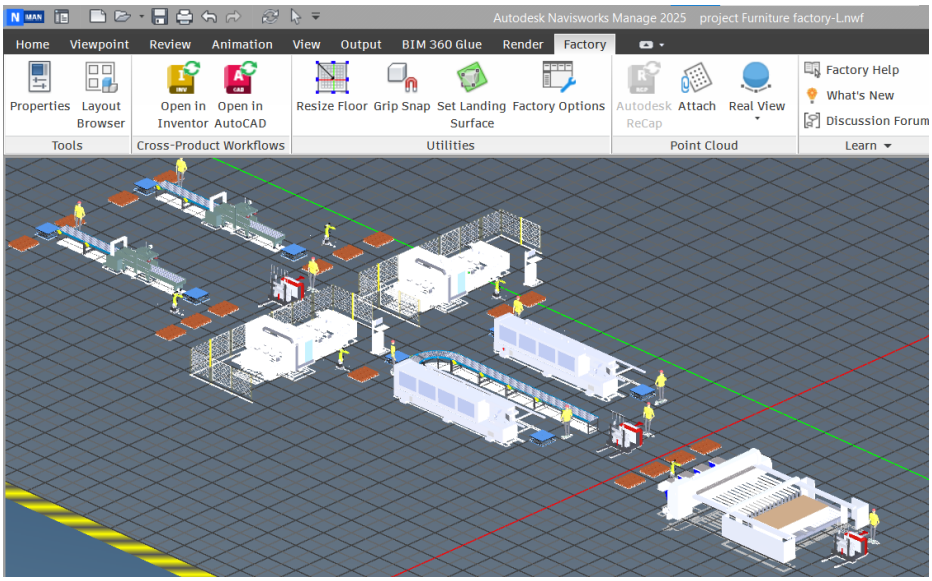
Резултатите се генерират много бързо и показват, че за изработка на детайли за 60 гардероба, за една смяна, се получават разходи от 52.9 USD за транспорт между станциите и разходи за обработка от 150.10 USD, или общо 203 USD (Фиг. 10), т.е. за производството на детайлите за 1 краен продукт – гардероб тези разходи възлизат на 3.38 USD.

В резултат на проведения анализ са получени и данни за натоварването на машините в така създадения прототип на производствената линия – Фиг. 11. Вижда се, че машините не са натоварени достатъчно – разкрояваща станция – 25%, кантираща – 46%, пробивна станция – 57% и пакетираща – 18%, като са консумирани общо 119 kWh електроенергия. Вижда се, че пробивната станция е най–натоварената, а пакетиращата станция /оцветена в жълто/ не е натоварена достатъчно – под 20%, т. е. при тази производствена програма е рационално да се изключат едната пакетираща машина и едната кантираща машина, което би намалило още разходите за транспорт между станциите и производствените разходи. По–правилен подход, обаче е да се увеличи обема на производствената програма, което би довело до усвояване на свободните производствени мощности или да се подменят машините с по–ниско производителни.

Резултатите от анализа са отразени в доклад, който се генерира от програмата *AutoCAD® Mechanical Factory*.

От *Inventor® Professional Factory* 3D прототипа на производствената линия автоматично е конвертирана в Navisworks® Manage Factory (Фиг. 12), където може да се обедини със други

помещения от фабриката, със сграда, да се добавят други инсталации. Програмата дава възможност да се направи оглед – виртуална разходка в така създадения дигитален прототип.



Фигура 12: Виртуален 3D прототип на линия за производство на корпусна мебел в *Navisworks® Manage Factory.*

ЗАКЛЮЧЕНИЕ

Предложен е подход за бързо 2D и 3D дигитално прототипиране на производствена линия от мебелна фабрика за производство на корпусни мебели с помощта на софтуера Autodesk Facroty Design Utilities®. Предложеният подход може да рационализира и намали значително времето за проектиране на производствена линия и планиране на производството. Подходът може успешно да се използва в обучението на студентите от спец. „Компютърни технологии в мебелната индустрия“ и „Мебелна индустрия 4.0“, ОКС „Магистър“ за придобиване на квалификация за дигитално прототипиране на мебелни фабрики, за да могат да отговорят на повишените изисквания в контекста на „*Индустрия 4.0*“.

ЛИТЕРАТУРА

МИЛЧЕВ Г., ГОЧЕВ Ж., АНГЕЛСКИ Д., АНГЕЛОВА Д., СТАНЕВА Н., ВИЧЕВ П. 2022. Дигитално образование във факултет „Горска промишленост“ в контекста на индустрия 4.0. Сборник доклади от 11та Международна научна конференция „Иновации в горската промишленост и инженерния дизайн ИННО 2022, 3–5 октомври, хотел Рила, Боровец, България: 237–248.

DAS A. 2024a. Using Simulation in Factory Layout Planning, available at: https://www.linkedin.com/pulse/using–simulation–factory–layout–planning–ayanangshu–das–evyjc?trk=portfolio_article–card_title.

DAS A. 2024b. Unlocking Operational Efficiency: Maximizing Factory Capacity through Simulation and Optimization using AnyLogic, available at: https://www.linkedin.com/ pulse/unlocking–operational–efficiency–maximizing–factory–capacity–das–svbic?trk= portfolio_article–card_title.

HOSSEINI–NASAB, H., FEREIDOUNI, S., GHOMI, S. M. T. F., AND FAKHRZAD, M. B. (2018) „Classification of facility layout problems: a review study,” International Journal of Advanced Manufacturing Technology, 94: 957–977.

KADANE, S. M. AND BHATWADEKAR, S. (2011) „Manufacturing Facility Layout Design and Optimization Using Simulation,” International Journal of Advanced Manufacturing Systems, vol. 2, no. 1, pp. 59–65.

SARDAR, V., POLSHETTIWAR, A., TRIVEDI, D., AND RAJHANS, N. R. (2016) „Optimization of Plant Layout Using Simulation Software," 6th International & 27th All India Manufacturing Technology, Design and Research Conference (AIMTDR–2016), vol. 6 (ISBN: 978–93–86256–27–0).

SAVSAR M. AND ALDEHAIM A. 2020. Analysis and Improvement of Facility Layout in a Furniture factory: A Case Application, Proceeding of the International Conference of Industrial Engineering and Operations Management Dubai, UAE, March 10–12, 2020: 436–447.

ZHANG Z., WANG X., WANG X., CUI F., CHEN H. 2019. A simulation–based approach for plant layout design and production planning. Journal of Ambient Intelligence and Humanized Computing (2019) 10:1217–1230 https://doi.org/10.1007/s12652–018–0687–5.

https://cadpoints.com/factory–design–utilities

https://help.autodesk.com/view/FDU/2025/

https://www.elephant–cnc.com/smart–factory/intelligent–factory–furniture–production–line–solution/

https://www.excitech–sh.com/news/how–to–make–panel–furniture–smart–factory

https://www.excitech–sh.com/smart–factory–for–panel–furniture–production–line.html

https://www.homag.com/en/topics/project–planning

https://www.homag.com/en/topics/furniture–production

https://www.homag.com/en/company/news/case–studies/detail/paradigm–shift–in–furniture–manufacturing–in–the–middle–kingdom

https://www.igoldencnc.com/cnc–furniture–production–line.html

https://www.i–vp.dev/de

https://www.jnigolden.com/automatic–panel–furniture–production–line–equipment/

PROCEEDINGS OF TWELFTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN – INNO 2024
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СРАВНИТЕЛНИ ИЗСЛЕДВАНИЯ НА АДХЕЗИЯТА НА ЗАЩИТНО – ДЕКОРАТИВНИ ПОКРИТИЯ ФОРМИРАНИ С ПОЛИУРЕТАНОВИ И АКРИЛАТНИ ФИЛМООБРАЗУВАЩИ СЪСТАВИ ВЪРХУ ОСНОВА ОТ MDF

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РЕЗЮМЕ

В настоящият доклад експериментално е изследвана адхезията на защитно – декоративни покрития, формирани с двукомпонентен полиуретанов лак „AL 107“ и водоразтворим акрилатен лак „Kiva 30“ към пробни тела, получени от плочи от дървесни влакна със средна плътност (MDF). Установено е влиянието на грапавостта, получена вследствие от механична обработка на повърхността, върху адхезията на защитно – декоративни покрития, формирани върху изделия, експлоатирани в интериора (мебели, ламперии, стълби, подови настилки).

Ключови думи: адхезия, двукомпонентен полиуретанов лак, водоразтворим акрилатен лак, грапавост.

ABSTRACT

In the present report, the adhesion of protective–decorative coatings formed with two–component polyurethane varnish „AL 107“ and water–soluble acrylate varnish „Kiva 30“ to sample bodies made of medium density wood fiber boards (MDF) was experimentally investigated. The influence of the roughness obtained as a result of mechanical surface treatment on the adhesion of protective–decorative coatings formed on products used in the interior (furniture, paneling, stairs, flooring) was determined.

Key words: adhesion, two–component polyurethane varnish, water–soluble acrylate varnish, roughness.

УВОД

Всеизвестен е факта, че в световен мащаб, поради намаляващият запас от масивна дървесина, дървопреработващата индустрия се стреми към все по– рационалното ѝ използване, а именно чрез производството на дървесни плочести материали – ПДЧ, ПДВ, OSB, MDF и т.н. Това се постига, чрез рециклиране на всички отпадъчни продукти, получени от различни по вид промишлености – дървообработваща, хартиено– целулозна както и други индустрии преработващи дървесината по химичен начин (Gothwal, R. K. et al., 2010; Yoo, C. G.,Ragauskas, A. J., 2021).

Обект на разглеждане в този доклад са плочите от дървесни влакна със средна плътност (MDF), тъй като от композитните дървесни материали, те са сред най– търсените на пазара, поради добрите им физични и механични свойства (Gardner et al., 2003; Zhou et al., 2013). Като основно предимство на MDF плочите пред останалите дървесни материали, освен лесната им механична обработка е, че те притежават равномерна и гладка повърхност, която представлява отлична основа за директно нанасяне на защитно – декоративни покрития или като основа за допълнително облагородяване на мебелни повърхнини посредством облицоването им (Ayrilmis et al., 2010). Като всички дървесни плочести материали и MDF плочите имат своите недостатъци. При продължителен престой в среда с по– висока влажност те променят своите размери по дебелина на плочата, които могат да не се възстановят след изсушаване. Освен високата влажност, неблагоприятно въздействие оказват и високите температури, които са причина за промени в свойствата на материала (Kojima et al., 2011), както и на неговата повърхност (Kalnins et al., 1993). Тези негативни въздействия на влагата и температурата се

отразяват не само върху повърхността на плочата, но и върху качеството на повърхностните покрития, като ги влошават.

Основната цел на довършителната повърхностна обработка върху MDF плочите е да се намали негативното въздействие на атмосферното влияние, т.е. да се удължи експлоатационният им срок, както и да подобри визуално външният им вид (Dilik et al., 2015). Съчетанието от структурни и химични изменения в материала се отразяват върху намокрянето на повърхността, грапавостта, цвета и гланца на покритието (Huang et al., 2012, Colom et al., 2003). Изборът на конкретен вид покритие, зависи от условията на околната среда (Singh et al., 2006), които оказват влияние върху механичните свойства на покритието, а именно адхезия и твърдост (Gindl et al., 2006). Според Йохам и кол. (2011) водоразтворимите системи са добра алтернатива за повърхностна обработка на MDF. Качеството на повърхността на готовото изделие е комплексен показател, който може да бъде повлиян от грапавостта на основата като функция на различните нива на относителна влажност (Ozdemir et al., 2009), от вида и химичният състав на покритието, както и от тяхната взаимовръзка, т.е. от адхезията. Независимо от вида на повърхностна обработка на плочите от дървесни влакна със средна плътност, адхезията е един от основните фактори, влияещи върху качеството на крайният продукт, както и върху ефективния му експлоатационен живот.

За постигане на добри стойности на адхезионна якост при защитно– декоративни покрития, формирани върху основа от MDF плочи е необходимо течният състав да притежава добра мокреща способност (Good, 1992). Механичната повърхностна обработка освен структурна промяна, поражда и изменение на повърхностната енергия и грапавостта на композитния дървесен материал. През (2008) Ролери и Рофаел допълват, че именно неравностите отчетени по повърхността на дървесните плочи са най– важният фактор, влияещ върху мокренето. Дървесно–влакнестият материал, притежава по–висок полярен характер на повърхностната свободна енергия, което е предпоставка за по–доброто му мокрене (de Moura et al., 2005; Rolleri, Roffael, 2008). През (2000) Акбулт и кол. споделят, че грапавостта на повърхността на MDF плочите може да се оценява и чрез мокрещата способност на течните защитно–декоративни покрития. Процесът на мокрене на повърхността на MDF може да се разглежда като зависимост от два фактора: суровина и производствени параметри. По–порестата анатомична структура на даден дървесен вид, от който е получена MDF плочата, довежда до увеличаване на повърхностната грапавост на дървесния субстрат, което повишава склонността на течността да бъде уловена от капилярните сили, в следствие на което довежда до увеличаване на повърхностната абсорбция на пробите от MDF. Освен анатомичната структура, производствени процесите като пресуване и шлайфане също оказват съществено значение върху повърхностната абсорбция и повърхностната грапавост на плочите (Akbulut et al., 2000). Десет години по– късно през (2010) Айръл мъз потвърждава със своите изследвания казаното от Акбулут и кол. (2000), че дървесно–влакнестите плочи шлайфани с по– голяма зърнистост на шкурката, показват по– ниски стойности на повърхностно мокрене в сравнение с тези пробни тела, които са шлайфани с по– малка зърнистост на шлифовъчният инструмент.

Широкото приложение на плочите от дървесни влакна със средна плътност налага и по–високи изисквания към декоративните и експлоатационните им свойства, което е в пряка взаимовръзка с адхезията на полимерните покрития.

Целта на настоящето изследване е да се направи сравнителен анализ на адхезионната якост на два вида защитно – декоративни покрития, формирани върху плочи от дървесни

влакна със средна плътност, с различна грапавост, експлоатирани в интериора, като получените данни ще са критерии за оценка, относно тяхното качеството, разглеждайки ги като готов повърхностно облагороден материал.

МЕТОДИКА

За осъществяване на експерименталната част от изследването е използвана плоча от дървесни влакна със средна плътност, производство на фирма Kronospan – гр. Бургас, със следните технически параметри, представени в таблица 1 (kronospan.com).

Таблица 1: Техническа характеристика на плочите от дървесни влакна тип МДФ EN 12460 – 5 (kronospan.com)

№	Технически характеристики	Мерни единици	Дебелина на плочата, mm	Страндарт
1.	Обемно тегло	[kg/m^3±7%]	720	EN 323
2.	Толеранс по дебелина	[mm]	±0,2	EN 324 – 1; EN 622 – 1
3.	Толеранс по дължина и широчина	[mm/m]	±2mm/m;maximum до 5 mm	EN 324 – 1; EN 622 – 1
4.	Отклонение от перпендикулярността на канта	[mm/m]	2	EN 324 – 2; EN 622 – 1
5.	Толеранс на праволинейността на ръба	[mm/m]	1,5	EN 324 – 2; EN 622 – 1
6.	Набъбване по дебелина след 24 часа	[%]	≤ 12	EN 317; EN 622 – 5
7.	Якост на огъване	[N/mm^2]	≥20	EN 310; EN 622 – 5
8.	Модул на еластичност при огъване	[N/mm^2]	≥2200	EN 310; EN 622 – 5
9.	Якост на опън	[N/mm^2]	≥ 0,55	EN 319; EN 622 – 5
10.	Емисия н а формалдехид	[mg/100g]	≤ 8	EN 12460 – 5; EN 622 – 1
11.	Съдържание на влага	[%]	4–10	EN 322; EN 622 – 1

За целта първоначално дървесно–влакнестата плоча е поставена в стайни условия за 24 часа, за да се кондиционира, при температура 20^{0}C и относителна влажност на въздуха 65%, за да достигне влажност от 8%, след което от нея са изработени 150 на брой образци с размери 50/50/18 mm. Преди полагане на филмообразуващите системи, 120 броя образци са шлайфани с различна зърнистост на абразивния инструмент, съответно 30 броя са шлайфани с шурка № 40, 30 броя с № 60, 30 броя пробни тела с №80 и 30 броя проби са обработени повърхностно с шкурка с № 120, а осталите 30 броя пробни тела са оставени с производствената грапавост на плочата, за да се проследи влиянието на грапавостта върху адхезионната якост. Шлайфането е извършено с вибрационен шлайф модел „Bosch GSS 23A” (фиг. 1).



Фигура 1: Вибрационене шлайф мод. „Bosch GSS 23 A”

На всяка проба е измерена повърхностната грапавост след механичното ѝ обработване и преди нанасяне на облагородяващите състави в участъка, където в последствие ще се изпитва

адхезионната якост на покритието. Параметрите на грапавост на получените повърхнини са измервани с профиломер модел SJ–210 на фирмата Mitutoyo, Япония (фиг. 2) със сензор с обратен ход и диамантен, V–образен връх на сондата с радиус R = 5 μm, съгласно БДС EN ISO 3274:2002. За изследването са направени следните настройки на профилометъра: профил – R, филтър на профила – Гаус; брой базови дължини n = *5*; дължина за оценяване ln =*12,5 mm*; горна граница на филтъра λc = *2,5 mm*; долна граница на филтъра λs = *8 μm*; скорост на измерване *0,25 mm.s*$^{-1}$.



Фигура 2: Профиломер мод. SJ–210 на фирмата Mitutoyo, Япония (euromarket.bg)

За определяне разхода на защитно–декоративните покрития, след отчитането на стойностите на повърхностната грапавост, пробите са притеглени на електронна везна с точност до 0,001g.

За формиране на защитно–декоративните покрития са избрани следните филмообразуващи системи: еднокомпонентен млечно бял водоразтворим полиуретанов грунд – FA580EC, млечно бял двукомпонентен водоразтворим полиуретанов лак AL107 и катализатор с антипожълтяващ ефект за водоразтворими полиуретанови лакове – C107, производство на фирма ICA S.p.A – Италия. Като акрилатни филмообразуващи покрития са използвани водоразредим изравняващ универсален бял грунд „Luja Yleispohjamaali" с възможност за тониране по каталог и водоразтворим полуматов акрилатен лак „Kiva 30", производство на финладската фирма Tikkurila**.**

Техническата характеристика на използваните филмообразуващи състави е дадена в табл. 2.

Таблица 2: Техническа характеристика на използваните състави

Наименование на филмообразуващите състави	Сухо съдържание, [%]	Вискозитет ВЗ – 4 [s]	pH	Външен вид и цвят
Полиуретанов грунд FA580EC	43	25	8	Млечно бяла течност
Полиуретанов водоразтворим лак AL107	36	50	7,8	Млечно бяла течност
Катализатор за полиуретанови лакове C107	–	100	–	Безцветна течност
Изравняващ универсален бял грунд Luja Yleispohjamaali	36	35	6	Бяла течност
Водоразтворим акрилатен лак Kiva 30	34	55	7	Млечно бяла течност

Представените състави са приложени в две филмообразуващи системи, които са както следва:

1. Еднокомпонентен полиуретанов грунд FA580EC, нанесен в един слой + два слоя полиуретанов двукомпонентен водоразтворим лак AL107, в който е добавен катализатор C 107;
2. Изравняващ универсален бял грунд Luja Yleispohjamaali + два слоя водоразтворим акрилатен лак Kiva 30.

Нанасянето и на двете филмообразуващите системи е извършено с мека четка. След всяко нанасяне на филмообразуващата течност пробните тела са претеглени (с цел определяне разхода по уравнение (1) и кондиционирани при стайни условия (t = 20^0C и φ = 65%) с цел втвърдяване на покритието в течение на 240 min.

След нанасянето на грунда и при двете филмообразуващи системи, пробните тела са междинно шлайфани с шкурка с № 320, а след нанасянето на първият слой лаково покритие пробите са междинно шлайфани с шкурка с № 400.

Всички измервания са извършени след кондициониране на пробните тела в стайни условия.

Преди всяко нанасяне и след всяко нанасяне на слой от защитно–декоративното покритие, пробните тела са претегляни с цел определяне на разхода.

Разходът на покритията е изчислен по уравнение (1).

$$M_{dc} = \frac{M_f - M_s}{S}, [g/m^2] \quad (1)$$

където:

M_f – масата след нанасянето на филмообразуващата система, g;

M_s – масата преди нанасянето на филмообразуващата система, g.;

S – площ на работното тяло, m^2;

Адхезията на покритието към дървесно–влакнестата повърхност е изпитана по метода на изтръгването на метален щемпел, регламентиран от БДС EN ISO 4624:2023, като за целта е използвана универсална изпитвателна машина „HECKERT FP 10/1“– Германия (фиг.3), която има обхват на изпитване (максимална сила) = 1000 kg.



Фигура 3: Универсална изпитвателна машина HECKERT FP 10/1за определяне стойностите на адхезията

Част от изпитаните на адхезионна якост образци са представени на фиг. 4 с формирано полиуретаново покритие и съответно на фиг. 5 с нанесено акрилатно покритие.





Фигура 4: Образци с изпитана адхезионна якост Фигура 5 Образци с изпитана адхезионна якост на полиуретаново покритие на акрилатно покритие

Адхезията е определена по уравнение (2)

$$\sigma = \frac{F}{S} = \frac{F}{\pi.R^2}, \text{ Mpa} \quad (2)$$

където:

F – максимална сила на натоварването, N;

S –изпитвана повърхност на покритието, mm (314 mm^2);

Получените резултати са обработени вариационно статистически по метода на най–малките квадрати, съгласно който се определя: Aver – средно аритметична величина по уравнение (3); D – дисперсия по уравнение (4); StD – средно квадратично отклонение по уравнение (5); Er – средна грешка: уравнение(6); V – вариационен коефициент по уравнение (7); p – показател на точност – уравнение (8) (Стоянов, 1986).

Средно аритметична величина:

$$Aver = \frac{\sum x_i}{n}, \quad (3)$$

Дисперсия

$$D = \pm \frac{\Sigma (x_i - Aver)^2}{n-1}, \quad (4)$$

Средно квадратично уравнение (стандарт)

$$StD = \pm \sqrt{\frac{\sum (X_i - Aver)^2}{n-1}}, \quad (5);$$

Средна грешка

$$Er = \frac{StD}{\sqrt{n}}, \quad (6)$$

Вариационен коефициент

$$V = \frac{StD}{Aver}.100,\%, \quad (7)$$

Показател на точност

$$p = \frac{Er}{Aver}.100,\%, \quad (8)$$

За установяване на достоверността на разликите между отделните варианти са изчислени стойностите на коефициента (критерия) на Стюдънт по уравнение (9):

$$m_d = \frac{Aver_1 - Aver_2}{\sqrt{Er_1^2 + Er_2^2}} \quad (9)$$

Резултатите са достоверни при md ≥ 3.00

РЕЗУЛТАТИ И АНАЛИЗИ

Получените резултати са обработени вариационно статистически и са представени в табличен вид.

В табл.3 са показани стойностите на началната грапавост на пробните тела след шлайфане с различна зърнистост на абразивната шлифовъчна хартия, разходът на покритието, характерът на разрушаване, както вариационните показатели относно стойностите на адхезията на защитно–декоративен филм, получен чрез нанасяне на полиуретановата система, състояща се от един слой грунд и два слоя лак.

Таблица 3: Адхезия на защитно–декоративен филм, формиран с еднокомпонентен полиуретанов грунд FA580EC и двукомпонентен водоразтворим полиуретанов лак AL107, при различни нива на грапавост

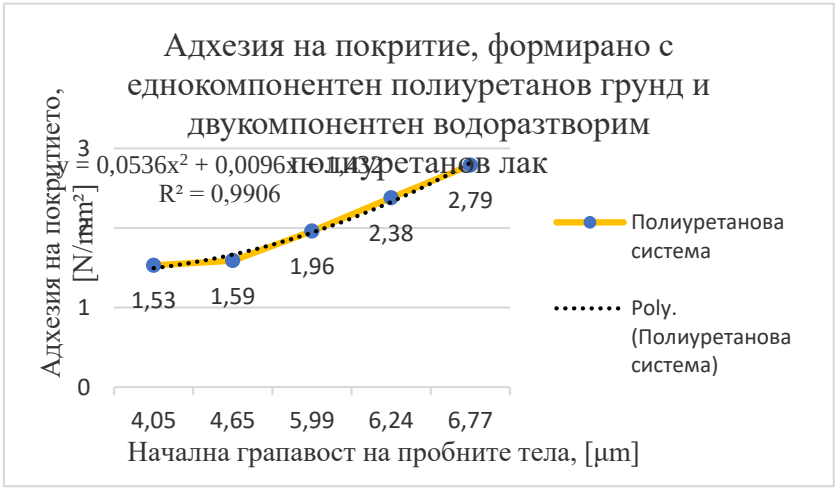
Индекс	n, [бр]	$R_{a–начал.}$, [µm]	m, [g/m²]	Вариационни показатели					XP, [%]	
				Aver, [N/mm²]	StD, [N/mm²]	Eror, [N/mm²]	V_x, [%]	p_x, [%]	Д	Л
MDF– произ.	15	4,05	198	1,53	0,33	0,09	21,74	5,61	65	35
MDF – №120	15	4,65	205	1,59	0,25	0,06	15,60	4,03	59	41
MDF – № 80	15	5,99	223	1,96	0,33	0,09	17,00	4,39	57	43
MDF – № 60	15	6,24	248	2,38	0,40	0,10	16,70	4,31	42	58
MD – № 40	15	6,77	283	2,79	0,35	0,09	12,65	3,26	39	61

Означения: n – брой пробни тела; R_a– средната стойност на грапавоста на облагородяваните повърхности; m–разх20,15од на покритието; XP– характер на разрушаване;

В табл.4 са представени стойностите на коефициентите на Стюдент, за потвърждение на разликите в адхезията на защитно–декоративен филм, получен с еднокомпонентен полиуретанов грунд FA580EC и двукомпонентен полиуретанов водоразтворим лак AL107 при различни нива на грапавост. На фиг.6 е представена графично зависимостта на стойностите на адхезията на защитно–декоративен филм, получен с полиуретанова система, в зависимост от грапавостта.

Таблица 4: Коефициенти на Стюдент за достоверност на адхезия на защитно–декоративен филм, формиран с полиуретанова система

индекс	40	60	80	120	произ.
40	–	3,15	6,38	10,91	9,69
60	3,15	–	3,00	6,58	6,54
80	6,38	3,00	–	3,36	3,31
120	10,91	6,58	3,36	–	0,55
произ.	9,69	6,54	3,31	0,55	–



Фигура 6: Влияние на грапавостта върху адхезията на защитно–декоративен филм, формиран с полиуретанова система

При сравнителният анализ се установява, че с увеличаване на началната грапавост на повърхностите, които ще се облагородяват, стойностите на адхезията нарастват.

При сравняване на сериите MDF – №120 и MDF – производствен се вижда, че разликата от 0,06 N/mm^2 в адхезионната якост на пробните тела не е достоверна, поради стойността на коефициента на Стюдент, който е 0,55, т.е. по– малък от 3. Зависимостта между началната грапавост на образците и адхезията на полиуретанова система се описва най– близко с уравнение от втора степен $y=0,0536x^2+0,0096x+1,432$; $R^2=9906$. В този случай довършителната повърхностна обработка на дървесно–влакнести плочи, извършена с шкурка с №120 е безпредметна, тъй като стойностите на получената грапавост не оказват влияние върху адхезионната якост.

При всички останали серии началната грапавост оказва влияние върху адхезионната якост на формираното покритие. Това твърдение е правдиво, тъй като получените стойности за коефициента на Стюдент са по– високи или равни на три, което установява достоверността на разликите.

В табл.5 са представени съответно стойностите на параметрите получени при повърхностното облагородяване на пробните тела с акрилатна система.

Таблица 5: Адхезия на защитно–декоративен филм, формиран с изравняващ универсален бял грунд Luja Yleispohjamaali и водоразтворим акрилатен лак Kiva 30, при различни нива на грапавост

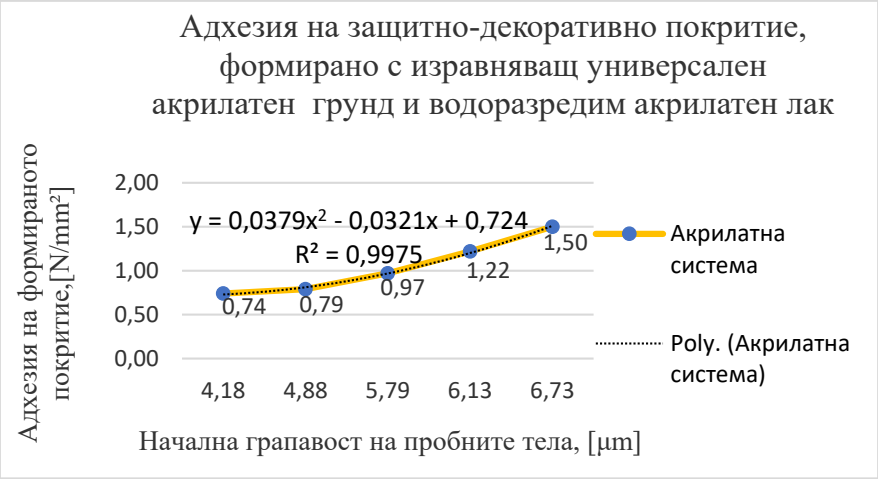
Индекс	n, [бр]	R_a начална, [µm]	m, [g/m^2]	Вариационни показатели					XP, [%]	
				Aver, [N/mm^2]	StD, [N/mm^2]	Eror, [N/mm^2]	V_x, [%]	p_x, [%]	Д	Л
MDF– произв.	15	4,18	163	0,74	0,12	0,03	15,77	4,07	73	27
MDF – №120	15	4,88	182	0,79	0,15	0,04	18,47	4,77	92	8
MDF – № 80	15	5,79	217	0,97	0,19	0,05	19,63	5,07	92	8
MDF – № 60	15	6,13	246	1,22	0,19	0,05	15,21	3,93	88	12
MD – № 40	15	6,73	225	1,50	0,21	0,05	14,29	3,69	78	22

Означения: n – брой пробни тела; Ra– средната стойност на грапавоста на облагородяваните повърхности; m–разх20,15од на покритието; XP– характер на разрушаване;

В табл.6 са представени стойностите на коефициентите на Стюдент, за достоверност на разликите в адхезията на защитно–декоративен филм, получен с акрилатна система, формирана от един слой грунд и два слоя лак. На фиг.7 е представена графично зависимостта на стойностите на адхезията на защитно–декоративен филм, получен с водоразредим акрилатен лак, в зависимост от грапавостта, като е представено и уравнението, което най–точно я описва тази зависимост.

Таблица 6: Коефициенти на Стюдент за достоверност на адхезия на защитно–декоративен филм, формиран с акрилатна система

индекс	40	60	80	120	произ.
40	–	4,00	7,57	11,83	12,67
60	4,00	–	3,57	7,17	8,00
80	7,57	3,57	–	3,00	4,17
120	11,83	7,17	3,00	–	1,00
произ.	12,67	8,00	4,17	1,00	–



Фигура 7: Влияние на грапавостта върху адхезията на защитно–декоративен филм, формиран с акрилатна система

Например, стойността на адхезията на защитно декоративният филм, формиран с еднокомпонентен водоразредим акрилатен лак, при серия MDF – №80 при грапавост 5,79µm е 0,97N/mm^2. Разликата от 0,18 N/mm^2 в адхезионната якост в сравнение със серия пробни тела MDF – №120 със стойност на грапавостта 4,88µm и адхезионна якост 0,79 N/mm^2 е достоверна, тъй като стойността на коефициента на Стюдент е 3,00. Тази зависимост се описва най–близко с уравнение y = 0,0379x^2–0,0321x+0,724; R^2 = 0,9975, т.е зависимостта е полиномна. При сравняване на сериите MDF – №120 и MDF – производствен се вижда, че разликата от 0,05N/mm^2 в адхезионната якост на пробните тела не е достоверна, поради стойността на коефициента на Стюдент, който е 1,00, т.е. по– малък от 3.

ЗАКЛЮЧЕНИЕ

От направените експерименти могат да се направят следните заключения:

1. С повишаване на началната грапавост, адхезионната якост и на двете покрития се увеличава правопропорционално, което най– добре се обяснява с механичната теория, според която защитно–декоративният филм се заклинва в микронеравностите по повърхността на MDF плочите, получени в резултат от довършителните механични обработки по повърхността – шлайфане. Но следва да се отбележи, че тази тенденция е лимитирана до определени стойности на грапавостта. Много високите стойности на микронеравностите са предпоставка за получаване на неравномерен филм.
2. Твърде ниската грапавост на дървесно–влакнестите плочи може да влияе негативно на адхезионната якост, поради намаляване на сцеплението между покритието и основата, в резултат на което се получава отлепване на повърхностния филм.
3. Адхезията на полимерните покрития, формирани върху плочи от дървесни влакна със средна плътност съществено зависи и от химическата природа на филмообразуващите вещества.

ЛИТЕРАТУРА

AKBULUT T., S. HIZIROGLU, N. AYRILMIS. 2000. Surface absorption, surface roughness, and formaldehyde emission of Turkish medium density fiberboard. Forest Products Journal, 50 (6), 45–48.

AYRILMIS N., Z. CANDAN, T. AKBULUT, O. D. BALKIZ. 2010. Effect of Sanding on Surface Properties of Medium Density Fiberboard. Drvna industrija 61 (3), 175–181.

COLOM X., F. CARRILLO, F. NOGU´ES, P. GARRIGA. 2003. Structural analysis of photodegraded wood by means of FTIR spectroscopy, Polymer Degrade Stability 80 (2003), 543–549, https://doi.org/10.1016/S0141–3910(03)00051–X.

DE MOURA L. F., R. E. HERN´ANDEZ. 2005. Evaluation of varnish coating performance for two surfacing methods on sugar maple wood, Wood Fiber Science 37 (2) (2005), 355–366.

DILIK T., S. ERDINLER, E. HAZJR, H. KOÇ, S. HIZIROGLU. 2015. Adhesion Strength of Wood Based Composites Coated with Cellulosic and Polyurethane Paints. Advances in Materials Science and Engineering Volume 2015, Article ID 745675, 5 p, http://dx.doi.org/10.1155/2015/745675.

GARDNER D. J., C. TASCIOGLU, E.P. WALINDER. 2003. Wood composite protection, Wood Deterioration and Preservation, ACS Symposium Series, 399–419.

GOTHWAL, R. K., MOHAN, M. K., GHOSH, P. 2010. Synthesis of low–cost adhesives from pulp & paper industry waste. Journal of Scientific & Industrial Research, 69, 390–395.

GINDL M., G. SINN, S.E. STANZL–TSCHEGG. 2006. The effects of ultraviolet light exposure on the wetting properties of wood, Journal Adhesives Science Technology 20 (8) (2006), 817–828, https://doi.org/10.1163/156856106777638653.

GOOD R. J. 1992. Contact angle, wetting, and adhesion: a critical review. Journal Adhesives Science Technology, 6 (12) (1992), 1269–1302, 10.1163/156856192x00629.

HUANG X., D. KOCAEFE, Y. KOCAEFE, Y. BOLUK, A. PICHETTE. 2012. Changes in wettability of heat–treated wood due to artificial weathering, Wood Science Technology 46 (2012), 1215–1237, https://doi.org/10.1007/s00226–012–0479–6.

JOCHAM C., T.W. SCHMIDT, G. WUZELLA, A. TEISCHINGER, A. KANDELBAUER. 2011. Adhesion improvement of powder coating on medium density fibreboard (MDF) by thermal pre–treatment Journal Adhesives Science Technology, 25 (15) (2011), 1937–1946, 10.1163/016942410X537189.

KALNINS M.A., M.T. KNAEBE. 1992. Wettability of weathered wood., Journal Adhesion SCI. Technology 6(12): 1325–1330.

KOJIMA Y., T. SHIMODA, S. SUZUKI. 2011. Evaluation of the weathering intensity of wood–based panels under outdoor exposure, Journal Wood Science 57 (2011), 408–414.

OZDEMIR T., S.HIZIROGLU, A. MALKOCOGLU. 2009. Influence of relative humidity on surface quality and adhesion strength of coated medium density fiberboard (MDF) panels. Materials & Design Volume 30, Issue 7, August 2009, 2543–2546.

ROLLERI A., E. ROFFAEL. 2008. Influence of climatic conditions and surface roughness on the wettability of medium density fiberboards (MDF). Holz als Roh–und Werkstoff, 66 (2008), 465–466, 10.1007/s00107–008–0274–0.

SINGH A.P., B.S.W. DAWSON. 2006. Microscopic assessment of the effect of saw–textured pinus radiata plywood surface on the distribution of a film–forming acrylic stain Journal Coating Technology 3 (3) (2006), 193–201, 10.1007/BF02774508.

YOO, C. G., RAGAUSKAS, A. J. 2021. Opportunities and Challenges of Lignin Utilization. In: Yoo and Ragauskas; Lignin Utilization Strategies: From Processing to Applications. ACS Symposium Series; American Chemical Society: Washington, DC. https://doi.org/130.204.194.243.

ZHOU J., H. ZHOU, C. HU, S. HU. 2013. Measurements of thermal and dielectric properties of medium density fiberboard with different moisture content, Bioresources 8 (3), 4185–4192.

СТОЯНОВ И. 1986. Математическо моделиране и оптимизиране на технологични обекти, ИК Техника, София 1986, 246 с.

БДС EN ISO 3274:2002. Изисквания към геометрията на продукти (GPS). Структура на повърхнина: Профилен метод. Номинални характеристики на контактни средства за измерване (ISO 3274:1996).

БДС EN ISO 4624:2023. Бои и лакове. Изпитване на опън за определяне на адхезията (ISO 4624:2023).
https://www.euromarket.bg.
https://www.icaforyou.com/eu/.
https://kronospan.com/bg.
https://tikkurila.com/.

PROCEEDINGS OF TWELFTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN – INNO 2024
7 – 9 October, Hotel Imperial Plovdiv, a member of Radisson Individuals, Plovdiv, Bulgaria

„ROUND TABLE“ ON „FORM–FORMATION“ – A TOOL FOR SOLVING DESIGN CASES IN THE EARLY STAGES OF ID TRAINING.

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ABSTRACT

The study examines the projects presented at „round table“ events during the academic years 2021/2022 and 2022/2023 with the students majoring in Engineering Design, the University of Forestry in their ear.

The purpose of the study is to evaluate the effectiveness of such an educational approach, as well as to predict its development. A descrption is made of the event being held, as well as of the students' projects in it. The scientific methodology include comparative analysis and classification.

Expected results are in the fields of design education, design and art theory, contemporary design and architecture.

Key words: design students, training, individual project, University of Forestry – Sofia,

„КРЪГЛА МАСА“ ПО „ФОРМООБРАЗУВАНЕ“ – СРЕДСТВО ЗА РЕШАВАНЕ НА ДИЗАЙНЕРСКИ КАЗУСИ В РАННИТЕ ЕТАПИ НА ОБУЧЕНИЕ ПО ИД

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РЕЗЮМЕ

В доклада се разглеждат проектите представяни на събития от тип „кръгла маса“ през учебните 2021/2022, 2022/2023 и 2023/2024 г. със студентите от специалност ИД, ЛТУ, втори курс.

Целта на изследването е да оцени резултатите на подобен обучителен подход, както и да прогнозира неговото развитие. Извършва се анализ на провежданото събитие, както и на проектите на студентите в него. Научната методика включва подбор на ключови примери, сравнителен анализ и класификация

Очакваните резултати са в областта на теория на дизайна и изкуството, съвременен дизайн и архитектура.

Ключови думи: студенти „ИД”, обучение, индивидуален проект, ЛТУ.

УВОД

Дисциплината „Формообразуване“ е част от обучението на студентите специалност ИДМ в ЛТУ във втори курс. В нея се акцентира на физическите и математическите характеристики на обектите и се дават познания за категориите „форма”, „пространство” и „организация” от гледна точка на дизайна. Проследяват се основни понятия като „симетрия”, „ритъм”, „конструкция“, „функция“, „бионика“, „трансформация“, както и ключови закономерности при систематизирането, структурирането и изграждането на формите. Между лекторите по дисциплината, намираме имената на ст. н. с. II ст. Цаньо Кънчев Иванов, на проф. Пенка Димитрова, на доц. Добрина Желева–Мартинс. Учебно помагало за курса е разработено от Добрина Желева–Мартинс и гл. ас. Мирослава Петрова (2015).

От учебната 2017/2018 г. водещ на лекциите по дисциплината е проф. Стела Ташева, а от 2021/2022 г., водещ на упражненията – ас. Кармелла Ломбарди.

ИЗСЛЕДОВАТЕЛСКИ МЕТОДИ

Обект на изследването са проектите представяни на заключителни събития от тип „кръгла маса“ през проведени през летния семестър на две последователни учебни години (месец май на 2022 и 2023г.). Целта е да се оценят резултатите на подобен обучителен подход, както и да се прогнозира неговото развитие. Проследяват се етапите и регламентите събития, и се анализират проектите на студентите в него по отношение на обучителните цели. Научната методика включва сравнителен анализ и класификация. Доколкото работата на студентите е етап от тяхната лична професионална еволюция, а успешността им в дизайнерското поприще впоследствие може да се определи само от голяма времева дистанция, статията не предлага изчерпателен каталог на техните решения или математически анализ на анкетни и проектни данни в тази връзка. Нашите стратегии като преподаватели по формообразуване и дизайн във втори курс залагат на камерния контакт със студентите и активна подкрепа.

При организацията и провеждането на събитието, основните обучителни цели, които преподавателския екип си поставя към студентите са в няколко направления:

- да усвоят основен обем от знания свързани с избраната обща тема на събитието, както и с функционалните изисквания в условията на заданието;
- да развият компетентност при определяне на характерни интериорни и процесуални проблеми в разглеждана среда;
- да приложат успешно подхода на формообразуване за съответното събитие (биомиметика, мултифунционалност и т.н.) в няколко концепции за решения;
- да могат самостоятелно да оценят качествата на предложенията си и да разработят в детайл най–удачния от своите варианти;
- да развият уменията си за макетиране и представяне.

Цялостното представяне на проектите на студентите се оценява на вътрешно и външно ниво. По този начин се отчита техния напредък във всяко едно споменатите направления.

В детайл, регламентът на провежданото събитие е разработен по време на онлайн обучението, а в последствие продължава да се усъвършенства от настоящия преподавателски екип. Акцентът е поставен не толкова на анализа на природните феномени и явления, а на разработваното дизайн–изделие.

В разглежданите две „кръгли маси”, подготовката и участието обхващат 6 седмици. В първите две се представя общата тема на разработваните изделия, разкриват се параметри и граници на заданията за проекти. Дефинират се и етапите на разработка, както и вида и съдържанието на представяните макети и презентации, уточняват се и се публикуват критериите за оценяване. За всеки студент се подготвя избор на индивидуална задача. Условието ѝ се диференцира според търсената функция на бъдещите продукти, възможните проблеми на потребителите и избраната зона в интериора. Студентите могат и да изменят част от задачата си с разрешение на преподавател. В следващите 4 седмици в упражненията се провеждат консултации върху работата на участниците. Задължителните, контролирани в упражненията фази на работа на студентите включват: общо и специализирано проучване, изготвяне на собствени скици–решения на поне 5 примерни изделия, (в които може да се изменя формата, но не и избрания за решаване проблем), подробно разработване на макет на едно избрано от тях, подготвяне на презентация. Допустими са концепции за решения от всякакъв мащаб и степен на сложност, стига да са съобразени с условията – тук става дума както за обзавеждане, осветителни тела и аксесоари, така и за интериорни среди, ансамбли или

отделни механизми. За финалното представяне е възприет формата на „кръгла маса” – поради равноправието на участниците в последователните им изяви, и задължителното публично изразяване пред поканени външни гости. За допълнителна мотивация, плакати–покани за събитията са разработени от ас. Кармела Ломбарди (Фиг. 1)



Фигура 1: Плакати на кръглите маси.

След всяка проведена „кръгла маса” преподавателския екип анализира представянията на студентите, оценките на външните гости както и предоставените от тях препоръки и наблюдения. Провеждат се и анкети и интервюта с участниците.

ДАННИ ЗА ПРОВЕЖДАНИТЕ КРЪГЛИ МАСИ

През 2022 г. темата е: „Бионика и динамика в дизайна на дома и хотела”. Доколкото спецификата на термина бионика не е предмет на статията, тук следва да се отбележи само, че за да се осигури висока степен на свобода на избор и проучване в работата на студентите–дизайнери, понятието е обобщено употребено в заглавието на събитието. Така, под бионика в случая се разбира заимстване и прилагане на форми, движения, конструкции, процеси и принципи от природата – в дизайна на разработваното изделие. При това, съгласно Чипев (2021 : 9) дори отделни елементи като „светлинните, а заедно с тях и цветовите сигнали биват пренесени интуитивно от природата в предметния свят на хората.” Във връзка с осигуряването на методическа яснота, за теоретична основа на темата в събитието е използвана класификацията от първа до четвърта степен на бионичните подходи в дизайна (Цекова 2018). Именно те и заедно с очаквана иновативност и оригиналност са заявени като водещ фактор при формообразуването на продукцията на участниците. Допълнителен акцент е поставен върху връзката на предлаганото дизайн–решение с избраната среда (дом, хотел), и е заложено очаквано ниво на качеството на представянето му.

Разработени са 28 проекта. След събитието за най–добре представили се са определени Елиз Денкова с темата „Динамика и бионика и в изделията за деца в хотела”, Николай Радованов с тема „Динамика и бионика и в изделията за осветление в градината” и Демет Мустафова с тема „Динамика и бионика и в изделията за релакс в градината”.

Съгласно проведените след това интервюта (и като се взима предвид общото ниво на студентите и сложността на задачите), оценката на гостите и наблюдателите е предимно положителна. Висок процент от студентите (86%) също оценяват провежданото събитие и своето участие като много полезно или полезно за бъдещата им дейност. Цялостната вътрешна

оценка на преподавателите, по отношение на изпълнение на заложените обучителни цели също е позитивна.

Тук ще систематизираме в табличен вид типовете заемки предложени от студентите. (Табл. 1)

Таблица 1: Типове на основни биомиметични заемки и брой на разработените проекти.

Тип основно биомиметично решение	Брой на проектите
Взаимстване от формата и организацията на цвете (мак, момина сълза, лале, детелина, теменужка, маргаритка)	6
Взаимстване от форма и структура на плод	4
Взаимстване от характеристиките на друг елемент от растителен вид (листо, дърво)	3
Взаимстване от форми, конструкции и процеси в животинските видове (медуза, пеперуда, фламинго)	3
Взаимстване от характеристиките на продукцията на животинските видове (медена пита, гнездо)	4
Взаимстване на принципи от екосистемна организация, включваща неживата природа (планински релеф, планета–звезда, кристални решетки на вещества)	8

Вижда се, че от растителни свят са потърсили заемки 13 студента, животинските видове са вдъхновили 7 студента, а 8 са акцентирали на комплексното възприятие на околония свят и връзката ни с неживата природа. В нашия анализ на представените презентации обаче, става ясно, че в въпреки различните основни направления, в най–сполучливите дизайнерски предложения са комбинирани повече от една заемки от природата и природните системи. Същевременно тези изделия се отличават и с ясни конструктивни характеристики, удачни функции в избраната интериорна среда и много добри естетически показатели.

През 2023 г. темата на кръглата маса е „Многофункционални изделия за хотели”. В нея съчетаването на няколко функции в едно изделие е и водещият фактор във формоизграждането и разработката на изделията. Допускат се предложения за изделия, аксесоари, механизми и продукти с поне две функции. Допълнителният акцент е поставен върху приложението на предложения продукт в хотелската среда, неговата обществена функция, лекота на използване, възможностите за подмяна и осигурената дълготрайност. В този случай, във връзка с иновативните търсения на студентите се приемаха както нетипични (нови) функционални комбинации, така и надграждането от студента–дизайнер на вече приети в практиката мултифункционални концепции с оригинални конструктивни, естетически или други характеристики във връзка с интериорните пространства на хотела.

Участват 41 студента и са разработени 41 проекта. Определени за най–добри са проектите на Дара Присадова – „Мултифункционално изделие за детската площадка на хотела“, Елица Иванова с „Мултифункционално изделие за зоната за съхранение в ресторанта на хотела“ и Симона Щерева с „Мултифункционално изделие за заседателните зали на хотела”.

Оценка на журито е в този случай е смесена – има редица положителни коментари, но присъстват и забележки, засягащи някои не напълно отразени функционални изисквания и стандарти за изделия, предназначени за хотел. Оценката на студентите за събитието е силно положителна – 90% от участниците определят работата по задачите и финалното представяне като полезни и много полезни. По отношение на изпълнение на заложените обучителни цели, вътрешната равносметка на преподавателите, отново е позитивна. Систематизацията на решенията предлагани от студентите е показана в табличен вид (Табл. 2)

Таблица 2: Типове на мултифункционалните решения и брой на проектите в тях.

Тип основно мултифункционално решение	Брой на проектите
Опити за надграждане на приети в практиката концепции на трансформируеми мебели (разтегаемо канапе, кресло, маса; сгъваем работен плот, стол, шезлонг)	9
Опити за надграждане на приети в практиката концепции на обзавеждане с две функции (сепаре, остров, секционен шкаф с вградени елементи, модулни мебели за седене, стол–маса и др.)	15
Иновативно съвместяване на две функции	10
Иновативно съвместяване на три и повече функции	7

Явно е, че повече от половината студенти са работили върху вече известни концепции за съчетаване на функции и/или мебелна трансформация. Нетипични, донякъде рискови, но и иновативни решения са предложили 17 участника – 41%. В тази втора група са по–високо оценените проектни решения, но към нея се отнасят и повечето ергономични и нормативни забележки.

РЕЗУЛТАТИ И ЗАКЛЮЧЕНИЕ

Въпреки условностите, сравнявайки резултатите от двете описани събития, можем да набележим някои общи тенденции. Една от тях е все по–доброто графично представяне на задачите и повишеното качество на модели. Явно е и включването на повече видове софтуер в изработката на презентациите и макетите в следващите години. Представените ръчни скици обаче не показват видима разлика в качеството на изпълнението. Във втората година малко се е увеличило приложението на чертожни изразни средства.

За нас като преподавателски екип студентите в известна степен са показали по–добри решения в темите свързани с бионика и биомиметика. Като цяло преди работата по дисциплината „Формообразуване” участниците не са подробно запознати с биомиметичните подходи. В този случай проучването им се състои в анализ на формите и функциите срещани в природата, и на начините, по които те могат да бъдат приложени успешно в дизайна на изделията. Това изглежда „освобождава” мисленето им и „разтоварва” проектите от твърде натрапчивия фокус върху приложението на самите продукти и изделия..

Темите с мултифункционалните изделия са по–познати за участниците. Затова те налагат по–задълбочено проучване на функционалните и ергономичните изисквания, както и на конструктивните вариации. Това води до не толкова широк спектър от иновативни решения и може би излишно вглеждане в детайла, без да се отчитат бъдещо развитие. Същевременно обаче, одобрението към заданието и събитието от страна на студентите е по–голямо именно за кръглата маса от 2023 г. Доколкото бе изяснено с последващи интервюта, именно тези теми изглеждат за обучаемите най–близки до практиката и реалистични за изпълнение.

„Днес няма човешка дейност, която да не е свързана с мебели...” пишат Кючуков и Живков (2016: 3). Тази нужда обаче, продуцира все по–голямо изобилие на решения за обзавеждане. А комплексният начин на живот в съвременността налага към тях все повече изисквания. По отношение на дизайна, Писарева определя периода от 1980 г. до XXI век като „характеризиращ се с разнопосочност на изразните средства и липса на формален език” (2002: 290). Смятаме, че тези характеристики са валидни особено силно днес, при агресивното навлизане на разнородни проектантски и фабрикационни технологии, а и все по–високите ограничения към жизнения цикъл на продуктите. Тези фактори силно влияят върху разбирането за „ценност” и „качество” на интериорните решения и обзавеждането. За нас именно през призмата на

значими съвременни концепции като биомиметика, мултифункционалност и др. студентите упражняват форма на облекчена навигация в оценките на дизайнерските практики. А събитията от тип „кръгла маса" се доказват като чудесна възможност за повишаване на знанията, компетентностите и уменията в областта.

ЛИТЕРАТУРА

ЖЕЛЕВА–МАРТИНС, Д., ПЕТРОВА, М. 2015. Формообразуване, Бисмар, София.

КЮЧУКОВ, Г., ЖИВКОВ, В. 2016. Конструиране на мебели. Конструктивни елементи и съединения в мебели. Бисмар, София.

ПИСАРЕВА, Е. 2002. Ръководство за упражнения по история на интериора и мебелите. ИК на ЛТУ, София

ЦЕКОВА, Н. 2018. Бионика и биомиметика в съвременната архитектура и дизайн. Архитектура, САБ, 2: 24–30.

ЧИПЕВ, Р. 2021. Дизайн вдъхновен от природата, НХА, София.

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ОПТИМИЗИРАНЕ НА УСЛОВИЯТА НА ПРЕДВАРИТЕЛНО ТРЕТИРАНЕ НА ИДУСТРИАЛЕН КОНОП ДО ГЛЮКОЗА

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РЕЗЮМЕ

Конопът (Cannabis sativa L.) е едногодишно тревисто растение с отлични аграрно–стопански характеристики и се използва от древността като суровина за производство на тъкани. Индустриалният коноп с високия си добив на биомаса от хектар има голям потенциал за производство на биогорива и ценни продукти. Нормативните документи в България разрешават отглеждането на канабисови растения само ако са предназначени за влакна, семена за храна на животни или посев и ако имат съдържание под 0,2% тетрахидроканабинол. Остатъците от коноп след такава обработка се характеризират, с много ниска обемна плътност, с високо съдържание на подобни на широколистната дървесина къси влакна, така и на дълги и груби влакна, които увеличават съдържанието на целулоза, докато съдържанието на хемицелулоза и лигнин е остава сравнително ниско. Спецификата на конопените стъбла и съдържанието на груби и дълги влакна, изискват допълнително размилане на масата след паровзривното третиране и преди ензимната хидролиза.

Ключови думи: Коноп, механична обработка, ензимна хидролиза, глюкоза.

УВОД

Индустриалният коноп (Cannabis sativa L.) е едногодишно тревисто растение, принадлежи към род Покритосеменни растения и семейство Конопови (Cannabinaceae). Той е богат източник на фибри и омега мастни киселини. По тази причин е ценен фармацевтичен продукт (Tsoumis 1991).

Конопът може да се култивира и отглежда при разнообразни климатични условия, тъй като се притежава голяма устойчивост към външната среда.

Поради климатичните изменения и енергийната криза в световен мащаб индустриалният коноп се разглежда като алтернатива суровина за получаване на биогорива (Kraszkiewicz 2019)

Стъблото на индустриалния коноп се състои от множество слоеве, които включват епидермис, флоема, ксилема и сърцевина (Jiang 2018)

При микроскопско изследване на изброените структури по външната повърхност на Cannabis sativa L. се наблюдават влакна (Sheedev 2018). Двете основни стволови влакна – флоем и ксилем, се различават по отношение на съдържанието си на целулоза и лигнин. Флоемните слоеве съдържат средно около 67–78% целулоза и от 2.9 до 13% лигнин, докато ксилема съдържа 40 % целулоза и 17 % лигнин (Shin 2009)

През последните десетилетия са разработени много различни методи за предварителна обработка, които се разделят на 4 основни групи методи: физически методи (смилане и размилане), химични методи (киселинни, алкални), физико–химични (високотемпературна хидролиза, пора–взривно третиране) и биологични методи (гъбички, бактерии и микроводорасли) (Kim 2018).

Физическите методи за предварителна обработка имат за цел да намалят размера на субстрата с което подобрят достъпа на ензимите, чрез понижаване на кристалността и степента на полимеризация (Wawro 2019).

Предварителната алкална обработка е метод използван за отстраняване на лигнин от биомасата. Основните предимства на този метод е именно във висока му ефективност при отстраняване на лигнина, ефективно отстраняване на ацетиловите групи от хемицелулоза и ниската му себестойност (Łukajtis 2018).

Паровзривното третиране е процес, при който конопа се обработва с пара при висока температура (190–230°C). Раздробяването на биомасата се дължи на моментално отваряне на клапана, с което налягането се намалява, а масата се раздробява и издухва в контейнер. Парната експлозия е процес, при който конопа е химически модифициран и механично дефибрилиране. Горещият пара омекотява материала и влакната се разделят чрез механичното действие при освобождаване от налягане. По време на процеса се образуват нежелани инхибитори на ензимните комплекси. Основните предимства на паро-взривната обработка са по–ниското въздействие влияние върху околната среда и малко или никакво използване на химикали [Foston 2018, Ximenes 2018, Kim 2018).

Thibaud Sauvageon и колектив предлагат паро-взривно третиране с време = 4.1 min, температура = 191°C и предварително импрегниране на масата с разтвор на NaOH (8%), което води до степен на дефибрилиране от 91.2% (Sauvageon 2018).

Pakarinen и колектив наблюдава, че съдържанието на глюкан в биомасата от коноп се увеличава от 46.1 на 69.6%, докато хемицелулозата намаляла от 9.5 на 5.5% след предварителна паро–взривна обработка при 200°C за 5 мин. (Pakarinen 2012).

Kuglarz и др. изследва паро–взривната обработка с добавяне на H_2SO_4 (0.5–2.0%) при 140–180°C и наблюдава, че предварителна обработка при 180°C в продължение на 10 минути и добавяне на 1% сярна киселина води до най-висок добиви на захар, за последваща ензимна хидролиза (Kuglarz 2014).

За да се намали използваната висока температурата при предварителната паро-взривна обработка и да се увеличи добивът на захар Sipos предлага импрегнирането с 2% SO_2, но въпреки предварителното импрегниране получава най–добър добив на захари при температура от 210°C за 5 минути реакционно време (Sipos 2010).

Настоящата работа има за цел да изследва ефекта от механичното размилане на конопената маса след паро–взривното третиране, върху добива на глюкоза след ензимна хидролиза и да определи оптималните условия за предварителната обработка с CO_2 в зависимост температурата и спецификата на използваната отпадъчна конопена маса.

МЕТОДИ И МАТЕРИАЛИ

Изследванията са проведени с две групи отпадъчни конопени стъбла, преминали първична обработка.

Химичните анализи са извършени, съгласно стандартните процедури на TAPPI: пентозани по T223 cm–10; лигнин по T222 om–11; пепел по T 211 om–12; вещества разтворими в гореща вода по T207 cm–08, а целулозата по метода на Кюршнер – Хофер.

Паро-взривната предварителна обработка на конопената биомаса се извършва в лабораторна автоклави от 2 L при съотношение твърдо вещество към течност 1:40 (w/v); начална температура 20°C; максимална температура 160–200°C; време за достигане на максималната температура 60 min. и задържане при максималната температура 10 min.; начално налягане 4 бара при добавяне на CO_2 и 0 бара без влагане на CO_2.

Преди ензимно третиране част от получената конопена биомаса се разсмиля в Йокро мелница за 5 минути.

Ензимната хидролиза се извършва в полиетиленови пликчета в предварително загрята водна баня до желаната температура (50°C) чрез използването на целулазни комплекси – Cellic® и CTec2. Ензимната хидролиза се провежда при 10% концентрация на маса, pH в диапазон 5.0–5.6, реакционно време до 72 часа и 5% разход на ензим.

Полученият твърд остатък се промива с дестилирана вода за отстраняване на разтворените компоненти. Филтратът се анализира за съдържание на глюкоза, ксилоза, арабиноза, фурфурал и 5–хидроксиметилфурфурал чрез високоефективен течн хроматография на фирма Dionex (Dionex Inc., Калифорния, САЩ), оборудван с детектор Shodex RI–101 RI (Showa Denko KK, Kawasaki, Япония), според аналитичен метод на Националната лаборатория за възобновяема енергия (NREL) за биомаса. Разделянето се извършва в колона Hi–Plex H, 7.7 mm × 300 mm (Agilent Technologies, САЩ) при 65°C с ултрачиста вода, произведена от система за пречистване на вода Simplicity® (Merck KGaA, Дармщат, Германия) като елуент при скорост на потока 0.5 mL/min. Инжектиран обем: 20 μL. Резултатите са оценени от софтуера Chromeleon 6.80. Количеството захари се изчислява като процент (%) на база сухо вещество.

РЕЗУЛТАТИ И ДИСКУСИЯ

Химичният анализ на двете групи отпадъчен коноп показва по–високо съдържание на целулоза и по–ниско на лигнин и пентозани в групата със запазени стъбла в сравненние с втората група от сравнително дребна фракция (Табл. 1). Разликите са в границите от 4% до 5%, като тази разлика може да се обясни с различното съдържание на дълги влакна в двете групи.

Установеното пепелно съдържание е сравнително ниско и съответсва на литературните данни, което е преимущество на конопа като суровина в сравнение със сламата и царевичните стъбла, които се характеризират с много високо пепелно съдържание.

Таблица 1: Химичен анализ на отпадъчни конопени стъбла

Вид на проба	I група стъбла от коноп	II група дребна фракция от коноп
Влага [%]	10.38 ± 0.02	12.76 ± 0.02
Вещества разтворими в гореща [%]	6.25 ± 0.05	1.90 ± 0.05
Пентозани [%]	21.45 ± 0.05	24.85 ± 0.05
Лигнин [%]	16.25 ± 0.05	20.50 ± 0.05
Целулоза [%]	49.00 ± 0.05	45.45 ± 0.05
Пепел [%]	1..60 ± 0.01	2.35 ± 0.01

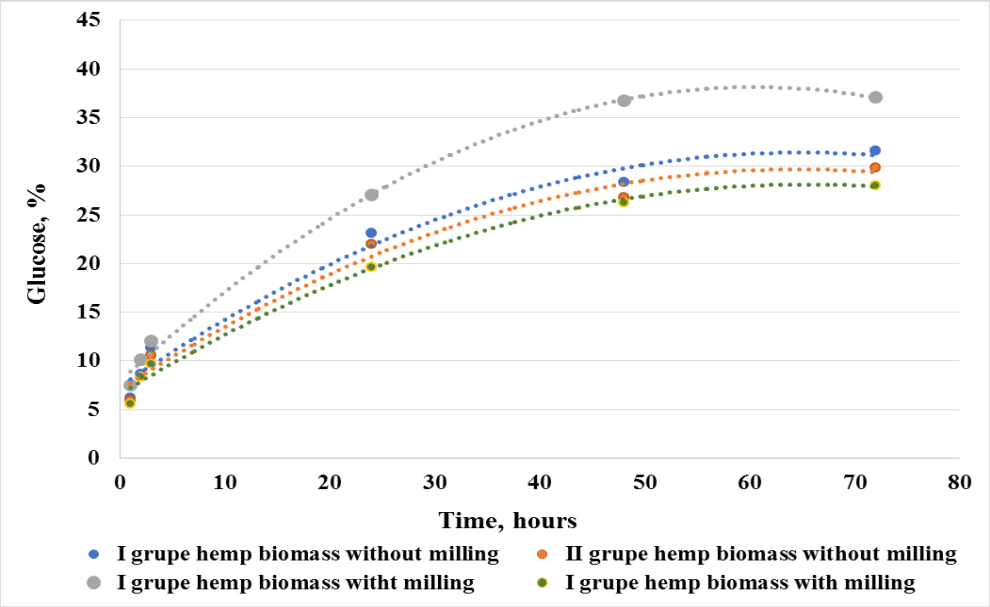
В табл. 2 са представени резултатите от анализа на получените хидролизати след паро–взривна хидролиза при различни температури и добавяне на CO_2. Както се вижда от таблицата добавянето на CO_2 ускорява процеса на хидролиза, поради по–киселата начална среда и води до пълна трансформация на хемицелоозите до монозахари на ксилан.

Наблюдава се и трансформация на монозахарите то фурфурал и HMF, което дава основание за провеждане на паровзривното третиране при по-ниска температура.

Таблица 2: Анализ на хидролизата след паро–взривно третиране при различни условия

Вид проба	Вид на паро–взривното третиране			
	без CO_2		с CO_2	
	I група стъбла конопи	II група стъбла конопи	II група стъбла конопи	
Температура	**200°C**		**190°C**	**200°C**
Ксилоза [%]	0.22	0.89	25.05	24.35
Фурфорал [%]	–	0.27	1.10	5.25
HMF [%]	–	–	–	1.75
Глюкоза [%]	–	0.50	–	3.17

Спецификата на конопените стъбла и съдържанието на груби и дълги влакна, налагат да се проведе допълнително размилане на масата след паровзривното третиране преди ензимната хидролиза. Влиянието на размилането върху количеството на глюкоза получено след проведената ензимна хидролиза на двете групи отпадъчна конопена биомаса претърпяла паро-взривна обработка при 200°C е представено на фиг. 1.



Фигура 1: Кинетични криви на процеса на ензимна хидролиза след паро-взривна обработка при 200°C без CO_2 в зависимост от допълнителното механично размилане и спецификата на отпадъчната конопена маса

Получените кинетични криви показват, че ефектът от механичното третиране върху добива на глюкоза достига 9% при I група конопена биомаса, която се характеризира с по–голяма количество целулоза и съответно по-голямо съдържание на груби влакна. Отделеното общо количество глюкоза е високо и надвишава добива на глюкоза от слама.

При размилане на тази отпадъчна група коноп в Йокро мелница се наблюдава сплитане на грубите влакна, което затруднява технологичния процеса.

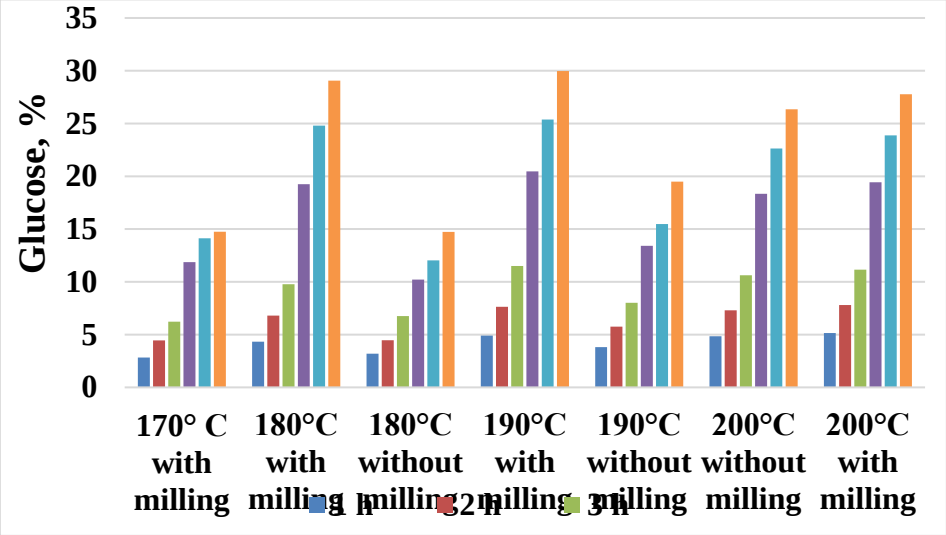
При втората група дребна фракция отпадъчен коноп не се наблюдаваха затруднения при размилането, а наблюдаваният ефект върху нарастването на съдържанието на глюкоза след ензимната хидролиза е под 2%.

Влиянието на температурата на паро-взривно третиране с CO_2 и на допълнителното размилане върху добива на глюкоза след ензимната степен, е изследвано за II група отпадъчен коноп (фиг. 2). Получените резултати показват възможността температурата на третиране да

се понижи до 180°C, но за това е необходимо и допълнително меко размилане преди ензимната хидролиза. Трябва да се отбележи, че това е валидно за дребната фракция от коноп, при която няма проблеми при размилането.

Вижда се, че с понижение на температурата на третиране нараства разликата в добива на глюкоза в резултат на размилането, като при паро-взривно третиране при 170°C практически не може да се провежда ензимна хидролиза без размилане.

Допълнителното механично раздробяване на биомасата спомага за увеличаване на достъпността на ензимите до целулозните вериги и добивът на глюкоза нараства значително. Причината за това е спецификата на конопа, който съдържа дълги и груби влакна, които не могат да се фибрилират само от взривният метод на обработка, както се случва с дървесината и сламата.



Фигура 2: Влиянието на температурата на паро–взривно третиране с CO_2 и размилането върху количеството глюкоза след ензимната хидролиза при II група коноп

ЗАКЛЮЧЕНИЕ

Установи се, че спецификата на конопената маса и съдържанието на дълги и груби влакна предопределят необходимостта от провеждането на механична обработка на масата след паро–взривното третиране и преди ензимната хидролиза.

Допълнителното размилане на конопената маса фибрилира грубите влакна на конопа и увеличава достъпността на ензимите до целулозните вериги, чрез което може да се повишава добива на глюкоза до стойности надвишаващи тези от слама.

Ефектът от размилането зависи от съдържанието на груби влакна и намалява с повишение на температурата на паро-взривното третиране.

Използването на дребна фракция отпадъчен коноп и добавянето на CO_2 при паро–взривната обработка, позволяват след прилагане на меко размилане, температурата на третиране да се понижи с 20°C.

БЛАГОДАРНОСТИ

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ЛИТЕРАТУРА

FOSTON, M., RAGAUSKAS, A.J. 2010. Changes in lignocellulosic supramolecular and ultrastructure during dilute acid pretreatment of Populus and switchgrass. Biomass Bioenergy, 34, 1885–1895.

JIANG, YUNHONG. LAWRENCE, MIKE et al. 2018. Cell wall microstructure, pore size distribution and absolute density of hemp, Royal Society Open Science., vol. 5, pp. 171945.

KIM, D. 2018. Physico-Chemical Conversion of Lignocellulose: Inhibitor Effects and Detoxification Strategies: A Mini Review. Molecules, 23, 309. https://doi.org/10.3390/molecules23020309.

KRASZKIEWICZ, A., M. KACHEL, S. PARAFINIUK, G. ZAJ, I. NIEDZIÓŁKA AND M. SPRAWKA. 2019. Assessment of the Possibility of Using Hemp Biomass (Cannabis Sativa L.) for Energy Purposes: A Case Study, Applied Sciences 9(20); doi:10.3390/app9204437.

KUGLARZ, M., I.B. GUNNARSSON, S. SVENSSON, T. PRADE, E. JOHANSSON, I. ANGELIDAKI. 2014. Ethanol production from industrial hemp: Effect of combined dilute acid/steam pretreatment and economic aspects, Bioresour Technol, 163, pp. 236–243, https://doi.org/10.1016/j.biortech.2014.04.049.

ŁUKAJTIS, R., RYBARCZYK, P., KUCHARSKA, K., KONOPACKA-ŁYSKAWA, D., SŁUPEK, E., WYCHODNIK, K., KAMIŃSKI, M. 2018. Optimization of Saccharification Conditions of Lignocellulosic Biomass under Alkaline Pre–Treatment and Enzymatic Hydrolysis. Energies, 11, 886. https://doi.org/10.3390/en110408867.

PAKARINEN A., J. ZHANG, T. BROCK, P. MAIJALA, L. VIIKARI. 2012. Enzymatic accessibility of fiber hemp is enhanced by enzymatic or chemical removal of pectin, Bioresour Technol, 107, pp. 275–281, doi.org/10.1016/j.biortech.2011.12.101.

SAUVAGEON T, LAVOIE J–M, SEGOVIA C, BROSSE N. 2018. Toward the cottonization of hemp fibers by steam explosion – Part 1: defibration and morphological characterization. Textile Research Journal, 88(9):1047–1055. doi:10.1177/0040517517697644.

SHEEDEV. ANTONY. ABEL. CHEROUAT. GUILLAUME, MONTAY. 2018. Experimental, analytical and numerical analysis to investigate the tensile behaviour of hemp fibre yarns. Composite Structures, vol. 202, pp. 482–490.

SHIN, SOO–JEONG. HAN, SIM–HEE ET AL. 2009. Monosaccharides from industrial hemp (Cannabis sativa L.) woody core pretreatment with ammonium hydroxide soaking treatment followed by enzymatic saccharification. Journal of Korea Technical Association of The Pulp and Paper Industry, vol. 41, pp. 15–19.

SIPOS B., E. KREUGER, S. SVENSSON, K. RECZEY, L. BJÖRNSSON, G. ZACCHI. 2010. Steam pretreatment of dry and ensiled industrial hemp for ethanol production, Biomass Bioenergy, 34, pp. 1721–1731 doi:10.1016/j.biombioe.2010.07.00.

TSOUMIS, G. 1991. Science and technology of wood; Structure, properties, utilization, Publishing House Kessel ISBN: 978–3–941300–22–4.

WAWRO, A., BATOG, J., GIEPARDA, W. 2019. Chemical and Enzymatic Treatment of Hemp Biomass for Bioethanol Production. Applied Sciences, 9 (24), 5348. https://doi.org/10.3390/app9245348.

XIMENES, E., KIM, Y., MOSIER, N., DIEN, B., LADISCH, M. 2011. Deactivation of cellulases by phenols. Enzyme and microbial technology 48(1), 54–60. DOI: 10.1016/j.enzmictec.2010.09.006.

PROCEEDINGS OF TWELFTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN – INNO 2024
7 – 9 October, Hotel Imperial Plovdiv, a member of Radisson Individuals, Plovdiv, Bulgaria

BIOSOURCED, RENEWABLE WOOD ADHESIVES

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ABSTRACT

Recent developments and trends in the field of eco–efficient bio–based adhesives are reviewed. Eco–efficient means efficient with regard to both ecological and economical aspects. The recent developments in tannin adhesives without the use of any aldehyde–yielding compounds under the conditions of use or even without the use of any hardeners, are described. Lignin adhesives are discussed next. Developments in protein adhesives, particularly the recent development in soy protein adhesives, are then addressed. Several new trends in carbohydrate adhesives, namely as modifiers of existing adhesives, by forming degradation compounds such as furanic compounds which can then be used as adhesives building blocks, and directly as wood adhesives, even in the form of liquified wood, are addressed. Unsaturated oil adhesives based on epoxidized unsaturated vegetable oils are also described, as well as an example of cashew nut shell oil modified by a new and inexpensive method of ozonolysis to yield an adhesive by self–condensation of the material.

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CONSIDERATIONS ON THE DEVELOPMENT OF MODELS FOR DETERMINING THE ENRGETIC EFFECTS DURING WOOD SAWING

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ABSTRACT

The work presents the development and suitability of computional models for determining the energetic effects (cutting power/cutting forces) while sawing wood. The proper optimization of the cutting processes calls for the appropriate approach for estimation of cutting forces, since it could help in a better understanding of the interaction of the tool and raw material. Simplifiest models which are present in web sources, models based on the specific cutting resistance, and model with elements of fracture mechanics involved that could be an alternative way are going to be presented. The latter model that includes work of separation in addition to plasticity and friction is capable of predictions not only of average values of cutting power but also its dynamical changes. It should be emphasized that raw material properties (fracture toughness, shear yield stresses) were determined empirically which is recommended as an alternate and effective way. Moreover, the conducted works at the Gdansk University of Technology revealed that this new approach seems to be useful for any kinematics of sawing.

Key words: sawing, specific cutting resistace, fracture mechanics, modelling, wood.

HOW TO COMMERCIALIZE RESEARCH OUTCOMES AT UNIVERSITIES? A CASE STUDY

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ABSTRACT

The process of commercializing research outcomes at universities involves transforming academic research into market–ready products or services. Establishing a professional all–in–one innovation division within universities is crucial, and it encompasses key steps such as identifying marketable research, protecting intellectual property, forming strategic partnerships with industry, developing prototypes, and engaging in licensing agreements. The talk emphasizes showcasing a case study to provide practical insights into the commercialization journey, highlighting the importance of a dedicated division and culture within academic institutions. The overall goal is to share the importance of bridging the gap between academia and the market, translating innovative ideas into tangible benefits for society.

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CHALLENGES AND OPPORTUNITIES FOR THE FURNITURE INDUSTRY IN BULGARIA

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ABSTRACT

In the last years, the furniture industry has faced several challenges globally and nationally. Such as global shortage of raw materials, transport problems and a rising cost of energy resources. This brought furniture companies several difficulties and challenges, but on the other hand, it also opened up new opportunities. Processes of optimisation, automation and robotisation of production, search for new raw materials, new energy sources, and energy efficiency improvement started. Increasingly, companies will pay attention to innovation and human capital.

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SEGMENTATION OF WOOD CT IMAGES FOR INTERNAL DEFECTS DETECTION BASED ON CNN: A COMPARATIVE STUDY

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ABSTRACT

Computed Tomography (CT) scanning enables the timelydetection of internal defects in wood, effectively increasing the utilization rate of wood and reducing processing costs.Efficient and accurate detection for internal defects in wood CT images remain significant challenges.Thepurpose of this study is to find an efficient way for detecting and segmenting internal wood defects to meet diverse performance requirements. Three commonly occurred internal wood defects were studied: knot, decay, and hollow. CT scanning was used for two logsscanning, and convolutional neural network (CNN) algorithms were applied to detect and segment defects based on CT images.Five CNN models (U–net, DeeplabV3+, PSPnet, HRnet, and YOLOv8–seg) were evaluated for their accuracy and efficiency in detecting and segmenting different internal wood defects.Results shown that U–net achieved the highest segmentation accuracy but with the lowest efficiency. YOLOv8–seg exhibited the best detection and segmentation efficiency, with segmentation accuracy second only to U–net. When considering both accuracy and efficiency, models rank as follows: YOLOv8–seg, HRnet, DeeplabV3+, U–net, and PSPnet. Additionally, performance of all models varied across the three defects. All models detected knot more rapidly and accurately compared to decay and hollow.YOLOv8–seg demonstrated superior detection and segmentation performance overall and is recommended for internal wood defect detection and segmentation tasks. U–net exceled in segmentation accuracy, suitable for scenarios prioritizing precision. This studyprovided a better and more flexible way for detecting and segmenting internal wood defects to help solving the practical problems in wood utilization.

Key words: Internal wood defect; Computed Tomography (CT) images; Convolutional Neural Network (CNN) model; Detection and segmentation performance.

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PROCESSING SAWLOGS INTO PARQUET BLANKS

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ABSTRACT

The term parquet refers to a floor covering made of solid wood, consisting of interconnected slats in a horizontal plane. A parquet strip is the principal constructional element of the parquet. This wooden strip is obtained as a result of processing the flooring blank. In the sawmill processing of the sawlogs, the flooring blanks are sawn from the sawlogs, mostly in the radial and tangential direction. For such a purpose, sawlogs from domestic species and foreign species are used. Most dominant in this manner are the hardwood species, although softwood species can be used too. Among the domestic species, the most are beech, oak, acacia, elm, ash, and from the softwood species pine and larch.

The paper focuses on the maximum quantitative yield of beech and oak sawlogs intended for processing into parquet blanks. The sawing was conducted on a bandsaw. The blanks were with a thickness of 25,0 mm. The sawlogs belonged to the I, II, and III quality classes. A total of 12 sawlogs were processed, 6 from beech (*Fagus sylvatica* L.) and 6 from oak (*Quercus robur*). All sawlogs were with a constant length of 3,0 m. The mean diameter for beech and oak sawlogs was in the range of 34,0 to 36,0 cm.

The average value for the quantitative yield for beech sawlogs from I, II, and III quality classes was 37,90%. For the oak sawlogs from I, II, and III quality classes the average value of the quantitative yield was 39,40%.

Key words: beech, oak, sawlogs, maximum quantitative yield, quality class, parquet blanks.

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BIOREFINERY OF LIGNIN: FUNCTIONAL MATERIALS AND BIOCHEMICAL PRODUCTION

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ABSTRACT

The intriguing biomass component lignin has attracted a lot of interest in the biorefinery community. For the generation of cellulosic ethanol, lignin and other lignocellulosic biomass—which is plentiful—have been the subject of intensive investigation. According to recent research, Lignin shows promise as a renewable bioresource that can be converted into valuable polymeric materials and biochemicals. Some featured properties of lignin can be utilized as a bioactive substance including antioxidant, antimicrobial, anti–UV, anti–aging, and high thermal properties. Therefore several domains of application such as high–performance materials such as nanoparticles, hydrogels, seed coating, slow–release fertilizer, 3D–printing–based biomaterials, active packaging, biomedical, tissue engineering, wound healing, energy production and storage as well as natural sunscreen are examples of lignin application. The conversion of lignin streams into polymeric materials or chemicals is determined by parameters such as native lignin structure, pretreatment conditions, and processability. With the phenolic structure, in aromatic structure, lignin has the potential to depolymerize into its dimmer or monomers as a source of biochemicals such as Benzene Toluene, Xylene (BTX) and vanillin. Two processes to extract lignin from biomass are cellulose first fractionation and lignin first fractionation. The former approach is focused on extracting „native–like lignin" with a noncondensed structure in the initial step such as RCF (reductive catalytic fractionation). By catalytic oxidative depolymerization and catalytic reductive depolymerization, this lignin can result in a mixture of biofunctional monoaromatics and a mixture of mono phenolics, respectively that can become a source of biochemicals While for cellulose first fractionation both sulfur bearing and nonsulphur bearing processes has been well applied in industry levels such as pulp and paper manufacture. The focus of this technique is to extract the cellulose and lignin as side products in black liquor. Lignin is extracted from this approach namely technical lignin with a commonly condensed structure that necessitates additional modification for specific purposes. To meet some required characteristics chemical modification and size modification can be carried out. Based on the treatment method and products, some processes such as pyrolysis, hydrogenolysis, oxidation, and gasification are performed for biochemical production. Both approaches have their merits and challenges. Finally, lignin, often considered a barrier, now offers exciting opportunities for long–term biorefinery applications. Its conversion into useful chemicals and materials helps to create a more sustainable and efficient future.

Key words: native–like lignin, technical lignin, biorefinery operation, fractionation processes, lignin active properties.

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SHRINKAGE AND SWELLING OF SPECIMENS WITH DECREASING DIMENSIONS

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ABSTRACT

As the water content changes, the wood cells shrink or swell. These are some of the processes characterizing the variability of wood. They greatly complicate processing and limit the application of wood materials. These properties depend on many factors, one of which is the scale (dimensions) of the wooden samples. Many observations show that the shrinkage and swelling processes proceed differently when the wooden samples is a few millimeters or a few centimeters. There is an even greater difference in the behavior of earlywood and latewood when they are examined separately.

The article study the processes of shrinkage and swelling during repeated wetting and drying. Samples with a constantly decreasing cross–section were investigated.

Key words: wood, shrinkage, swelling, Douglas fir.

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SOME MECHANICAL PROPERTIES OF DOUGLAS–FIR WOOD FROM BULGARIA

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ABSTRACT

The Douglas–fir is a perspective species for Europe, introduced in Bulgaria long ago. During this time many studies have been made on the growth and productivity of forests of this tree species. Mechanical properties are an important part in the design of timber structures and the calculation of processing regimes. The values given for the properties depend on the altitude and the location of the wood under study in the stem.

The subject of the research in this study is the Douglas fir wood and the determination of some mechanical properties of the wood, which has been done for the first time in our country. Standard methods and test bodies were used to establish the mechanical properties in this study.

Key words: Douglas fir, wood density, bending strength, compressive strength, hardness.

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EXAMINATION OF THE DEGREE OF SHRINKAGE AND SWELLING OF THE CELL WALL

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ABSTRACT

Upon sorption of water, wood swells, and this swelling can be directly measured at the macroscopic level of the scale. The reverse process is called shrinkage. The two processes are reciprocal and can be studied at different levels of scale. More difficult to observe and measure is the sub–microscopic level, i.e. how the cell wall swells and shrink. There is a difference in the structure of the radial and tangential cell walls due to the different dynamics of cambium division.

The article study the swelling and shrinkage of radial and tangential cell walls. An attempt has been made to geometrically model these processes at the cell level. Douglas early and late wood zones were studied.

Key words: wood, shrinkage, swelling, cell wall, Douglas fir.

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HOW TO FIND RESONANCE WOOD?

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ABSTRACT

Wood is widely used for the production of sound emitters (decks) of musical instruments. This wood is called resonant. Although this name does not quite accurately reflect the physical nature of the phenomena occurring in wood when used in musical instruments, it is widely used in practice and is used in technical literature.

The article examines the parameters that make a wood resonant. It is suggested that wood should be tested when it meets only part of the requirements and does not have good sound qualities. In this way, the influence of one or several factors can be isolated and its importance on the quality of the wood can be determined.

Key words: resonance wood, spruce, musical instruments.

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IMPACT OF FEED RATE ON ROUGHNESS OF THE CUT SURFACE AND ENERGY CONSUMPTION DURING CUTTING DRY BEECH WOOD WITH A CIRCULAR SAW

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ABSTRACT

The feed rate during mechanical processing of wood is one of the factors that has a high influence on the roughness of the cut surface and energy consumption.

The roughness of the cut surface caused by traces of the cutting tool has an influence on the hydrothermal treatment and all other mechanical treatments of the wood. Greater roughness, due to faster evaporation of moisture from the wood, increases the percentage of drying errors. On the other hand, higher roughness values decrease the lumber yield.

Energy consumption is an indicator of the cutting resistance and it depends directly proportionally, or inversely proportionally when the thickness value of the sawdust is less than 0,1 mm. At the same time, the teeth do not cut the wood and they do not create sawdust but wood dust.

In this research, three different feed rates were applied (U_1=12 mmin^{-1}, U_2=16 mmin^{-1} and U_3=20 mmin^{-1}) for a constant cutting height of 45 mm in dry beech wood with moisture content W=10±1%. The measurements were made with a circular saw with diameter of cutting tool D=250 mm, number of teeth Z=40 and width of the cut b=3,2 mm. The number of rounds was n=5500 min^{-1}.

Roughness measurements were taken with a digital comparator, according to the Rmax criterion.

Measurement data for energy consumption were taken with a clamp amperemeter.

The obtained results showed a pronounced significance, directly proportional dependence of the roughness of the cut surface and energy consumption on the feed rate.

Key words: beech wood, circular saw, roughness, energy consumption, the feed rate

MECHANICAL – MATHEMATICAL MODELS FOR STUDYING THE DYNAMICS OF A WOODWORKING MILLING MACHINE

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ABSTRACT

This work presents an analysis of the mechano–mathematical models for studying the dynamics of a woodworking milling machine, used to analyze its dynamic behavior. First, a mechano–mathematical model for the study of torsional oscillations only was examined and analyzed. Then mechano–mathematical models for the study of the general oscillations of a woodworking milling machine are considered and analyzed. Possibilities for modeling various machine faults are explored. The influence of the wear of the machine's elements on its dynamic processes was also investigated.

Key words: milling machines, torsional and spatial oscillations

MACHINES FOR PRIMARY LOG CUTTING: PART I – A STUDY ON SOME OPERATIONAL INDICATORS

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ABSTRACT

The paper presents experimental results obtained during the processing of logs with different machines for primary cutting of logs – a vertical band saw machine with a carriage feed mechanism (*Üstünkarli* – Turkey), circular saw machine for logs (*Kallion Konepaja Oy* – Finland) and a mobile horizontal band saw machine (*Arsov 90 Ltd.* – Bulgaria). The places for conducting the research are the manufacturing conditions of Training and Experimental Forest Range „G. Avramov“ – the village of Yundola, Training and Experimental Forest Range „Petrohan“ – the village of Burzia and „Petnop“ Ltd. – the town of Varshets. The influence of basic parameters related to processing with these machines – feed speed and cutting amount, on the quality of the obtained wood materials, was determined. The evaluation metrics measured are dimensional accuracy and surface roughness. The productivity of the machines was also determined. The studied wood species was Scots pine (*Pinus sylvestris L.*). The obtained results were analyzed and practical recommendations were proposed.

Key words: log cutting machines, Scots pine, productivity, roughness, work accuracy.

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MACHINES FOR PRIMARY LOG CUTTING: PART II – COMPARATIVE ASSESSMENTS AND ANALYSIS

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ABSTRACT

In the paper a developed methodology is presented, which will be useful in a comparison between individual machines for primary cutting of logs – a vertical band saw machine with a carriage feed mechanism (*Üstünkarli* – Turkey), circular saw machine for logs (*Kallion Konepaja Oy* – Finland) and a mobile horizontal band saw machine (*Arsov 90 Ltd.* – Bulgaria). On the basis of the obtained experimental results, which are presented in the first part of the current study and the technical parameters of the machines, the following evaluation indicators were selected: productivity, dimensional accuracy, roughness of the obtained surfaces, width of the cut, required power, cutting tools, etc. The obtained quantitative results were transformed into point scores. For each of the indicators, a weighting coefficient is also selected, depending on its importance. The advantages and disadvantages of the studied machines are indicated and an analysis of the results is carried out.

Key words: log cutting band saw, log cutting circular saw, mobile horizontal band saw, productivity, dimensional accuracy.

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INFLUENCE OF CUTTING SPEED OVER VIBRATION SPEED WHEN MILLING WHITE PINE DETAILS ON A UNIVERSAL WOOD SHAPER

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ABSTRACT

This study presents how the cutting speed influence over vibrations of the cutting mechanism in a woodworking shaper. The experiment was carried out at different operating rotation frequencies and cutting tools with different diameters. During the experiment, white pine test samples were milled. Measurements are made at four points in the radial direction. Two of them are located in the upper bearing housing the other two in the lower bearing housing. A universal milling machine with a lower position of the working shaft is used for the experiment. During the research, attention was paid to some technological factors such as the feed speed of the processed material which is from4m.min–1to 16m.min–1, milling width 12 mm and thickness of removed layer 12 mm. The study is aimed at improving the reliability and efficiency of a wood shaper machine as well as to ensure the accuracy and quality of products.

Key words: Wood shapers, cutting speed, vibration speed.

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INCREASING EFFICIENCY IN THE PRODUCTION OF DETAILS FOR SOLID WOOD PANELS

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ABSTRACT

Improving efficiency is a primary goal and task of any manufacturing activity. This can be achieved by reducing production costs and enhancing the quality indicators of the final product. The current research is part of a scientific project dedicated to the integrated study and modelling of the influence of technological factors on the production of engineered wood. In this section, results from theoretical studies on the costs associated with producing components (lamellae) for solid wood panels, intermediate layers of CLT structures, etc., are presented and analysed. These results aim to identify possibilities for reducing large waste and to determine certain technological factors in the subsequent bonding of wood to improve the quality of the final product.

Key words: wood panels, CLT, trapezoidal cross–section, yields

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EVALUATION OF THE MACHINED SURFACE QUALITY OF SCOTS PINE (*PINUS SYLVESTRIS* L.) WOOD SPECIMENTS, DEPENDING ON THE CUTTING MODE OF A CNC MACHINE

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ABSTRACT

In this paper, the surface quality of scots pine *(Pinus sylvestris L.)* wood specimens, processed with a CNC woodworking drilling and milling machine with a negative face mill helix, has been investigated. The changes in the surface roughness, depending on the changes in main factors, determining the cutting process, such as cutting tool rotation speed (n); feed speed (V_f) and radial depth of cut (h) have been evaluated. The quality of the processed surfaces was evaluated by the roughness parameter R_z, measured with a portable roughness tester, model *Surftest SJ–210* (Mitutoyo, Japan).

Based on the performed experiments, graphical dependencies, presenting the influence of the individual factors on the quality of the processed surface were derived. A regression model was derived, that could be used for quantitative prediction of the surface roughness of Scots pine wood specimens, when processed with a CNC machine, depending on the changes of the variable factors (n, V_f, h).

Key words: surface quality, CNC machines, cutting mode, milling, Scots pine, rotational speed, radial depth of cut, feed speed.

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A REVIEW OF SOME FACTORS AFFECTING THE ACCURACY OF MEASURING THE GEOMETRIC CHARACTERISTICS OF MORTISE AND TENON JOINTS

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ABSTRACT

The geometric characteristics of mortise and tenon joints represent their ideal shape as well as the permitted deviations from that shape. Measurement accuracy as part of production metrology is of crucial importance for maintaining tolerances and fits as well as quality control in production. The closeness of the measurement results to the actual true value of the measurand depends on many factors. Some factors that affect the accuracy of a measurement are caused by the measuring equipment, the environment in which the measurement is performed, the operator who performs the measurement, the method and procedure of the measurement and the properties of the material.

This review paper presents an investigation of the factors and their affect on the accuracy of measurement of mortise and tenon joints while maintaining manufacturing tolerances. The purpose of this investigation is to consider the possibility of their minimization to obtain a more accurate measurement.

According to the theoretical analysis, the group of factors that express the heterogeneity and hygroscopicity of wood as a material have a great effect on the accuracy of the measurement.

Key words: measurement, accuracy, mortise and tenon joints, geometric characteristics.

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THE STUDY ON THERMAL PROPERTIES OF ECO–FRIENDLY PARTICLEBOARD FOR INNOVATIVE CONSTRUCTION, PACKAGING SOLUTIONS AND FURNITURE

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ABSTRACT

The study aims to examine the environmental significance and practical applications of eco–friendly particleboard suitable as a construction material for energy–efficient buildings, furniture, and packaging. The knowledge of thermophysical properties of particleboard made of spruce wood chips with the addition of various components such as tires, seals and carpets, painted and unpainted bumpers, flammable and non–flammable cables, fuel tanks, tires and graphite, seals, carpets and graphite were examined at room temperatures using Hot Disk 2500s Method. The lowest thermal conductivity accounted for was 0.1881 (W/ m·K) for spruce wood mixed with 10% seals and carpets with better insulation properties with a density of 683.230 kg/ m^3. Whereas the highest thermal conductivity recorded was 0.2125 (W/ m·K) with a density of 757.073 (kg/ m^3) for spruce wood mixed with 10% of seals, carpets, and graphite considering the mean deviations in the ten to the power of negative five. Similarly, the lowest thermal diffusivity was 0.1665 (mm^2 / s) for spruce wood mixed with 10% of fuel tanks, and the highest was 0.2296 (mm^2/ s) for spruce wood mixed with 10% of seals, carpet, and graphite. The measurements were performed under isotropic conditions; therefore, it was possible to calculate theoretically the specific heat capacity of all wood composites. The experiment was performed under room temperature conditions with 320 seconds of total duration, adding stabilization and temperature variation time before starting the measurement. To ensure the accuracy of data, all the results were considered with the mean deviations in the ten to the power of negative five. The results contribute to the understanding of the heat transfer phenomena of particleboard and provide essential details for various industries where thermal management is crucial.

Key words: Hot Disk Method, thermophysical properties, sustainable construction material, particleboard.

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SCALES IN WOOD–BASED COMPOSITES IN IRAN

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ABSRACT

Wood is a renewable raw material in different kinds and varieties that nature has provided for mankind to be used in a myriad of applications since before history. With the rapid increase in poulation on earth, and the consequent growing need for wood, fast–growing trees became of more importance every day though their properties are considered rather poor. However, they can satisfactorily be used in wood–based composite panels, like particleboard, medium–density fiberboard (MDF), high–density fiberboard (HDF), flakeboard, plywood, oriented strand lumber (OSL), and so on. Still, production and application of these composite panels have some troublesome drawbacks, including vulnerability to water and high humid areas, and hot–press as a bottleneck in the production process. Over the past two decades or so, studies were carried out to overcome these drawbacks and to improve properties in composite panels from different aspects, using metal and mineral materials at nano– and micro–scales as resin reinforcement and additive. The present article tries to briefly provide an outlook on the strengths and weaknesses of the most important materials that have been used in Iran with an aim of giving an idea to young researchers for their future studies.

Key words: Cellulose–based composites, Minerals, Nano– and Micro–materials, Natural fibers, Resin reinforcement, Wollastonite.

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PRODUCTION OF FURNITURE ELEMENTS WITH PARTICLEBOARD CUTTING WASTE CORE

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ABSTRACT

The scarcity of natural resources and the generation of waste without adequate disposal are a worldwide concern related to the linear production model. The present study is part of a research project to create a technology for the utilization of laminated particleboard cutting waste in furniture element production. A layer of waste details was laminated on both sides with High Pressure Laminate (HPL) with a thickness of 0.8 mm. Polyvinyl acetate adhesive was used for lamination. The influence of the lamination process conditions and the arrangement scheme of the core details on the appearance, bending strength, and processing features in the subsequent technological phases of the manufacturing process has been established.

Key words: waste utilization, laminated particleboard, lamination, HPL.

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EFFECT OF STAINING ON THE ROUGHNESS OF BEECH FURNITURE SURFACES

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ABSTRACT

Staining is a process of transparent wood surface colouring. Stains are liquid systems that wet and penetrate treated surfaces, changing their properties, including their roughness. The article presents research on the surface roughness change of beech, beech plywood, and beech veneered wood–fibre boards after treatment with waterborne and solvent–based stains, as well as waterborne stain with PVA resin additive. Before staining, the surfaces were sanded with P150–grain sandpaper. A contact roughness tester model SJ–210 and a standard Gaussian filter were used to evaluate the roughness. The influence of the substrate structure, the stain dilution and the type of thinner on the surface roughness was determined. The parameters *Ra*, *Rpk*, *Rk*, *Rvk* and the composite parameter *Rpk+Rk+Rv*k were analysed. The results are presented graphically and also in tables.

Key words: waterborne stain, solvent–based stain, roughness, beech, beech plywood.

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INFLUENCE OF THE MOISTURE CONTENT OF FROZEN LOGS ON ENERGY REQUIRED FOR THEIR DEFROSTING IN BOILING PITS

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ABSTRACT

With the help of our own non–stationary model, the temperature field and defrosting durations of frozen beech logs with a diameter of 0.4 m, initial temperature of −10°C, and moisture content of 0.4 kg·kg^{-1}, 0.6 kg·kg^{-1}, and 0.8 kg·kg^{-1} were determined at water temperatures in the boiling pit equal to 80 °C. Using the determined durations, the change in energy required for carrying out of the entire defrosting process and that for each of the 5 components of the pit's thermal balance was calculated. Computer simulations were performed for a well–insulated concrete pit with working volume of 20 m^3 and degree of filling with logs *f* equal to 25%, 50%, and 75%. It was found that at maximum possible value *f* = 75% the total energy consumption of the pit increases from 145.1 kWh.m^{-3} to 180.2 kWh·m^{-3}, i.e. by 24.2% when the moisture content of the frozen logs increases from 0.4 kg·kg^{-1} to 0.8 kg·kg^{-1}. With a decrease in *f*, the thermal efficiency of the pit decreases almost proportional to *f*, mainly due to the increase in the specific energy required to heat the water in the pit.

Key words: concrete pits, heat balance, defrosting of logs, wood moisture content, energy consumption.

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APPLYING THE SOFTWARE PACKAGE TABLE CURVE 2D FOR CALCULATING THE ENERGY REQUIRED FOR MELTING OF FROZEN BOUND WATER IN WOOD

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ABSTRACT

A mathematical description of the energy $Q_{ice–bw}$ required for melting the temperature dependent part of frozen bound water in wood, using a software package Table Curve 2D v.5.01 has been presented. This package allows for the selection of equations, which provide the best similarity between the calculated with them values of $Q_{ice–bw}$ during thermal treatment of wood containing ice and the respective numerical data obtained with an adequate temperature–energy model of $Q_{ice–bw}$. The type and coefficient values of the Table Curve equations for $Q_{ice–bw}$ in this work have been determined for the case of thermal treatment of frozen beech wood with an initial temperature of −1 °C, −10 °C, −20 °C, −30 °C, −40 °C and moisture content of 0.4 kg·kg^{-1}, 0.6 kg·kg^{-1}, and 0.8 kg·kg^{-1}. The equations obtained for $Q_{ice–bw}$ can be used for development and automatic implementation of scientifically based energy–efficient regimes for steaming or boiling of frozen wood materials with different parameters.

Key words: calculation of energy, wood containing ice, melting frozen bound water, thermal treatment, Table Curve 2D.

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WOOD–BASED BUILDING MATERIALS WITH A THERMAL ENERGY STORAGE FUNCTION

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ABSTRACT

Encapsulating of phase change materials (PCM) in ceilings, floors and walls improved energy storage in buildings. The results show 10% saving of thermal energy by using bio–based, building materials with added functionality.

The environmental impact of fossil–based materials on the construction industry and significant energy consumption in housing have driven the production of bio–based, renewable and sustainable materials for building applications. This is achieved by incorporating bio–based PCM into wood materials for thermal energy storage in residential buildings.

Phase change materials absorb and release heat when changing from a solid to a liquid state. Organic PCM in form of fatty acids or esters produced from renewable resources, e.g. vegetable oils are suitable for the purpose. PCM can be impregnated in solid wood, wood fibres or sawdust and in the developed wood–based composite materials.

The bio–composites store and release heat energy in the human comfort temperature range of 18–21°C. A step in the technology is the development of a bio–composite consisting of sawdust impregnated with ethyl palmitate (EP) as PCM and linseed oil as bio–based binder. The composite consists of 25% ester and has 50 J/g latent heat while being thermally stable up to 200°C.

The new building materials are exposed in models for long–term monitoring and data collection for material behaviour and LCA. The thermal energy saving after 1 year of exposure was 10% and the model house had a better climate performance with 5.4% lower impact during its lifetime in comparison to the model house without PCM.

Key words: bio–based phase change materials, bio–based composites, building materials, impregnation, wood materials, thermal energy storage.

EFFECT OF DIFFERENT FORMALDEHYDE SCAVENGERS ON THE PROPERTIES OF MEDIUM–DENSITY FIBERBOARDS

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ABSTRACT

The shift toward a circular, low–carbon wood–based panel industry, coupled with growing environmental concerns about unsustainable petroleum–based resources and stringent legislative requirements for formaldehyde emissions from engineered wood composites, has significantly boosted research and development efforts in creating eco–friendly wood–based materials. Formaldehyde is one of the most common and significant indoor pollutants. Prolonged exposure to formaldehyde may result in numerous health hazards, such as damage to the central nervous system, immune system issues, asthma, respiratory discomfort, and even cancer. This led to the implementation of more stringent formaldehyde emission regulations in different countries worldwide, e.g., in Europe, the USA, and Japan, which have raised the industrial focus on creating new wood adhesives that emit extremely low levels of formaldehyde. Notably, emission class E0 (formaldehyde content below 4 mg/100 g o.d.) will become mandatory for the European Union member states since 2026. A viable strategy to reduce the free formaldehyde emissions from wood–based panels involves incorporating a range of various organic, inorganic, and mineral formaldehyde scavengers into the adhesive systems. The aim of this work was to investigate and evaluate the effect of adding ammonium–hydrogen–sulfite and urea–metabisulfite as formaldehyde scavengers on the physical and mechanical properties of medim–density fiberboard (MDF) panels. The effect of both scavengers was studied at a content varied from 0% to 5% compared to absolutely dry urea–formaldehyde (UF) resin. A comparative analysis of the effect of both substances was carried out. On this basis, conclusions and recommendations were drawn regarding the optimal content of formaldehyde scavengers in the adhesive system used.

Key words: medium-density fiberboard, formaldehyde content, formaldehyde scavengers, urea-metabisulfite, ammonium-hydrogen-sulfide.

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PROPERTIES OF THREE-LAYERED PARTICLEBOARDS WITH THE PARTICIPATION OF WOOD FIBERS IN THE FACE LAYERS

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ABSTRACT

The two main types of wood–based panels used in furniture manufacturing are particleboards and fiberboards, mainly medium-density fiberboard (MDF) panels. Markedly, MDF panels have significantly better properties than particleboards, but at the expense of increased production costs, mainly due to the defibering process. Combined wood–based panels with face layers of wood fibers and a core layer of particles can partly overcome this drawback. The presented study investigated the properties of panels fabricated with combined face layers of wood particles and fibers. For this purpose, the fiber content of the face layers was varied from 0% to 50%, with a step of 10%. The main properties of the laboratory–made composites were determined, and relevant conclusions and recommendations were drawn.

Key words: combined wood–based panels, wood particles, wood fibers, physical and mechanical properties.

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INVESTIGATION OF THE ADHESION STRENGTH OF HEMP SHIVES PANELS AS A MATERIAL USED IN FURNITURE CONSTRUCTION

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ABSTRACT

Engineered wood–based panels are one of the primary materials used in furniture construction. The lack of wood raw material worldwide requires searching for alternative sources for this type of material. Hemp shives panels represent precisely this type of raw material, characterized by good exploitation properties.

In this article, a comparative analysis is made of the suitability of panels from hemp shives for glue joints in furniture constructions. For this purpose, the adhesion strength of laboratory panels made of hemp shives was determined, and the obtained results of the relevant properties were compared with those of conventional particleboards.

It has been established that boards made of hemp shives are a suitable substitute for boards made of wood, with significantly better adhesion strength properties, affecting the performance of bonded joints in furniture constructions.

Key words: hemp shives panels, adhesion strength, furniture constructions, glue joints.

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FAST PROTOTYPING WITH THE HELP OF AUGMENTED REALITY AND VIRTUAL REALITY

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ABSTRACT

A current theme in the wood industry is the use of digital technologies such as Virtual Reality (VR) and Augmented Reality (AR). Through these technologies, furniture designers can analyze prototypes of furniture pieces in real or virtual spaces. Therefore, designers and subsequently customers can view and interact with 3D models in virtual environments, allowing them both to analyze the product in different configurations (dimensions, colors, textures, segmentation) and to identify potential design errors. Thus, VR and AR offer to the client a preview of the designed furniture, and they are able in real–time, to make changes in some details and preview the results. In conclusion, virtual and augmented reality technologies save time, effort and resources, and contribute to faster product development and innovation. In this project, several furniture models were 3D designed using a specialized CAD program and then analyzed in real and virtual spaces using specific software and devices in the frame of AR and VR technologies. Following the analysis carried out for different variants of furniture prototypes, it was concluded that the two technologies are very useful for selecting the most appropriate variant of design.

Key words: Furniture design, CAD, Virtual Reality, Augmented Reality, 3D modelling.

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EDUCATION IN DESIGN FIELD: MANUAL – MATERIAL CULTURE APPROACHES

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ABSTRACT

In this paper several guidelines and methodological approaches for non–formal education in the field of design are presented. The main focus in this research is based on manual – material culture and the connection/interconnection with the design process. The research is based on thirteen years experiences of the authors in organizing and conducting one week of international (Romanian and Austrian students and teachers) design workshops in Romania and Austria.

Key words: non-formal education, design, manual – material culture, workshop.

FRAGMENTATION IN MACEDONIAN TRADITIONAL ARCHITECTURE IN RELATION TO THE WOOD AS A STRUCTURAL ELEMENT

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ABSTRACT

Intricate concepts of spatial organization characterize the traditional Macedonian architecture of the 19th century. The limitations imposed by specific materials and technological constraints during that era stimulated the development of intelligent and versatile spatial models. Among the defining features of that architecture is the intricate use of wood as a primary constructional element. This research seeks to investigate the qualities of fragmentation of the form and their practical application.

The study will commence by defining the concept of fragmentation as a fundamental aspect of architectural expression. It will then systematically analyse its physical and formal properties from various aspects such: Materials, Spatial structure, Construction, Grouping of window openings. It will also analyse aspects of human experience and perception, evident through: Perception and experience, Identity, Functionality. The study will examine approximately 200 houses from this period.

Key words: fragmentation, rhythmic formations, spatial configuration, traditional architecture.

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ADVANCING FABRIC MATERIAL DIGITALIZATION THROUGH PHOTOMETRIC STEREO RECONSTRUCTION

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ABSTRACT

Photometric stereo reconstruction is a contemporary approach to digitizing fabric surfaces. By capturing multiple images of the surface illuminated from various angles and analyzing the resulting shadows, this method reconstructs the material's volume. It excels in capturing intricate texture details, particularly in surfaces with microscopic intricacies like fabric materials.

Key words: photometric stereo reconstruction, textures, fabric surfaces, Adobe Substance Designer.

SYMBOLISM AS THE FACE OF CONTEMPORARY FURNITURE

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ABSTRACT

We live in a world where everyone can express their individuality in many different ways such as their behavior; and the apparel that they own or are associated with. The furniture that we equip our homes with is also a way of expressing ourselves. The image of contemporary furniture designs is influenced by the individuality of the symbolism. This article aims to reveal and analyze the different types of symbolism and the ways of their application as well as the reasons why certain users are associated with different groups of symbolism.

The chosen methodology is based on literary research and analysis of various furniture samples, as well as their interpretation and classification.

Key words: symbolism, contemporary furniture design.

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APPLICATION OF ANALOGY BY EXTERNAL FORM IN FURNITURE DESIGN

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ABSTRACT

The article considers one of the main types of analogies – Analogies by External Form and its application in the design of modern furniture. Examples of biomorphization and imitation of the appearance of natural objects are illustrated; imitation and pseudomorphization of technical objects; copying the shapes of the object; manifestation of specific external properties of one object on another; imitation of the coloration, texture of other technical objects. The possibilities for applying analogies not only in appearance but also in texture and compositional means are covered.

The effectiveness of applying this type of analogy technique for achieving efficient and functional solutions in furniture design has been proven.

Key words: analogies by external form, furniture design.

VIDEO CLIP THE MARATHON – AN APPROVED EDUCATIONAL APPROACH TO TRAINING „THEORY OF COMPOSITION“ AT THE UNIVERSITY OF FORESTRY

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ABSTRACT

The article examines events – public presentations of „video clips“ held annually for a decade with the students of the University of Forestry, Engineering design, third year. The purpose of the study is to assess the advantages and problems of such an educational approach, as well as to trace its evolution. The types of student development are systematized. Scientific methodology includes selection of key examples, comparative analysis and classification. Expected results are in the fields of design theory and art, contemporary design and architecture.

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CHANGES IN THE SURFACE PROPERTIES OF WOOD DURING BROWN ROT

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ABSTRACT

Fungal decay is a risk for wood and wood products exposed to a humid outdoor environment. Under certain conditions, wood rot can also occur indoors, e.g. on wooden floors, furniture in bathrooms and kitchens or in joinery. Visible signs of wood decay usually only appear when it is already too late for repair or less demanding restoration.

It is therefore important to detect fungal infestation as early as possible. We investigated the applicability of instrumented microscratching and microindentation methods in the study of fungal decay of wood. Samples of Norway spruce wood (*Picea abies*) were exposed to the brown rot fungus *Gloeophyllum trabeum* using the miniblock method. The progression of decay was monitored at one–week intervals during the 8–week fungal exposure. The results were complemented by hyperspectral imaging. A gradual increase in scratch depth was observed after 2 and 5 weeks of exposure, reaching values of approximately 500 μm after 8 weeks at 15 N load. This reflects the decrease in hardness as decay progresses. The cyclic indentation measurements showed that the control wood and the wood exposed to the fungus for one week had different indentation hardness and indentation modulus depth profiles than the wood that had rotted for 2, 5 or 8 weeks. To summarise, the first signs of decay were detected by microscratching and microindentation measurements after only two weeks of exposure.

Key words: Norway spruce wood, fungal decay, hyperspectral imaging, microscratching, microindentation.

SURFACE FINISHED OF FURNITURE PARTS CONSISTS FROM HARD WOOD AND HARDENED EPOXIDE POURING RESINS

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ABSTRACT

This paper is focuses on investigation of the finished surfaces durability of composite materials formed by combing epoxy casting resins and different kinds of soli woods such as olive, oak, walnut ash. In the article there is analysing the effect of surface treatment, using different kind of coating materials on the effect of surface treatment. In this paper the response of this material to various external factors including mechanical wear, water vapour exposure of the effect of temperature alternation are introduced.

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INVESTIGATIONS OF PAINTABILITY OF INNOVATIVE BUSH WILLOW PRODUCT

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ABSTRACT

A study was conducted on the paintability of material produced from consolidated shrub willow wood rods with commercial lacquer products. In the first stage, the tested material was prepared under laboratory conditions. Then, the selection of lacquer products and the parameters of the technological process of their application were made. Lacquer products in commercial acrylic and polyurethane products were used for testing. Tests were carried out on the wettability of the surface of lacquer coatings formed on the test material, taking into account the assumptions of the adsorption theory of adhesion of polymers to lignocellulosic materials. The surface free energy with the dispersive and polar shares were determined for the lacquer coatings. In addition, the surface energy of willow material and lacquer coatings was determined using specialized colored test inks with known surface tension and the adherence of coatings to the substrate. Based on the results, the suitability of the acrylic and polyurethane lacquer products used in the study for finishing the test material's surface produced from consolidated shrub willow wood rods was established.

Wettability measurements as a function of time showed a reduction in the contact angle values. The surface free energy for the analyzed finishes for times of 10 and 20 s took values of 31–43 mJ/m^2. All coatings from the tested lacquer products showed good adhesion to the substrate. However, this parameter was in the value range of 3.11÷3.58 MPa, with varying delamination mechanisms.

Key words: willow, lacquer product, coating, surface free energy, adherence.

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SOME ASPECTS OF INTERLAYER ADHESION IN FINISHING HONEYCOMB PANELS

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ABSTRACT

There were recently introduced into wood companies' technologies for finishing wood species and wood–based composites using acrylic or waterborne UV products. Such varnishes need unique lamps for very fast curing and hardening of coatings. Systems „in standard form" have been used for finishing honeycomb panels since 2005. Gallium and mercury lamps can be used in this technology. Unfortunately, the use of these lamps has many disadvantages. In recent years, some companies have started to use new energy–saving energy sources for ecological lacquer systems. During applications from 5 to 12 layers, the fundamental is the highest interlayer adhesion between each layer.

In the BORNE FURNITURE Company in Poland, workers started using this technology. In the frame of a PhD. work, the adhesion strength and adhesion phenomena were estimated. Experimental materials were prepared in the industrial conditions. Such parameters were changed: amount of applied lacquer products, amount of energy and number of lumps. Adhesion strength tests of the tested systems were performed acc. to the PN–EN ISO 4624 standard, using an automatic hydraulic PostiTest apparatus. Images of delamination under destructive loadings were evaluated using a visual method.

Based on the obtained results, the appropriate parameters have been selected for use in the industrial conditions and further analysis.

Key words: finishing, hardening, coating, adhesion strength, UV LED lamp.

SALIXDUO RESISTANCE TO MOULD

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ABSTRACT

The mycological test of SalixDuo obtained from bush willows was carried out based on the guidelines contained in the BS–3900g6 standard. This is a standard that very well reflects the material's susceptibility to mold. A sample with dimensions of 10×7×2.5 cm (first dimension along the fibers) was used for testing.

The following test organisms were used as test microfungi: *Aspergillus niger* van Tieghem BAM–4, *Penicillium pinophilum* BAM–23, *Chaetomium globosum* Kunze:Fries BAM–12, a mixture of fungi (*Aspergillus niger* van Tieghem BAM–4, *Penicillium pinophilum* BAM–23, *Paecyliomyces varitii* BAM 19, *Trichoderma (Gliocladium) virens* BAM 34).

Based on the tests performed, it was found that the sample surfaces were covered with up to 10% of the surface within 7 to 10 days. Complete fouling of the samples occurred in the 6th week of the mycological test. After about two weeks, the glue joints broke due to the swelling of the wicker wood.

Conclusions

SalixDuo can be used in wood use class 1 according to PN–EN–335.

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PRELIMINARY STUDY ON FUNGICIDE EFFECTS OF PYROLYSIS LIQUIDS USED AS WOOD PRESERVATIVE

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ABSTRACT

When determining the fungistatic effect of wood preservative in the first phase of research (screening), the most widely used method is the nutrient–agar method. Access to quick results obtained from current fungi. Neglecting the use of LD_{100} wood tar substances. The concentration of such a tested preparation in the agar medium completely limits the growth of the mycelium of the test fungus.

Mycological tests on four fungi normally used in this type of research. These were: *Rhodonia (Poria) placenta* BAM 113 (FPRL 280), *Coniophora puteana* BAM 112 (BAM Ebw. 15), *Gleophyllum trabernum* BAM 115 (BAM Ebw. 109), *Trametes versicolor* BAM 116 (CTB 863 A). The fungistatic properties of tars that were introduced into the agar medium were summarized: 10%;1%; 0.75%; 0.5%; 0.25%; 0.1%.

Based on screening, LD_{100} values were obtained for all possible wood tar fractions, and the two most active wood tars were selected. These were wood tars obtained at a temperature of 450^{o}C from pine wood and at 500^{o}C from birch wood. In accordance with the adopted purpose of screening tests, the above–mentioned wood tars will be used to determine the fungicidal limit value according to the modified EN–113 standard.

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EFFECT OF BONDING AREA SIZE ON BENDING STRENGTH AND STIFFNESS OF FIXED JOINTS OF LAMINATED WOOD PARTS UNDER BENDING LOADING

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ABSTRACT

The paper presents results on the flexural strength of glued corner joints of structural elements made of beech veneer plywood. Flexural strength with shoulder collection is determined for five end corner joints (L–shaped) and four middle corner joints (T–shaped). The greatest bending strength has the end corner joints with slot and pin (305.3 N.m), and the smallest – L–shaped corner joints with dowels Ø 8 mm (219.5 N.m). It is important to note that a strong relationship between the size of the bonding surface and the flexural strength of the joints was found, which provides new directions for the design and manufacture of plywood furniture. Given the significant influence of the bonding area on the bending strength of corner joints, when choosing the type of joints in the construction of plywood furniture, comparative data on the bending strength of corner joints made of plywood should be taken into account. This recommendation is of particular importance to designers and builders seeking to optimize the strength and durability of engineered plywood furniture.

Key words: plywood joints, bonding area, bending strength, stiffness.

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INFLUENCE OF THE COMPONENTS OF THE WINDOW ON THERMAL CONDUCTIVITY

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ABSTRACT

The purpose of the windows as a construction product is to provide the building with natural light and the opportunity to ventilate the interior and at the same time providing protection to the room against external influences such as wind and rain, as well as to prevent uncontrolled cooling or heating of the room or the whole building in which they are built in. A window is a complex product which is constructed of different parts that could be made of different materials. In addition to providing light and protection from external influences such as rain and wind, the window has a key part in the energy efficiency of buildings. Energy efficiency as a term is usually associated in with two separate approaches, energy effects of devices and energy efficiency measures. When it comes to an energy–efficient device, then it is the device that has a high degree of energy utilization, while measures related to energy efficiency are all that we can do to reduce energy consumption. In order to protect the energy of the buildings, among other things, well–chosen windows of good quality and their proper installation play a key role in it. This research is focused on how much the component parts of the window have an influence on the thermal conductivity of the entire window, in fact, how different combinations of profiles that are used and glass packages affect the coefficient of thermal conductivity of the windows.

Key words: construction carpentry, window, thermal conductivity, energy efficiency.

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INCORPORATING SOCIAL DESIGN FOR DISABILITY–INCLUSIVE SOCIAL ENTREPRENEURSHIP: A CATALYST FOR SOCIETAL TRANSFORMATION

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ABSTRACT

This study uses the potential of social design as a tool to promote social entrepreneurship involving people with disabilities. Social design, with its human–centered, empathic and collaborative approach, is being explored as a key strategy for creating business models that effectively meet the needs and aspirations of people with disabilities.

This article uses social design principles and explores how they can be incorporated into social entrepreneurship to promote disability inclusion, improve accessibility and generate socio–economic impact. This approach highlights the need to further explore the unique experiences and requirements of people with disabilities, thereby promoting the development of innovative, tailored solutions.

Key words: social design, social entrepreneurship, people with disabilities.

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MANAGEMENT PRACTICES FOR SUSTAINABLE DEVELOPMENT OF THE FURNITURE SECTOR

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ABSTRACT

The focus of economic development at the national and regional level is to increase competitiveness through sustainability. According to research by the Organization for Economic Co–operation and Development (OECD), global value chains (GVCs) create significant economic opportunities for companies and the regions in which they operate. Innovation can also be a factor in economic development with sustainable results. The development presents the results of conducted standardized sociological surveys and a Delphi survey regarding the views of experts on the opportunities, risks and challenges of the participation of enterprises in GVDS and their innovation to achieve sustainability.

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CHALLENGES IN THE CIRCULAR ECONOMY OF BULGARIA

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ABSTRACT

The transition towards a circular economy presents a transformative challenge with the potential to yield extensive economic, environmental, and societal benefits. In Bulgaria, the shift from a traditional linear economy to a circular one is fraught with a unique set of challenges, which this paper meticulously examines. Through qualitative and quantitative analysis, the paper identifies the primary barriers impeding the adoption of circular economy practices, including inadequate regulatory frameworks, insufficient technological infrastructure, and the entrenched habits of consumption and production that resist change. It explores the role of government policy, business innovation, and consumer engagement in fostering a conducive environment for the circular economy. The paper also discusses the potential for economic growth and sustainability that a circular economy can offer within the Bulgarian context, suggesting strategic approaches to leverage indigenous resources, and encouraging collaboration between sectors. Through this exploration, the paper provides valuable insights and proposes actionable recommendations that aim to guide policymakers, business leaders, and civil society in overcoming these challenges and achieving a sustainable circular transition in Bulgaria.

Key words: circular economy, challenges, success factors.

PRODUCTION AND TRADE OF WOODEN PRODUCTS IN BULGARIA FOR THE PERIOD 2007–2021 – QUANTITATIVE ANALYSIS AND FACTORS OF INFLUENCE

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ABSTRACT

The study provides a comprehensive examination of Bulgaria's wood product industry over a fourteen–year period. This analysis utilizes quantitative methods to explore production volumes, export and import trends, and the balance of trade in wooden products. Key influencing factors, including economic policy changes, and market demand shifts are assessed for their impact on the sector's performance. The study employs statistical tools to identify growth patterns and anomalies in production and trade flows, correlating these with national and international events. By mapping the trajectory of Bulgaria's wooden product sector, the analysis reveals both the resilience and the vulnerabilities of the industry, offering insights that could guide future strategic decisions for stakeholders within the sector.

Key words: wood products, market demand, trends.

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MODELING INNOVATIVE PRODUCTS THROUGH DESIGN THINKING

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ABSTRACT

„Design thinking“ (DT) is an innovative concept for making and implementing new business solutions (products, services, processes), contributing to an increase in their quality, according to the expectations and requirements of their users. His methodology involves thorough research and understanding of stakeholders, and qualitative changes to the outcome with rapid implementation of corrective actions.

„Design thinking“ is also a modern tool for achieving innovation through creative co–creation of the final solution by work teams together with customers. Because of this, his methodology is increasingly used in making management decisions of a different nature, especially in product management – the area in which the goal is to create quality product innovations.

In connection with the practical interpretation of the DT methodology in product management, in making operational management decisions related to innovation and modeling of innovative products, the authors also created a short–term training course program for specialists in the field of standardization and quality management, members on „Club 9000“.

The purpose of the training is to present the methodology of DT, its algorithm and the possibilities of its use as an innovative tool in the process of creating new products, while minimizing risk. At the same time, it is aimed to support through interactive training the building of practical skills for work, using tools from the specially created Manual for the application of DT in modeling innovative products in a specific sector (Woodworking and furniture industry).

Key words: design thinking, innovative products, product management, innovation, innovative programs, training.

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INFORMATION MODELING OF SUSTAINABLE BIOENERGY AND BIOFUEL PRODUCTION

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ABSTRACT

The European Union's Circular Economy project aims to protect the environment and reduce dependence on raw materials. The present study examines the state and the perspective for the sustainable production and use of bioenergy and biofuels as one of the key factors for the realization of the circular economy. For the purpose, an information model is presented. The methodology for building such model includes: definition of target, scope and users; a generalized scheme of an information system for maintenance of criteria and certificates for sustainability of bioenergy and biofuel production; consideration about software platforms and resources for implementation and publication of the information model. On the base of the generalized schema, a prototype information system is developed consisting of user interface, functional scripts and database of bioenergy and biofuel production in Bulgaria. The analysis of data shows the necessity to develop a unified standards and classifiers resolving inconsistencies between bioenergy/biofuel production datasets in all European Union countries.

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Key words: bioenergy and biofuel production, information modeling, information system, sustainable certificate.