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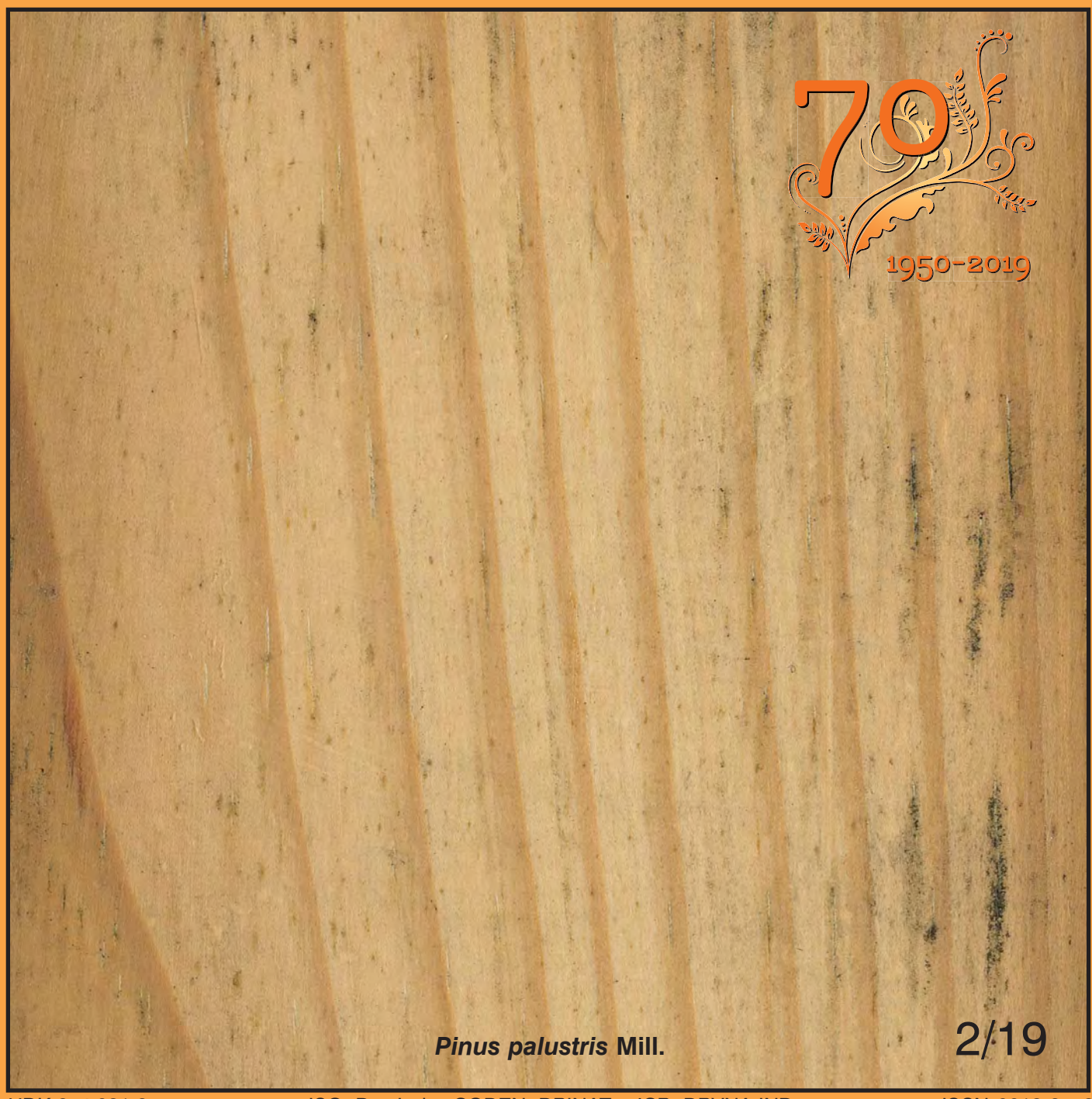

***Pinus palustris* Mill.**

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Chemical and Application Properties of Some Solvent and Water Based Coatings on Wooden Substrate

Kemijska svojstva i primjena premaznih materijala na bazi vode i organskih otapala na drvu

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ABSTRACT • *Wood finishes are used extensively to improve the aesthetic value and protect wood products from moisture. These organic coatings generally contain volatile organic compounds (VOC) as solvents that evaporate when the coatings cure over the surface. Due to strict legislations against these hazardous VOCs, the buyers across the globe are shifting towards products finished with water borne coats. Two of the most commonly used wood coatings in India are polyurethane and nitrocellulose (NC) lacquer. This paper aims at comparing these two wood coatings with their water borne counterparts. The study was conducted on the wood substrate of Melia dubia. Chemical characterization of the cured coats was attempted through FTIR spectroscopy. Physical appearances in terms of gloss and film thickness were also studied. Bands of urethane, urea and nitric groups were identified, which helped in understanding the changes in chemical structure of the finishes after curing. The thickness of the organic coatings was significantly higher than that of their water-borne counterparts. Gloss of water based coatings was observed to be lesser than that of their organic solvent based counterparts in either coating material. In case of lacquer, the reduction was up-to 33 %. whereas in case of PU, gloss dropped down by about 54 %.*

Keywords: *organic coatings, water borne coatings, NC lacquer, polyurethane, Melia dubia, film thickness, FTIR, gloss*

SAŽETAK • *Premazni se materijali primjenjuju na drvu kako bi se očuvao njegov estetski izgled i drvni proizvodi zaštitili od vlage. Organski premazni materijali u osnovi sadržavaju hlapljive organske spojeve (HOS) kao otapala koja isparavaju dok premazni materijal otvrdnjava na površini drva. Zbog strogih propisa o tim opasnim hlapljivim organskim spojevima kupci diljem svijeta prelaze na vodene premazne materijale. Dva najčešće upotrebljavana premazna materijala za drvo u Indiji jesu poliuretanski i nitrocelulozni (NC) lak. Cilj rada bio je usporediti ta dva premazna materijala s istim premaznim materijalima na bazi vode. Istraživanje je provedeno na drvu Melia dubia. Kemijska karakterizacija otvrdnutih premaza provedena je primjenom FTIR spektroskopije. Također su proučavani sjaj i debljina filma. Identificirane su skupine uretana, ureje i nitratne skupine koje su pridonijele razumijevanju promjena u kemijskoj strukturi premaza nakon otvrdnjavanja. Debljina premaza na bazi organskih otapala bila je znatno veća od debljine premaza na bazi vode. Uočeno je da je sjaj premaza na bazi vode manji od sjaja premaza na bazi organskih otapala. Za NC lak to je smanjenje bilo do 33 %, a sjaj PU laka smanjio se za oko 54 %.*

Ključne riječi: *premazi na bazi organskih otapala, premazi na bazi vode, NC lak, poliuretan, Melia dubia, debljina filma, FTIR, sjaj*

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1 INTRODUCTION
1. UVOD

Wood has always been a much appreciated material for its structural and aesthetic properties. It represents a renewable resource and is widely used in many applications for exterior and interior purposes. Being an organic compound, wood is subject to degradation due to the weathering process. Organic coatings are used to protect the wood surface and to improve its aesthetics. The required properties and formulation of wood coatings depend on their end-use application: indoors or outdoors. In the case of interior products, more emphasis is placed on appearance with different aesthetic requirements. Finishing adds beauty by enhancing the aesthetic value of wood and improving its luster, also known as gloss. It is an attribute of finished surfaces that gives them shiny or lustrous metallic or matte appearance. Gloss is based on the ability of a surface to reflect directed light (Živković, 2004). This property of finishes is used widely as a parameter to evaluate and compare the quality of finishes.

Polyurethane (PU) is a hard, abrasion-resistant and durable wood coating, and is known to act as a good moisture barrier for wood based products (Poaty *et al*., 2013). It has been reported by Carter (2012) that PU-based varnishes possess good mechanical strength, adhesion to the surface as well as ease of applying multiple coats. In spite of the above advantages, PU based finishes are not very much favored for outdoor uses since they are prone to UV degradation (Kurtoğlu, 2000). Nitrocellulose lacquers are widely used by the solid wood industry in India. They are prevalent in this sector as they result in a very hard, flexible and durable finish on wood surfaces (Cakicier *et al*., 2011). Niimura (2014), has reported that lacquer is a good coating material for wood due to its ability to cure into a tough film with resistance to temperature. Though preferred by the wood coating industry, lacquers are generally considered hazardous due to the flammable and volatile nature of the solvents used (Kurtoğlu, 2000), and therefore, they are no more the choice of industries in EU and many parts of the world.

An important concern today is the current legislation regarding both the environmental impact and human health. In Europe, coatings are mostly based on water–borne technology, in particular decorative coatings. Conversely, in the industrial sector in India, the conventional solvent-borne coatings are still widely used. The 2010 phase of the VOC in Paints Directive (2004/42/CE) promotes more strongly the transition from solvent to water-borne coatings for interior applications. The challenge with water borne coatings is the maintenance of the appearance obtainable by using the solvent-borne technology. Therefore, a continuous improvement in formulating waterborne systems is necessary in coatings industry in order to satisfy the increasing requirements.

Melia dubia (Synonym *Melia composita*) has been found to be a useful timber for solid wood products. The wood of *M. dubia* has a diffuse porous structure (Saravanan *et al*., 2013a). This species has been found suitable for paper pulp production by Saravanan *et al*. (2013b). Studies on mechanical gluing and bonding properties showed that this species is a good candidate for the plywood industry as well (Saravanan *et al*. 2014; Uday *et al*. 2012). Some studies on finishing properties using common coating materials have generated data showing value added to solid wood products made of this wood (Gupta *et al*., 2016b, c).

Against this background, a study was conducted on physical appearance and chemical characterization of solvent borne and water borne commercial coatings on *Melia dubia*. Two of the most commonly used wood coatings, polyurethane (PU) and nitrocellulose lacquer, were chosen for the study. The aim was to observe the changes that take place in the chemical structure and physical appearance of the coatings by changing their solvents from organic volatile compounds to water.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Planks of 3.2 cm thickness were sawn from a freshly felled log of *Melia dubia* and they were kiln-dried to 12 % moisture contents. These planks were further planed with a surface planer to make the surface level flat. From a defect free plank, 48 samples of size 15 cm×10 cm×2.5 cm (Axial × Tangential × Radial) were cut and then sanded with 80, 100, 120 grit sized sandpapers progressively to prepare smooth surfaces for coating. Samples were then kept in a humidity controlled chamber for conditioning at 300 °C temperature and 35 % RH. This conditioning was continued until the weights of the samples became constant.

The two coating polymers - Polyurethane and NC Lacquer with different solvents (organic and water) were procured from Plantag Coatings India Ltd. The procured coatings had the following physical and chemical specifications.

Organic Solvent based PU: One coat system with hardener addition 5 % wt
- Solubility (water): Insoluble
- Viscosity at 250 °C: 25 – 27 sec (4 mm)
- Solid content: 21.39 % Wt.

Water based PU: One coat system
- Solubility (water): Easily soluble at 200 °C
- Viscosity at 250 °C: 90 – 110 sec (4 mm)
- Solid content: 29.46 % Wt.

Organic solvent based NC Lacquer: Single pack system
- Solubility (Water): Insoluble
- Viscosity at 250 °C: 50 – 55 sec (4 mm)
- Solid content: 24.56 % Wt.

Water based NC lacquer: Single pack system

Water based NC lacquer consists of one active solvent for nitrocellulose, plasticizer, water and anionic surfactant.
- Solubility (water): Easily soluble at 200 °C
- Viscosity at 250 °C: 100 – 105 sec (4 mm)
- Solid content: 32 % wt.

The above solid contents were estimated in the laboratory following the method by Zhu *et al*., (2018). Three coats of each combination were applied on the samples and were allowed to cure completely for 2 hrs

between successive coats. 12 samples were each prepared with four coatings. Coatings were applied with painting brush to observe the ease of application of different coating combinations.

For chemical characterization of cured coatings, FTIR spectroscopy was adopted by using a FTIR Spectrometer (Bruker Germany, Tensor- 27 model) equipped with an ATR probe. The spectral resolution was 4 cm^{-1} and the rate of scans/measurement was 64. Spectra were recorded for all the samples after 7 days of coating and were averaged for each combination. To study the luster of coats, gloss was measured at 5 random places on the tangential coated surface of each sample with the help of a gloss meter with 60 degrees gloss head angle. Thickness of the coating material was measured with the help of film thickness measuring unit in microns. A DeFelsko PosiTector 200, which conforms to ASTM D6132 and ISO 2808, was used for this purpose. This instrument uses ultrasound technology to measure the coating thickness non-destructively (Gupta *et al.*, 2016). The thickness was also measured at five random places on the surfaces of the coated samples. Thus, there were 60 random readings for both gloss and thickness for each coating.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Characterization of the coatings used
3.1. Karakterizacija premaznih materijala

FTIR spectra obtained for the coated samples were examined to identify the known absorption bands. Polyurethane wood coatings cure to form urethane polymer film. It consists of an activator pack and a paint pack, whose active ingredients include isocyanates (-N=C=O) and hydroxyl groups (-O-H), respectively. Reaction of isocyanates and hydroxyl results in formation of urethane (H-N=C=O). From the FTIR spectra, the bands of (-N=C=O), (-O-H) and (H-N=C=O) could be identified.

R-N=C=O + R'-OH -----→ R-NH-C=O-R'
Polyisocyante Polygol Polyurethane

Figure 1 gives the FTIR spectrum of the PU coated wood surface, while the identified absorption bands are presented in Table 1.

The most important bands to take note are those at 2270 to 2280 cm^{-1} (–NCO vibration), 3360 to 3380 cm^{-1}(–NH vibration) and the shoulder around 3530 to 3550 cm^{-1} (–OH vibration). Other bands normally given a lot of importance are 1720 to 1730 cm^{-1} (urethane C=O vibration), 1680 to 1690 cm^{-1} (urea –C=O vibration) and 1600 cm^{-1} (aromatic v(C=C) vibration). The strong band in the range of 1720 to 1730 cm^{-1} in Figure 1 clearly indicates the formation of urethane in cured coatings. Bands of OH and NCO on the lower side give a clear indication that they have reacted together to form urethane. The band at 1460 cm^{-1} indicates the C-H bond in the polymeric chain. C-O-C molecular vibrations in the chain structure of PU are well indicated by vibration bands at 1230 cm^{-1} (Yang *et al.*, 2001). Figure 2 shows the FTIR spectrum of the cured water-based PU used in the study.

Table 1 Identified bands in the FTIR spectrum of cured PU
Tablica 1. Identificirane vrpce na FTIR spektru otvrdnutog PU premaza

Wavenumber / *Valni broj*	**Assignments** / *Pripisane vrpce*	**Wavenumber** / *Valni broj*	**Assignments** / *Pripisane vrpce*
1600 cm^{-1}	Aromatic v(C=C) vibration	2270-2280 cm^{-1}	–NCO vibration
1680-1690 cm^{-1}	Urea –C=O vibration	3360-3380 cm^{-1}	–NH vibration
1720-1730 cm^{-1}	Urethane –C=O vibration	3530-3550 cm^{-1}	–OH vibration

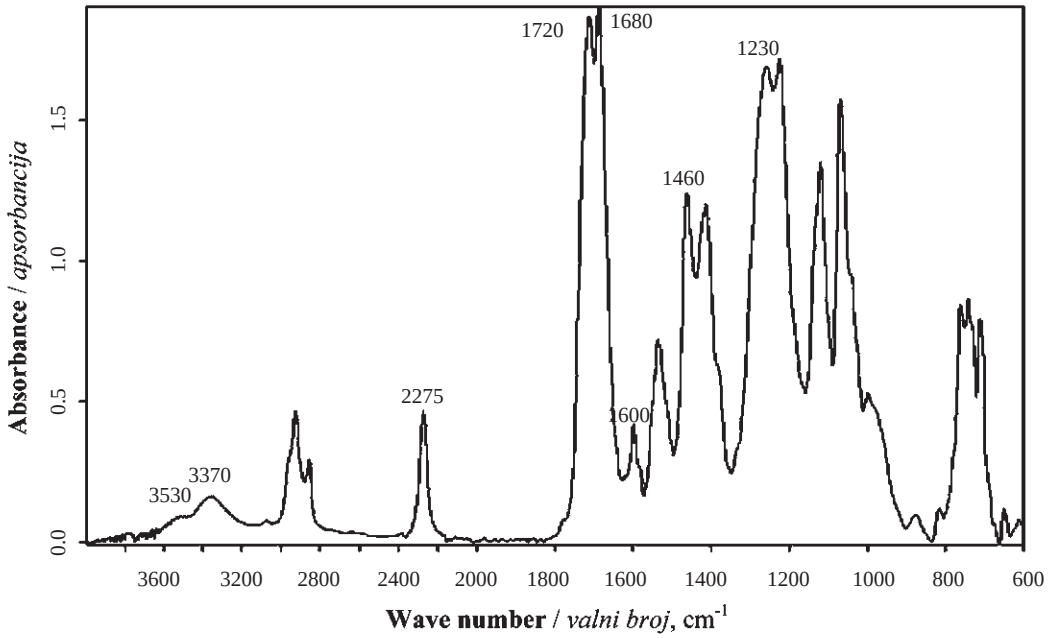

Figure 1 FTIR spectrum of cured PU wood coating
Slika 1. FTIR spektar otvrdnutog PU premaza

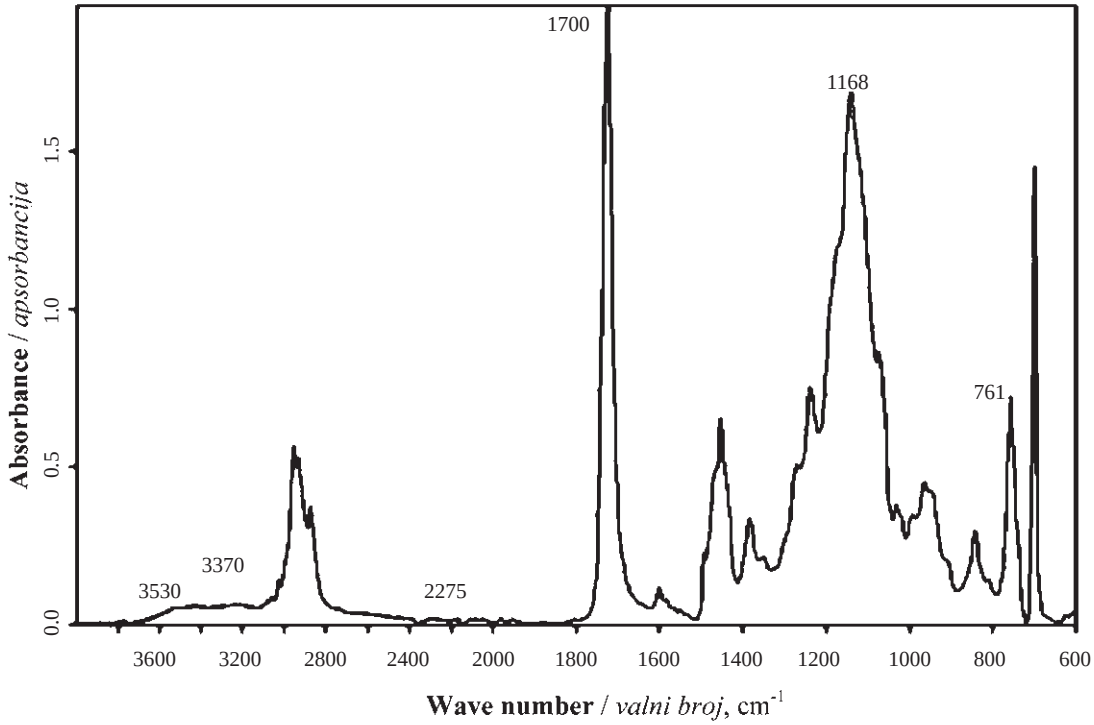

Figure 2 FTIR spectrum of cured water based PU wood coating
Slika 2. FTIR spektar otvrdnutog vodenog PU premaza

An examination of Figure 2 reveals that the wide and strong –OH absorptions between 3444 cm^{-1} and 3533 cm^{-1} have reduced. The NCO absorption band at 2275 cm^{-1} is not seen indicating that the –NCO group has reacted completely with OH of water solvent. The sharp band at 1700 cm^{-1} is attributed to C=O stretch vibration, which indicates that a reaction between water and –NCO has taken place resulting in formation of urethane. The sharp and strong band at 761 cm^{-1} is due to C–N bond vibration. All these indicate the presence of urethane bond and urea bond formation. A new band appearing at 1168 cm^{-1} is attributed to the C–N–C stretch vibration in the isocyanurate ring in the hydrophilic-modified curing agent (Zhang *et al*., 2007). Figure 3 shows the IR spectrum of organic solvent based NC lacquer coated surface.

Nitrocellulose lacquers contain nitrocellulose with oils as plasticizers and spreading agents. In Figure 3, nitrocellulose is identified by the nitric group at 1652, 1275 and 843 cm^{-1}. The main bands reported for nitro-

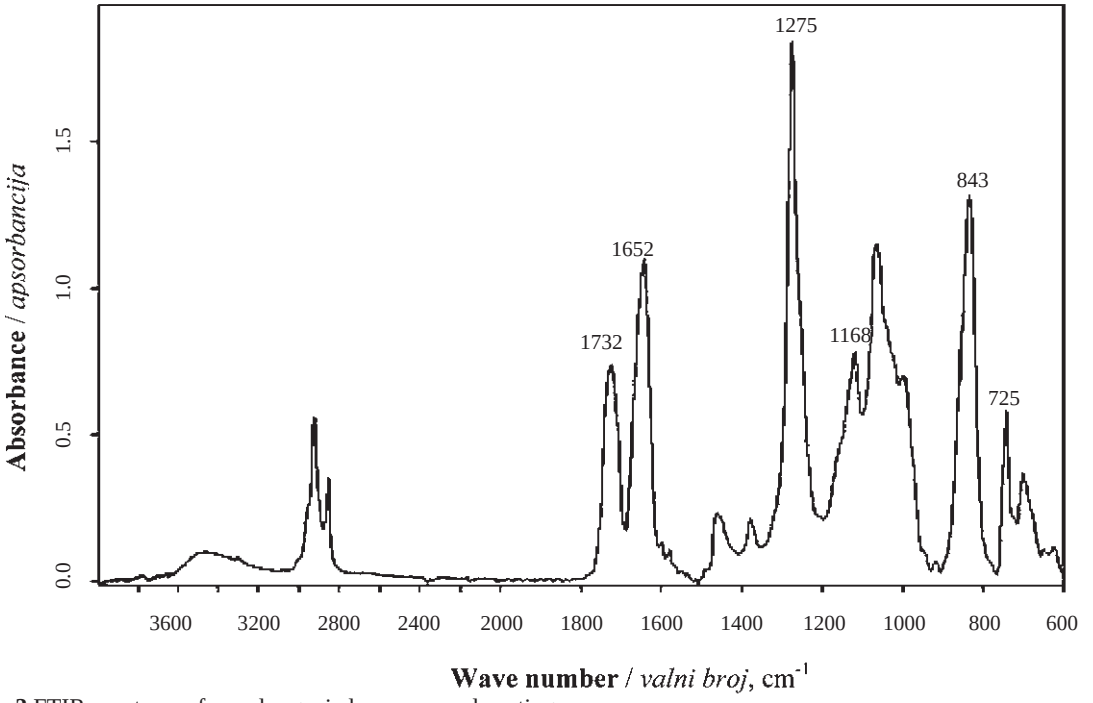

Figure 3 FTIR spectrum of cured organic lacquer wood coating
Slika 3. FTIR spektar osušenoga nitroceluloznog laka

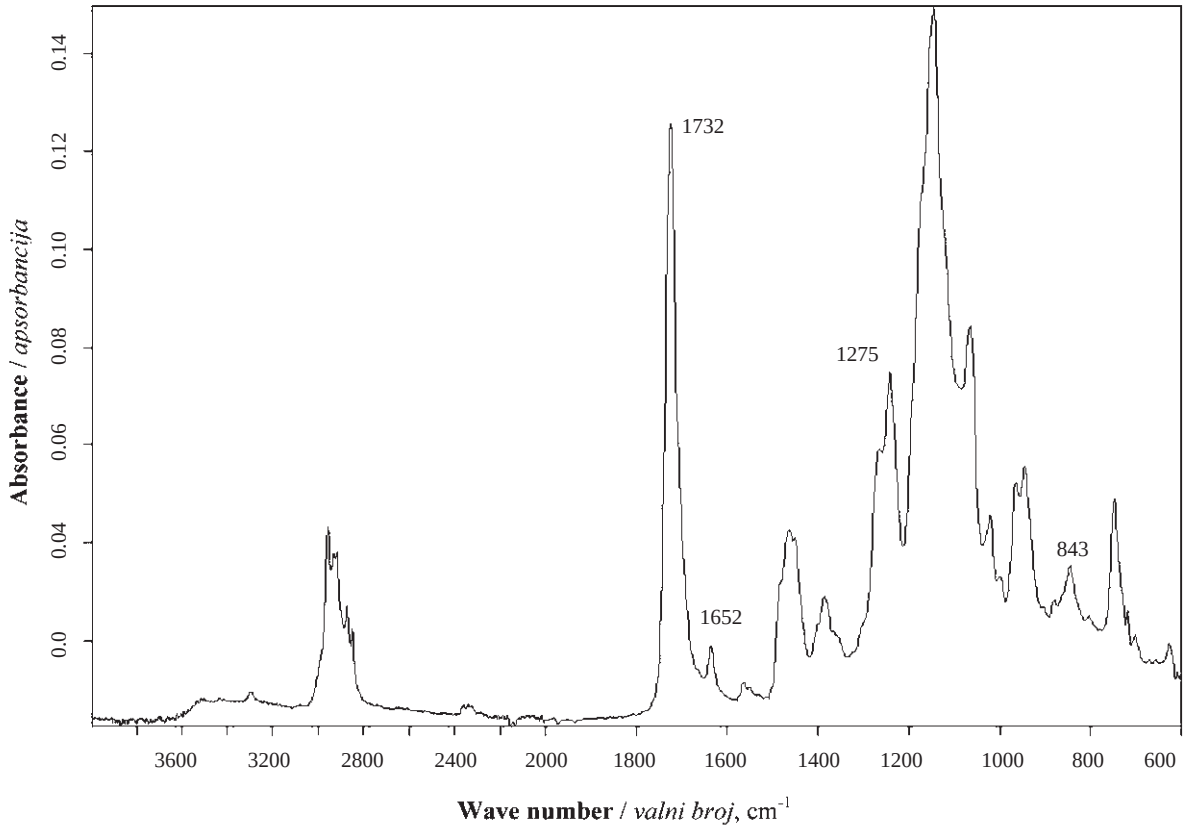

Figure 4 FTIR spectrum of cured water based lacquer wood coating
Slika 4. FTIR spektar osušenoga vodenog nitroceluloznog laka

cellulose are around 1660, 1280 and 840 cm^{-1}. Lopez *et al*. (2010) attributed these to be antisymmetric and symmetric stretching of NO_2 and valence stretching of NO. Cakic *et al*. (2007) also had earlier reported valence vibrations of the nitric group specifically occurring at the wave numbers of 1660 cm^{-1} (asymmetric valence vibration) and at 1280 cm^{-1} (symmetric valence vibration). The oil is verified with a carbonyl band at 1732 cm^{-1} and in the finger print regions at 1240, 1168, 1009 and 725 cm^{-1} (Dredge *et al*., 2014). Kovalenko *et al*. (1994) have also reported bands in the 950 – 1200 cm^{-1} region due to vibrations of CO group. Figure 4 represents the FTIR spectrum of water-based lacquer coated surface.

Water based lacquers contain oils as well as water as solvent medium. In order to reduce the emissions from organic VOC (Volatile Organic Compounds), coating particles are dispersed in the medium with more water and a lower amount of organic solvent. They are tiny dispersions, or droplets, of a cured reactive finish (cross-linked within the droplets) emulsified in water. Water serves as a thinner. A very slow evaporating solvent (usually glycol ether) is added to the coating so that droplets can cure as a film. When the solvent evaporates, droplets coalesce together to form a film. The main difference that can be noted in Figure 4 with respect to Figure 3 is that the intensities of nitric group bands have considerably reduced (843, 1275 and 1652 cm^{-1}). Larsson (2015) argues that the nitric group bands show up intensely only when enough concentration of nitrocellulose is present in the emulsion and sometimes the low intensity bands get hidden in other intense bands of other groups. According to Ossa *et al*. (2012), nitrocellulose is often applied in paints, lacquers, varnishes, inks, etc. in lower concentrations than in explosives. Low concentration (< 35 %) of nitrocellulose in water based formulations of nitrocellulose lacquer has also been patented (Quinlan 1989). Figure 4 confirms the existence of stretching absorption of –C-C(O)-C- in the range of 1260 – 1230 cm^{-1} for acetate esters, which could be the binders. Many other esters result in bands in the 1210 – 1160 cm^{-1} range as seen in Figure 4.

3.2 Physical characteristics of coated surfaces
3.2. Fizička svojstva premazanih površina

Primary observations on physical appearance of the four types of coatings on the common wood substrate of *Melia dubia* revealed interesting results. Comparing two widely used wood coatings (Lacquer and Polyurethane) with their water borne counterparts on the grounds of ease of application, curing time and physical appearance was the main objective of this study.

During application by brush, it was observed that organic solvent based finishes were easy to apply on the surface in comparison to the water based ones. The wood of *Melia dubia* is reported to be of diffuse porous structure (Saravanan *et al*., 2013a). Diffuse porous hardwoods are reported to have high water uptake (Michalec and Niklasova, 2006). The wood fibers on the surface absorbing the solvent (water) of these finishes and making them too tacky to be spread properly might also be causing the application of such finishes a bit tedious. Torn grains causing fuzziness and roughness are common defects found with hardwoods unless sanded with high grit sizes (Laina *et al*., 2017; Varanda

et al., 2010). The drying (curing) time of water based coatings was found to be much less compared to that of organic solvent based coatings. They were almost dry to touch after applying, whereas organic based coatings started to become tacky after 15 min from the time of application and cured properly after about 2 hours. Such low dry to touch (15 min) and tack (1.5 h) times for PU has been reported on Eucalyptus and teak surfaces (Pandey *et al*., 2007). The surface coated with organic solvent based coatings was smooth to touch while the surfaces coated with water based coatings became quite rough to touch. This was due to rising up of wood fibers after absorption of water from the coatings.

3.3 Characteristics of coated films
3.3. Svojstva filma premaza

Having looked at the physical characteristics of the coated surfaces, a look at their lustre would be interesting. Table 2 gives the gloss values measured for four types of coatings.

Table 2 presents two facts: the gloss of PU seems to be consistently greater compared to that of lacquer, while the gloss of water based coating seems to be less than that of its organic solvent based counterpart in both coating materials. The water based lacquer has resulted in 32.6 % less gloss compared to its organic based coating. In the case of PU, this reduction in gloss is 53.9 %. Gloss is the result of specular reflection, where the reflecting surface is expected to be very smooth and mirror-like (Nadal *et al*., 2006). The presence of torn grains, raised grains or any such imperfections can interfere with the extent of smoothness of the coated surface. As already explained above, the water based coats had caused a certain amount of defects on the surface. Hence, the reduction in gloss with water based coats is in expected lines. The natural grains of wood influenced the aspect of the coating and gloss features of Tanganyika wood substrate when coated with water based PU (Scrinzi *et al*., 2011).

To ascertain the differences between the glosses of water-based and organic-solvent based coatings of both PU and lacquer, individual readings were analyzed through One-way ANOVA and the results are given in Table 3.

Table 3 clearly indicates that the gloss values of water based coatings in either case are significantly lower compared to gloss values of the corresponding organic solvent based coatings. A gloss value of 90.3 GU on *Melia dubia* substrate was reported with four consecutive coatings of PU (Gupta *et al*., 2016b). However, the value for lacquer is much less than that reported for nitrocellulose lacquer. The coating thickness achieved must have affected the gloss value achieved in the present study. However, the gloss values of lacquer in the present study are similar to those reported for two bamboo species (*Bambusa polymorpha* and *Dendrocalamus giganteus*), where two coats of lacquer were applied on their surfaces (Shukla *et al*., 2015). The values of water based lacquer coatings in the present case classify them into the category of gloss level 3 (Egg shell like finish), whereas those of organic solvent based lacquer coating give “satin like” finish, i.e. the gloss level 4 (MPI Architectural standards: mpi.arcomone.com). The measured gloss values of water based PU coating are categorized as a semi-gloss finish at gloss level 5 and those of organic solvent based PU coating are high gloss wood finish at gloss level 7.

It would now be interesting to see the thicknesses of the four coatings with an equal number of coats. Table 4 gives the results of the film thickness measurements carried out for all the four coatings on the wood substrate.

Table 2 Gloss values for organic solvent based and water based coatings
Tablica 2. Vrijednosti sjaja premaza na bazi organskih otapala i vode

Coating / *Premaz*	**Number of readings** *Broj mjerenja*	**Minimum** *Minimum*	**Maximum** *Maksimum*	**Mean** *Srednja vrijednost*	**Standard deviation** *Standardna devijacija*
Organic Lacquer *nitrocelulozni premaz na bazi organskih otapala*	60	20.7	36.5	27.6	4.0
Water based Lacquer *nitrocelulozni premaz na bazi vode*	60	14.6	23.6	18.6	2.6
Organic Polyurethane *poliuretanski premaz na bazi organskih otapala*	60	73.6	114.9	92.4	11.3
Water based Polyurethane *poliuretanski premaz na bazi vode*	60	33.3	56.3	42.6	6.3

Table 3 ANOVA of gloss values of PU and Lacquer with the two solvents
Tablica 3. ANOVA analiza sjaja poliuretanskih i nitroceluloznih lakova

Source of Variation / *Izvor varijacije*	**Df**	**Ms**	**F**	***P*-value**	***F* crit**
Between two lacquer coatings *između dva nitrocelulozna premaza*	1	2408.45	216.20	<0.001	3.92
Error / *pogreška*	118	11.14			
Total / *ukupno*	119				
Between two PU coatings / *između dva PU premaza*	1	74431.08	885.45	<0.001	3.92
Error / *pogreška*	118	84.06			
Total / *ukupno*	119				

Table 4 Film thickness (μm) of organic solvent and water based coatings
Tablica 4. Debljina filma (μm) premaza na bazi organskih otapala i vode

Coating / *Premaz*	**Number of readings** *Broj mjerenja*	**Minimum** *Minimum*	**Maximum** *Maksimum*	**Mean** *Srednja vrijednost*	**Standard deviation** *Standardna devijacija*
Organic Lacquer *nitrocelulozni premaz na bazi organskih otapala*	60	30	50	38	5.1
Water based Lacquer *nitrocelulozni premaz na bazi vode*	60	27	41	34	3.2
Organic Polyurethane *poliuretanski premaz na bazi organskih otapala*	60	29	51	35	6.5
Water based Polyurethane *poliuretanski premaz na bazi vode*	60	28	37	32	2.7

Table 5 ANOVA of film thickness values of PU and Lacquer with two solvents
Tablica 5. ANOVA analiza debljine filma poliuretanskih i nitroceluloznih lakova

Source of Variation / *Izvor varijacije*	**df**	**MS**	**F**	***P*-value**	***F* crit**
Between two lacquer coatings / *između dva nitrocelulozna premaza*	1	418.13	22.89	<0.001	3.92
Error / *pogreška*	118	18.27			
Total / *ukupno*	119				
Between two PU coatings / *između dva PU premaza*	1	330.01	13.31	<0.001	3.92
Error / *pogreška*	118	24.79			
Total / *ukupno*	119				

Table 4 shows that the thicknesses of water based coats are slightly on the lower side than those of their organic counterparts. To ascertain the differences between the thicknesses of water-based and organic-solvent based coatings of both PU and lacquer, individual readings were analyzed through one way ANOVA and the results are given in Table 5.

Table 5 clearly indicates that the film thickness of organic solvent based lacquer and PU coats are indeed significantly higher than that of their water based counterparts. This reduction is due to the absorption of water based coatings by the wood fibers as discussed earlier instead of resulting in a clean film on the substrate. The important observation is that the thickness (35 μm) of three coats of PU achieved on *Melia dubia* is far less than the value (57.5 μm) reported for *Dalbergia sissoo* (Gupta *et al*., 2016a). The thickness obtained with two coats of an acrylic varnish containing PU on the surface of pine was 66.5 μm, which was attributed to the greater volume of voids in pine (Fernandez *et al*., 2013). It is interesting to see that the water based coatings resulted in significantly lower coating thicknesses than their organic counterparts in spite of having higher solid contents. This observation also supports the fact that the two water based formulations used in this study might have penetrated easily into the substrate.

4 CONCLUSIONS
4. ZAKLJUČAK

The characteristic IR absorption band around 2270-2280 cm^{-1} due to –NCO vibrations seen in organic solvent based PU is absent in its water borne counterpart indicating faster curing of water based PU. The water based lacquer band used in the study gave low intensity bands for the nitric group indicating lower nitrocellulose concentration in the coating formulation. It was observed that organic solvent based coatings were easy to apply and waterborne coatings resulted in less smoother surfaces. The film thickness was significantly lower for water borne coatings as compared to that of organic solvent borne coatings despite the fact that the former ones had higher solid contents. Water borne coatings resulted in gloss reductions of 32.6 % for lacquer and 53.9 % for PU compared to their organic solvent borne counterparts.

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5 REFERENCES
5. LITERATURA

1. Cakic, S.; Raskovic, L.; Lacnjevac, C.; Rajkovic, M.; Barac, M.; Stojanovic, M., 2007: Physical-mechanical properties of nitrodopes affected by ultra-violet radiation. Sensors**,** 7: 2139-2156. https://doi.org/10.3390/S7102139.
2. Çakicier, N.; Korkut, S.; Güler, F. D., 2011: Effects of heating treatment on some of the physical properties of varnish layers applied on various wood species. African Journal of Biotechnology**,** 10(9): 1578-1585. http://www.academicjournals.org/AJB.
3. Carter, N., 2012: Scavenge moisture and cut pinholes in a trice. European Coatings Journal**,** 6: 18-21.
4. Directive 2004/42/CE of the european parliament and of the council 2004. Official journal of the European Union. L 143/87.
5. Dredge, P.; Puskar, L.; Aleen, L.; Sawicki, M.; Wuhrer, R., 2014: Binders used in metallic paints investigated by micro-FTIR and synchrotron-sourced FTIR. In: Proceed-

ings of 11th infrared and Raman users group conference, Boston, US, pp. 21-26.
6. Fernández, I.; Fernández, M. Á.; Rodríguez, K.; Baño, V.; Dieste, A., 2013: The effect of wood species on the anti-skid resistance of coatings. Maderas-Cienc Tecnol., 15 (1): 65-72. http://doi.org/10.4067/S0718-221X2013005000006.
7. Gupta, S.; John A.; Kishan Kumar, V. S., 2016a: Studies on effect of coat thickness on the moisture uptake by a hardwood substrate. Maderas-Cienc Tecnol., 18 (3): 443-456. http://revistas.ubiobio.cl/index.php/MCT/article/view/2459.
8. Gupta, S.; Shukla, S.; Kishan Kumar, V. S., 2016c: Efficiency of some common coatings in controlling water vapour absorption by wood substrate. Indian Forester, 142 (8): 774-780.
9. Gupta, S.; Singh, C. P.; Kishan Kumar V. S., 2016b: Gloss of four common wood coatings measured before and after their exposure to high humidity. Ciência da Madeira, 7 (2): 94-99. https://periodicos.ufpel.edu.br/ojs2/index.php/cienciadamadeira/article/view/6982.
10. Kovalenko, V. I.; Mukhamadeeva, R. M.; Maklakova, L. N.; Gustova, N. G., 1994: Interpretation of the IR spectrum and structure of cellulose nitrate. Journal of Structural Chemistry, 34 (4): 540-547.
11. Kurtoğlu, A., 2000: Wood material surface treatments, General information, vol. 1. Istanbul University Publication No: 4262, Faculty of Forestry Publication No: 463, ISBN 975-404-590-9.
12. Laina, R. R.; Lobera, A. S.; Villasante, A.; Espí, P. L. P.; Rojas, J. A. M.; Hermosilla, J. A.; Montero, R. S.; Peña, S. V., 2017: Effect of the anatomical structure, wood properties and machining conditions on surface roughness of wood. Maderas-Cienc Tecnol., 19 (2): 203-212. http://doi.org/10.4067/S0718-221X2017005000018.
13. López-López, M.; Ossa, M. Á. F. de la; Galindo, J. S.; Ferrando, J. L.; Vega, A.; Torre M.; García-Ruiz, C. 2010: New protocol for the isolation of nitrocellulose from gunpowders: Utility in their identification. Talanta, 81 (4): 1742-1749.
14. Michalec, J.; Niklasova, S., 2006: Water uptake of hardwoods. Thesis work no. TD083/2006. Dept. of forest and wood technology, Vaxjo University, School of Technology and design, TD. pp 10.
15. Nadal, M. E.; Early, E. A.; Thompson, E. A., 2006: Specular Gloss. NIST Special Publication SP250-70. National Institute of Standards and Technology, Technology Administration, U.S. Department of Commerce, AFRL/HEDO, 2650 Loiuse Bauer Drive, Brooks City-Base, TX 78235, 72 pp.
16. Niimura, N., 2014: Evolved Gas Analysis of a Japanese Lacquer Film. Journal of Chemistry and Biochemistry, 2, n. 1, pp. 23-29.
17. Ossa, M. Á. F. de la; Torre M.; García-Ruiz, C., 2012: Nitrocellulose in propellants: characteristics and thermal properties. In: Advances in Materials Science Research. Wythers, M. C. (ed.). Nova Science Publishers, 7(4).
18. Poaty, B.; Riedl, B.; Blanchet, P.; Blanchard, V.; Stafford, L., 2013: Improved water repellency of black spruce wood surfaces after treatment in carbon tetrafluoride plasmas. Wood Science and Technology, 47: 411-422. https://doi.org/10.1007/s00226-012-0505-8.
19. Quinlan, G. L., 1989: Waterborne nitrocellulose compositions. US 4814015. Mar. 21, 1989.
20. Saravanan, V.; Parthiban, K. T.; Kumar, P.; Marimuthu, P., 2013b: Wood Characterization studies on *Melia dubia* cav. for Pulp and Paper Industry at different Age Gradation. Research Journal of Recent Sciences, 2 (ISC-2012): 183-188.
21. Saravanan, V.; Parthiban, K. T.; Sekar, I.; Kumar, P.; Vennila, S., 2013a: Radial variations in anatomical properties of *Melia dubia* cav. at five different ages. Scientific Research and Essays, 8 (45): 2208-2217.
22. Saravanan, V.; Parthiban, K. T.; Thiruneraiselvan, S.; Kumar, P.; Vennila, S.; Kanna, S. U., 2014: Comparative study of Wood Physical and Mechanical properties of *Melia dubia* with *Tectona grandis* at different Age Gradation. Research Journal of Recent Sciences, 3 (ISC-2013): 256-263.
23. Scrinzi, E.; Rossi, S.; Deflorian, F.; Zanella, C., 2011: Evaluation of aesthetic durability of waterborne polyurethane coatings applied on wood for interior applications. Progress in Organic Coatings, 72: 81-87. http://doi.org/10.1016%2Fj.porgcoat.2011.03.013.
24. Shukla, S.; Gupta, S.; Kishan Kumar, V. S., 2015: Staining effects on moisture resistance and gloss of lacquer coated bamboo surfaces. Journal of Bamboo and Rattan, 14(1-4): 53-62. http://www.library.kfri.res.in/JBR/jbr/2015/links/JBR_14(1-4)_53-62.pdf.
25. Uday, D. N.; Sujatha, D.; Pandey, C. N., 2012: Suitability of *Melia dubia* (malabar neem wood) for plywood manufacture. Journal of the Indian Academy of Wood Science, 8 (2): 207-211. https://www.tib.eu/en/search/id/BLSE%3ARN313109299/Suitability-of-Melia-dubia-malabar-neem-wood-for/.
26. Varanda, L. D.; Alves, M. C. S.; Gonçalves, M. T. T.; Santiago, L. F. F., 2010: Influência das variáveis no lixamento tubular na qualidade das peças de *Eucalyptus grandis*. Cerne Lavras, 16: 23-32. http://www.dcf.ufla.br/ebramem/Artigo%2004.pdf.
27. Yang, X. F.; Vang, C.; Tallman, D. E.; Bierwagen, G. P.; Croll, S. G.; Rohlik, S., 2001: Weathering degradation of a polyurethane coating. Polymer degradation and stability, 74: 341-351. https://doi.org/10.1016/S0141-3910(01)00166-5.
28. Zhang, F. A.; Yu, C. L., 2007: Application of silicone-modified acrylic emulsion in two component water borne polyurethane coatings. Journal of Coating Technology and Research, 4 (3): 289-294. https://doi.org/10.1007/s11998-007-9045-9.
29. Zhu, Z.; Li, R.; Zhang, C.; Gong, S. 2018: Preparation and Properties of High Solid Content and Low Viscosity Waterborne Polyurethane-Acrylate Emulsion with a Reactive Emulsifier. Polymers, 10 (2): 17p. https://doi.org/10.3390/polym10020154.
30. Živković, V., 2004: Gloss and gloss measurement. Drvna industrija, 55(3): 145-150. https://bib.irb.hr/prikazi-rad?&rad=229413.
31. ***MPI Architectural Standards: mpi.arcomone.com/DT201arcom/Manuals_ ASM/Misc/standards.asp (accessed on 5-12-2017).

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Factors Affecting Consumer-Based Brand Equity from the Perspective of Turkish Consumers

Čimbenici koji utječu na tržišnu vrijednost proizvoda iz perspektive turskih potrošača

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ABSTRACT • *This paper contributes to the consumer-based brand equity literature by researching what brand equity means for Turkish consumers and by defining factors that, from their perspective, affect Consumer-Based Brand Equity (CBBE). According to our literature review, although some important cross-cultural studies about CBBE can be found, some aspects of this topic require further research. The target population of the study is households in the Western Black Sea Region. This region was chosen because it is a manageable size, geographically close to the researchers, and statistically representative of the Turkish people. Turkish panel furniture (PF) brands were chosen as the sample, and a stratified sampling method was used to determine the questionnaires sample size. Data were analysed in SPSS, incorporating statistical tests such as factor analysis, correlation analysis and chi-square tests. Factors that affected CBBE were marketing activities, perceived quality, brand awareness, brand association and price.*

Keywords: *consumer-based brand equity, Turkey, consumer behaviour, panel products, furniture*

SAŽETAK • *Zahvaljujući provedenom istraživanju značenja vrijednosti robne marke za potrošače u Turskoj, ovaj rad pridonosi obogaćivanju literature o tržišnoj vrijednosti robne marke. Uzimajući u obzir perspektivu potrošača u Turskoj, definirani su čimbenici koji utječu na tržišnu vrijednost robne marke (CBBE). Iz pregleda literature može se vidjeti da još postoje određeni aspekti područja tržišne vrijednosti robne marke koje treba dodatno istražiti premda su objavljene neke važne studije s tog područja. Ciljna populacija u ovom istraživanju bila su kućanstva u Zapadnoj crnomorskoj regiji, koja je odabrana jer je odgovarajuće veličine, zemljopisno je bliska istraživačima i statistički je reprezentativna za populaciju Turske. Za uzorke su odabrani proizvodi turskoga pločastog namještaja (PF), a za određivanje veličine uzorka primijenjena je metoda stratificiranog uzorkovanja. Podatci su analizirani u SPSS-u upotrebom statističkih testova kao što su faktorska analiza, korelacijska analiza i χ^2-testovi. Čimbenici koji su utjecali na tržišnu vrijednost robne marke bili su marketinške aktivnosti, percipirana kvaliteta, prepoznatljivost marke, udruživanje robnih marki i cijena.*

Ključne riječi: *tržišna vrijednost robne marke, Turska, ponašanje potrošača, pločasti materijali, namještaj*

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1 INTRODUCTION
1. UVOD

Because of its importance for building brand loyalty and awareness, many academics and practitioners have been showing interest for the concept of brand equity for a long time (Erdem *et al.*, 1999). It has been an important marketing concept since the 1980s (Keller, 1998). Today, the literature has different definitions of brand equity, which can be approached from the perspective of an investor, manufacturer, retailer, or consumer (Cobb-Walgren *et al.*, 1995). Aaker (1991) defined brand equity as a set of assets and liabilities linked to a brand's name and symbol, which add to or subtract from its intrinsic value. Keller (1993) defined brand equity as the effect that brand knowledge has on a consumer's response to that brand's marketing efforts. McQueen (1991) defined brand equity as the difference between the value of a branded product versus a non-branded one.

All these definitions agree that a brand's value correlates directly with its effect on consumers. Consequently, if a brand has no value to a consumer, it has little value to investors, manufacturers, and retailers (Farquhar, 1989; Crimmins, 1992).

In the literature, brand equity has been examined from a financial and a consumer-based perspective (Lassar *et al.*, 1995). When anonymous financial data are used to measure brand equity, it is defined as financially based brand equity. In contrast, when individual consumer surveys are performed, this is consumer-based brand equity (CBBE) (Koçak *et al.*, 2007). This paper emphasises the latter perspective in favour of the former, for two reasons. First, CBBE provides financial gains to firms. Secondly, managers have no consumer-based instrument to measure brand equity (Lassar *et al.*, 1995).

Recent studies such as Colicev *et al.* (2018); Swimberghe *et al*. (2018); Datta *et al*. (2017); Girard *et al*. (2017) prove that the concept of consumer-based brand equity (CBBE) has grown in importance. The literature conceptualises CBBE in several ways (Netemeyer *et al*., 2004). For instance, Yoo and Donthu, leading researchers on brand equity, described the CBBE as consumers' different responses to a focal brand and an unbranded product, when both have the same level of marketing stimuli and product attributes (Yoo and Donthu, 2001).

True consensus about the definition of CBBE is elusive. Several alternative methods have been offered for measuring brand equity. Despite the large number of suggested alternatives, no single measure is ideal (Cobb-Walgren *et al*., 1995). Various brand equity measurement methods have been suggested, based on a consumer's perspective and marketing, but their use is limited (Pappu *et al.*, 2005).

This paper adopted the multidimensional scale of Yoo and Donthu. According to the literature, this scale is widely used in this kind of studies and is also the most robust brand equity scale (Baalbaki and Guzmán, 2016). In addition, Yoo and Donthu claim that their scale is reliable, valid, and useable across several cultures and product categories (Yoo and Donthu, 2001). However, as already mentioned above, there are still disagreements about a globally accepted measurement instrument (Ioannou and Rusu, 2012).

Our literature review shows that cross-cultural tests of scales may be different. For instance, in 2007, using the exact same scale developed and tested in Spain, Koçak and friends tried to replicate the results of Vazquez *et al.* (2002) in Turkey. They found that the scale did not work well in Turkey and that it had to be modified, concluding that the reason behind this difference was cultural differences (Koçak *et al*., 2007). Overall, cross-cultural research on brand equity has been insufficient (Ioannou and Rusu, 2012).

The aim of this research is to fill an important gap in the literature by using a widely adopted scale, examining its validity in a different culture and industry, and determining factors affecting CBBE.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Households in seven city centres on the Western Black Sea were the target population of this study. Comprehensive, recent and reliable data about the population and housing from a census conducted by Turkstat in 2011 were used. It was determined that an examination of just provincial centres sufficed. Therefore, we limited our research in the region to only seven provinces, specifically: Bartın, Sinop, Karabük, Bolu, Düzce, Kastamonu, and Zonguldak. The study covers the period from 2015-2017.

The questionnaire directly focused on consumers. Like most related research, we used Aaker and Keller's CBBE approach. As noted earlier, we chose Yoo and Donthu's (2001) multidimensional brand equity scale, and we modified it based on industry investigations and opinions of expert academics. Their scale subdivides brand equity into different subcategories, such as brand awareness, brand associations, perceived quality and brand loyalty. It was chosen because Yoo and Donthu were the first to develop a multidimensional CBBE scale to test its psychometric properties (Pappu *et al.*, 2005). Since our goal was to test the Turkish consumer behaviour, brand reaction and brand equity, the scale fitted our purposes.

The questionnaire uses 5-point Likert scale type questions, open-ended questions, and dichotomous questions. The questionnaire contains 47 items for testing the CBBE. The items are: "The price of the brand is high", "The price of the brand is low", "The brand deserves the price", "The brand is constantly reminded to the consumers", "The ad campaigns for the brand seem very expensive, compared to campaigns for competing brands", "The ad campaigns for the brand are seen frequently", "Price deals for the brand are frequently offered", "Discounts for the brand are made many times.", "Price deals for the brand are shown to be more advantageous than they actually are.", "The

products are sold in high quality products selling stores.", "The products are sold in luxury stores.", "The products are sold in stores that sell well known brands", "More stores sell the brand, as compared to its competing brands.", "The brand has more dealers, as compared to its competing brands.", "The brand is distributed through as many stores as possible", "The brand is of high quality", "The likely quality of the brand is extremely high", "The likelihood that the brand's new products would be functional is very high", "The brand has an experienced and long-established history.", "The brand uses high technology", "The products deserve their prices", "I trust the brand as a company very much.", "The brand's products must be of very high quality.", "The brand's products seem to be of very poor quality", "I feel faithful to the brand.", "The brand is my first choice in shopping", "If the brand is in the store, I don't buy other brands.", "I am aware of the brand", "I can recognise the brand among other competing brands", "I have enough knowledge of the brand", "Some characteristics of the brand come to my mind quickly", "I can easily remember the brand's logo or symbol", "I have difficulty in imagining the brand in my mind", "The brand has an international reputation", "The brand has effective ads", "The slogans of the brand are catchy", "The brand is a top selling brand", "The product variety of the brand is a lot", "Even if another brand is exactly the same, I would prefer to buy the brand", "Even if another brand has the same features as the brand, I would prefer to buy the brand", "Even if another brand is as good as the brand, I would prefer to buy the brand", "Even if another brand is as good as the brand and more economical, I would prefer to buy the brand", " Since the brand will make me more satisfied with the after sales technical support than the competitors, I would prefer to buy the brand", "It makes sense to buy the brand instead of any other brand, even if they are the same", "It is preferable because of being a domestic brand", "It is preferable because of being a foreign brand" and "It is important for me that the brand contributes to social projects".

Data were collected by using web-based surveys and face-to-face interviews. Google forms were used for web-based surveys. The e-mail addresses of the people living in the target cities were collected via social media and from various governmental organisations' web-sites such as universities, hospitals, etc. The surveys could only be answered by one person in each household. IP-based restrictions prevented multiple answers from the same household.

Initially, the sample size was calculated and then the questionnaires were given to the target population. Then the data were analysed and interpreted by using appropriate statistical methods. From the perspective of Turkish consumers, this identified the important factors about CBBE.

The following equation (1) was used (Daniel, 1999):

$$n = \frac{Z^2 \cdot N \cdot P \cdot Q}{N \cdot D^2 + Z^2 \cdot P \cdot Q} \quad (1)$$

Where:

n – is the required sample size

N – is the population size

Z – is the confidence level (typical levels of confidence for surveys are 95 %, in which case Z is set to 1.96.)

P and Q – are the population proportions (they are both set to 0.5)

D – is the accuracy of sample proportions (set to 5 %).

Therefore, the sample size was calculated as (2):

$$n = \frac{1.96^2 \cdot 629000 \cdot 0.5 \cdot 0.5}{629000 \cdot 0.05^2 + 1.96^2 \cdot 0.5 \cdot 0.5} = 384 \quad (2)$$

The intention was to cover all the provinces, but because household amounts were not homogeneous, stratified sampling was applied. This sampling method is preferred when the sample is not homogeneous, because it can affect the dependent variable (Can, 2014).

Basic statistics for all the provinces are given in Table 1 below.

Based on the data in Table 1, the percentage distribution of questionnaires, by provinces, is shown in the following graph.

The following methods were used for statistical evaluation.

Table 1 Samples
Tablica 1. Uzorci

Province *Pokrajina*	**Number of households (thousand)** *Broj kućanstava (u tisućama)*	**Number of questionnaires required (according to stratified sampling)** *Broj potrebnih anketa (prema stratificiranom uzorkovanju)*	**Number of answered questionnaires** *Broj ispunjenih anketa*
Bartın	53	32	42
Sinop	63	38	57
Karabük	66	40	65
Bolu	79	48	49
Düzce	90	55	65
Kastamonu	105	64	91
Zonguldak	173	106	122
West Black Sea *Zapadna crnomorska regija* (Total / *ukupno*)	629	384	491

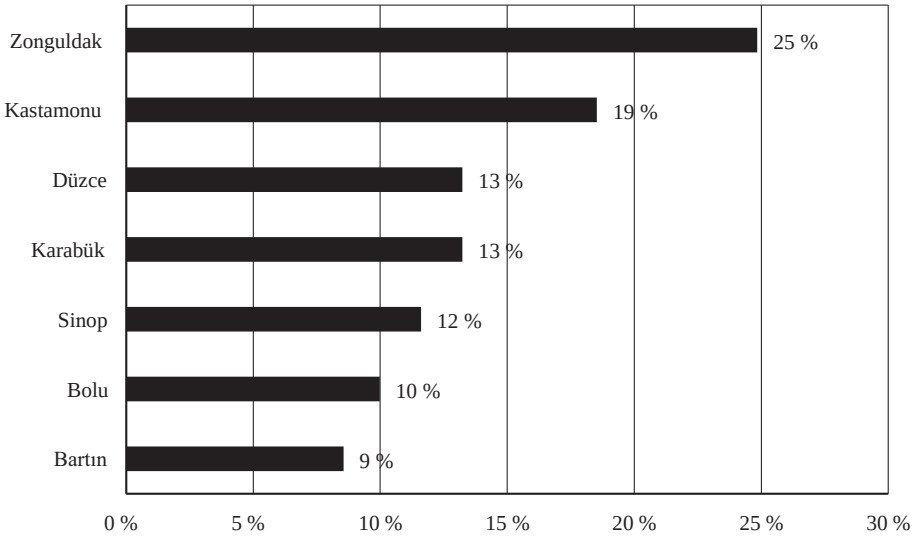

Figure 1 Percentage distribution of questionnaires, by province
Slika 1. Postotna raspodjela anketa prema pokrajinama

1. Reliability Analysis

Reliability analysis assesses the reliability of questionnaires, tests, or scales used for measurement (Kalayci, 2009). Cronbach's alpha coefficient was used in this study.

According to an analysis by IBM SPSS Statistics (the programme used for all statistical tests in this study), the scale's reliability coefficient (α) was calculated as 0.9005, which means that it is extremely reliable.

2. Factor Analysis

Factor analysis is a multivariate statistical method that creates fewer unrelated and conceptually significant new variables (factors or dimensions) by combining interrelated variables ('p units') (Büyüköztürk, 2014).

Factor analysis is a statistical method that aims to explain measurement by collecting variables of the same structure or quality.

In this study, factor analysis was used to express the 47 items in the questionnaire more clearly, and to reduce the number of existing items. For the factor analysis, in the beginning, the number of factors to be retained needs to be decided. Therefore, the SPSS default rule was used, which cuts off the factor eigenvalues less than 1. Then the items that had less than 50 % of communality variance were removed and the factor analysis was repeated. The number of factors was calculated as 5. Afterwards, the analysis was repeated again for the last time. As suggested by Hair *et al*. (2014), as the sample size was over 350, the cut-off point was accepted as 0.30, and then the overlapping items in the factors were removed and the final result was obtained.

3. Correlation Analysis

Correlation analysis is a statistical method used to evaluate either the existence of a linear relationship between two variables or the strength and direction of the relationship between one or more variables (Kalaycı, 2009; Büyüköztürk, 2014). Correlation analysis was done according to outcomes of factor analysis.

4. Chi-Square Test

The chi-square test consists of three different types of analysis: goodness of fit, a test of independence and a test for homogeneity, all of which are useful for this study (Kalaycı, 2009).

A chi-square analysis was used to examine if there was any statistical relationship between consumers' favourite panel furniture brand and their demographics.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The total number of analysed questionnaires is 491. Respondents' genders were balanced, 53.2 % (261) male and 46.8 % (230) female. 50.3 % (247) of respondents were under 30 years old and 49.7 % (244) were between 30 and 60 years of age. The study's cut-off age was 61.

Questionnaires used a stratified sampling method. For this reason, the largest number of questionnaires (122) was distributed in Zonguldak, the provincial centre, which has the highest number of households. The lowest number of questionnaires (42) was distributed in Bartın, also a provincial centre, which has the smallest number of households in the Western Black Sea region. The Zonguldak surveys constituted 24.8 % of the total, while those from Bartın constituted 8.6 %.

Culling the respondents by different categories yielded the following results:

– 52.3 % (257) of the respondents were single, and 47.7 % (234) were married.
– 41.5 % (204) were university graduates, 28.8 % (141) were postgraduates, 23 % (113) were high school graduates, 3.7 % (18) were middle school graduates and 3.1 % (15) were primary school graduates.
– 69.8 % (343) were working, 26.1 % (128) did not work, and 4.1 % (20) were retired.
– 26.1 % (128) earned less than 1000TL (167 €) per month, 17.3 % (85) earned 1000-1999TL (167-333

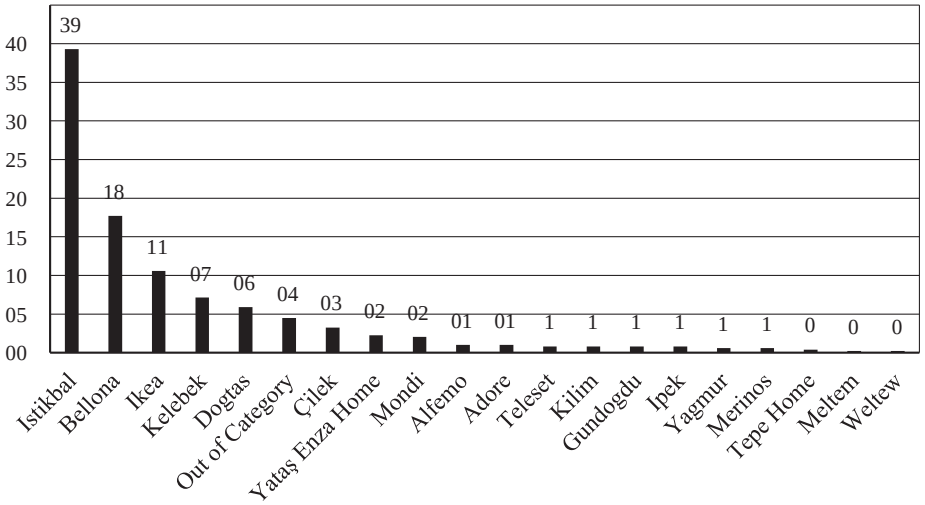

Figure 2 Panel furniture consumer recollection rate (%)
Slika 2. Stupanj prisjećanja potrošača pločastog namještaja (%)

€) per month, 20.8 % (102) earned 2000-2999TL (334-500 €) per month, 22.26 % (111) earned 3000-3999TL (501-666 €) per month, and 13.2 % (65) earned 4000TL (667 €) or more per month. The currency conversions were made as of December 2018.

Participants were randomly selected, and approximately 71 % (350 responses) of the questionnaires were answered face-to-face. The remaining 141 questionnaires (approximately 29 %) were answered via the Internet.

When the respondents were asked about the remembered panel furniture brands, the results were as follows: İstikbal was remembered by 193 people, Bellona by 87 people, Ikea by 52 people, Kelebek by 35 people, Doğtaş by 29 people, Yağmur and Merinos by 3 people, Tepe Home by 2 people, and Meltem and Weltew by 1 person. In the questionnaire, only 24 large panel furniture manufacturers were examined. A more detailed explanation can be seen in Figure 2.

In Table 2 below, consumers were asked why they preferred certain brands, i.e. what were their priorities for purchasing a branded product. The most important reason as the first priority (26.3 %) for choosing a brand is the experience with the brand, meaning that the customers have used the brand before. The most important reason as the second priority (23.0 %) is distribution: customers can find products easily. The most important reason as the third priority (22.0 %) is

Table 2 Reasons to buy preferred brands
Tablica 2. Razlozi za kupnju željene robne marke

1st Priority *1. izbor*			**2nd Priority** *2. izbor*			**3rd Priority** *3. izbor*		
Reason *Razlog*	***N***	**Percentage** *Postotak*	**Reason** *Razlog*	***N***	**Percentage** *Postotak*	**Reason** *Razlog*	***N***	**Percentage** *Postotak*
For being used at home *namijenjena je uporabi kod kuće*	129	26.3	Products can be found everywhere *može se pronaći bilo gdje*	113	23	For being a trusted brand *to je marka kojoj vjerujem*	108	22
For being the best quality brand *to je marka najbolje kvalitete*	126	25.7	For being the best-quality brand *to je marka najbolje kvalitete*	112	22.8	Products can be found everywhere *može se pronaći bilo gdje*	100	20.4
For being a trusted brand *to je marka kojoj vjerujem*	118	24	For being a trusted brand *to je marka kojoj vjerujem*	109	22.2	For being used at home *to je marka kojoj vjerujem*	80	16.3
Products can be found everywhere *može se pronaći bilo gdje*	62	12.6	For being used at home *namijenjena je uporabi kod kuće*	53	10.8	For being the best-quality brand *to je marka najbolje kvalitete*	75	15.3
Because there are too many ads *ima previše oglasa*	38	7.7	Because there are too many ads *ima previše oglasa*	46	9.4	Because there are too many ads *ima previše oglasa*	57	11.6
Because the product is very affordable *pristupačna je*	18	3.7	Because the product is very affordable *pristupačna je*	35	7.1	Because the product is very affordable *pristupačna je*	45	9.2

Table 3 Consumers' favourite brands
Tablica 3. Robne marke koje kupci preferiraju

Rank *Poredak*	**Brand** *Robna marka*	***N***	**Percentage** *Postotak*
1	İstikbal	196	39.9
2	Bellona	94	19.1
3	Ikea	45	9.2
4	Doğtas	41	8.4
5	Kelebek	38	7.7
6	Yataş Enza Home	21	4.3
7	Çilek	16	3.3
8	Kilim	8	1.6
9	Teleset	6	1.2
10	Adore	6	1.2
11	Tepe Home	4	1
12	Yağmur	3	1
13	Merinos	3	1
14	Alfemo	2	0
15	Mondi	2	0
16	Gündoğdu	2	0
17	İpek	2	0
18	Meltem	1	0
19	Weltew	1	0

reliability. When these results are analysed, it becomes clear that some values are closer than others. This will be addressed in the conclusion.

Identifying consumers' favourite brands and the variables that affect brand equity requires analysis. For this reason, 491 respondents were asked to indicate their favourite panel furniture brands (see Table 3).

Istikbal was the favourite brand, preferred by 39.9 % of respondents. Bellona was in second place (19 %), and Ikea took the third position (9.2 %). Despite being a Scandinavian brand, Ikea has a sizeable market share in the Turkish panel furniture market. Statistics for other preferred brands are shown in Table 3.

When consumers' panel furniture purchase experience was tested, it was found that 93.1 % (457) of consumers bought panel furniture (from any brand), while 6.9 % (34) have never purchased panel furniture. Also, not all consumers purchased their favourite brands. According to findings, 84.5 % (415) of consumers did buy their favourite PF brands, while 15.5 % (76) did not.

Table 4 shows that 88.3% of consumers preferred the İstikbal brand, which they had experienced before. Rates of experience with other brands are also shown in Table 4.

It was also found that 90.8 % (415) of all respondents purchased something from their favourite brand, while 9.2 % (42) did not, even though they purchased other brands.

To examine statistical relationships between consumers' favourite panel furniture brands and their demographics, a chi-square analysis was used: At a significance level of 5 %, favourite panel furniture brands related to gender, age, city, marital status, education level and monthly income.

As seen in Table 5, two-sided asymptotic values are significant ($p < 0.05$). Therefore, the null hypotheses (H0) related to the criteria were rejected. Hence,

Table 4 Details about consumers' favourite panel furniture brands
Tablica 4. Detalji o preferiranim robnim markama pločastog namještaja

Favourite panel furniture brands *Preferirana marka pločastog namještaja*		**Bellona**	**İstikbal**	**Kelebek**	**Doğtaş**	**Tepe Home**	**Alfemo**	**Ikea**
Yes	***N***	80	173	29	32	1	2	39
	%	85.10 %	88.30 %	76.30 %	78.00 %	25.00 %	100.00 %	86.70 %
No	***N***	14	23	9	9	3	0	6
	%	14.90 %	11.70 %	23.70 %	22.00 %	75.00 %	0.00 %	13.30 %
Favourite panel furniture brands *Preferirana marka pločastog namještaja*		**Yataş Enza Home**	**Yağmur**	**Kilim**	**Mondi**	**Gündoğdu**	**Merinos**	**İpek**
Yes	***N***	17	2	5	2	2	3	2
	%	81.00 %	66.70 %	62.50 %	100.00 %	100.00 %	100.00 %	100.00 %
No	***N***	4	1	3	0	0	0	0
	%	19.00 %	33.30 %	37.50 %	0.00 %	0.00 %	0.00 %	0.00 %
Favourite panel furniture brands *Preferirana marka pločastog namještaja*		**Teleset**	**Adore**	**Çilek**	**Meltem**	**Weltew**		**Total** *Ukupno*
Yes	***N***	5	5	14	1	1		415
	%	83.30 %	83.30 %	87.50 %	100.00 %	100.00 %		84.50 %
No	***N***	1	1	2	0	0		76
	%	16.70 %	16.70 %	12.50 %	0.00 %	0.00 %		15.50 %

Table 5 Chi-Square analysis and related criteria
Tablica 5. χ^2 analiza i srodni kriteriji

Chi-Square tests *χ^2-testovi*				**Chi-Square tests** *χ2-testovi*			
The chosen, favourite brand * Gender *preferirana marka* spol*	Value	*df*	Asymptotic significance (2-sided)	The chosen, favourite brand * City *preferirana marka* grad*	Value	*df*	Asymptotic significance (2-sided)
Pearson Chi-Square	32.377[a]	18	0.02	Pearson Chi-Square	152.381[a]	108	0.003
Chi-Square tests *χ2-testovi*				**Chi-Square tests** *χ2-testovi*			
The chosen, favourite brand * Age *preferirana marka* starost*	Value	*df*	Asymptotic significance (2-sided)	The chosen, favourite brand * Marital status *preferirana marka* bračni status*	Value	*df*	Asymptotic significance (2-sided)
Pearson Chi-Square	213.937[a]	162	0.004	Pearson Chi-Square	32.703[a]	18	0.018
Chi-Square tests *χ2-testovi*				**Chi-Square tests** *χ2-testovi*			
The chosen, favourite brand * Education level *preferirana marka* razina obrazovanja*	Value	*df*	Asymptotic significance (2-sided)	The chosen, favourite brand * Monthly income level *preferirana marka* mjesečni dohodak*	Value	*df*	Asymptotic significance (2-sided)
Pearson Chi-Square	148.273[a]	90	0	Pearson Chi-Square	100.344[a]	72	0.015

the relevant criteria influenced the chosen favourite PF brands. They varied depending on the above criteria.

Explanatory factor analysis has been applied to 47 items in the questionnaire. Its findings are as follows:

As seen in Table 6, the calculated KMO value was 0.884 (very good), which means that the data set is suitable for factor analysis. The Bartlett test's significance value shows that the test is significant. With these high correlations, the data set is suitable for factor analysis (see Table 7 below).

Factor analysis of Table 7 shows that 47 items were reduced to 28 and collected in five different factors, including *marketing activities, perceived quality, brand awareness, brand association* and *price* (see Table 8 below).

As shown in Table 8, the cumulative contribution of these five factors to the variance is 52.466 %. In practice, especially in the social sciences, it is considered sufficient if the variance explained in multi-factorial patterns is between 40 % and 60 % (Çokluk *et al*., 2012). In this context, contribution of the defined factors to the variance is sufficient.

To reveal the validity of the factors identified in this paper, it is useful to mention the following points: This paper and many others that focus on CBBE, followed Aaker and Keller's models. The summary of the factors in their models is as follows: brand loyalty, brand awareness (recognition and recall), perceived quality, brand associations (image), brand assets, and brand knowledge (Aaker, 1991; Keller, 1993).

In this context, while the factors determined in this paper are consistent with the literature, there also are some differences. First of all, the identified factors are marketing activities, perceived quality, brand awareness, brand association and price. Since, this study was based on Aaker's model, factors affecting

Table 6 KMO and Bartlett's test results
Tablica 6. Rezultati KMO i Bartlettova testa

KMO and Bartlett's tests		
Kaiser-Meyer-Olkin measure of sampling adequacy.		0.884
Bartlett's test of sphericity	Approx. Chi-Square	9.425.015
	df	1081
	Significance	0

CBBE in the panel furniture industry are mostly consistent with the original model. However, unlike in Aaker's model, marketing activities and price have been identified as two new factors that affect CBBE.

In this paper, brand loyalty and brand assets dimensions of Aaker's model were not identified as important variables. Perhaps this is because Turkish consumers' behaviour is different from the behaviour of other countries' consumers, or because of the structure of the furniture industry, which is extremely large and costlier than many other industries in CBBE studies. In other words, variables arising because of market structure can also help consumers value the brands. On the other hand, 'other proprietary brand assets', in Aaker's brand equity model, is generally used in financial studies rather than in CBBE studies. It is also necessary to keep in mind that some factors, noted above, interact with each other.

As already mentioned, we adopted Yoo and Donthu's (2001) CBBE scale, which is based on that of Aaker and Keller. The principal factors of their scale are effective in creating CBBE and in keeping factors substantially consistent. The factors (dimensions) in Yoo and Donthu's scale are the perceived quality, brand loyalty, brand awareness, and brand association (Yoo and Donthu, 2001).

A correlation analysis was performed to determine the relationships between items in factor groups and their significance levels.

In this paper, moderate and high correlation values were taken into account, and related items were examined. Items with low correlation values were not examined. The findings of our analysis are as follows:

The items in Table 9 were listed and abbreviated as follows:

"A." The advertising campaigns for the brand are seen frequently; "B." The brand has effective ads; "C." The brand's slogans are catchy; "D." The brand is constantly reminded to the consumers; "E." The brand goes on sale frequently; "F." More stores sell the brand,

Table 7 Factor analysis final results
Tablica 7. Konačni rezultati faktorske analize

Rotated Component Matrix[a]					
	Component / *Sastavnica*				
	1	2	3	4	5
Advertising campaigns for the brand are seen frequently / *Često se vide reklamne kampanje za robnu marku*	0.792	0.018	0.017	-0.035	0.048
The brand has effective ads / *Robna marka ima efektne oglase*	0.741	0.081	0.094	-0.035	0.138
The brand's slogans are catchy / *Slogani robne marke su privlačni*	0.732	0.094	0.177	-0.008	0.081
The brand is constantly reminded to the consumers / *Potrošače se stalno podsjeća na robnu mar*ku	0.720	0.061	0.011	-0.128	-0.032
More stores sell the brand, versus competing brands / *Robna se marka prodaje u više trgovina nego konkurentski proizvodi*	0.620	0.136	-0.075	0.274	0.027
The brand goes on sale frequently / *Robna je marka često na popustu*	0.614	-0.047	0.083	0.009	-0.186
The brand has high market share / *Robna marka ima visok tržišni udio*	0.578	0.292	0.194	-0.072	0.062
The brand is distributed through as many stores as possible / *Robna se marka distribuira putem što više trgovina*	0.556	0.218	-0.010	0.273	-0.042
Compared to competing brands, ad campaigns for the brand are more costly *Oglasne su kampanje skuplje od kampanja konkurentskih marki*	0.508	0.025	0.161	0.234	0.242
The brand has good product variety / *Robna marka ima dobru raznolikost*	0.492	0.256	0.186	-0.232	-0.067
The products are sold in stores that offer well-known brands / *Proizvodi se prodaju u trgovinama s dobro poznatim robnim markama*	0.419	0.258	-0.206	0.216	0.028
The products are priced fairly / *Proizvodi imaju poštenu cijenu*	0.135	0.742	0.071	-0.139	0.009
Brand quality is likely extremely high / *Kvaliteta robne marke vjerojatno je vrlo visoka*	0.096	0.738	0.104	0.019	-0.008
The brand is high-quality / *Robna je marka visoke kvalitete*	0.093	0.734	0.041	0.047	0.196
The likelihood that the brand's new products will be functional is very high *Vrlo je velika vjerojatnost da će novi proizvodi biti funkcionalni*	0.081	0.677	0.134	-0.138	0.036
The brand is priced fairly / *Robna marka ima poštenu cijenu*	0.075	0.634	0.131	-0.051	-0.091
Even if another brand has the same features, I prefer to buy this brand / *Čak i ako druga robna marka ima jednaka obilježja, radije bih kupio/kupila ovu robnu marku*	0.071	0.497	0.358	0.000	-0.067
The brand uses high technology / *Robna se marka proizvodi visokom tehnologijom*	0.212	0.471	0.237	-0.099	0.143
It makes sense to buy this brand instead of any other, even if they are essentially the same / *Ima smisla kupiti ovu robnu marku umjesto bilo koje druge, čak i ako su jednake*	0.084	0.462	0.243	0.226	0.003
I can recognise the brand among other competing brands / *Tu robnu marku mogu prepoznati među ostalim konkurentskim proizvodima*	0.090	0.152	0.823	0.036	0.027
I am aware of the brand / *Svjestan/svjesna sam robne marke*	0.073	0.218	0.781	-0.070	0.081
I have enough knowledge about the brand / *Imam dovoljno znanja o toj robnoj marki*	0.152	0.201	0.744	0.011	-0.032
Some characteristics of the brand come to my mind quickly / *Nekih se obilježja robne marke odmah sjetim*	0.040	0.178	0.666	0.103	-0.027
The brand's products seem to be of very poor quality / *Proizvodi marke vrlo su loše kvalitete*	0.023	-0.158	0.059	0.780	-0.146
I have difficulty imagining the brand in my mind / *Teško mi je zamisliti robnu marku*	0.054	0.047	-0.051	0.737	0.094
The brand is preferable because it is from another country / *Robna je marka poželjnija jer je iz druge zemlje*	0.004	-0.094	0.086	0.663	-0.186
The price of the brand is high / *Cijena robne marke je visoka*	0.071	0.041	0.027	0.029	0.864
The price of the brand is low / *Cijena robne marke je niska*	-0.016	-0.048	0.014	0.369	-0.752

Extraction Method: Principal Component Analysis. / *Metoda ekstrakcije: analiza glavnih komponenata.*
Rotation Method: Varimax with Kaiser Normalization. / *Metoda rotacije: Varimax s Kaiserovom normalizacijom.*
[a]Rotation converged in 6 iterations. / *Rotacija je konvergirala u šest ponavljanja.*

Table 8 Total variance explained by factors
Tablica 8. Ukupna varijanca objašnjena uz pomoć faktora

Total variance explained / *Objašnjenje ukupne varijance*						
Component/*Sastavnica*	Initial eigenvalues			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1- Marketing activities / *marketinške aktivnosti*	6.189	22.102	22.102	4.463	15.939	15.939
2- Perceived quality / *percipirana kvaliteta*	3.065	10.947	33.049	3.666	13.094	29.033
3- Brand awareness / *prepoznatljivost marke*	2.340	8.356	41.406	2.790	9.965	38.998
4- Brand association / *povezanost marke*	1.734	6.194	47.599	2.179	7.782	46.780
5- Price / *cijena*	1.363	4.867	52.466	1.592	5.686	52.466

Table 9 Correlation analysis results of items in Factor Group 1
Tablica 9. Rezultati korelacijske analize stavki za grupu 1.

		A	B	C	D	E	F	G	H	I	J	K
A	Pearson correlation	1	0.505**	0.523**	0.605**	0.436**	0.433**	0.424**	0.330**	0.429**	0.320**	
	Significance (2-tailed)		0	0	0	0	0	0	0	0	0	
B	Pearson correlation		1	0.675**	0.470**	0.339**	0.369**	0.447**	0.323**	0.343**	0.342**	
	Significance (2-tailed)			0	0	0	0	0	0	0	0	
C	Pearson correlation			1	0.429**	0.347**	0.389**	0.446**	0.356**	0.337**	0.383**	
	Significance (2-tailed)				0	0	0	0	0	0	0	
D	Pearson correlation				1	0.387**	0.343**	0.359**		0.328**	0.327**	
	Significance (2-tailed)					0	0	0		0	0	
E	Pearson correlation					1	0.319**		0.326**			
	Significance (2-tailed)						0		0			
F	Pearson correlation						1		0.508**	0.306**		0.412**
	Significance (2-tailed)								0	0		0
G	Pearson correlation							1	0.314**		0.524**	
	Significance (2-tailed)								0		0	
H	Pearson correlation								1			0.375**
	Significance (2-tailed)											0

**Correlation is significant at the 0.01 level (2-tailed). / ***Korelacija je značajna na razini 0,01 (dvostrana).*
*Correlation is significant at the 0.05 level (2-tailed). / **Korelacija je značajna na razini 0,05 (dvostrana).*

versus competing brands; "G." The brand has high market share; "H." The brand is distributed through as many stores as possible; "I." Compared to competing brands, ad campaigns for the brand are more costly; "J." The brand has good product variety; "K." The brand's products are sold in stores that offer well-known brands.

Examining the data in Table 9, correlation values of items in marketing activities provided the following findings. *The brand has effective ads* and *The brand's slogans are catchy* had the strongest correlation value (.675**) in this factor set. Therefore, a partly high positive correlation is seen in these items. On the other hand, *The advertising campaigns for the brand are frequently seen* and *The brand is constantly reminded to the consumers* items showed a moderately positive correlation (.605**), the second-strongest value in this factor set. Finally, *The brand has high market share* and *The brand has good product variety* showed a moderately positive (.524**) correlation, the third-strongest value in this factor set. Table 9 shows other moderate and high correlation values.

Table 10 Correlation analysis results of items in Factor Group 2
Tablica 10. Rezultati korelacijske analize stavki za grupu 2.

		L	M	N	O	P	R	S	T
L	Pearson correlation	1	0.500**	0.446**	0.441**	0.450**	0.333**	0.414**	0.316**
	Sig. (2-tailed)		0	0	0	0	0	0	0
M	Pearson correlation		1	0.508**	0.521**	0.385**	0.307**	0.359**	
	Significance (2-tailed)			0	0	0	0	0	
N	Pearson correlation			1	0.462**	0.397**	0.312**	0.365**	
	Significance (2-tailed)				0	0	0	0	
O	Pearson correlation				1	0.378**	0.337**	0.362**	
	Significance (2-tailed)					0	0	0	
R	Pearson correlation						1		0.382**
	Significance (2-tailed)								0

**Correlation is significant at the 0.01 level (2-tailed). / ***Korelacija je značajna na razini 0,01 (dvostrana).*
*Correlation is significant at the 0.05 level (2-tailed). / **Korelacija je značajna na razini 0,05 (dvostrana).*

Items in Table 10 were listed and abbreviated as L, M, N, O, P, R, S and T.

"L." The products are priced fairly; "M." Brand quality is likely extremely high; "N." The brand is of high quality; "O." The likelihood that the brand's new products will be functional is very high; "P." The brand is priced fairly; "R." Even if another brand had the same features, I prefer to buy this brand; "S." The brand uses high technology; "T." It makes sense to buy this brand instead of any other brand, even if they are essentially the same.

Examining the data in Table 10, the correlation value of *Brand quality is likely extremely high* and *The likelihood that the brand's new products will be functional is very high* provided the strongest value (.521**) in this factor set. Accordingly, there is a moderately positive correlation between these items. *Brand quality is likely extremely high* and *The brand is of high quality* give a moderately positive correlation (.508**), the second-highest in this factor set. Finally, *The brand is priced fairly* and *The likelihood that the brand's new products will be functional is very high* gives a moderately positive (.500**) correlation, the third-strongest value in this factor set. Other correlation values are shown in Table 10.

The items in Table 11 were listed and abbreviated as U, V, Y and Z.

"U." I can recognise the brand among other competing brands; "V." I am aware of the brand; "Y." I have enough knowledge about the brand; "Z." Some characteristics of the brand come to my mind quickly.

Examining the data in Table 11, the correlation value of the statements *I can recognise the brand among other competing brands* and *I am aware of brand items* have the strongest value (.704**) in this factor set. On the other hand, the statements *I can recognise the brand among other competing brands* and *I have enough knowledge about the brand* items have a moderately positive correlation (.554**), the second-strongest value in this factor set. Finally, *I have enough knowledge of the brand* and *Some characteristics of the brand come to my mind quickly* have a moderately positive (.517**) correlation, the third-strongest value in this factor set. Only the three strongest correlation values are mentioned here.

The items in Table 12 were listed and abbreviated as W, Q and X.

"W." The brand's products seem to be of very poor quality; "Q." I have difficulty imagining the brand in my mind; "X." The brand is preferable because it is from another country.

Examining the data in Table 12, the correlation value of *The brand's products seem to be of very poor quality* and *I have difficulty imagining the brand in my mind* showed the strongest value (.473**) in this factor set. There was a moderately positive correlation between these items. On the other hand, *The brand's products seem to be of very poor quality* and *The brand is preferable because it is from another country* had a moderately positive correlation (.468**), the second-strongest value in this factor set. Finally, the statements *I have difficulty imagining the brand in my mind* and

Table 11 Correlation analysis results of items in Factor Group 3
Tablica 11. Rezultati korelacijske analize stavki za grupu 3.

		U	V	Y	Z
U	Pearson correlation	1	0.704**	0.554**	0.425**
	Significance (2-tailed)		0	0	0
V	Pearson correlation		1	0.504**	0.414**
	Significance (2-tailed)			0	0
Y	Pearson correlation			1	0.517**
	Significance (2-tailed)				0

** Correlation is significant at the 0.01 level (2-tailed).
** *Korelacija je značajna na razini 0,01 (dvostrana).*
* Correlation is significant at the 0.05 level (2-tailed).
* *Korelacija je značajna na razini 0,05 (dvostrana).*

Table 12 Correlation analysis results of items in Factor Group 4
Tablica 12. Rezultati korelacijske analize stavki za grupu 4.

		W	Q	X
W	Pearson correlation	1	0.473**	0.468**
	Significant (2-tailed)		0	0
Q	Pearson correlation		1	0.309**
	Significant ((2-tailed)			0

**Correlation is significant at the 0.01 level (2-tailed).
** *Korelacija je značajna na razini 0,01 (dvostrana).*
*Correlation is significant at the 0.05 level (2-tailed).
* *Korelacija je značajna na razini 0,05 (dvostrana).*

Table 13 Correlation analysis results of items in Factor Group 5
Tablica 13. Rezultati korelacijske analize stavki za grupu 5.

		A1	A2
A1	Pearson correlation	1	−0.487**
	Significance (2-tailed)		0

**Correlation is significant at the 0.01 level (2-tailed).
***Korelacija je značajna na razini 0,01 (dvostrana).*
*Correlation is significant at the 0.05 level (2-tailed).
**Korelacija je značajna na razini 0,05 (dvostrana).*

The brand is preferable because it is from another country showed a moderately positive (.309**) correlation, the third-strongest value in this factor set.

The items in Table 13 were listed and abbreviated as A1 and A2.

"A1." The price of the brand is high; "A2." The price of the brand is low.

Examining the data in Table 13, the correlation value of *The price of the brand is high* and *The price of the brand is low* was (−.487**), suggesting a moderately negative correlation between these items.

The foregoing correlation analysis placed items in different categories, with largely low and moderate correlations being found. However, as a result of the performed correlation analysis, a special case has been identified: the existence of moderate interactions was observed between some of the items from different categories. For a better explanation, see Table 14.

Items and factor groups examined by correlation analysis can be summarised as follows:
Eleven items about marketing activities were made:
1. Ad campaigns for the brand are seen frequently.
2. The brand has effective ads.
3. The brand's slogans are catchy.
4. The brand is constantly reminded to the consumers.
5. More stores sell the brand, versus competing brands.
6. The brand goes on sale frequently
7. The brand has high market share.
8. The brand is distributed through as many stores as possible.
9. Compared to competing brands, ad campaigns for the brand are more costly.
10. The brand has good product variety.
11. The brand's products are sold in stores that offer well-known brands.

Eight items about perceived quality were made:
1. The products are priced fairly.
2. The brand quality is likely extremely high.
3. The brand is of high quality.
4. The likelihood that the brand's new products will be functional is very high.
5. The brand is priced fairly.
6. Even if another brand has the same features, I prefer to buy this brand.
7. The brand uses high technology.
8. It makes sense to buy this brand instead of any other, even if they are essentially the same.

There were four brand awareness items:
1. I can recognise the brand among other competing brands.
2. I am aware of the brand.
3. I have enough knowledge about the brand.
4. Some characteristics of the brand come to my mind quickly.

There were three brand association items:
1. The brand's products seem to be of very poor quality.
2. I have difficulty imagining the brand in my mind.
3. It is preferable because it is from another country.

Finally, the two price-factor items were:
1. The price of the brand is high.
2. The price of the brand is low.

As can be seen from the correlation analysis, items in the same factor group directly affect each other. As in Yoo and Donthu (2001)'s original scale, items are clustered by similar factors. Therefore, the determining factors of the developed scale and the items in the factor groups are consistent with the literature.

4 CONCLUSIONS
4. ZAKLJUČAK

According to the consumer demographics, the categorical distribution of 491 people in this research was found balanced.

In the beginning of the survey, respondents were asked some questions. All of them (100%) were able to recall at least one brand. However, the number of consumers was decreasing, while the number of recalled brands was increasing. Most respondents were able to recall a maximum of three brands. In addition, the three most preferred brands were the same as the three brands recalled by the consumers.

Table 14 Correlation values of items from different factor groups
Tablica 14. Vrijednosti korelacije stavki iz različitih grupa

		I can recognise the brand among other competing brands / *Tu robnu marku mogu prepoznati među konkurentskim proizvodima*	I am aware of the brand *Svjestan/ svjesna sam robne marke*	I have enough knowledge about the brand / *Imam dovoljno znanja o toj robnoj marki*
Even if another brand had the same features, I prefer to buy this brand /*čak i ako druga robna marka ima jednaka obilježja, radije bih kupio/kupila ovu robnu marku*	Pearson correlation	0.320**	0.351**	0.316**
	Significance (2-tailed)	0	0	0

**Correlation is significant at the 0.01 level (2-tailed). / ***Korelacija je značajna na razini 0,01 (dvostrana).*
*Correlation is significant at the 0.05 level (2-tailed). / **Korelacija je značajna na razini 0,05 (dvostrana).*

When consumers were asked to rank brands, they preferred the brands that they had tried in the past. The quality, distribution and attainability of the brand were also very important. Consumers want to reach the products of the brands in the market. Another important reason was brand credibility.

When consumers were asked to define their favourite panel furniture brands, the results were as follows:

– They preferred domestic brands over foreign brands.
– The reasons why consumers preferred certain panel furniture brands were largely the same as why consumers preferred brands in general.

According to the chi-square analysis, the favourite panel furniture brand related to gender, age, city, marital status, education level and monthly income. Other demographics had no effect on the choice of favourite panel furniture brands.

Respondents were asked to give brands personality traits. While positive attributes such as modernity, a pioneering nature, and assertiveness were associated with consumers' favourite brands, attributes such as imitative, passive, unstable and untested were associated with the least-favourite brands.

Overall, 47 items were reduced to 28, and they were collected in five different factor groups: 'marketing activities', 'perceived quality', 'brand awareness', 'brand association', and 'price'. To examine the relationship between items in the factor groups, correlation analyses were performed, which found that most items in a factor group are interrelated and trigger each other.

If any firm wants to create or strengthen CBBE, they should consider the major factors and criteria defined in this paper one by one. For doing so, items under the relevant factors should be taken into account. In this manner, firms can save time and money by creating CBBE strategy.

Some respondents' brand-equity views, not directly examined in this paper, can shed light on future research. Even though they define the brands they have enjoyed in the past as valuable, most consumers are very open to change. Also, unlike in the literature, consumers' previous brand loyalty was found to be unimportant. This may have been caused by the structure of the panel furniture sector (as mentioned earlier), or it may have been due to the purchasing habits of Turkish consumers. This can be an important starting point, especially for future studies.

Brands' contribution to social responsibility projects is very important for consumers. However, consumers frequently do not have any information about this issue. Therefore, if brands contribute to socially responsibility projects, it is very important for enterprises to emphasise this point when creating brand awareness and brand perception.

Brands that stand behind their products and investigate consumer satisfaction after the sale make consumers feel important. These companies are seen as trustworthy, which creates positive brand perception. To improve a brand's general perception, we recommend that large companies set up call centres. In our survey, an important criticism was that companies do not value consumers after they make purchases.

Finally, according to respondents, brands should be represented by a dealer in every region. Although consumers respond to advertisements, they stated that it is also important to see products physically, which might cause them to make a different purchase decision. Therefore, enterprises looking to create CBBE should pay particular attention to distribution networks and point-of-sale marketing efforts.

5 REFERENCES
5. LITERATURA

1. Aaker, D. A., 1991: Managing Brand Equity. New York: The Free Press.
2. Baalbaki, S.; Guzmán, F., 2016: A consumer-perceived consumer-based brand equity scale. Journal of Brand Management, 23: 229-251. https://doi.org/10.1057/bm.2016.11.
3. Büyüköztürk, Ş., 2014: Sosyal Bilimler İçin Veri Analizi El Kitabı, 19. Baskı, Pegem Akademi, Ankara.
4. Can, A., 2014: SPSS ile Bilimsel Araştırma Sürecinde Nicel Veri Analizi, 2. Baskı, Pegem Akademi, Ankara.
5. Cobb-Walgren, C. J.; Ruble, C. A.; Donthu, N., 1995: Brand Equity, Brand Preference, and Purchase Intent. Journal of Advertising, 24: 25-40.
6. Colicev, A.; Malshe, A.; Pauwels, K., 2018: Social Media and Customer-Based Brand Equity: An Empirical Investigation in Retail Industry. Administrative Sciences, 8(3): 1-16. https://doi.org/10.3390/admsci8030055.
7. Crimmins, J. C., 1992: Better measurement and management of brand value. Journal of Advertising Research, 32(4): 11-19.
8. Çokluk, Ö.; Şekercioğlu, G.; Büyüköztürk, Ş., 2012: Sosyal Bilimler İçin Çok Değişkenli İstatistik SPSS ve Lisrel Uygulamaları, 2. Baskı, Pegem Akademi, Ankara.
9. Daniel, W. W., 1999: Biostatistics A Foundation for Analysis in the Health Sciences, sixth edition. Hoboken, John Wiley & Sons, Inc.
10. Datta, H.; Ailawadi, K. L.; van Heerde, H. J., 2017: How Well Does Consumer-Based Brand Equity Align with Sales-Based Brand Equity and Marketing-Mix Response? Journal of Marketing 81: 1-20. https://doi.org/10.1509/jm.15.03.
11. Erdem, T.; Swait, J.; Broniarczyk, S.; Chakravarti, D.; Kapferer, J.-N.; Keane, M.; Roberts, J.; Steenkamp, J. E. M.; Zettelmeyer, F., 1999: Brand Equity, Consumer Learning and Choice. Marketing Letters 10: 301-318.
12. Farquhar, P. H., 1989: Managing Brand Equity, Marketing Research, 1 (September), 24-33.
13. Girard, T.; Trapp, P.; Pinar, M.; Gulsoy, T.; Boyt, T. E., 2017: Consumer-Based Brand Equity of a Private-Label Brand: Measuring and Examining Determinants. Journal of Marketing Theory and Practice, 25: 39-56. https://doi.org/10.1080/10696679.2016.1236662.
14. Hair, J. F.; Black, W. C.; Babin, B. J.; Anderson, R. E.; 2014: Multivariate data analysis, Pearson.
15. Ioannou, M.; Rusu, O., 2012: Consumer-Based Brand Equity: A Cross-Cultural Perspective. Journal of Promotion Management, 18: 344-360. https://doi.org/10.1080/10496491.2012.696462.
16. Kalaycı, Ş., 2009: SPSS Uygulamalı Çok Değişkenli İstatistik Teknikleri, 4. Baskı, Asil Yayın Dağıtım, Ankara.

17. Keller, K. L., 1993: Conceptualizing, measuring, and managing customer-based brand equity. Journal of Marketing, 57 (1): 1-22.
18. Keller, K. L., 1998: Strategic Brand Management: Building, Measuring, and Managing Brand Equity. Upper Saddle River, NJ: Prentice Hall.
19. Koçak, A.; Abimbola, T.; Özer, A., 2007: Consumer Brand Equity in a Cross-cultural Replication: An Evaluation of a Scale. Journal of Marketing Management, 23: 157-173. https://doi.org/10.1362/026725707X178611.
20. Lassar, W.; Mittal, B.; Sharma, A., 1995: Measuring customer based brand equity. Journal of Consumer Marketing, 12: 11-19. https://doi.org/10.1108/07363769510095270.
21. McQueen, J., 1991: Leveraging the Power of Emotion in Building Brand Equity, ARF Third Annual Advertising and Promotion Workshop, February 5-6.
22. Netemeyer, R. G.; Krishnan, B.; Pullig, C.; Wang, G.; Yagci, M.; Dean, D.; Ricks, J.; Wirth, F.; 2004: Developing and validating measures of facets of customer-based brand equity. Journal of Business Research, 57: 209-224. https://doi.org/10.1016/S0148-2963(01)00303-4.
23. Pappu, R.; Quester, P. G.; Cooksey, R. W., 2005: Consumer based brand equity: improving the measurement – empirical evidence. Journal of Product and Brand Management, 14: 143-154. https://doi.org/10.1108/10610420510601012.
24. Swimberghe, K.; Darrat, M. A.; Beal, B. D.; Astakhova, M., 2018: Examining a psychological sense of brand community in elderly consumers. Journal of Business Research, 82: 171-178. https://doi.org/10.1016/j.jbusres.2017.09.035.
25. Turkstat, 2011: Population And Housing Census, Number of Households by Household Size, Turkish Statistical Institute, Ankara, viewed 15 September 2016. http://www.turkstat.gov.tr/HbGetir.do?id=15843&tb_id=2.
26. Yoo, B.; Donthu, N., 2001: Developing and validating a multidimensional consumer-based brand equity scale. Journal of Business Research, 52: 1-14. https://doi.org/10.1016/S0148-2963(99)00098-3.

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Analysis of Implementation of Integrated Information Systems in Croatian Wood Processing Industry

Analiza primjene integriranih informacijskih sustava u hrvatskoj drvoprerađivačkoj industriji

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ABSTRACT • *It can be said that Integrated Information Systems (IIS) are a fundamental operating tool in modern business systems and form the basis of successful company management. The goal of our research was to determine the IT level of business operations in Croatian wood processing industry and to assess how significant it has been in enhancing its business performance. A survey method was used to collect data, which resulted in gathering predominantly small and medium-sized companies. Our results indicate an average use of IIS modalities among surveyed companies. Using cluster analysis, three types of companies were identified with respect to the degree of system implementation. Analysis of financial benefits of the IIS implementation did not find any statistically significant relationship. However, subjective impressions on non-financial indicators show that companies in all three clusters see the greatest benefit of IIS in the improved inventory efficiency and sales efficiency.*

Keywords: *Integrated Information Sytems (IIS), ERP, Croatian wood processing industry, bussines performance*

SAŽETAK • *Možemo reći da su integrirani informacijski sustavi (IIS) temeljni operativni alat u modernim poslovnim sustavima i čine osnovu uspješnog upravljanja poduzećem. Cilj našeg istraživanja bio je utvrditi razinu informatizacije poslovanja u hrvatskoj drvoprerađivačkoj industriji i ocijeniti koliko je ona važna za poboljšanje poslovnih rezultata poduzeća. Za prikupljanje podataka primijenjena je anketna metoda, koja je rezultirala odzivom pretežito malih i srednjih poduzeća. Naši rezultati upućuju na osrednju upotrebu modaliteta unutar IIS-a u anketiranim poduzećima. Klasterskom su analizom identificirana tri tipa poduzeća s obzirom na stupanj integracije sustava. Analiza financijskih koristi implementacije IIS-a nije se pokazala statistički značajnom. Međutim,*

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subjektivni dojmovi o nefinancijskim pokazateljima govore da poduzeća u sva tri klastera vide najveću korist IIS-a u poboljšanju učinkovitosti upravljanja zalihama i poboljšanju učinkovitosti prodaje.

Ključne riječi: *integrirani informacijski sustavi, ERP, hrvatska drvoprerađivačka industrija, poslovna učinkovitost*

1 INTRODUCTION
1. UVOD

Meeting the demands of today's global market (broad product range, high quality, competitive prices) imposes quick product development and manufacturing. Contrary to the traditional approach of developing new production technologies first, and subsequently creating new products and services, nowadays these phases are carried out simultaneously.

Establishing company-wide high-quality information systems is one of the key prerequisites for preparing companies to enter international markets and play an active role in globalization processes. Besides improving the logistical support for production and services and aiding company management to control and manage company operations better, the information systems should also provide a sufficiently flexible platform for communicating both with clients and suppliers. This holds true especially for small- and medium-sized companies, which operate within the supply chain involving bigger companies (Loch and Koh, 2004).

Considering wood-processing industry as a predominantly production-oriented industry, the requirements on information systems go beyond the increased productivity, achieved through better logistical and IT support (CAD/CAPP systems, NC/CNC machines, flexible production lines, etc.). The needs of companies in this sector extend to facilitated exchange of technical drawings and technological processes, material ordering, product labeling (EAN codes) and dispatching, and finally to carrying out invoicing and payments in line with current standards and protocols in developed countries (Kalem *et al.*, 2018; Majdandžić, 2004). Certainly, Information Technology (IT) is pivotal in managing such companies.

Great logistical advancements have been made towards creating flexible, customer-oriented, flow production (Majdanđić, 2004). In general, production modernization via introducing integrated information systems (IIS) aims at reducing production times and labor costs, while increasing quality and minimizing material waste (Schneider and Andersson, 2016; Venkatraman and Fahd, 2016). In wood-processing industry, the most crucial of the four is minimizing material waste, since the cost of raw material alone can account for 30-80 % of the total production cost (Grladinović *et al.*, 2003). For this reason, in recent years, many companies have embraced a new class of planning and resource management software systems to integrate processes, enforce data integrity, and better manage resources.

0.1 Integrated Information Systems
0.1. Integrirani informacijski sustavi

Today, IIS are a fundamental operating tool in modern business systems and form the basis of successful company management (Bingi *et al.*, 2006; Mabert *et al.*, 2003; Maditinos *et al.*, 2011; Schneider and Andersson, 2016; Shatat, 2015; Zach *et al.*, 2014). Designed as integrated application platforms for company business organization, management and supervision, IIS are commonly referred to as Enterprise Resource Planning systems (ERP), and have evolved from Materials Requirements Planning (MRP) to Manufacturing Resource Planning (MRP II) systems.

Generally speaking, an ERP platform unites information, collected from all departments and functions across a company, into a single system that caters to the unique and varied needs of different departments (human resources, finances, supplies, etc.), while at the same time enabling all departments to access any other relevant business information. This integrated ERP bridge improves the efficiency and effectiveness of all operations. The departments that most benefit from ERP implementation are typically accounting and finance, production operations, sales, product development teams, purchasing and procurement and quality management.

Much progress has been made since Dillard and Yuthas noted in 2006 that most multinational companies were using ERP software packages and even more small and midsize companies were on the route of adopting them. According to industry reports (Market Research Store, 2017), the Global ERP Software Market is expected to grow at a compound annual growth rate of around 7.4 % over the next decade and reach approximately $63.1 billion by 2025. The most noticeable current trends are growing demand for ERP from medium- and small-sized enterprises, and moving to mobile and cloud applications.

ERP solutions can be either generic or industry-specific. Companies usually prefer industry-specific solutions, which contain features addressing their specific challenges. Since creating or adapting an ERP product to a new industry is complicated and expensive, most ERP vendors nowadays choose to specialize in a few specific branches/sectors.

It is imporant to note that ERP systems are very large and complex and require careful planning and execution of their implementation. According to Bingi *et al*. (1999), Nah and Lau (2001), Mabert *et al*. (2003), Maditinos *et al*. (2011) and Shatat (2015), the key factors to consider when implementating such complex systems are:

Implementation stages and costs: Implementing an ERP package sometimes takes several years and needs a lot of capital investment - practice has shown that less than 75 % of the ERP system' effectiveness is utilized, which translates to 25 % of investments not being fully justified;

- Training time: Training and getting used to an ERP system takes a long time and can be costly. Therefore, initially companies tend to assign only a few employ-

ees to the task of setting up the ERP system and later rely on them to train the others;
- Data migration: Migration of historical data to the new information system is often overlooked. However, companies need this data for forecasting purposes and sometimes for compliance or legal reasons;
- Top management support: Implementing an ERP system is not a matter of changing software systems. Rather, it is a matter of repositioning the company and transforming the business practices. Some companies make the grave mistake of handing over the responsibility of ERP implementation to the technology department;
- Consultant support: ERP implementation demands multiple skills, such as functional, technical, and interpersonal. Finding the right people with hands-on experience and keeping them through the implementation is a major challenge.

1.2 Overview of Croatian wood processing industry
1.2. Pregled hrvatske drvoprerađivačke industrije

Historically, the growth of Croatian wood-processing industry, which includes wood-processing and furniture manufacturing companies, was mainly driven by rich natural supplies of high raw material, while its global recognition came from innovations and know-how in manufacturing solid wood furniture and other products. It is worth noting that an important element in the growth of this sector of Croatian economy today is the business collaboration between wood-processing companies and the main supplier of lumber in Croatia, state-owned company *Hrvatske šume* (Croatian Forests), in particular in the area of certified products export (Klarić *et al.*, 2016; Paluš *et al.*, 2018). As a branch of processing industry, wood-processing industry is an essential part of Croatian economy given that it is one of the rare sectors reporting higher export than import. According to Croatian Bureau of Statistics (2019), total export value in this sector in 2018 was 831 million HRK.

Besides its role as an export-oriented sector, wood-processing industry was an instrument in enhancing the development and employment in rural parts of Croatia. However, according to the recent research of Basarac-Sertić *et al.* (2018), a decline in employment has been observed in recent years. This can be attributed to the combined effects of rural flight, migration of workforce from Croatia to developed countries, historically low wages and salaries, and a long-term slow decline in interest for education in the specialized wood-processing trade schools, and even higher education in this field, among the youth (Kropivšek *et al.*, 2011; MINGO, 2014; MPS, 2017). The roots of this problem can be traced to difficulties affecting the whole sector, such as unavailable capital, small local market (the companies must turn to export and compete in bigger markets with much tougher competition), low success rate in obtaining financial support and grants from available sources, low added value in terms of product completion (products sold only go through primary processing), large differences in the economic power of different regions, product standardization issues, etc. (MPS, 2017; MINGO, 2014).

A large proportion of firms within the wood-processing industry in Croatia can be regarded as privately-owned, small- and medium-sized enterprises (SMEs) (this is also true on the state-wide level: the biggest share of Croatian economy is comprised small businesses, namely micro-, small- and medium-sized companies, similar to other European countries). There is a trend for these firms towards penetrating niche markets. Research done by Perić (2015), conducted on a sample of wood-processing companies facing the abovementioned difficulties, has shown that most of these businesses are run by a single manager with only high-school education and average IT skills, while the IT level of the company was rated as below average. However, financial data and other business indicators of companies, which have declared a high IT level and higher average education level of their employees, deviate positively from the statistical mean. This clearly indicates the path to be followed by the whole wood-processing sector in order to successfully compete in national and international markets. Similar conclusions were reached in their research by other EU member states (Sujová *et al.*, 2015; Hitka *et al.*, 2018). They recommend continuous investments in innovations in operational and production processes, new product development and employment of highly trained staff.

1.3 Role of Integrated Information Systems for wood processing industry
1.3. Uloga integriranih informacijskih sustava za drvoprerađivačku industriju

Wood processing industry faces increasing demands on its products and services by the global market, such as high product quality, low production costs and short time to market. These challenging demands are often hard to meet, mainly due to insufficient financial power of wood processing companies for continuous investment into business and production processes (Perić, 2015; MPS, 2017). Consequently, the following issues are common to most companies in this sector: low utilization of raw material, long production planning periods, slow development and introduction of new products to customers, low implementation rate of e-commerce platforms necessary for managing business operations within EU, lack of systematic daily output logging of production lines, individual machines and employees in order to increase efficiency and avoid production stoppages, slow and inefficient archiving of business and technical documentation (a large share of documents still circulate in paper form), insufficient quality control, etc. (Grladinović *et al.*, 2003; Grladinović *et al.*, 2007). One of the ways to combat all these shortcomings, and thereby increase the competitiveness of Croatian wood processing industry in general, could be the implementation of integrated information.

The goal of our research was to determine the IT level of business operations in Croatian wood processing industry and to assess how significant its role has been in enhancing the business performance of compa-

nies in this sector, in particular considering the conditions and circumstances outlined in Croatia. It is worth mentioning that, according to literature review, no similar research has been carried out yet in the wood processing sector in Croatia. Therefore, the preliminary results reported herein present the very first step in a long-needed comprehensive analysis of this topic.

To fulfill the objectives of this investigation, answers to the following questions were sought:

What are the levels of IIS implementation?

What are the criteria for IIS selection?

What are the benefits of IIS implementation?

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The initial target population for this research was taken from the Register of Business Entities supervised by Croatian Chamber of Commerce (HGK, 2017). The sample included all active companies with more than 5 employees, classified in the Register under "C 16 - Wood Processing" or "C 31 - Furniture Manufacturing" according to their core business activities, the classification based on National Classification of Activities 2007 (NN, 2016). This non-specific population was targeted because there is no record on the implementaion of IIS within the field, which could narrow down the target population. Data on the use of IIS in Croatian wood processing industry was collected via a survey method (Dillman, 2000). The questionnaire consisted of three parts, with a total of twenty-six questions. The first part of the questionnaire contained general questions about the company. The second part addressed specifically the level of implementation measured with seven functional modules and its variables, as follow: *Finance & Accounting (*5 variables), *Human Resource*s (6 variables), *Production Management* (6 variables), *Inventory Management* (5 variables), *Purchase* (3 variables), *Quality Management* (4 variables) and *Sales* (5 variables), and criteria selection of IIS (measured with 7 variables). Finally, the third part examined the benefits of IIS implementation (measured with 5 variables), the motives for IIS implementation (measured with 10 variables) and other questions. Open questions and five-point Likert scale were used for some of the measurements of the analyzed variables (1 = "strongly disagree" through 5 = "strongly agree") or (1 = "very unimportant" through 5 = "very important"). The responses 4 and 5 were considered positive, 1 and 2 were considered negative and 3 was taken as neutral. The neutral responses were not included in the analysis. Data from target population was collected via Survs - online questionnaire. A total of 310 companies were asked to participate in the survey by filling out the questionnaire. 55 companies responded, and after performing all necessary controls, 43 were kept for data analysis (the unusable surveys were the companies that were not interested in survey participation, and/or companies whose main business activities were not in wood processing sector), which corresponds to the response rate of 18.85 %. Financial reports needed for calculating profitability ratios were obtained for the fiscal year 2017 from business information portal Bisonde.hr (2018). The research was conducted during March and July 2017. Data were analyzed using descriptive statistics, Two Step Cluster Analysis, χ2- test, Levene›s test homogeneity, One-way analysis of variance (ANOVA), Shapiro-Wilk normality tests, Cronbach´s α measure for internal consistency, Principal Component Analysis and Pearson correlation, with the use of the statistical packages SAS® University Edition.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Demographic profile of respondents
3.1 Profil ispitanika

Among the considered population, 55.8 % of the respondents declared themselves as wood processing companies and 44.2 % as furniture manufacturing companies. All companies were privately-owned. Regarding production type, 48.5 % companies claimed to have single production, 39.5 % produce small batches, and 11.6 % focus on large batch production. In relation to company size, most respondents belong to small- and medium-sized companies (62.8 % and 18.6 %, respectively), while only 4 companies have more than 250 employees or less than 10 employees. Figure 1 shows that 80.9 % of the respondents had annual income in 2017 of less than 5 million EUR.

3.2 IIS in wood processing companies
3.2. IIS u drvoprerađivačkim poduzećima

In this research, only wood processing companies that claimed to use IIS solutions were considered. The IIS application was categorized as either for business processes or for production processes or for both of them. As shown in Table 1, most companies declared the use of IIS solutions predominantly for business and production processes (70.0 %). More than half of the surveyed companies (62.8 %) have been using IIS solutions from 1 to 3 years, while only 9.3 % implemented them more than 5 years ago. It is interesting to note that, despite IIS platforms like MAPICS and QAD having evolved directly from MRP II packages, the majority of the surveyed companies opted for IIS systems tailored to their specific needs, with 72.0 % of

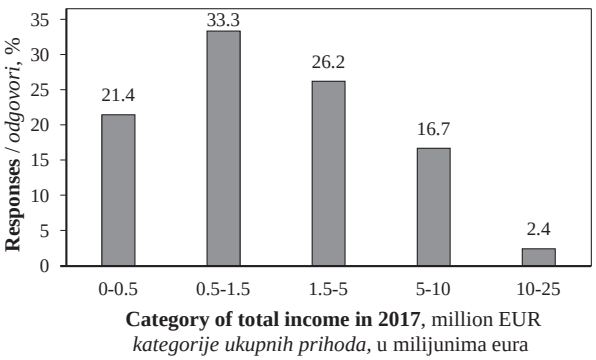

Figure 1 Total income in 2017
Slika 1. Ukupni prihodi u 2017.

Table 1 Industry and IIS
Tablica 1. Industrija i IIS

Characteristics / *Obilježja*	**Description** / *Opis*	%
Classification of IIS use / *klasifikacija primjene IIS-a*	Business processes / *poslovni procesi*	14.0
	Production processes /*proizvodni procesi*	16.0
	Business and production processes / *poslovni i proizvodni procesi*	70.0
IIS vedors / *ponuditelji IIS-a*	Oracle	9.0
	QAD	5.0
	PANTHEON™	5.0
	Microsoft Dynamics NAV	5.0
	MAPICS	2.0
	SAP	2.0
	Custom IIS solutions / *rješenja IIS-a prilagođena naručitelju*	72.0

them declaring to use customized integrated information systems. Major ERP providers like Oracle, QAD, PANTHEON™ and Navision together share only 24.0 % of the IIS market in the analyzed industry.

3.3 IIS application statistics in wood processing industry
3.3. Statistika primjene IIS-a u drvoprerađivačkoj industriji

The main characteristic of ERP systems is their multifunctionality, i.e. they provide modules for managing various business functions ranging from core business management, to resources, human resources and finance management. Our survey results indicate an average use of 64.3 % of the seven groups of modalities queried in the questionnaire (Table 2). The most frequently used module was Finance and Accounting at a rate of 86.0 %, followed by Purchase at 70.0 %. At the other end of the spectrum lie Quality Management and Human Resources modules, with an implementation rate of only 43.0 % and 42.9 %. These results agree well with previous studies reported in the literature (Olhager and Selldin, 2003; Mabert *et al.*, 2003).

Cluster analysis, specifically Two-Step Cluster Method, was conducted to gain a better insight into the differences in IIS use among the surveyed companies. Three clearly distinguishable clusters of companies were identified based on relationship patterns among the clustering variables presented in Table 2.

According to the results obtained, the first cluster groups around the mean of 81 % of IIS modules/functionalities used, and can be designated as companies with a high level of IIS implementation (group A). The second cluster (group B) is made of companies with medium level of IIS implementation, which group around the mean of 65 % of used IIS modules. Finally, the cluster grouping around a value of 45 % was designated as low IIS implementation cluster (group C).

The characteristics distinguishing the three clusters from one another were investigated applying Chi-Square statistic. Test showed that there is a statistically significant difference between clusters mean across almost all modules, with the exception of the module Quality Management ($p > 0.05$), which according to the results obtained has the lowest level of implementation (42.9 % of total).

Differences between Clusters A and B are less immediate. Both use different IIS modules in similar proportions. The most relevant difference between Clusters A and B was detected when using the module Human

Table 2 Profile of company's A, B, C levels of implementation of each module (N=43)
Tablica 2. Profil poduzeća s obzirom na razinu implementacije integriranih informacijskih sustava (N = 43)

Module groups *Grupe modula*	**Two Step Cluster** *Klasterska analiza*			
	A N = 10	**B** N = 7	**C** N = 26	**Average** *Srednja vrijednost*
	% of total implementation *postotak potpune implementacije*	% of total implementation *postotak potpune implementacije*	% of total implementation *postotak potpune implementacije*	% of total implementation *postotak potpune implementacije*
Finance & Accounting / *financije i računovodstvo*	100.0	96.4	61.5	86.0
Human Resources / *ljudski resursi*	68.0	29.0	32.0	43.0
Production Management / *upravljenje proizvodnjom*	92.0	65.7	40.8	66.2
Inventory Management / *upravljanje zalihama*	92.0	65.7	42.3	66.7
Purchase / *nabava*	87.7	81.0	41.0	70.0
Quality Management / *upravljanje kvalitetom*	50.0	37.1	41.5	42.9
Sales / *prodaja*	77.5	78.6	50.8	69.0
Average / *srednja vrijednost*	81.5	65.6	45.8	63.4

Table 3 Classification of cluster companies by number of employees
Tablica 3. Klasifikacija klasterskih poduzeća prema broju zaposlenih

	A	**B**	**C**	**Total** *Ukupno*	**Chi-Square Tests**		
	N = 10	*N* = 7	*N* = 26	*N* = 43	χ^2	*df*	*p*
Micro companies / *Mikropoduzeća* (Less than 10 / *Do 10)*	0	2	2	4	9.57	6	0.14
Small companies / *Mala poduzeća* (From 11 to 50 / *od 11 do 50)*	7	3	17	27			
Medium-sized companies / *Srednje velika poduzeća* (From 51 to 251 / *od 51 do 251)*	2	0	6	8			
Large companies / *Velika poduzeća* (More than 251 / *više od 251)*	1	2	1	4			

*p** - significant at the 0.05 level / *statistička značajnost na razini od 0,05*

Table 4 Classification of cluster companies by duration of IIS implementation and core activity
Tablica 4. Klasifikacija klasterskih poduzeća prema godini uvođenja IIS-a i temeljnoj djelatnosti

	A	**B**	**C**	**Total** *Ukupno*	**Chi-Square Tests**		
	N = 10	*N* = 7	*N* = 26	N = 43	χ^2	*df*	*p*
Less than 1 year/ *Manje od jedne godine*	1	4	2	7	11.08	4	0.02*
From 1 to 3 years / *Od 1 do 3 godine*	0	0	0	0			
3 years to 5 years / *Od 3 do 5 godina*	3	0	8	11			
More than 5 years / *Više od 5 godina*	6	3	16	22			
C16 – Wood processing / *Prerada drva*	7	3	14	24	1.33	2	0.51
C31 – Furniture manufacturing / *Proizvodnja namještaja*	3	4	12	19			

*p** - significant at the 0.05 level / *statistička značajnost na razini od 0,05*

Resources ($p = 0.00$). Relating these findings to the demographics (Table 3 and 4) of clusters, it can be noticed that Cluster B predominantly consists of micro and small-sized companies, which have coincidentally declared to have implemented IIS solutions within less than one year (57.1 %). This is in strong contrast to Clusters A and C, where IIS systems have been mostly used for longer than 5 years (60.0 % and 61.5 %, respectively) and where the dominant population consists of micro and small-size companies (70.0 % and 73.1 %, respectively). There are statistically significant differences in the duration of use and level of implementation of all IIS modules in favor of Cluster A ($p < 0.00$). The most indicative, albeit not statistically significant (shown in Table 4, $p > 0.05$), marker distinguishing Clusters A and C is the strong prevalence of wood processing companies (70 % in sector C16) in Cluster A.

3.4 Criteria for selecting Integrated Information System
3.4. Kriteriji pri odabiru integriranoga informacijskog sustava

As mentioned in the Introduction, ERP implementation is expensive and challenging for all businesses, and even more so for small businesses with specific production demands, as is the case of the wood processing sector. To fully exploit the potential of ERP, each organization should choose the right solution or module already in pre-implementation phase because the costs of changing it once deployed become prohibitive. In the survey, we assessed the main criteria for deciding on a particular IIS solution from the company perspective.

To this end, a formative five-point Likert scale was used to measure the perceived value of particular IIS feature, where the responses 4 and 5 were considered positive, 1 and 2 were considered negative and 3 was taken as neutral. Table 5 summarizes the responses related to IIS criteria selection. On top of the scale were *Customizability* and *Upgradeability* (86.0 % and 79.1 %, respectively). This could be in part due to the limited budgets available to small- and mid-size companies operating within the restrictions of a midsize local market. Similar results were obtained in other studies investigating manufacturing companies (Marebet *et al.*, 2003; Van Everdingen *et al.*, 2000).

With a fairly small spread between the most and the least important criterion of just above 20 %, no statistically supported conclusions could be drawn as to the relative importance of different criteria. Interestingly, the least important criterion in the survey was Software price, which deviates from the above interpretation of companies working on limited budgets. However, previous study of Mabert *et al*. (2003) conducted on US manufacturers found that ERP implementation costs were associated with company size and were higher for large companies, due to higher consulting and training costs arising from more complex company organization. As our target population is composed of predominantly small- and mid-size companies, the overall reasonably low implementation costs could explain the relative unimportance of IIS price in the selection process when weighted against the potential benefits of its introduction in the business processes.

Table 5 Summary responses for criteria selection of IIS
Tablica 5. Sažetak odgovora o kriterijima odabira implementacije IIS-a

Criteria selection / *Kriteriji odabira*	**A** *N* = 10	**B** *N* = 7	**C** *N* = 26	**Total** *Ukupno N = 43*	***p***
Customizability / *prilagodljivost*	90.0	100.0	80.8	86.0	0.49
IT infrastructure of company / *IT infrastruktura poduzeća*	70.0	100.0	69.2	74.4	0.21
Software price / *cijena softvera*	50.0	100.0	61.5	65.1	0.07
Maintenance costs / *troškovi održavanja*	70.0	100.0	73.1	76.7	0.06
Employees IT competencies / *informatičke vještine zaposlenika*	80.0	71.4	73.1	74.4	0.80
Implementation costs / *troškovi implementacije*	80.0	85.7	61.5	69.8	0.11
Upgradeability / *nadogradivost*	60.0	85.7	84.6	79.1	0.19

*p** - significant at the 0.05 level / *statistička značajnost na razini od 0,05*

An anomaly noticed when performing two-step cluster analysis on this set of questions further supports this hypothesis. While for Clusters A and C, the Software price was ranked lowest among all selection criteria, in Cluster B, it shared the first place with 100 % of companies declaring its importance. Bearing in mind that Cluster B is composed of what we could designate as "late-adopters" (58.0 % of companies acquired their IIS systems within the last year), the high importance assigned to software price in this cluster could be related to the still fresh memory of the investment needed for the implementation.

3.5 Level of IIS implementation and businesses performance
3.5. Razina implementacije i poslovna učinkovitost

Integrated information systems affect all aspects of a business. Their real benefits can be seen outside the IT domain, in the changes in organizational activities that the IT system has enabled (Su & Yang, 2010). As far as financial performance is concerned, previous studies have reported a positive impact of ERP systems on the financial performance and competitive advantage of the adopting organization (Hendricks *et al.*, 2007; Marbert *et al.*, 2003). In their work, they examined the most common business performance gains: Return on Sales (ROS), Return on Assets (ROA) and Operational Efficiency (OE).

To explore the benefits of IIS implementation on business performance of Croatian wood-processing industry, a One-way ANOVA test was run. However, this test showed no statistically significant differences between the clusters introduced in previous sections, with *p*-values greater than 0.05. In other words, our results discard the financial performance indicators as useful measures of assessing IIS implementation benefits in Croatian wood-processing industry. A similar phenomenon has already been observed by Elragal and Al-Serafi (2011), who explain that the financial findings can be too aggregate to give an accurate picture of the company.

Without financial indicators, in order to provide insight into the impacts of IIS implementation on company business process performance, non-financial performance indicators such as Sales Efficiency (SE), Inventory Efficiency (IE), Process Efficiency (PE), Organizational Efficiency (OE) and Computer&Communication Skills (CCS) were further examined, using a 5-point Likert scale, where the responses 4 and 5 were considered positive, 1 and 2 were considered negative and 3 was taken as neutral. This approach has already been used by Pertoni (2003), who noted that benefits associated with the implementation of IIS could also be measured in terms of enhanced performance and user satisfaction.

Table 6 summarizes cluster-wise IIS performance measures, validated with One-factor ANOVA test. Overall, the survey results show that the companies in all three clusters see the greatest benefit of IIS in the improved Inventory Efficiency (above 80.0 %) and Sales Efficiency (above 78.0 %). The least improvements were reported in Computer & Communication Skills segment. However, the statistical significance of measured indicators is below the threshold ($p > 0.05$). This absence of strong relationship between IIS implementation and business performance was also found by other studies (Hendricks *et al.*, 2007; Mabert *et al.*, 2003), and can be related to the IT productivity paradox phenomenon (Brynjolfsson, 1993) and the complex nature of IIS platforms, which makes it hard to evaluate their effect with only one (financial) measure. Furthermore, it takes time to achieve the expected benefits when adopting new "business intelligence", and in our case, 41 % of surveyed companies reported to have introduced IIS systems within the last 5 years.

As already mentioned, IIS platforms provide a broad range of solutions covering many aspects of business organization. It is crucial to identify the main objective of implementing IIS. The question is less: "Should we implement ERP?" and more: "What should ERP be implemented for?" The IIS implementation strategy should be derived from analyzing key performance indicators and defining key business objectives, in order to cover both present issues and future projections, thus enabling the company to adapt to the ever-changing business environment.

In order to analyze motives regarding the desired process and business improvements in pre-implementation phase to the actual IIS performance in post-implementation phase, a formative scale was built, presented in Table 7. Our hypothesis is that ERP systems would generate larger benefits when implemented with a clear, unified strategy. For this purpose, a list of 10 variables was offered to respondents to evaluate IIS implementation motives. The variables were partly

adapted to the present investigation from several previous sources (Mabert *et al*. 2003; Petroni, 2002; Soja, 2006). Common variables defining mutually independent strategies were identified using Principal Component Analysis (PCA) with Oblimin rotation, following the rule by Brown (2009).

PCA revealed three dimensions (strategies), which explain over 71.0 % of the variance: *Improving Controlling Efficiency* (ICE), *Improving Production Quality* (IPQ) and *Improving Production Efficiency* (IPE). The Kaiser-Meyer-Olkin measure of sampling adequacy was high, suggesting that factor analysis was appropriate for this data set. Bartlett's test of sphericity was large and the associated significance level small ($p < 0.05$). Furthermore, high alpha values (> 0.7) confirm high reliability of detected factors (Brown, 2009).

The difference in strategic orientation of the three clusters is examined in Table 7. It can be seen from mean ratings that no cluster opted for a focused strategic approach, with Cluster A spreading its goals most evenly across all strategies. Companies in Cluster B gave slight preference to ICE strategy, while Cluster C inclined slightly towards IPE strategy.

To explore the link between the identified IIS implementation strategies (Table 8) and perceived performance indicators (Table 6), correlation analysis was done for all three clusters, as shown in Table 9. As a consequence of balanced strategic approach of all three clusters, most statistically significant correlation coefficients were low to moderate ($0.3 < r < 0.6$), leaving the low-level analysis inconclusive. However, observing the link on the macroscopic level with an overall IIS implementation satisfaction grade, calculated as the mean value of ratings given to all five performance indicators defined previously, it can be seen that companies in Cluster B are the most satisfied with IIS implementation outcome (average grade 3.87, compared to 3.58 in Cluster A and 3.48 in Cluster C). This is likely due to their strategic approach addressing their needs best (highest priority given to ICE strategy, which covers sales and inventory efficiency, as well as process efficiency to some extent, which in turn were identified as the most important aspects of IIS within Cluster B (see Table 8). Supporting this hypothesis, the most consistent statistical significance with moderately high positive correlation coefficients was noticed in Cluster B between the corresponding variables (SE, IE, PE) and preferred strategy (ICE).

4 CONCLUSION
4. ZAKLJUČAK

The main purpose of integrated information systems (IIS systems) is to integrate all administrative and manufacturing processes within a company, thus providing timely information to all end-users and increasing efficiency on all levels. Numerous studies (Loch

Table 7 Motives for IIS implementation
Tablica 7. Razlozi implementacije IIS-a

Variables / *Varijable*	**Reliability Statistics** *Inicijalna dimenzionalnost mjerne skale*		**Principal Component Analysis** *Analiza glavnih komponenata*			
	M	Cronbach α *Cronbachov α*	ICE	IPQ	IPE	Cronbach α *Cronbachov α*
Employee management / *koordinacija zaposlenika*	3.72	0.854	**0.925**			0.843
Work procedure standardization / *standardizacija radnih postupaka*	4.00		**0.873**			
Inventory control / *kontrola zaliha*	3.91		**0.729**			
"Real-time" support for customers / *pravodobna potpora kupcima*	3.88		**0.672**		0.293	
Improving product quality / *poboljšanje kvalitete proizvoda*	3.98			**0.902**		0.866
Quality control / *kontrola kvalitete*	3.93		**0.142**	**0.864**		
New production processes / *novi proizvodni procesi*	3.79		**0.420**	**0.566**	0.168	
Delivery management / *kontrola rokova isporuke*	4.30		**0.244**	-0.297	**0.828**	0.821
Reducing manufacturing lead time / *skraćivanje vremena proizvodnog procesa*	3.84		**-0.126**	0.394	**0.673**	
Cost management / *kontrola troškova*	3.84			0.366	**0.553**	

*Bold values indicate significant factors; Extraction method: PCA; Rotation method; Oblimin with Kaiser Normalization / *Zadebljane vrijednosti označavaju značajne čestice; metoda ekstrakcije: PCA; metoda rotacije; oblimin s Kaiser normalizacijom; M-Mean / aritmetička sredina*

Table 8 Strategic priorities of IIS implementation according to Cluster A, B and C
Tablica 8. Strateški prioriteti implementacije IIS-a u klasterima A, B i C

Strategic orientation / *Strateška usmjerenost*	**A**	**B**	**C**
	M	**M**	**M**
Improving controlling efficiency / *poboljšanje kontrolinga*	4.00	4.25	3.73
Improving production quality / *poboljšanje kvalitete proizvodnje*	4.10	3.90	3.82
Improving production efficiency / *poboljšanje proizvodne učinkovitosti*	4.00	3.95	4.15

*M-Mean / *aritmetička sredina*

Table 9 Correlation matrix for Clusters A, B and C
Tablica 9. Matrica korelacija za klastere A, B i C

Cluster mark *Oznaka klastera*			ICE	IPQ	IPE	**SE**	**IE**	**PI**	**OE**	**CCS**
			r	***r***	***r***	***r***	***r***	***r***	***r***	***r***
A	**ICE**	*r*	1	0.496	0.236	0.426*	0.547*	0.306	0.404*	-0.074
	IPQ	*r*		1	0.395	0.267	-0.096	-0.206	0.508*	0.386
	IPE	*r*			1	-0.238	0.086	-0.250	0.429*	0.180
	SE	*r*				1	0.486*	0.656*	0.173	-0.106
	IE	*r*					1	0.858**	0.415	0.196
	PI	*r*						1	0.149	0.149
	OE	*r*							1	0.507
	CCS	*r*								1
B	**ICE**	*r*	1	0.802*	0.733	0.626*	0.460*	0.574*	0.264	0.130
	IPQ	*r*		1	0.730	0.573*	0.382	0.508*	0.214	0.317
	IPE	*r*			1	0.388	0.215	0.412*	0.711*	0.331
	SE	*r*				1	0.907**	0.874*	0.253	0.568
	IE	*r*					1	0.910**	0.335	0.742
	PI	*r*						1	0.380	0.636
	OE	*r*							1	0.684
	CCS	*r*								1
C	**ICE**	*r*	1	0.400*	0.415*	0.310	0.328	0.137	0.524**	0.273
	IPQ	*r*		1	0.497**	0.061	0.119	-0.039	0.383	0.289
	IPE	*r*			1	0.418*	0.315	0.382	0.506**	0.534**
	SE	*r*				1	0.820**	0.823**	0.519**	0.273
	IE	*r*					1	0.723**	0.492*	0.251
	PI	*r*						1	0.433*	0.380
	OE	*r*							1	0.789**
	CCS	*r*								1

ICE - improving controlling efficiency */ poboljšanje kontrolinga; IPQ* - improving production quality / *poboljšanje kvalitete proizvodnje: IPE* - improving production efficiency / *poboljšanje proizvodne učinkovitosti;* SE - sales efficiency / *prodajna učinkovitost*; IE - inventory efficiency / *u*činkovitost upravljanja zalihama; PI - process efficiency / *procesna učinkovitost*; OE - organizational efficiency / *organizacijska učinkovitost*; CCS - computer and communication skills / *kompjutorske i komunikacijske vještine; r* - Pearson correlation coefficient / *Pearsonov koeficjent korelacije*
*Correlation is significant at the 0.05 level / *korelacija je značajna na razini 0,05*
**Correlation is significant at the 0.01 level / *korelacija je značajna na razini 0,01*

and Koh, 2004; Mabert *et al.*, 2003; Maditinos *et al.*, 2011; Zach *et al*., 2014) have shown the growing trend in the application of IIS systems in companies – small and large alike – as a lever for increasing business efficiency, productivity and market competitiveness in order to combat growing competition and global market demands. The aim of the present research was to determine to what extent the informatization of business operations has been implemented in Croatian wood processing companies, and whether or not it has resulted in better business performance.

IIS implementation level and demographic profile of respondents were assessed via a questionnaire distributed among Croatian wood processing companies. In the collected population sample, the greatest share was occupied by small- and medium-sized companies. The majority of respondents apply IIS in their businesses, but to a different extent. Most of the implemented IIS systems are tailored to address the particular needs of a company, while the highest level of IIS implementation has been achieved in the administrative aspects of business (finances, accounting, and procurement).

Using cluster analysis, three types of companies with respect to the degree of system implementation have been identified: high degree (cluster A), medium degree (cluster B) and moderate degree (cluster C) of IIS implementation. Clusters A and C consist mostly of small- and medium-sized wood processing companies (sector C16), which have mostly been using IIS for more than 5 years. Conversely, Cluster B hosts mainly micro and small-sized furniture manufacturing companies (sector C31), which declare using IIS less than one year. Given the limited size of the examined population sample, the differences between Clusters A and B were statistically insignificant, while differences between Clusters A and C were statistically significant in most of the analyzed points. All three clusters have indicated customizability, upgradeability and maintenance costs as the most important factors in selecting IIS, which is not surprising given the average company size in the surveyed sample (the majority were small- and medium-sized companies), whose financial possibilities are modest compared to big companies.

Many studies (Elragal and Al-Serafi, 2011; Hendricks, *et al.*, 2007; Marbert *et al.*, 2003; Venkatraman and Fahd, 2016) indicate the positive effects of IIS implementation on business operations. In this research, IIS implementation level was tested with respect to 7 functional modules that are the building blocks of modern universal ERP solutions, while the success of implementation was measured via financial indicators

and subjective ratings. The analysis of the entire population showed no statistically significant correlation between IIS implementation level and company's profitability indicators. In terms of subjective ratings, measured via Likert's scale on five qualitative indicators (sales efficiency, inventory efficiency, process efficiency, organizational efficiency and computer & communication skills), by implementing IIS, the biggest improvements were observed by surveyed companies in inventory and sales efficiency.

The motives for introducing IIS into business operations were divided in ten elementary reasons in this research. By using the Principal Components Analysis (PCA), the investigated companies could be grouped into three basic implementation strategies, based on their stated priorities: improving control efficiency, improving production quality and improving production efficiency. Correlating the identified clusters with individuated strategies, however, it was shown that no cluster had opted for a focused IIS implementation strategy. Instead, they globally decided on a combined strategic approach, with a slight prevalence of ICE strategy in Cluster B and a slight prevalence of IPE strategy in Cluster C. Due to small differences and limited sample size, no statistically significant results were obtained in this part of our investigation. Still, comparing the mean observed values, one can detect the highest level of satisfaction by the introduction of IIS systems into their business operations among Cluster B. This can be explained by the fact that the preferred basic strategy ICE of Cluster B prioritizes the business operation aspects that have been underlined by all surveyed companies as the most important ones. Bearing that in mind, the ICE strategy could be recommended to other companies aiming to introduce IIS systems.

The uneven distribution of companies among categories, mediocre response rate, as well as some common traits of Croatian wood processing companies, e.g. below-average application of business and manufacturing innovations compared to the industry average, were the constraints due to which this research was not able to fully correlate the use of integrated information systems to the measurable benefits, or confidently identify optimal IIS implementation strategies. However, considering this investigation as a first step in a comprehensive analysis of this topic, we hope that subsequent investigations, focusing more on medium- and large-scale companies with higher business and credit ratings, will explain these relations.

5 REFERENCES
5. LITERATURA

1. Basarac Sertić, M.; Pirc Barčić, A.; Klarić, K., 2018: Economic Determinants and Analysis of the European Union Wood Industry SMEs Employment. BioResources, 13 (1): 522-534.
2. Braglia, M.; Petroni, A., 1999: Shortcomings and Benefits Associated with the Implementation. Logistics Information Management, 12 (6): 428-430.
3. Brown, D. J., 2009: Statistics Corner. Questions and answers about language testing statistics: Choosing the Right Type of Rotation in PCA and EFA. Shiken: JALT Testing & Evaluation SIG Newsletter, 13 (3): 20-25.
4. Bingi, P.; Sharma, M. K.; Godla, J. K., 1999: Critical Issues Affecting an ERP Implementation. Information Systems Management, 16 (13): 7-140. https://doi.org/100.1201/1078/431970.16.30.19990601/313100.20.
5. Brynjolfsson, E., 1993: The productivity paradox of information technology. Communications of the ACM, 36 (12): 66-77. http://dx.doi.org/10.1145/163298.163309.
6. Dillard, J. F.; Yuthas, K., 2006: Enterprise resource planning systems and communicative action. Critical Perspectives on Accounting, 17: 202-220. http://dx.doi.org/10.1016/j.cpa.2005.08.0030.
7. Dillman, D. A., 2000: Mail and Internet Surveys: The Tailored Design Method, second edition. John Wiley & Sons, Inc, New York.
8. Grladinović, T.; Benić, D.; Jelačić, D.; Motik, D., 2003: A Dynamic System of Material Flows in Wood Industry Companies. Strojarstvo, 1-3: 65-73.
9. Grladinović, T.; Oblak, L.; Hitka, M., 2007: Production management information system in wood processing and furniture manufacture. Drvna industrija, 58 (3): 141-146.
10. Hendricks, K. B.; Singhal, V. R.; Stratman, J. K., 2007: The impact of enterprise systems on corporate performance: A study of ERP, SCM, and CRM system implementations. Journal of Operations Management, 25: 65-82. http://dx.doi.org/10.1016/j.jom.2006.02.002.
11. Hitka, M.; Lorincova, S.; Bartakova, G. P.; Lizbetinova, L.; Starchon, P.; Li, C.; Zaborova, E.; Markova, T.; Schmidtova, J., 2018: Strategic tool of human resource management for operation of SMEs in the wood-processing industry. BioResources, 13 (2): 2759-2774. http://dx.doi.org/10.15376/biores.13.2.2759-2774.
12. Kalem, M.; Lečić-Cvetković, D.; Glavonjić, B., 2018: Application of The Bar-Code Technology in a System of Production Management: Caste Study of Serbian Producer of Wood Based Panel Furniture. Increasing the Use of Wood in the Global Bio-Economy University of Belgrade, Faculty of Forestry, WoodEMA, Belgrade, 267-275.
13. Klarić, K.; Greger, K.; Klarić, M.; Andrić, T.; Hitka, M.; Kropivšek, J., 2016: An Exploratory Assessment of FSC Chain of Custody Certification Benefits in Croatian Wood Industry. Drvna industrija, 67 (3): 241-248. http://dx.doi.org/10.5552/drind.2016.1540.
14. Kropivšek, J.; Jelačić, D.; Grošelj, P., 2011: Motivating Employees of Slovenian and Croatian Wood-industry Companies in Times of Economic Downturn. Drvna industrija, 62 (2): 97-103, http://dx.doi.org/10.5552/drind.2011.1040.
15. Loch, T. C.; Koh, S. C., 2004: Critical elements for a successful enterprise resource planning implementation in small and medium-sized enterprises. International Journal of Production Research, 42 (17): 3433-3455. http://dx.doi.org/10.1080/00207540410001671679.
16. Mabert, V. A.; Soni, A.; Venkataramanan, M. A., 2003: The impact of organization size on enterprise resource planning (ERP) implementations in the US manufacturing sector. Omega, 31: 235-246. http://dx.doi.org/10.1016/S0305-0483(03)00022-7.
17. Maditinos, D.; Chatzoudes, D.; Tsairidis, C. C., 2011: Factors affecting ERP system implementation effectiveness. Journal of Enterprise Information Management, 25 (1): 60-78. http://dx.doi.org/http://dx.doi.org/10.1108/17410391211192161.
18. Majdanđić, N., 2004: Izgradnja informacijskih sustava proizvodnih poduzeća. Strojarski fakultet Slavonski Brod, Slavonski Brod.

19. Nah, F. H.; Lau, L.-S. J., 2001: Critical factors for successful implementation of enterprise systems. Business Process Management Journal, 7 (3): 285-296.
20. Olhager, J.; Selldin, E., 2003: Enterprise resource planning survey of Swedish manufacturing firms. European Journal of Operational Research, 146: 365-373.
21. Plauš, H.; Parobek, J.; Vlosky, V. R.; Motik, D.; Oblak, L.; Jošt, M.; Glavonjić, B.; Dudík, R.; Wanat, L., 2018: The status of chain-of-custody certification in the countries of Central and South Europe. European Journal of Wood and Wood Products, 76 (2): 699-710. http://dx.doi.org/10.1007/s00107-017-1261-0.
22. Perić, I., 2015: Assessment of Factors of Competitiveness in Furniture Manufacturing Companies, PhD thesis. University of Zagreb, Faculty of Forestry, Zagreb.
23. Petroni, A., 2002: Critical factors of MRP implementation in small and medium-sized firms. International Journal of Operation & Production Management, 22 (3): 329-348. http://dx.doi.org/10.1108/01443570210417623.
24. Schneider, C.; Andersson, O., 2016: Examining Levels of Automation in the Wood Processing Industry – A case study, M. Sc. thesis. Jönköping University, School of Engineering, Jönköping.
25. Shatat, A., 2015: Critical Success Factors in Enterprise Resource Planning (ERP) System Implementation: An Exploratory Study in Oman. The Electronic Journal of Information Systems Evaluation, 18 (1): 36-45.
26. Soja, P., 2006: Success factors in ERP systems implementations: lessons from practice. Journal of Enterprise Information Management, 19 (6): 646-661.
27. Su, Y.; Yang, C., 2010: Why are enterprise resource planning systems indispensable to supply chain management? European Journal of Operational Research, 203: 81-94.
28. Sujová, A.; Hlaváčková, P.; Marcineková, K., 2015: Evaluating the Competitiveness of Wood Processing Industry. Drvna industrija, 66 (4): 281-288. http://dx.doi.org/10.5552/drind.2015.1432.
29. Van Everdingen, Y.; Van Hillegerberg, J.; Waarts, E., 2000: ERP adoption by European midsize companies. Communications of the ACM, 43 (4): 27-31.
30. Venkatraman, S.; Fahd, K., 2016: Article Challenges and Success Factors of ERP Systems in Australian SMEs. Systems, 4 (20): 1-18. doi:10.3390/systems4020020
31. Zach, O.; Munkvold, B. E.; Olsen, D. H., 2014: ERP system implementation in SMEs: exploring the influences of the SME context. Enterprise Information Systems, 8 (2): 309-335. http://dx.doi.org/10.1080/17517575.2012.702358.
32. ***Bisonde, 2018: Boniteti Hrvatska. https://www.bisnode.hr (accessed December 20, 2018).
33. ***CBS, 2019: Foreign Trade in Goods of the Republic of Croatia − Provisional Data January – October 2018 and January – November 2018. Croatian Bureau of Statistics, Zagreb. https://www.dzs.hr (accessed January 10, 2019).
34. ***HGK, 2017: Hrvatska gospodarska komora. https://www.hgk.hr (accessed June 2018).
35. ***Market Research Store, 2017: Global ERP Software Market Analysis & Trends – Industry Forecast to 2025. Research and Markets – The World´s largest Research Store. https://www.researchandmarkets.com (accessed December 10, 2018).
36. ***MINGO, 2014: Ministarstvo gospodarstva. https://www.mingo.hr. pdf (accessed December 10, 2017).
37. ***MPS, 2017: Strategija razvoja prerade drva i proizvodnje namještaja Republike Hrvatske 2017. – 2020. s akcijskim planom provedbe 2017. – 2020. Vlada Republike Hrvatske, Ministry of Agriculture, Zagreb. http://www.mps.hr (accessed June 10, 2017).
38. ***NN, 2016: Narodne novine. Državni zavod za statistiku. https://narodne-novine.nn.hr. (accessed March 10, 2017).
39. ***SAS® University Edition. https://www.sas.com (accessed October, 2018).

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Laboratorij za ispitivanje namještaja i dijelova za namještaj

Dobra suradnja s proizvođačima, uvoznicima i distributerima namještaja čini nas prepoznatljivima

akreditirani laboratorij za ispitivanje kvalitete namještaja i dijelova za namještaj prema HRN EN ISO/IEC 17025

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istraživanje drvnih konstrukcija i ergonomije namještaja

ispitivanje zapaljivosti i ekološčnosti ojastučenog namještaja

sudska stručna vještačenja

Kvaliteta namještaja se ispituje i istražuje, postavljaju se osnove normi za kvalitetu, razvijaju se metode ispitivanja, a znanost i praksa, ruku pod ruku, kroče naprijed osiguravajući dobar i trajan namještaj s prepoznatljivim oznakama kvalitete. Kvalitete koja je temelj korisniku za izbor namještaja kakav želi. Taj pristup donio je Laboratoriju za ispitivanje namještaja pri Šumarskom fakultetu međunarodno priznavanje i nacionalno ovlaštenje te članstvo u domaćim i međunarodnim asocijacijama, kao i suradnju s vodećim europskim institutima i laboratorijima.

Laboratorij je član udruge hrvatskih laboratorija CROLAB čiji je cilj udruživanje hrvatskih ispitnih, mjeriteljskih i analitičkih laboratorija u interesu unaprjeđenja sustava kvalitete laboratorija te lakšeg pridruživanja europskom tržištu korištenjem zajedničkih potencijala, dok je Šumarski fakultet punopravni član udruženja INNOVAWOOD kojemu je cilj doprinijeti poslovnim uspjesima u šumarstvu, drvnoj industriji i industriji namještaja s naglaskom na povećanje konkurentnosti europske industrije.

Istraživanje kreveta i spavanja, istraživanja dječjih krevetića, optimalnih konstrukcija stolova, stolica i korpusnog namještaja, zdravog i udobnog sjedenja u školi, uredu i kod kuće neka su od brojnih istraživanja provedena u Zavodu za namještaj i drvne proizvode, kojima je obogaćena riznica znanja o kvaliteti namještaja.

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Effect of Pine (*Pinus Sylvestris*) Bark Dust on Particleboard Thickness Swelling and Internal Bond

Utjecaj dodatka prašine napravljene od borove kore na debljinsko bubrenje i čvrstoću raslojavanja ploča iverica

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ABSTRACT • *Increasing demand for wood resulted in competition between different branches of wood-based production. High intensity production, like the production of wood-based panels, is forced to look for other lignocellulosic resources. Bark is a possible source for wood-based panel industry, especially for particleboards. Bark chips were crushed into bark dust, which were used for the production of single-layer particleboards. The share of bark dust was 0 %, 0.5 %, 1 %, 5 % and 10 %. The boards were tested on thickness swelling (immersion in water, exposure to humid conditions) and internal bond. The highest internal bond was determined in the particleboard with 1 % bark share. Thickness swelling of boards with added bark was higher compared to boards without bark. The highest swelling was observed in boards with 10 % bark dust (immersion in water) or 5 % (humid conditions). Bark based boards absorbed less water.*

Keywords: *bark dust, particleboard, thickness swelling, water absorption, internal bond*

SAŽETAK • *Sve veća potražnja drva pojačala je konkurenciju među različitim granama proizvodnje na bazi drva. Proizvodnje velikog kapaciteta kao što je proizvodnja ploča na bazi drva prisiljene su tražiti i druge lignocelulozne resurse za svoju proizvodnju. Jedan od mogućih izvora za proizvodnju drvnih ploča, posebno ploča iverica, jest drvna kora. Za potrebe ovog istraživanja sječka proizvedena od kore usitnjena je u drvnu prašinu koja je iskorištena za proizvodnju jednoslojnih iverica. Udio usitnjene kore u pločama bio je 0; 0,5; 1; 5 i 10 %. Ispitano je debljinsko bubrenje proizvedenih ploča (nakon potapanja u vodi, nakon izlaganja vlažnim uvjetima) te čvrstoća raslojavanja. Najveća čvrstoća raslojavanja utvrđena je za ploču ivericu s 1 % udjela kore. Debljinsko bubrenje ploča s dodatkom kore bilo je veće od bubrenja ploča bez dodatka kore. Najveće debljinsko bubrenje zabilježeno je u ploča s 10 % usitnjene kore (nakon potapanja u vodi) ili s 5 % usitnjene kore (nakon izlaganja vlažnim uvjetima). Rezultati istraživanja pokazali su da ploče iverice proizvedene s dodatkom usitnjene kore upijaju manje vode.*

Ključne riječi: *usitnjena kora, iverica, debljinsko bubrenje, upijanje vode, čvrstoća raslojavanja*

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1 INTRODUCTION
1. UVOD

In the last decade(s), the production of wood-based panels has been constantly increasing (FAO, 2016), causing an increasing demand for wood and also resulting in competition between different companies that depended on wood supply (sawmill, construction, wood-based panels, energy production). Due to the increasing demand for wood, not only for wood-based panel production, but also for other purposes (sawmill, energy), wood-based panel industry is forced to look for other lignocellulosic resources. Bark is also a potential resource. Bark is one of the most common residues generated by the forest industry, the sawmilling industry or by the wood-based panel industry. Although bark is used for energy and landscaping, pharmacy, as tannin source, most of the bark is unused (Pizzi, 2008; Miranda *et al*., 2012; Feng *et al*., 2013; Kemppainen *et al*., 2014)

Already in 1970s, several researchers dealt with the usability of bark for particleboards. Aaron (1973, cited in Muszynski and McNatt, 1984) determined that up to 10 % bark does not have a significant effect on particleboard properties. Lehmann and Geimer (1974); Muszynski and McNatt (1984), Nemli and Çolakoğlu (2005) determined a decrease in strength properties with the increased share of the bark. Muszynski and McNatt (1984) also determined the increase in thickness swelling and water absorption. Similar relation towards thickness swelling was determined by Blanchet *et al*. (2000), Ngueho Yemele *et al*. (2008). Regarding the bark and its impact on thickness swelling, Nemli and Çolakoğlu (2005) determined that the increase in bark share resulted in the decrease of thickness swelling. Ružiak *et al*. (2017) determined that the addition of the bark, as filler in plywood production, influences thickness swelling.

The purpose of this investigation is to show the effect of bark dust addition on thickness swelling, water uptake/absorption and internal bond of particleboards.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Pine (*Pinus sylvestris*) bark chips were used for the experiment. Bark chips (Figure 1) were crushed in a laboratory mill (Retsch SM2000) to obtain bark dust (Figure 2). The particles that passed through a sieve size of 0.237 mm were characterized as pine bark dust. The use of bark dust is related to the fact that using small bark particles results in better internal bonding (Ngueho Yemele *et al*., 2008; Marashdeh *et al*., 2011).

Wood particles (Figure 3) were produced from wood chips (softwood 40 % and hardwoods 60 %) using a laboratory chipper (Condux LT 61).

The size related structure of wood particles is presented in Table 1.

Since wet material was crushed, wood particles and bark dust needed to be dried prior to blending.

Figure 1 Pine bark chips
Slika 1. Iverje borovine

Figure 2 Pine bark dust
Slika 2. Drvna prašina napravljena od borovine

Figure 3 Wood particles
Slika 3. Drvne čestice

Table 1 Sieve analysis of wood particles
Tablica 1. Granulometrijski sastav usitnjenog drva

Sieve opening in mm *Otvor sita*, mm	**Share in %** *Udjel*, %
4.000	0.74
2.000	20.98
1.500	17.38
1.270	11.18
1.000	13.63
0.600	21.73
0.237	12.46
0 (bottom)	1.90

Table 2 Composition of laboratory made particleboards
Tablica 2. Sastav laboratorijski proizvedenih ploča iverica

Boards *Ploče*	**Share of wood** *Udjel drva* %	**Share of bark** *Udjel kore* %
A	100	0
B	99.5	0.5
C	99	1
D	95	5
E	90	10

Both constituents were dried for 16 hours at 70 °C to achieve moisture content less than 4 %.

Prior to blending, the appropriate amount of wood particles and bark dust was weighted (Table 2).

To produce single layer particleboards, melamine-urea-formaldehyde resin (Meldur H97) obtained from a local resin producer (Melamin Kočevje, Slovenia) was used.

The resin share was 11 % (dry resin weight/dry particles weight). The blending was done in a laboratory blender. Resin was sprayed through a nozzle. Total blending time was 6 minutes (3 minutes resin spraying and mixing and 3 minutes additional mixing). Afterwards, resinated material was hand formed into particle mat with dimensions 500×500 mm^2. The target thickness was 16 mm, and target density was 0.6 g/cm^3. The temperature of pressing was 200 °C, and the pressure was set to 3 N/mm^2. Total pressing time was 4 minutes.

After 7-day storage period, particleboards were cut into samples. The following properties were determined:

- Thickness and density (EN 323): sample size 50×50 mm^2, 6 samples
- Density profile: sample size 50×50 mm^2, 5 samples: density profile was determined using the density profile measurement device – Dense Lab X
- Moisture content (EN 322): sample size 50×50 mm^2, 4 samples
- Thickness swelling and water uptake after 24-hour immersion (EN 317): sample size 50×50 mm^2, 6 samples
- Thickness swelling and water uptake after exposure to humid environment: sample size 50×50 mm^2, 5 samples: Samples were exposed to humid environment (temperature 20 °C, relative air humidity 85 %) for 28 days
- Internal bond (IB) strength: sample size 50×50 mm^2, 6 samples: samples were glued on 18 mm beech plywood blocks using a hot melt adhesive applied by hot melt gun (EN 319).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The presence of bark dust in boards influenced their thickness compared to control boards (without bark dust) (Table 3).

Significant differences between boards with and without bark dust were observed in moisture content (p<0.05), while regarding density, the difference was statistically significant (p<0.05) only in boards with the highest bark dust share. Similar differences as those determined for board density can be seen more clearly in density profiles (Figure 4).

Density profile shows the negative aspect of using bark dust. The lower part of the board is on the right, while the upper surface layer is on the left. The structure of particles enables the migration of dust particles towards the lower board section. That migration causes board asymmetry due to differences in the board upper and lower density. In boards with bark dust such asymmetry is more pronounced due to a higher share of dust particles.

Although Lehmann and Geimer (1974); Muszynski and McNatt (1984), Nemli and Çolakoğlu (2005) found that strength properties decreased with the increase of bark share, the results of internal bond strength (Figure 5) test show that the addition of bark dust causes both the increase (lower bark share) and decrease of IB (higher bark share).

The internal bond values achieved support the findings of Ngueho Yemele *et al*. (2008), Marashdeh *et al*. (2011), since the highest internal bond strength was determined in the particleboard with 1 % bark dust. Statistically significant differences were determined between particleboards produced by adding 1 %, 5 % and 10 % bark dust. Despite the higher density of the board and the board core layer with 10 % bark dust, the IB strength was lower compared to the control board

Table 3 Thickness, density and moisture content based on board composition (values in brackets represent standard deviation)
Tablica 3. Debljina, gustoća i sadržaj vode za određeni sastav ploče (vrijednosti u zagradama označavaju standardnu devijaciju)

Board *Ploča*	**Composition (wood %/bark %)** *Sastav ploče (udjel drva/udjel kore)*	**Thickness** *Debljina* mm	**Density** *Gustoća* kg/m^3	**Moisture content** *Sadržaj vode* %
A (control)	100/0	15.57 (0.108)	604 (45.211)	9.0 (0.094)
B	99.5/0.5	15.31 (0.074)	649 (48.998)	9.1 (0.082)
C	99/1	15.51 (0.098)	626 (52.448)	9.3 (0.141)
D	95/5	15.43 (0.015)	639 (18.260)	9.3 (0.118)
E	90/10	15,67 (0.119)	683 (38.253)	9.3 (0.073)

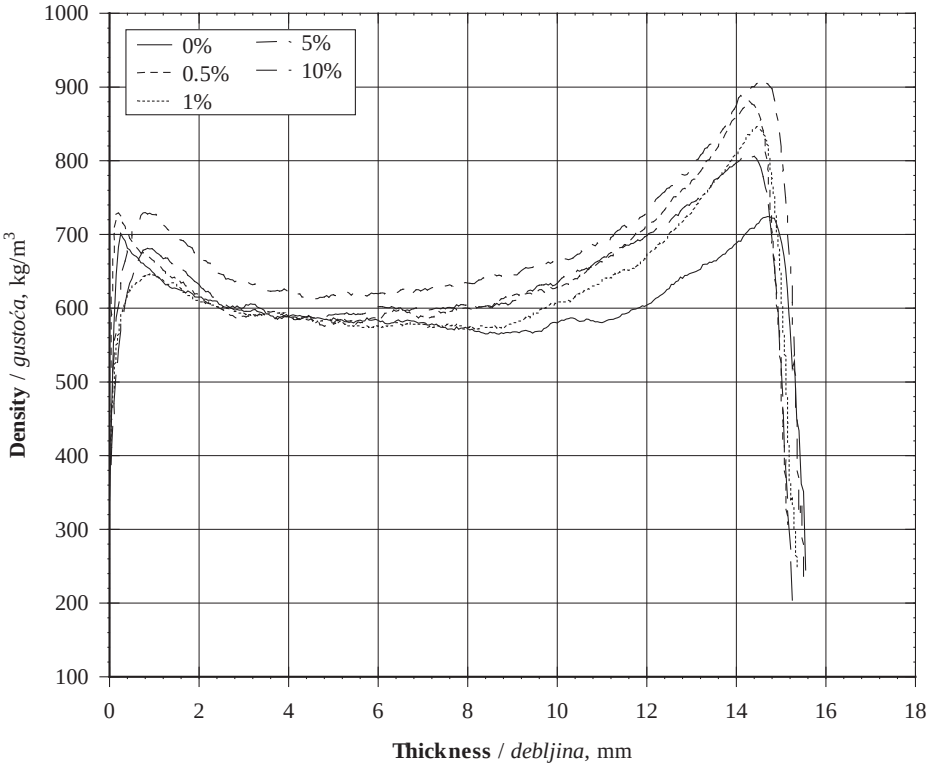

Figure 4 Density profile depending on bark share
Slika 4. Profil gustoće ploča u ovisnosti o udjelu kore

indicating the negative impact of higher bark share. According to Blanchet *et al*. (2000), the reason for lower internal bond strength of bark-based particleboards is related to lower bonding ability of blended bark particles compared to wooden particles, and to decreased heat transfer rate in boards with higher bark share (indicating thermal insulation properties of the bark).

The effect of bark dust on thickness swelling of particleboard is shown in Figure 6 and Figure 7.

The analysis of the results after immersion in water (α=0.05) showed significant difference between the con-

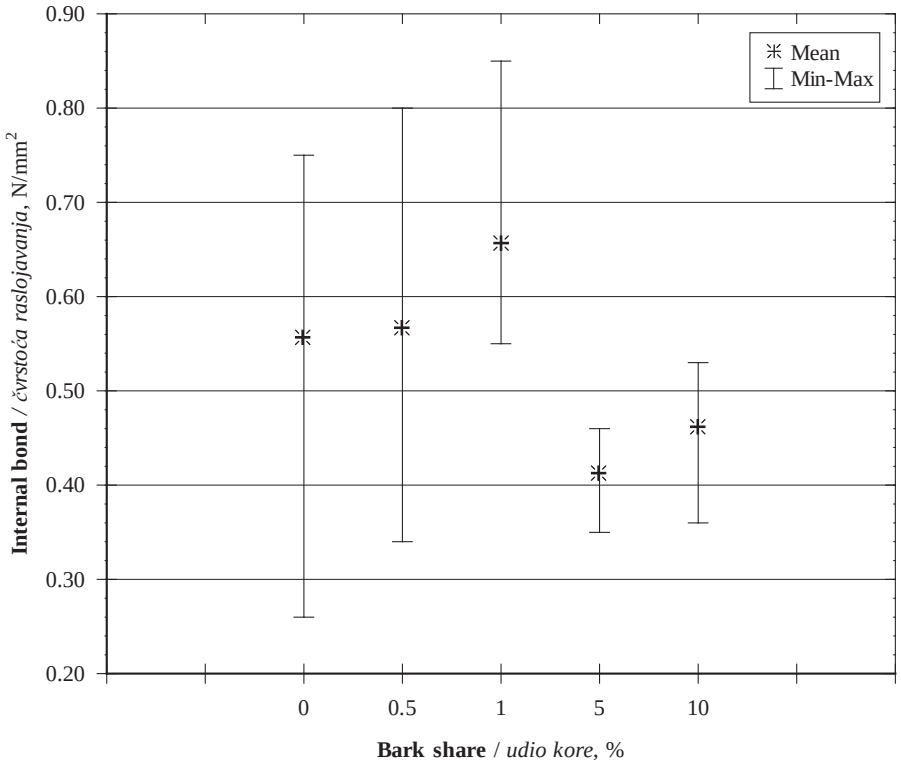

Figure 5 Internal bond strength depending on bark share
Slika 5. Čvrstoća raslojavanja ploča u ovisnosti o udjelu kore

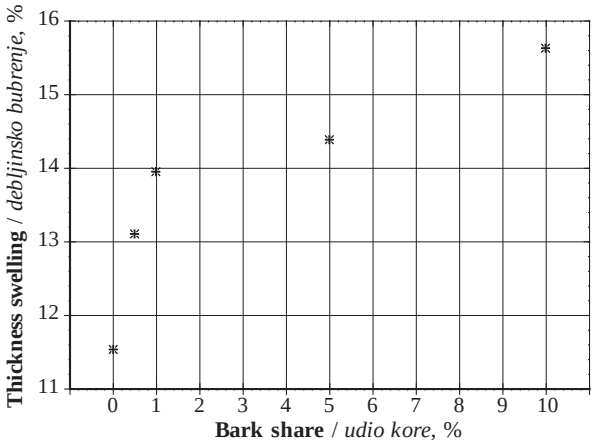

Figure 6 Thickness swelling after 24-hour immersion in water depending on bark share
Slika 6. Debljinsko bubrenje ploča nakon 24-satnog potapanja u vodi u ovisnosti o udjelu kore

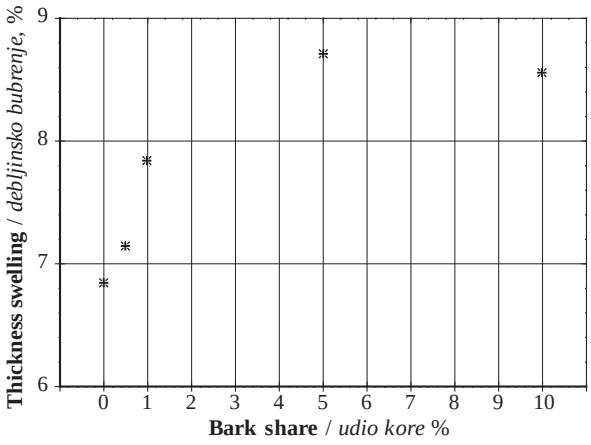

Figure 7 Thickness swelling after exposure to humid environment depending on bark share
Slika 7. Debljinsko bubrenje ploča nakon izlaganja vlažnim uvjetima u ovisnosti o udjelu kore

trol board (0 % dust) and the board with bark dust added. When comparing the values of thickness swelling of the boards with bark dust added, there is a significant difference between boards with 10 % bark and others, while there is little or no significant difference between boards with 0.5 %, 1 % and 5 % bark addition (p value > 0.05).

The increase in bark share resulted in the increase in thickness swelling after 24-hour immersion in water, although the increase is not linear. The initial difference (at 0.5 % bark share) was almost 15 %, while at bark share of 10 %, the difference in thickness swelling was 35 %.

At exposure to humid environment, the significant difference occurred between control boards and the board with 0.5 % bark compared to boards with 1 %, 5 % and 10 %. No significant difference was observed when comparing the thickness swelling of boards with 5 % and 10 % bark share (p value > 0.05). Lower thickness swelling of the board with 10 % bark share (compared to boards with 5 % bark share) could be related to higher density observed in boards with 10 % bark share. Higher board density results in higher resistance against water absorption, and hence slower water absorption and lower thickness swelling. The highest increase rate at exposure to humid environment occurred when the bark share was raised to 1 % (almost 15 %) and 5 % (almost 28 %).

The main reason for the negative effect of bark is due to bark natural swelling potential, which is higher than that of wood (Martin and Crist 1968). The in-

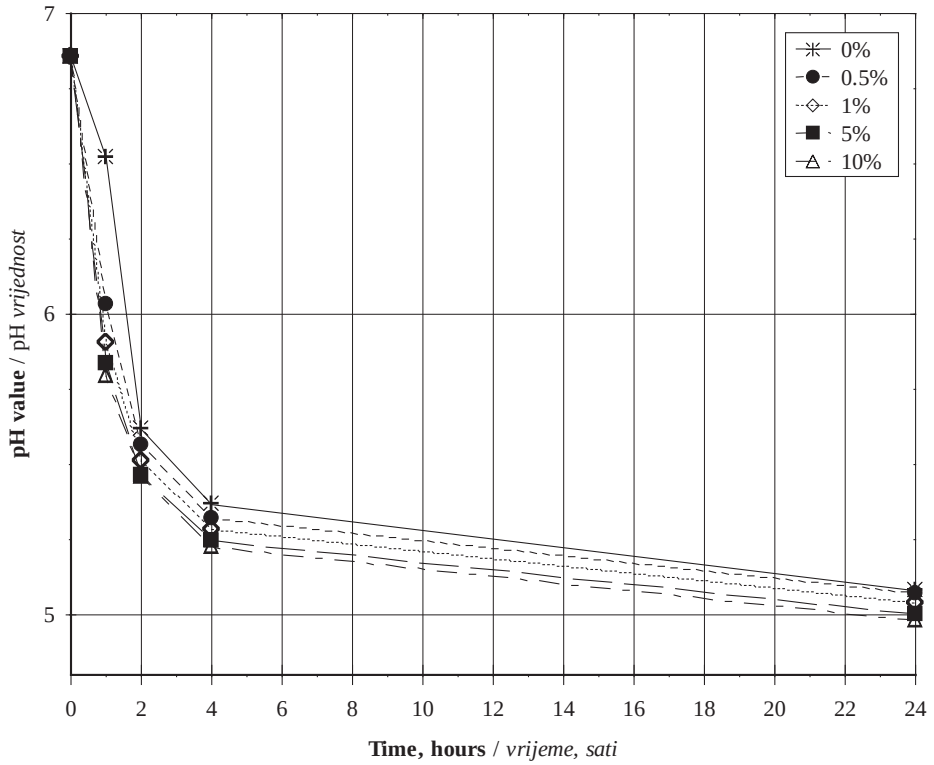

Figure 8 pH value change during immersion in water
Slika 8. Promjena pH vrijednosti tijekom potapanja ploča u vodi

crease in swelling with increasing bark share was also determined by Nemli and Colakoglu (2005). Another reason for swelling is related to stress relaxation (swelling of particles and regaining original position prior to pressing) of wooden and bark-based particles, which also causes the failure of bonds between particles.

A possible reason for higher thickness swelling in boards with higher bark share (at water immersion) could be related to the change of water pH-value that occurs during immersion in water (Figure 8).

The initial pH-value was similar for all board variations (6.86). After 24-hour immersion, the decrease in pH-value depended on the share of bark dust in the board. The highest decrease was observed in boards with the highest share of bark dust (1.87), and the lowest in boards without bark dust and with 0.5 % bark dust (1.78).

The change in water pH-value and increase in thickness swelling indicate that, during exposure to water, the failure of bond line occurs due acid conditions.

The change in the sample mass due immersion in water (water uptake) or exposure to humid environment (water absorption) is presented in Figure 9 and Figure 10.

In both cases, the change in mass was higher in boards without bark (control boards), while the addition of bark resulted in lower water uptake/absorption, although the differences were not significant when the boards were exposed to humid conditions. Lower water uptake after 24-hour immersion was also determined by Dost (1971).

Comparing the results of water uptake/absorption (Figure 9 and Figure 10) and thickness swelling (Figure 6 and Figure 7), it can be seen that bark particles, although absorbing less water than wooden particles, do swell more, which was also reported by Martin and Crist 1968 and Nemli and Colakoglu (2005).

4 CONCLUSIONS
4. ZAKLJUČAK

The availability of bark is relatively high since it is not used for wood-based products. In this study, bark dust was used as material that could partially substitute wood particles in particleboards. Although bark content was below 10 %, the effect of bark use was visible in internal bond and thickness swelling.

At bark content of up to 1 %, an increase (+18 %) in internal bond was determined, while higher bark content resulted in lower internal bond (-26 %).

The increase in bark content resulted in the increase of thickness swelling, while water uptake/absorption was lower (compared to boards without bark).

Acknowledgement – Zahvala

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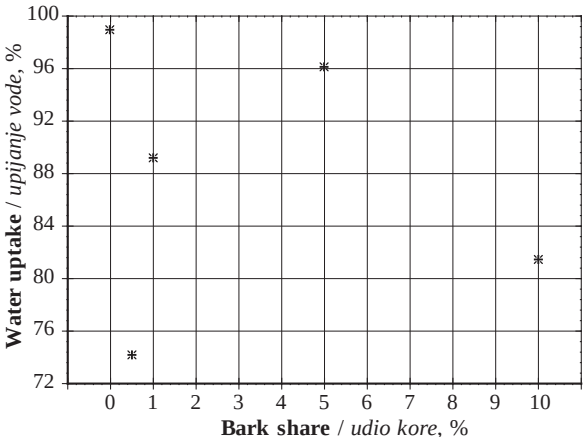

Figure 9 Water uptake after 24-hour immersion in water depending on bark share
Slika 9. Upijanje vode ploča nakon 24-satnog potapanja u vodi u ovisnosti o udjelu kore

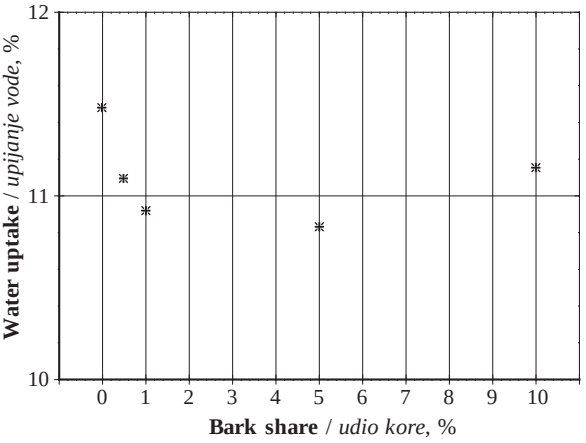

Figure 10 Water absorption after exposure to humid environment regarding the bark share
Slika 10. Upijanje vode ploča nakon izlaganja vlažnim uvjetima u ovisnosti o udjelu kore

5 REFERENCES
5. LITERATURA

1. Blanchet, P.; Cloutier, A.; Riedl, B., 2000: Particleboard made from hammer milled black spruce bark residues. Wood Science and Technology, 34: 11-19. doi.org/10.1007/s002260050003.
2. Dost, W. A., 1971: Redwood bark fiber in particleboard. Forest Products Journal, 21 (10): 38-43.
3. Kemppainena, K.; Siika-Ahoa, M.; Pattathilb, S.; Giovandoc, S.; Kruusaa, K., 2014: Spruce bark as an industrial source of condensed tannins and non-cellulosic sugars. Industrial Crops and Products, 52: 158-168. doi.org/10.1016/j.indcrop.2013.10.009.
4. Lehmann, W. F.; Geimer, R. L., 1974: Properties of structural particleboards from Douglas-fir forest residues. Forest Products Journal, 24 (10): 17-25.
5. Martin, R. E.; Crist, J. B., 1968: Selected physical-mechanical properties of eastern tree barks. Forest Products Journal, 13 (10): 419-426.
6. Muszynski, Z.; McNatt J. D., 1984: Investigation on the use of spruce bark in the manufacture of particleboard in Poland. Forest Products Journal, 34 (1): 28-38.
7. Marashdeh, M. W.; Hashim, R.; Tajuddin, A. A.; Bauk, S.; Sulaiman, O., 2011: Effect of particle size on the characterization of binderless particleboard made from *Rhiz-*

ophora spp. mangrove wood for use as phantom material. BioResources, 6 (4): 4028-4044.
8. Nemli, G.; Çolakoğlu, G., 2005: Effects of Mimosa Bark Usage on Some Properties of Particleboard. Turkish Journal of Agriculture and Forestry, 29: 227-230.
9. Ngueho Yemele, M. C.; Blanchet, P.; Cloutier, A.; Koubaa, A., 2008: Effects of bark content and particle geometry on the physical and mechanical properties of particleboard made from black spruce and trembling aspen bark. Forest Products Journal, 58 (11): 48-56.
10. Shanghuan, F.; Shuna, C.; Zhongshun, Y.; Mathew, L.; Chunbao, X., 2013: Valorization of bark for chemicals and materials: A review. Renewable and Sustainable Energy Reviews, 26: 560-578. doi.org/10.1016/j.rser.2013.06.024.
11. Wang, X. M.; Fang, H.; Feng, M.; Zhang, Y.; Yan, N., 2015: Manufacturing Medium-Density Particleboards from Wood-Bark Mixture and Different Adhesive Systems. Forest Products Journal, 65 (1/2): 20-25. doi.org/10.13073/FPJ-D-14-00038.
12. *** http://www.fao.org/forestry/statistics/80938/en/ (28.05.2018).
13. *** EN 317: 1993. Particleboards and fibreboards – Determination of swelling in thickness after immersion in water.
14. *** EN 319: 1993. Particleboards and fibreboards – Determination of tensile strength perpendicular to the plane of the board.
15. *** EN 322: 1993 Wood-based panels – Determination of moisture content.
16. *** EN 323: 1993 Wood-based panels – Determination of density.

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Thermal Stability of Wood Fibers Produced from Recycled Medium Density Fiberboards

Toplinska stabilnost drvenih vlakana proizvedenih od recikliranih srednje gustih ploča vlaknatica

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ABSTRACT • *In this study, thermal stability of fibers obtained from recycled MDF was investigated and compared with virgin fibers by using thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC). Two different methods, including electrical heating and hydrothermal treatment, were used for recycling the MDF wastes. Electrical heating method was performed at two different times (2 and 4 min) and hydrothermal method was done at three different temperatures (105, 125 and 150 °C). Chemical structure of wood fibers was also studied. TGA and DSC analysis showed higher weight loss of recycled fibers as compared to virgin fibers in a similar degradation region, which means that thermal stability of recycled fibers is lower than virgin fibers. In fact, thermal behavior of recycled fibers was medium between wood and UF resin. DSC analysis showed two exotherms at around 340 and 475 °C. The transition at around 340 °C in fibers thermogram was considered to be due to polysaccharides thermal deterioration and the exotherm at 475 °C was related to lignin carbohydrate complex deterioration. The results of chemical structure analysis showed that lignin and hemicellulose content of recycled fibers was significantly lower than that of virgin fibers, which resulted in decreased thermal stability.*

Keywords: *thermal stability, recycled fibers, MDF, electrical heating, hydrothermal*

SAŽETAK • *U ovom je istraživanju proučavana toplinska stabilnost vlakana dobivenih od recikliranih MDF ploča te je uz pomoć termogravimetrijske analize (TGA) i diferencijalne skenirajuće kalorimetrije (DSC) uspoređena s izvornim vlaknima. Za recikliranje otpadnih MDF ploča primijenjene su dvije različite metode – električno zagrijavanje i hidrotermička obrada. Metoda električnog zagrijavanja provedena je tijekom dva različita vremenska trajanja (2 i 4 min), a hidrotermička metoda provedena je pri tri različite temperature (105, 125 i 150 °C). Proučavana je i kemijska struktura drvnih vlakana. Analize TGA i DSC pokazale su veći gubitak mase recikliranih vlakana u usporedbi s izvornim vlaknima u sličnoj fazi razgradnje, što znači da je toplinska stabilnost recikliranih vlakana niža od toplinske stabilnosti izvornih vlakana. Zapravo, toplinsko ponašanje recikliranih vlakana nalazi*

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se između drva i UF smole. DSC analizom dobivena su dva egzotermna pika na oko 340 i 475 °C. Prijelaz na oko 340 °C u termogramu pripisuje se propadanju polisaharida, a egzotermna reakcija na 475 °C posljedica je propadanja spojeva ugljikohidrata i lignina. Rezultati analize kemijske strukture pokazali su da je sadržaj lignina i hemiceluloze u recikliranim vlaknima znatno manji od njegova sadržaja u izvornim vlaknima, što je rezultiralo smanjenjem toplinske stabilnosti.

Ključne riječi: *toplinska stabilnost, reciklirana vlakna, MDF ploče, električno zagrijavanje, hidrotermička metoda*

1 INTRODUCTION
1. UVOD

Nowadays, wood based panels, especially medium density fiber boards, are considered the main raw materials used in the furniture industry. However, increased production and consumption of MDF boards leads to generation of large volumes of waste and this trend will continue in the future. The generated waste is usually disposed in land filling or burned, which introduces some adverse environmental effects, especially CO_2 and CH_4 emissions (greenhouse gases) (Lykidis and Grigoriou, 2008). These methods have already been forbidden in many European countries due to environmental considerations (Athanassiadou *et al.*, 2005).

In addition, the depletion of wood fiber resources and continuous rising cost of raw materials initiated the search for alternative sources of raw materials, among which wood and panel board wastes such as MDF wastes (Wolff and Siempelcamp, 2000; Michanickle and Boehme, 2003) and recycling started being considered the most environmentally friendly method of managing wood wastes (Lykidis and Grigoriou, 2008). Reuse of fibers contained in MDF wastes can return part of raw material to the production and improve the efficiency of board production and processing plants.

The use of recycled fibers for manufacturing MDF boards requires a comprehensive understanding of their characteristics as compared to virgin fibers. The properties of recycled fibers might be different from virgin fibers, which can effectively impact the quality of manufactured MDF boards. The recycled fibers are exposed to severe conditions in two different processes including board manufacturing and hydrothermal recycling treatment. These fibers undergo gluing and pressing steps when they are used for board manufacturing. The effect of possible residues of resins on the surface of fibers might seriously affect the quality of recycled fibers and this should be investigated. Feng *et al*. (2012) studied the influence of urea formaldehyde resins on pyrolysis characteristics of wood based panels. They found that UF resin used in wood based panels accelerated the degradation of wood based panels at lower temperatures and prevented the degradation at higher temperatures.

Chen *et al*. (2015) investigated the influence of urea formaldehyde resin on pyrolysis characteristics and gas evolution of waste MDF. The results of their study showed that the process of MDF pyrolysis could be divided into three main phases. The degradation rate of MDF was higher than that of wood fibers due to the influence of UF resin.

Additionally, changes in chemical structure of recycled fibers occurred during heating processes, which could influence the thermal stability of fibers (Lykidis and Grigoriou, 2008). One of the most important properties of wood fibers used in MDF manufacturing is thermal stability, which is changed in recycled fibers. Thermal stability of fibers means the resistance against high temperature during hot pressing and influences the chemical structure of fibers, which can seriously affect the physical and mechanical properties of manufactured MDF boards.

In this study, thermal stability of recycled fibers was investigated and compered with that of virgin fibers. The chemical composition of recycled fibers was also measured and compared with virgin fibers.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

For this study, MDF wastes (trimmings) and virgin fibers were collected from Pars Neopan MDF plnt located in Nashtarood, Mazadaran, North of Iran. Then, the MDF wastes were cut to smaller size, and chipped using a laboratory drum chipper.

The recycled MDF chips were defibrated applying two different methods; hydrothermal and electrical heating methods.

In hydrothermal method, the chips were steamed using laboratory autoclave at 105 ˚C for 150 min, under four bar pressure. Then, the steamed heated and softened chips were defibrated using 25 cm single disc refiner to produce fibers. Electrical heating of MDF chips was performed using laboratory scale device designed and manufactured especially for this study (Figure 1). The system consists of an isolating transformer and a heating cell.

The heating cell is a polypropylene rectangular shaped chamber with the dimension: length of 30 cm; width of 6 cm and height of 10 cm. Two removable stainless steel electrodes with thickness of 0.2 cm are installed inside the longer walls of the chamber. For heating the MDF chips by electrical heating, first the chips were crushed and then soaked in warm water for 30 minutes. Then, the mixture of wet chips and electrolyte (saltwater) was poured into the chamber. The device was turned on and electrical current was passed through the mixture starting the heating treatment. The temperature of the mixture during the heating treatment was adjusted at ultimate temperature of 100 °C. Two heating times of 2 and 4 minutes were selected to find the best time for treatment. The fibers were dried at 100±3 °C in an oven to reach the target moisture content (3-4 %).

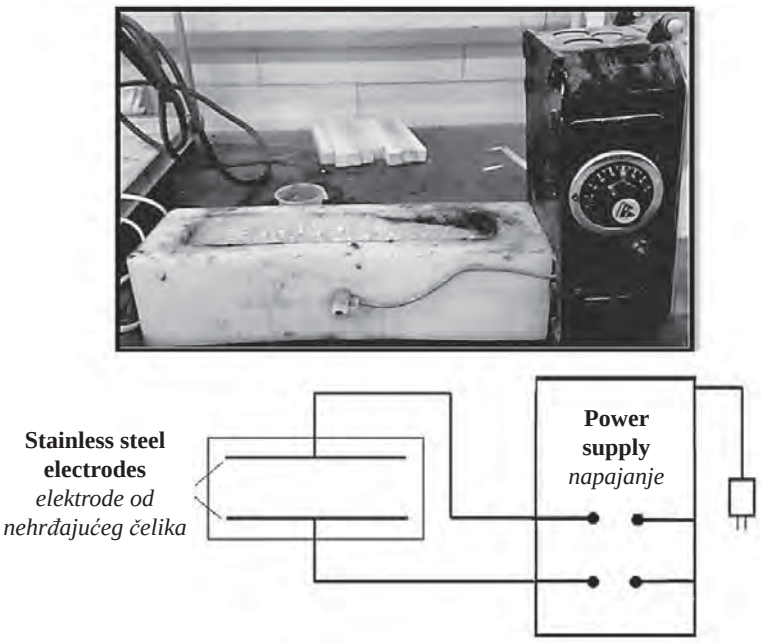

Figure 1 Laboratory electrical heating device for recycling MDF wastes
Slika 1. Laboratorijski električni grijač za recikliranje otpadnih MDF ploča

Chemical analyses

The samples for chemical analysis were taken randomly from dried fibers of each treatment. The chemical analysis was performed in three replications and the mean values for each component was reported. Relevant Tappi test methods used for chemical analysis were as follows: Sample preparation; T267-om 85: Extractives soluble in organic solvent; T207-om 97: Cellulose; T264-om 88: Lignin; T222-om 97: Holocellulose; Useful method 249- um 75.

Thermal stability analysis

Thermal behavior of recycled and virgin fibers was determined using Simultaneous Thermal Analysis (TGA/DSC) in a Mettler Toledo Analyzer, which was fully supported by computer – controlled software options for control and data handling. Ten mg of each sample was placed on a balance located in the furnace and heating was applied over the temperature range from room temperature up to 600 °C. The analysis was run under a dynamic nitrogen atmosphere flow at 20 mL/min and at a scanning rate of 20 °C/min. The derivatives of the weight loss vs. temperature thermograms were obtained to better show the different decomposition processes.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The results of measurement of chemical composition of fibers are shown in Table 1.

As can be seen in Table 1, extractives and hemicelluloses contents of recycled fibers (RF-1, RF-2 and RF-3) were significantly lower than those of virgin fibers. Lignin content was also changed during the recycling process, especially for fibers recycled via hydrothermal method (RF-3). However, cellulose content of fibers was not significantly reduced after the recycling process.

During thermal treatments, hemicelluloses usually undergo the highest degree of degradation as compared to other chemical compositions of wood due to their amorphous structure (MC Kendry, 2002; Rao and Sharma, 1998). Hemicelluloses show lower thermal stability among wood constituents due to the presence of acetyl groups (Hill, 2006). Hence, in mild thermal treatment and acidic conditions, hemicelluloses can easily hydrolyze (Tjeerdsma and Militz, 2005).

Lignin can be degraded in a wide temperature range, which begins at low temperatures (Nassar and Mackay, 1984). However, thermal degradation of cel-

Table 1 Chemical constituents of virgin and recycled fibers (electrical heating 2 min: RF-1; electrical heating 4 min: RF-2; Hydrothermal heating: RF-3)
Tablica 1. Kemijski sastav izvornih i recikliranih vlakana (električno zagrijavanje u trajanju 2 min: RF-1; električno zagrijavanje u trajanju 4 min: RF-2; hidrotermičko zagrijavanje: RF-3)

Fiber type *Vrsta vlakana*	**Lignin** *Lignin* %	**Hemicellulose** *Hemiceluloza* %	**Cellulose** *Celuloza* %	**Extractives** *Ekstraktivi* %
Virgin / *izvorno*	23.4	20.14	46.15	3.8
RF-1	22.45	15.42	46.2	1.57
RF-2	22.3	15.2	45.12	1.4
RF-3	19.5	14.44	46.18	1.22

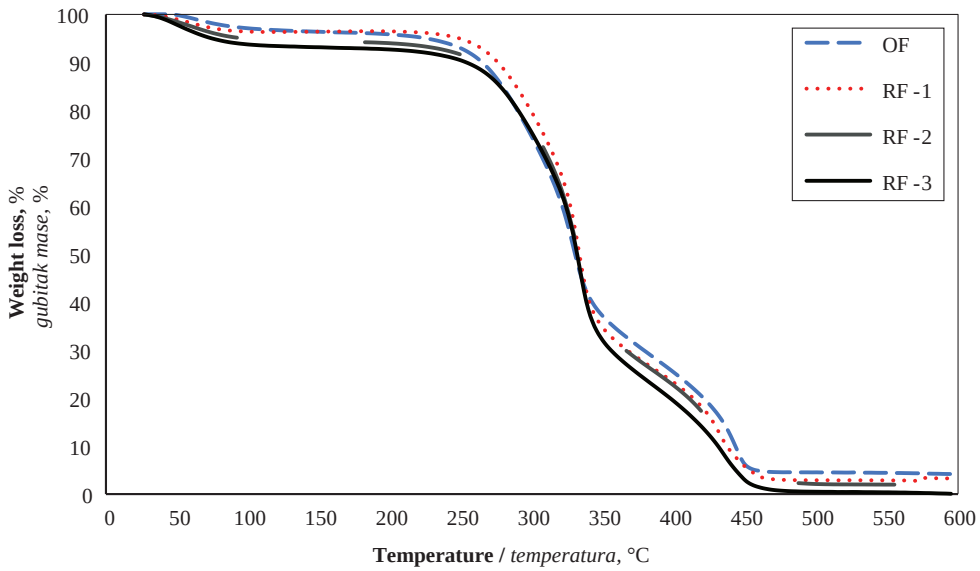

Figure 2 TGA curves of virgin fibers and recycled fibers; ohmic heating 2 min (RF-1), ohmic heating 4 min (RF-2) and hydrothermal heating (RF-3)
Slika 2. TGA krivulje izvornih i recikliranih vlakana: omsko zagrijavanje u trajanju 2 min (RF-1), omsko zagrijavanje u trajanju 4 min (RF-2) i hidrotermičko zagrijavanje (RF-3)

lulose occurred at higher temperatures (above 210 °C) (Bodirlau *et al*. 2009; Yang *et al*., 2007; Wang *et al*., 2007; Lumming *et al*., 2013). It is obvious that the chemical structure of recycled fibers ought to be different from virgin fibers due to several heating treatments. Chemical constituents are considered as main factors affecting the properties of wood fibers and such changes have an obvious influence on the quality of manufactured boards.

Figures 2-3 show TGA thermograms of virgin and recycled fibers, respectively. According to TGA results, three regions can be determined for the approximate starting and ending points of thermogravimetric analysis curve. The thermal degradation mechanism of woods generally includes three regions. The first region (60 to 100 °C) shows evaporation of water and extractives (Feng *et al*., 2012; Bodirlau *et al*., 2009). The second region (130 to 345 °C) is due to decomposition of major wood chemical constituents and the highest weight loss occurs in this step (Feng *et al*., 2012; Aydemir *et al*., 2011). The third region begins around 400 °C in which decomposition of wood occurs. The thermal degradation steps found in our experiment are in agreement with the results reported by Aydemir *et al*., 2011. Summary data of TGA are presented in Table 2.

The results illustrated in Table 2 show that the weight loss of virgin fibers was lower than that of recycled fibers. However, it is necessary to focus on details. The trend of changes in the amount of weight loss from the first phase to the third phase confirmed that in the first phase (60-130 °C), i.e. at lower temperature, the weight loss was 3.63 % in virgin fibers and about 5-6 % in recycled fibers, which showed that at this low temperature, the degradation of recycled fibers is faster in recycled fibers as compared to virgin fibers. In the second phase (130-345 °C), along with rising temperature, the difference between the amount of weight loss in recycled and virgin fibers was decreased and they were nearly equal; (58.35 % weight loss in virgin fibers and about 62 % in recycled fibers). Finally, in the third phase (345-600 °C), i.e. at a higher range of temperature, the weight loss in virgin fibers (33.94 %) was obviously higher than that in recycled fiber (30 % in average), which shows that at higher temperatures the presence of UF resin prevents further degradation of

Table 2 TGA results for virgin and recycled fibers
Tablica 2. TGA rezultati izvornih i recikliranih vlakana

Samples *Uzorci*	T_i-T_f, °C	T_m, °C	W_{T1}, %	W_{max} **(second region)** W_{max} *(drugo područje)*, %	W_{Tf}, %	**Weight loss in the first phase** *Gubitak mase u prvoj fazi*, %	**Weight loss in the second phase** *Gubitak mase u drugoj fazi*, %	**Weight loss in the third phase** *Gubitak mase u trećoj fazi*, %	**Residues** *Ostatci*, %
virgin	130-147	440	3.63	58.35	33.94	3.63	58.35	33.94	4.23
RF-1	130-480	420	3.64	62.87	30.21	3.62	62.87	30.21	3.26
RF-2	130-500	420	5.52	62.63	30.08	5.52	62.63	30.08	1.79
RF-3	135-515	425	6.69	62.86	30.33	6.69	62.86	30.33	0.1

T_i-T_f - temperature corresponding to the beginning and ending of decomposition, respectively / *temperatura na početku i na kraju razgradnje*; T_m - temperature corresponding to the maximum rate of mass loss / *temperatura pri maksimalnom gubitku mase*; *W* - weight loss / *gubitak mase*

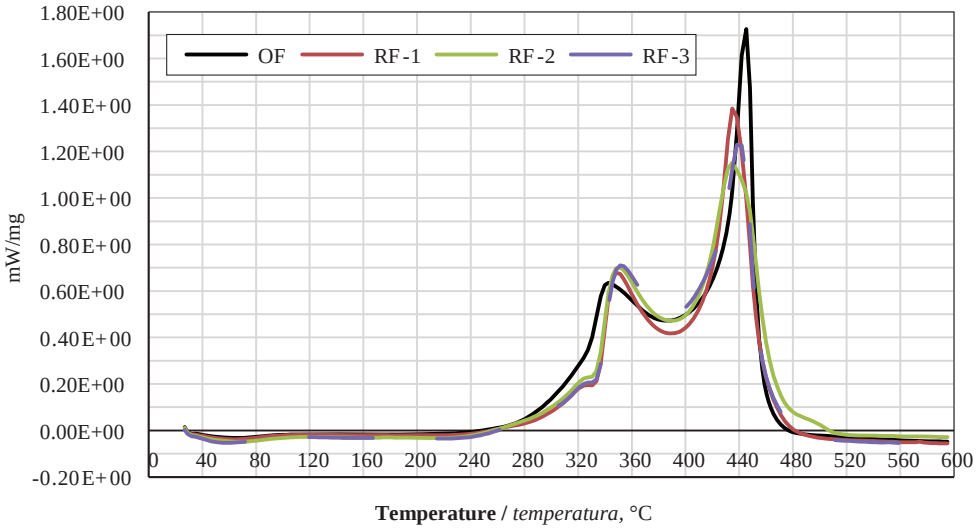

Figure 3 DSC thermograms of virgin fibers (OF), recycled fibers by ohmic heating method for 2 min (RF-1), ohmic heating method for 4 min (RF-2) and hydrothermal method (RF-3)
Slika 3. DSC termogrami izvornih i recikliranih vlakana dobivenih omskim zagrijavanjem u trajanju 2 min (RF-1), omskim zagrijavanjem u trajanju 4 min (RF-2) i hidrotermičkim zagrijavanjem (RF-3)

fibers. The reason for this variable effect of UF resin was referred to its behavior during pyrolysis at different temperatures. These results are in accordance with the findings of Feng *et al*. (2012) and Chen *et al*. (2015). Overall, it was found from the amount of residues that the presence of UF resin totally decreased the thermal stability of fibers, because maximum weight loss occurred in the second phase and it was higher in recycled fibers.

It was also observed that decomposition temperature (T_d) in the second region was lower in virgin fibers as compared to recycled fibers. Similar result was reported by Chen *et al*. (2015). It can be concluded that the rate of degradation of virgin fibers was lower in comparison with recycled fibers.

The final mass residues of virgin fibers (4.23 %) was higher than that of recycled fibers and the lowest mass residues of recycled fibers was observed in fibers under hydrothermal treatment (0.1 %). The residues of RF-1 an RF-2 were 3.26 % and 1.79 %, respectively, which shows higher thermal stability of virgin fibers. Feng *et al*. (2012) and Peng *et al*. (2011) also reported that the pyrolysis of wood material in combination with UF resin is not independent from decomposition of wood and UF resin. They concluded that UF resin accelerates the chemical reactions in wood based panels at a lower temperature and inhibits the degradation at higher temperatures during the pyrolysis process. The presence of UF resin residues on the surface of recycled fibers resulted in a lower amount of residues after decomposition of recycled fibers as compared to virgin fibers, which was reported on wood based panels by Chen *et al*. (2015). The greater weight loss shows the lowest thermal stability (Aydemir *et al*., 2011).

Generally, it can be concluded that the thermal stability of fibers was reduced after the recycling process and thermal behavior of fibers confirmed the existence of UF resin residues on the surface of recycled fibers, which can increase the thermal stability of fibers at the temperature above 400 °C.

Figure 3 shows the results of DSC analysis on recycled and virgin fibers.

In DSC curves of virgin and all recycled fibers, two main peaks can be observed at 330 to 360 °C and 470 to 480 °C, respectively, related to carbohydrate degradation and lignin-carbohydrate complex degradation. (Islam *et al*., 2011, Tsujiyama, 2001; Tsujiyama and Miamouri, 2000).

The change in the peak shape at 320 to 325 °C observed in recycled fibers is related to the existence of UF resin residues, which degraded completely in this temperature range (Raval *et al*., 2005).

In recycled fibers, the second peak, which is related to lignin-carbohydrate complex, appears at the temperature lower than that of virgin fibers (440 °C instead of 470 °C) as a result of lignin decrease and its effect on the peak (Tsujiyama and Miamouri, 2000; Reh *et al*., 1986). According to the results obtained from chemical structure analysis, recycled fibers con-

Table 3 Results of DSC analysis of virgin and recycled fibers
Tablica 3. Rezultati DSC analize izvornih i recikliranih vlakana

Fibers *Vlakna*	**Exotherm peaks,** °C *Egzotermni pikovi,* °C		**Reaction enthalpy Δ*H*,** J/gm *Entalpija reakcije ΔH,* J/gm	
	2st	1st	2st	1st
virgin	444.86	342.53	5957.73	4364.72
RF-1	436.30	349.98	5491.45	3938.86
RF-2	434.58	350.51	5769.30	4139.96
RF-3	439.69	352.81	5197.72	4111.30

tain lower amounts of lignin as compared to virgin fibers due to degradation reactions but no change has been observed in cellulose. The results presented in Table 3 show that the temperature of the first peak is lower in virgin fibers compared to recycled fibers, while the second peak is quite the opposite.

The reaction enthalpy in virgin fibers is higher than that of recycled fibers. The intensity of peaks shows that the level of degradation at the lower intensity corresponds to higher stability (Islam *et al*., 2011). Accordingly, it can be said that stability of recycled fibers is lower than that of virgin fibers, which confirms the results obtained from TGA.

The thermal properties of the lignocellulosic fibers are mainly influenced by their composition; cellulose, hemicelluloses and lignin content (Ornaghi jr. *et al*., 2014; Poletto *et al.*, 2012b). The results of Table 1 revealed that recycled fibers have a lower content of hemicellulose, lignin and extractives in comparison with virgin fibers, which can be the reason for decreased thermal stability of recycled fibers. The degradation of wood due to high temperatures can lead to the loss of wood mechanical strength and also produces MDF with low mechanical properties (Poletto, 2016). Indeed, the chemical structure of fibers and their thermal stability have a mutual effect on each other. Changes in chemical structure lead to decreased thermal stability of fibers and decreased thermal stability results in the change of chemical structure of fibers. This interaction might be the reason for the inferior quality of recycled MDF boards.

4 CONCLUSIONS
4. ZAKLJUČAK

The results showed that the existence of UF resin residues accelerated the thermal degradation of fibers at lower temperatures, while in the final step (complete degradation), the level of degradation of virgin fibers was higher than that of recycled fibers. The thermal behavior of recycled fibers was medium between wood and urea formaldehyde resin. Finally, the amount of residues of recycled fibers was much lower than that of virgin fibers.

The results obtained from DSC confirmed the results of TGA. The changes in the position of the second peak in recycled fibers showed the decrease of lignin content. Generally, it can be concluded that the chemical structure of recycled fibers has been changed due to the primary manufacturing process of MDF boards and recycling process. The structure of recycled fibers is completely different from that of virgin fibers. Gluing, pressing and heating processes, followed by heating and defiberation steps in recycling these fibers from MDF wastes, result in weakened fibers and cause a notable change in the chemical structure of fibers as compared to virgin fibers. Additionally, the existence of UF resin residues on the surface of recycled fibers seriously affects thermal stability. Consequently, the thermal stability of recycled fibers significantly decreased in comparison with virgin fibers and the recycled fibers could not endure high temperatures during hot pressing in MDF board manufacturing due to their damaged chemical structure and deceased thermal stability. It is very important to consider the different properties of recycled fibers when these fibers are used in MDF board manufacturing.

5 REFERENCES
5. LITERATURA

1. Athanassiadou, E.; Roffael, E.; Mantanis G., 2005: Medium Density Fiberboards from RecycledFibers.http://www.academia.edu/3005311/Medium_density_fibreboards_MDF_from_recycled_fibres, 9 pp.
2. Aydemir, D.; Gunduz, G.; Altuntas, E.; Ertas, M.; Turgut, S.; Alma, H., 2011: Investigating changes in the chemical constituents and dimensional stability of heat- treated Hornbeam and Uludag Fir wood. BioResources, 6 (2): 1308-1321. https://doi.org/10.15376/biores.6.2.1308-1321.
3. Boehme, C., 2003: Altholz bleibt wichtig fur Horzwerkst off industrie (English translation: Waste wood is important for the wood-based products industry). Holz-Zetralblatt, 4: 101.
4. Bodirlau, R.; Teaca, C. A.; Spiridon, I., 2009: Preparation and characterization of composites comprising modified hardwood and wood polymers/ poly (vinyl chloride). BioResources, 4 (4): 1285-1304.
5. Chen, S. H.; Li, S.; Mu, J.; Feng, Y., 2015: Influence of urea formaldehyde resin on the pyrolysis characteristics and gas evolution of waste MDF. Wood Research Journal, 60 (1): 113-124. http://doi.org/ 10.15376/biores.13.2.2218-2232.
6. Feng, Y.; Mu, J.; Chen, S. H.; Huang, Z. H.; Yu, Z. H., 2012: The influence of urea formaldehyde resins on pyrolysis characteristics and products of wood based panels. BioResources, 7 (4): 4600-4613. https:// doi.org/ 10.3964/j.issn.1000-0593.
7. Hill, C. A. S., 2006: Wood modification: Chemical, thermal and other processes. John Wiley & Sons, New York. 249 pp.
8. Islam, M. D.; Hamdan, S.; Rahman, R.; Jusoh, I.; Ahmed, A. S., 2011: Dynamic young's modulus, morphological and thermal stability of 5 tropical light hard woods modified by benzene diazonium salt treatment. BioResources, 6 (1): 737-750.
9. Lumming, J.; Sulaiman, O.; Sugimoto, T.; Hashim, R.; Said, N.; Sato, M., 2013: Influence of chemical components of oil palm on properties of binderless particle board. BioResources, 8 (3): 3358-3371. https://doi.org/ 10.15376/biores.8.3.3358-3371.
10. Lykidis, C.; Grigoriou, A. 2008: Hydrothermal recycling of waste and performance of the recycled wooden particleboards. Waste Management, 28: 57-63. https://doi.org/10.1016/j.wasman.2006.11.016.
11. McKendry, P., 2002: Energy production from biomass (part 1): overview of biomass. Bioresource Technology, 83: 37-46. https://doi.org/10.1016/S0960-8524(01)00118-3.
12. Michanickl, A.; Boehme, C., 2003: Method for recovering chips and fibers of bonded wood materials involves passing of steam through a vessel with such materials which have been soaked with a heated impregnation solution. Patent No. DE10144793. WO03026859.
13. Nassar, M. M.; Mackay, G. D., 1984: Mechanism of thermal decomposition of lignin. Wood and Fiber Science, 16: 441-453.

14. Ornaghi, Jr. H. L.; Poletto, M.; Zattera, A. J.; Amico, S. C., 2014: Correlation of the thermal stability and the decomposition kinetics of six different vegetal fibers. Cellulose, 2: 177-188. https://doi.org/ 10.1007/s10570-013-0094-1.
15. Peng, Y. C.; Shi, S. Q.; Ingram, L., 2011: Chemical emissions from adhesive- bonded wood products at elevated temperatures. Wood Science and Technology, 45: 627-644. https://doi.org/ 10.1007/s00226-010-0366-y.
16. Poletto, M., 2016: Thermal degradation and morphological aspects of four wood species used in lumber industry. Revista Árvore, 40 (5): 941-948. https://doi.org/ 10.12953/2177-6830/rcm.v7n2p111-118.
17. Poletto, M.; Zattera, A. J.; Sanatama, R. M. C., 2012: Structural differences between wood species: evidence from chemical composition, FT-IR spectroscopy and thermogravimetric analysis. Journal of Applied Polymer Science, 126: 336-343. https://doi.org/ 10.1002/app.36991.
18. Rao, T. R.; Sharma, A., 1998: Pyrolysis rates of biomass materials. Energy, 23 (11): 973-978. https://doi.org/ 10.1080/15567030801952268.
19. Raval, D. K.; Narola, B. N.; Patel, A. J., 2005: Synthesis, characterization and composites from resorcinol – urea-formaldehyde-casein resin. Iranian Polymer Journal, 14 (9): 775-784.
20. Reh, U.; Kraeplin, G.; Lamprecht, I., 1986: Use of Differential scanning calorimetry for structural analysis of fugally degraded wood. Applied Environmental Microbiology, 52 (5): 1101-1106. https://doi.org/10.1007/978-1-4684-3333-3_2.
21. Tsujiyama, S.; Miyamori, A., 2000: Assignment of DSC thermograms of wood and its components, Thermochimica Acta, 351: 177-181. https://doi.org/10.1016/S0040-6031(00)00429-9.
22. Tsujiyama, S., 2001: Differential scanning calorimetric analysis of the lignin-carbohydrate complex degraded by wood-rotting fungi. Journal of Wood Science, 47: 497-501. https://doi.org/10.1007/BF00767905.
23. Wang, S.; Liu, Q.; Luo, Z.; Wen, L.; Cen, K., 2007: Mechanism study on cellulose pyrolysis using thermogravimetric analysis coupled with infrared spectroscopy. Front Energy Power Eng. China, 1 (4): 413-419. https://doi.org/10.1007/s11708-007-0060-8.
24. Wolff, S.; Siemplekamp, G., 2000: Post-consumer wood waste as raw material for particleboard and MDF. In: Proceedings of 5th Pacific Bio-Based Composites Symposium. Evans, P. D. (ed.). Canberra, Australia, pp. 572-579.
25. Yang, H.; Yan, R.; Chen, H.; Lee, H. D.; Zheng, C., 2007: Characteristics of hemicelluloses, cellulose and lignin pyrolysis. Fuel Processing Technology, 90: 939-946. https://doi.org/10.1016/j.fuel.2006.12.013.

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Nencho Deliiski, Natalia Tumbarkova[1]

Modeling Latent Heat Fluxes of Water in Logs during their Freezing

Modeliranje latentnih toplinskih tokova vode u trupcima tijekom zamrzavanja

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ABSTRACT • *This paper suggests a methodology for mathematical modeling and research of two interconnected problems: 2D non-stationary temperature distribution in logs subjected to freezing and change in the latent heat fluxes of the free and bound water in logs during the freezing process. For the purpose of this methodology, a 2-dimensional mathematical model has been created, solved, and verified for the transient non-linear heat conduction in logs during their freezing at convective boundary conditions. The model includes a mathematical description of the specific latent heat fluxes, $q_{LHv\text{-}fw}$ and $q_{LHv\text{-}bw}$, formed by the freezing of the free and bound water in the logs, respectively. The paper presents solutions of the model with explicit form of the finite-difference method in the calculation environment of Visual Fortran Professional and its verification in accordance with our own experimental studies. The paper presents the results of simulation analysis of 2D non-stationary temperature distribution in the longitudinal section of pine log with a diameter of 0.24 m, length of 0.48 m, and moisture content above the hygroscopic range during its 30-hour freezing in a freezer at the temperature of the processing air medium of approximately –30 °C. The change in the latent heat fluxes $q_{LHv\text{-}fw}$ and $q_{LHv\text{-}bw}$ during the log freezing is presented, visualized, and analyzed.*

Keywords: *2D mathematical model, pine logs, freezing, latent heat sources, free water, bound water*

SAŽETAK • *Predložena je metodologija za matematičko modeliranje i istraživanje dvaju međusobno povezanih problema: dvodimenzionalne nestacionarne raspodjele temperature u smrznutim trupcima i promjene u protoku latentne topline slobodne i vezane vode u trupcima tijekom zamrzavanja. Za realizaciju metodologije izrađen je i provjeren dvodimenzionalni matematički model za nelinearno provođenje topline u trupcima tijekom zamrzavanja pri konvekcijskim rubnim uvjetima. Model obuhvaća matematički opis specifičnih latentnih tokova topline $q_{LHv\text{-}fw}$ i $q_{LHv\text{-}bw}$, koji nastaju zamrzavanjem slobodne i vezane vode u trupcima. U radu su prikazana rješenja modela s eksplicitnim oblikom metode konačnih razlika u računalnom sučelju Visual Fortran Professional i njegova provjera prema vlastitim eksperimentalnim istraživanjima autora. Predstavljeni su rezultati simulacijskog istraživanja dvodimenzionalne nestacionarne raspodjele temperature u uzdužnom presjeku borovih trupaca promjera 0,24 m, dužine 0,48 m i sadržaja vode iznad higroskopskog raspona tijekom 30 sati smrzavanja u zamrzivaču, pri temperaturi zraka oko –30 °C. Također su prezentirane i analizirane promjene protoka latentne topline $q_{LHv\text{-}fw}$ i $q_{LHv\text{-}bw}$ tijekom zamrzavanja trupaca.*

Ključne riječi: *dvodimenzionalni matematički model, borovi trupci, zamrzavanje, latentni izvori topline, slobodna voda, vezana voda*

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1 INTRODUCTION
1. UVOD

It is known that the duration and energy consumption of the thermal treatment of frozen logs in the winter, aimed at their plasticizing for the production of veneer, depend on the degree of the logs' icing (Chudinov, 1966, 1968, 1984; Kollmann and Côté, 1984; Shubin, 1990; Požgaj *et al*., 1997; Trebula and Klement, 2002; Videlov, 2003; Pervan, 2009; Deliiski and Dzurenda, 2010; Deliiski, 2011, 2013b). In the available specialized literature, there are limited reports about the temperature distribution in frozen logs subjected to defrosting (Steinhagen, 1986, 1991; Steinhagen and Lee, 1988; Khattabi and Steinhagen, 1992, 1993, 1995; Deliiski, 2004, 2009, 2011; Deliiski and Dzurenda, 2010; Deliiski *et al*., 2015; Hadjiski and Deliiski, 2015, 2016) and there is very little information about research of the temperature distribution in logs during their freezing (Deliiski and Tumbarkova, 2016, 2017, 2018). That is why the modeling and the multi-parameter study of the freezing process of logs are of considerable scientific and practical interest.

For different engineering and technological calculations, it is necessary to be able to determine the non-stationary temperature field in logs depending on the temperature of the gaseous or liquid medium and on the duration of their staying in this medium. Such calculations are carried out using mathematical models, which describe adequately the complex processes of the freezing of both free and bound water in the wood. The specific latent heat fluxes are an important part of these models, and they are formed by the freezing of the free and bound water in the wood. These fluxes are opposed to the external cooling heat flux whose purpose is to freeze the logs. The joint action of the fluxes affects the duration and energy consumption of the logs' freezing process. In the available literature for hydrothermal treatment of frozen wood materials, there is no information about quantitative determination of the specific latent heat fluxes of water in logs during their freezing.

The aim of the present paper is to suggest a methodology for mathematical modeling and research of two interconnected problems: 2D non-stationary temperature distribution in logs subjected to freezing and change in the specific latent heat fluxes of the free and bound water in the logs during the freezing process.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Mathematical model of 2D temperature distribution in logs during their freezing
2.1. Matematički model dvodimenzionalne raspodjele temperature u trupcima tijekom zamrzavanja

The mechanism of the temperature distribution in logs during their freezing can be described by the equation of heat conduction. When the length of the logs does not exceed their diameter by at least 3 ÷ 4 times, then the heat transfer through the frontal sides of the logs cannot be neglected, because it influences the change in temperature of their cross sections, which are equally distant from the frontal sides (Chudinov, 1966, 1968; Shubin, 1990; Deliiski, 2011). In such cases, for the calculation of the change in the temperature in longitudinal sections of the logs (i.e. along the coordinates r and z of these sections) during their freezing in air processing medium, the following 2D model can be used (Deliiski and Tumbarkova, 2017):

$$c_{\mathrm{we}}\rho_{\mathrm{w}}\frac{\partial T(r,z,\tau)}{\partial\tau}=\lambda_{\mathrm{wr}}\left[\frac{\partial^2 T(r,z,\tau)}{\partial r^2}+\frac{1}{r}.\frac{\partial T(r,z,\tau)}{\partial r}\right]+$$
$$+\frac{\partial\lambda_{\mathrm{wr}}}{\partial T}\left[\frac{\partial T(r,z,\tau)}{\partial r}\right]^2+\lambda_{\mathrm{wp}}\frac{\partial^2 T(r,z,\tau)}{\partial z^2}+$$
$$+\frac{\partial\lambda_{\mathrm{wp}}}{\partial T}\left[\frac{\partial T(r,z,\tau)}{\partial z}\right]^2+q_{\mathrm{v}} \quad (1)$$

with an initial condition

$$T(r,z,0)=T_{\mathrm{w0}} \quad (2)$$

and boundary conditions for convective heat transfer:

- along the radial coordinate r on the logs' frontal surface during the freezing process:

$$\frac{\partial T(r,0,\tau)}{\partial r}=-\frac{\alpha_{\mathrm{wp\text{-}fr}}(r,0,\tau)}{\lambda_{\mathrm{wp}}(r,0,\tau)}\left[T(r,0,\tau)-T_{\mathrm{m\text{-}fr}}(\tau)\right], \quad (3)$$

- along the longitudinal coordinate z on the logs' cylindrical surface during the freezing process:

$$\frac{\partial T(0,z,\tau)}{\partial z}=-\frac{\alpha_{\mathrm{wr\text{-}fr}}(0,z,\tau)}{\lambda_{\mathrm{wr}}(0,z,\tau)}\left[T(0,z,\tau)-T_{\mathrm{m\text{-}fr}}(\tau)\right]. \quad (4)$$

Equations 1 to 4 represent a common form of a mathematical model of 2D temperature distribution in logs during their freezing. Mathematical descriptions of individual variables in the model needed for its solution are discussed below.

2.2 Mathematical description of the latent heat fluxes in logs during their freezing
2.2. Matematički opis toka latentne topline u trupcima tijekom zamrzavanja

In Eq. 1, the specific heat flux in the logs' volume, q_{v}, reflects the influence of the latent heat of water in 1 m^3 of wood on the freezing process of logs. As pointed out above, in the available literature for hydrothermal treatment of frozen wood materials, no information can be found on the quantitative determination of the specific heat flux q_{v}. That is why a methodology for the determination of q_{v} during the freezing of logs, which has already been applied for the determination of the specific heat flux, q_{Mv}, during the process of solidification of melted metal (Salcudean and Abdullah, 1988; Dantzig, 1989; Hu and Argyropoulos, 1996; Mihailov and Petkov, 2010), is used in (Deliiski and Tumbarkova, 2018). According to this methodology, the heat source q_{Mv} is equal to

$$q_{\mathrm{Mv}}=\rho_{\mathrm{MS}}\cdot L_{\mathrm{crM}}\frac{\partial\psi_{\mathrm{MS}}}{\partial\tau} \quad (5)$$

In solving the models of metal solidification, the current value of metal density has been calculated according to the following equation:

$$\rho_M = \Psi_{MS} \cdot \rho_{MS} + (1 - \Psi_{MS}) \cdot \rho_{ML} \quad (6)$$

The following details of the solidification process have been reflected in Eq. 6: at the beginning of that process, the metal is in a liquid state and consequently $\Psi_{MS} = 0$ and $\rho_M = \rho_{ML}$; at the end of the process, the metal is in a solid state and then $\Psi_{MS} = 1$ and $\rho_M = \rho_{MS}$.

The specifics of the wood freezing process differ significantly from those of the metal solidification process. During wood cooling at temperatures $t > 0$ °C, both free and bound water are in a liquid state. Our experiments have proven that, in the range from 0 °C to -1 °C, the crystallization of free water occurs and the relative icing degree of the wood, which is formed from the freezing of that water, $\Psi_{ice\text{-}fw}$, changes from $\Psi_{ice\text{-}fw} = 0$ to $\Psi_{ice\text{-}fw} = 1$ (Deliiski and Tumbarkova, 2016, 2017).

When the wood temperature decreases below -1 °C, the gradual freezing of the bound water begins. In his doctoral thesis, Chudinov (1966) determined that even at an extremely low climate temperature on the earth, a certain portion (approximately 0.12 kg/kg) of the bound water in the wood remains in a liquid state. This means that the relative icing degree of the wood, which is only caused by the freezing of bound water, $\Psi_{ice\text{-}fw}$, changes from $\Psi_{ice\text{-}fw} = 0$ to $\Psi_{ice\text{-}fw} < 1$ (refer to p. 3.4 below).

It is known that the ice formed freely at atmospheric pressure has a density less than 8 % compared to that of liquid water (https://bg.wikipedia.org/wiki/%D0%9B%D0% B5%D0%B4). It is also known that the lignin sharply reduces the elasticity of the cell walls and, therefore, the conditions for ice formation by both free and bound water deteriorate. As a consequence, the ice in the wood has crystal lattice modifications, which are denser in comparison to the crystal lattice of the ice formed freely.

In the specialized literature on wood thermal treatment, it has been determined and accepted that the density of the wood that contains ice is practically equal to the density of the wood containing liquid water. This allows us to use the equality of the density ρ_{wS} and ρ_W in the mathematical description of the latent heat flux in logs subjected to freezing, q_{LHv}, i.e.

$$\rho_{wS} = \rho_W \quad (7)$$

Where ρ_{wS} is the density of the wood containing frozen water, kg/m^3, ρ_W – density of the non-frozen wood above the hygroscopic range, which can be calculated (in kg/m^3) according to the below equation, which is widely accepted in the specialized literature (Chudinov, 1968; Shubin, 1990; Požgaj *et al.*, 1997; Pervan, 2009; Deliiski *et al.*, 2015; Hrčka, 2017)

$$\rho_W = \rho_b \cdot (1+u) \quad (8)$$

ρ_b – basic density of the wood based on dry mass divided by green volume, kg/m^3;
u – wood moisture content, kg/kg.

Thus, in accordance with Eq. 5, it could be written for the latent heat flux of the water in the wood, q_v, which participates in (1), that

$$q_{Lat\text{-}v} = \rho_{wS} \cdot L_{cr-ice} \frac{\partial \Psi_{ice}}{\partial \tau} = \rho_w \cdot L_{cr\text{-}ice} \frac{\partial \psi_{ice}}{\partial \tau} \quad (9)$$

Where L_{cr-ice} is the latent heat of the water, also known as the "heat of crystallization". This heat is released in the wood during the water freezing and it is equal to $L_{cr-ice} = 3.34 \cdot 10^5$ J/kg for both free and bound water (Chudinov, 1966, 1968; Efimov, 1985; Rogers and Yau, 1989; Pahi, 2010; Deliiski and Tumbakova, 2016, 2018); $\Psi_{ice\text{-}fw}$ – relative icing degree of logs subjected to freezing.

Analogously to eq. (9), during the freezing of the free water in the log, the consequently formed specific latent heat flux in its volume, $q_{LHv\text{-}fw}$, is equal to

$$q_{LHv\text{-}fw} = \rho_w \cdot L_{cr\text{-}ice} \frac{\partial \psi_{ice\text{-}fw}}{\partial \tau} \quad (10)$$

Where $\Psi_{ice\text{-}fw}$ is the relative icing degree of the log, which results from the freezing of the free water in it. An approach and an algorithm for the calculation of $\Psi_{ice\text{-}fw}$ is given in Deliiski and Tumbarkova (2017).

Using Eq. 10, it is possible to calculate the specific latent heat flux $q_{LHv\text{-}fw}$ for the frozen state of the whole amount of the free water in 1 m^3 of the log. The current value of $q_{LHv\text{-}fw}$ for each moment $n \cdot \Delta\tau$ of the freezing process of logs can be calculated according to the following equation, simultaneously with the solving of the mathematical model (1) ÷ (4):

$$q^n_{LHv-fw} = \rho_w \cdot L_{cr\text{-}ice} \frac{\partial \psi^n_{ice-fw}}{\partial \tau} \cdot \frac{N^n_{ice-fw}}{N_{total}} \quad (11)$$

Where N^n_{ice-fw} is the current number of knots of the calculation mesh for solving of the model (1) to (4), in which the temperature has already been decreased below 273.15 K (i.e. below 0 °C) and then temperature conditions for crystallization of the free water have been arisen separately for each knot; N_{total} – total number of knots of the calculation mesh; n – time level: n = 0, 1, 2; $\Delta\tau$ – interval between time levels, i.e. step along the time coordinate, used for solving the model.

In accordance with Eq. 10, during the freezing of the bound water in the log, the consequently formed specific latent heat flux in its volume, $q_{LHv\text{-}fw}$ is equal to

$$q_{LHv\text{-}bw} = \rho_w \cdot L_{cr\text{-}ice} \frac{\partial \psi_{ice\text{-}bw}}{\partial \tau} \quad (12)$$

Where $\Psi_{ice\text{-}bw}$ is the relative icing degree of the log, which results from the freezing of certain portion of the bound water in it, depending on $T < 271.15$ K. An approach and an algorithm for the calculation of $\Psi_{ice\text{-}bw}$ are given in Deliiski and Tumbarkova (2017).

With the help of Eq. 12, it is possible to calculate the heat flux, $q_{LHv\text{-}bw}$, which corresponds to the whole amount of the frozen bound water in 1 m^3, which is in a frozen state in the log at the end of its freezing. The current value of $q_{LHv\text{-}bw}$ for each moment $n \cdot \Delta\tau$ of the freezing process of logs can be calculated according to the following equation, simultaneously with solving the model (1) ÷ (4):

$$q^n_{LHv-bw} = \rho_w \cdot L_{cr\text{-}ice} \frac{\partial \psi^n_{ice-bw}}{\partial \tau} \cdot \frac{N^n_{ice-bw}}{N_{total}} \quad (13)$$

Where N^n_{ice-bw} is the current value of the knots of the calculation mesh for solving the model (1) to (4), in which the temperature has already been decreased

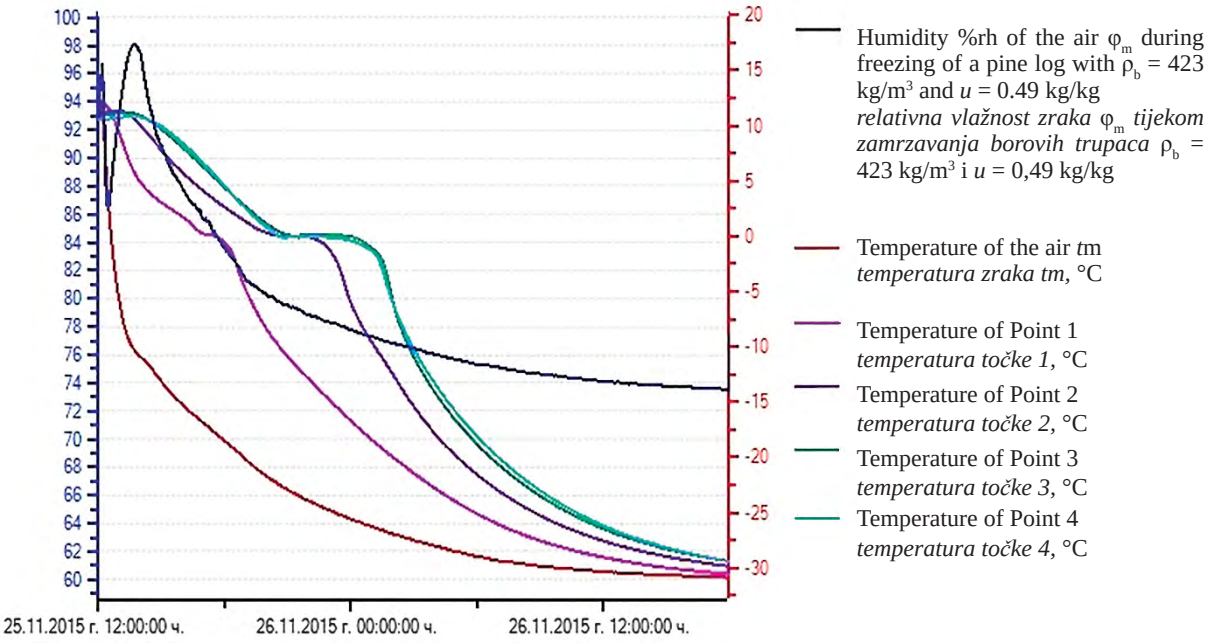

Figure 1 Experimentally determined change in t_m, φ_m, and t at four points of the pine log during its 30 h freezing in a freezer
Slika 1. Eksperimentalno utvrđene promjene parametara t_m, φ_m i t u četiri točke istraživanih borovih trupaca tijekom 30 sati zamrzavanja

below 272.15 K (i.e. below -1 ˚C) and then conditions for the crystallization of the bound water have been arisen separately for each knot.

2.3 Experimental research of the freezing process of pine logs
2.3. Istraživanje procesa zamrzavanja borovih trupaca

In order to verify the above suggested mathematical model, we needed experimentally obtained data about the change in the temperature field in logs during their freezing. That is why we carried out such experiments. The logs subjected to experimental research had the following characteristics: diameter D = 240 mm, length L = 480 mm, and moisture content above the hygroscopic range. They were produced from the sapwood of a freshly felled pine trunk (*Pinus sylvestris* L.). Before the experiments, 4 holes with diameters of 6 mm and different lengths were drilled in each log parallel to its axis until reaching the characteristic points of the log (Deliiski and Tumbarkova, 2016). Sensors with long metal casings were placed in these 4 holes for the measurement of wood temperature during the experiments.

The coordinates of the log points are as follows: Point 1: along the radius r = 30 mm and along the length z = 120 mm; Point 2: with r = 60 mm and z = 120 mm; Point 3: with r = 90 mm and z = 180 mm and Point 4: with r = 120 mm and z = 240 mm (center of the log). Thanks to these points coordinates, the impact of the heat fluxes on the temperature distribution in logs during their freezing can be simultaneously determined in radial and longitudinal directions.

For log freezing in accordance with the methodology suggested by the authors (Deliiski and Tumbarkova, 2016), a horizontal freezer was used with adjustable temperature range from -1 °C to -30 °C. Each log equipped with temperature sensors was horizontally placed on a special stand in the open freezer at room temperature. After closing the freezer, it was switched on at full power and the temperature of its freezing air medium, t_m, was gradually lowered until reaching approximately -30 °C.

The automatic measurement and recording of temperature and humidity of the air processing medium in the freezer as well as temperature for four points of the logs during the experiments was carried out with the help of Data Logger type HygroLog NT3 produced by the Swiss firm ROTRONIC AG (http:/www.rotronic.com).

Figure 1 presents, as an example, the change in temperature of the processing air medium, t_m, and in its humidity, φ_m, as well as the temperature for the four characteristic points of a pine log with basic density of 423 kg/m^3 and moisture content of 0.49 kg/kg during its 30 h freezing. The left coordinate axis in Figure 1 is graduated at % of φ_m, and the left one is graduated at °C of t.

All data were recorded automatically by Data Logger at 5 min intervals. The Data Logger has HW4 software for the graphical presentation of the experimentally obtained data.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The mathematical descriptions of the latent heat fluxes $q_{LHv\text{-}fw}$ and $q_{LHv\text{-}bw}$ created above and mathematical descriptions of the thermo-physical characteristics of frozen and non-frozen wood suggested earlier (Deliiski, 2004, 2009, 2011, 2013a) are introduced in the mathematical model of the freezing process of logs, which consists of Eq. 1-13. Our study has shown that, for the calculation of the radial and longitudinal trans-

fer coefficients of the logs, $\alpha_{wr\text{-}fr}$ and $\alpha_{wp\text{-}fr}$, respectively, in the boundary conditions (3) and (4) of the model, the following equations are most suitable (Telegin *et al.*, 2002):

- in the radial direction on the cylindrical surface of the horizontally mounted logs:

$$\alpha_{wr-fr} = 2.56\left[T(0,z,\tau) - T_{m-fr}(\tau)\right]^{E_{fr}} \quad (14)$$

- in the longitudinal direction on the frontal surface of the logs:

$$\alpha_{wp-fr} = 1.123\left[T(r,0,\tau) - T_{m-fr}(\tau)\right]^{E_{fr}} \quad (15)$$

Where E_{fr} is an exponent, whose values are determined during solving and verification of the model through minimization of the root mean square error (*RMSE*) between the results calculated by the model and experimentally obtained results on the temperature change fields in logs subjected to freezing.

For the numerical solution of the mathematical model, a software program was prepared in the calculation environment of Visual FORTRAN Professional. With the help of the program, computations were made for the determination of the 2D non-stationary change of *t* in the longitudinal sections of a pine log, whose experimentally determined temperature distribution is shown in Figure 1. Simultaneously, calculations of the change in heat fluxes $q_{LHv\text{-}fw}$ and $q_{LHv\text{-}bw}$ during the freezing were carried out.

The model was solved with the help of explicit schemes of the finite difference method in a way analogous to the one used and described in (Deliiski, 2009, 2011, 2013c; Deliiski *et al.*, 2015) for the solution of a model of the heating process of prismatic and cylindrical wood materials. For this purpose, the calculation mesh was built on ¼ of the longitudinal section of the log due to the fact that this ¼ was mirror symmetrical to the remaining ¾ of the same section.

The model was solved with step $\Delta r = \Delta z = 0.006$ m along the coordinates *r* and *z* and with the same initial and boundary conditions, as used during the experimental research. The interval between the time levels, $\Delta\tau$, (i.e. the step along the time coordinate), was determined by the software according to the condition of stability for explicit schemes of the finite difference method (Deliiski, 2013b) and in our case it was 6 s.

The mathematical description of the thermophysical characteristics of pine wood with fiber saturation point $u_{fsp}^{293.15} = 0.30$ kg·kg^{-1} was used for solving the model (Nikolov and Videlov, 1987; Deliiski and Dzurenda, 2010).

3.1 Mathematical description of the freezer temperature during log freezing

3.1. Matematički model temperature u zamrzivaču tijekom zamrzavanja trupaca

The curvilinear change in the freezing air medium temperature, $T_{m\text{-}fr}$, which is shown in Figure 1, with high accuracy (correlation 0.99 for the studied log and Root mean square error $\sigma = 0.84$ °C) was approximated with the help of the software package Table Curve 2D available on Internet (http://www.sigmaplot.co.uk/products/tablecurve2d/tablecurve2d.php) using the Eq. 16

$$T_{m-fr} = \frac{a_{fr} + c_{fr}\tau^{0.5}}{1 + b_{fr}\tau^{0.5} + d_{fr}\tau} \quad (16)$$

whose coefficients are: $a_{fr} = 285.7898447$, $b_{fr} = 0.0015713223$, $c_{fr} = 0.123970584$, and $d_{fr} = -1.5621 \cdot 10^{-6}$.

Equation 16 was introduced in the software for solving Eq. 3 and 4 of the model.

3.2 Computation of 2D temperature distribution in the log during its freezing

3.2. Izračun 2D raspodjele temperature u trupcu tijekom zamrzavanja

The mathematical model of the freezing process of logs was solved with different values of the exponent E_{fr} in Eq. 14 and 15. The temperature change at the four characteristic points of the longitudinal log section calculated by the model with each of the used values of E_{fr} during freezing was compared mathematically with the corresponding experimentally determined change of *t* in the same points at 5 min interval. The aim of this comparison was to find that the value of E_{fr} can ensure the best qualitative and quantitative compliance between the calculated and experimentally determined temperature field in the log longitudinal section.

The minimum value of *RMSE*, σ_{avg}, was used as a criterion of the best compliance between the compared values of the temperature for all four characteristic points.

A software program in MS Excel 2010 was prepared for the determination of *RMSE*. With the help of *RMSE*, a total of 1200 temperature-time points were covered simultaneously during 30 h of log freezing. During the simulations, the same initial and boundary conditions were used as during the experiment. A minimum value of *RMSE*, equal to $\sigma_{avg} = 1.69$ °C was obtained for all 4 characteristic points of the log.

Figure 2 presents the calculated change in $t_{m\text{-}fr}$, log surface temperature t_s, and *t* of 4 characteristic points in the pine log.

The comparison between analog curves in Figure 1 and 2 show good qualitative and quantitative conformity between the calculated and experimentally determined changes of complex temperature field of the logs during their freezing. During extensive simulations with the mathematical model, we observed good compliance between the computed and experimentally established temperature fields during the freezing of logs of different wood species and different moisture content. The overall *RMSE* for the four characteristic points in the logs does not exceed 5 % of the temperature ranges between the initial and final temperatures of the logs subjected to freezing. Generally, the larger the differences in moisture content in the logs volume, the larger is the obtained value of *RMSE*.

The curves in Figure 1 and 2, placed on the characteristic points of the log inner layers, show the specific almost horizontal sections with temperature retention for a long period of time in the range from 0 °C to -1 °C, while complete freezing of the whole amount of the free water in the log is occurring in these points. Our experiments and simulations showed that the further the point from the log surface and the larger the amount of the free water in the wood, the greater is the extension of these

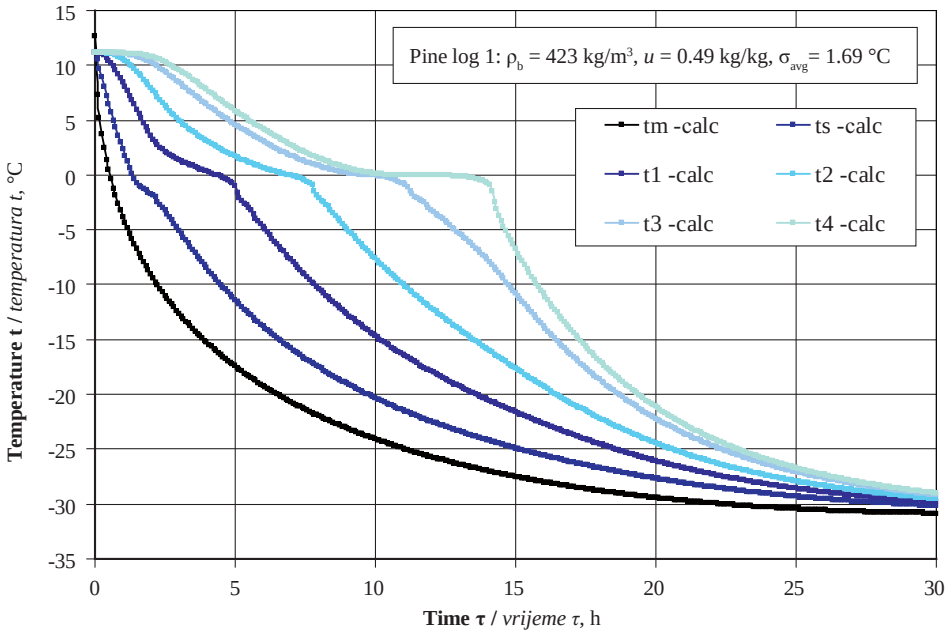

Figure 2 Calculated change in t_m, t_s, and t for four points of the pine log during 30 h of freezing
Slika 2. Izračunana promjena t_m, t_s, i t u četiri točke ispitivanoga borova trupca tijekom 30 sati zamrzavanja

sections with temperature retention. The reason of such a long retention of the wood temperature is the very low temperature conductivity of the wood due to freezing of the free water (Deliiski *et al.*, 2015).

3.3 Change of the current number of knots $N_{ice\text{-}fw}$ and $N_{ice\text{-}bw}$ of the calculation mesh
3.3. Promjena trenutačnog broja čvorova $N_{ice\text{-}fw}$ i $N_{ice\text{-}bw}$ računalne mreže

Figure 3 presents the calculated change in the number of knots $N_{ice\text{-}fw}$ and $N_{ice\text{-}bw}$ during the 30 h freezing of the studied log. The analysis of the results shows that during the first 1.50 h of the log cooling, the temperature decreases in its surface layers from the initial value of 11.1 °C until reaching 0 °C. Only after this 1.50 h, crystallization of free water in the knots begins, starting with free water situated the nearest to the frontal and cylindrical surfaces of the logs. After that, the number of knots $N_{ice\text{-}fw}$ increases almost linearly and reaches a value of $N_{ice\text{-}fw} = N_{total} = 800$ at 11.50th h from the beginning of the freezing process.

When the temperature in the log surface layers decreases below -1 °C, the increase of the number of knots $N_{ice\text{-}bw}$ from 0 to 800 begins. This occurs from 2.50th h to 14.25th h of the freezing process. The hori-

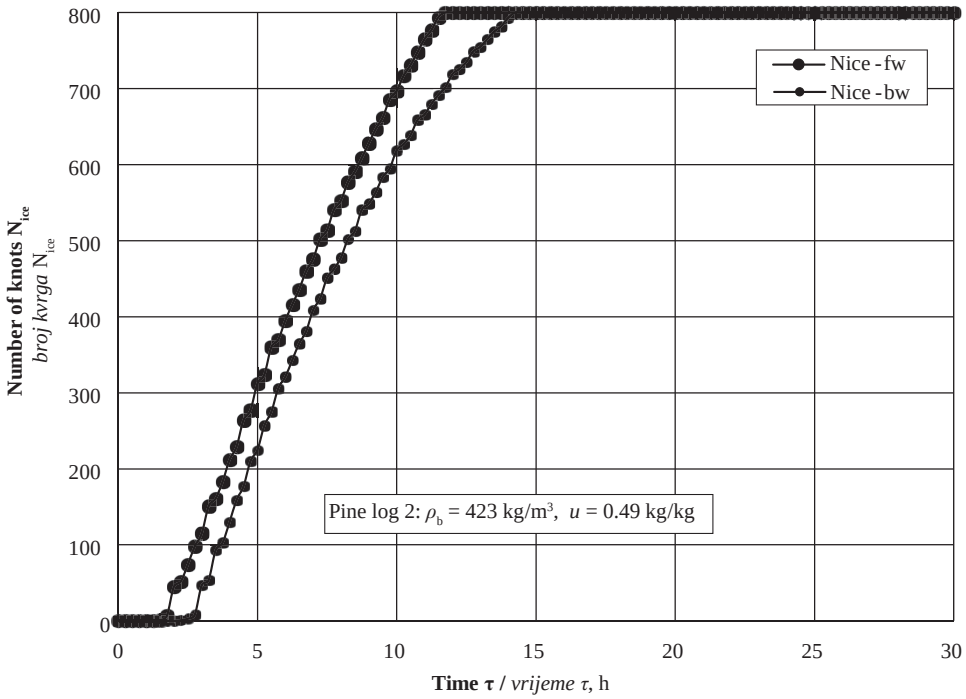

Figure 3 Change in knots $N_{ice\text{-}fw}$ and $N_{ice\text{-}bw}$ during log freezing
Slika 3. Promjene u čvorovima $N_{ice\text{-}fw}$ i $N_{ice\text{-}bw}$ tijekom zamrzavanja istraživanog trupca

zontal distances between the paired graphs of $N_{ice\text{-}fw}$ and $N_{ice\text{-}bw}$ in Figure 3 correspond to the time intervals in which the knots temperature decreases from 0 °C to -1 °C in separate layers of the log. During these intervals, the crystallization of free water in the log occurs.

3.4 Change of log icing degrees $\Psi_{ice\text{-}fw}$ and $\Psi_{ice\text{-}bw}$ and their derivatives

3.4. Promjena stupnja zaleđivanja trupca $\Psi_{ice\text{-}fw}$ i $\Psi_{ice\text{-}bw}$ i njihovih derivata

The icing degree $\Psi_{ice\text{-}fw}$ is calculated simultaneously with the model solving according to the equation

$$\Psi^{n}_{ice-fw} = \frac{N^{n}_{ice-fw}}{N_{total}} \quad (17)$$

During the first 1.50 h of the log cooling process, the whole amount of both free and bound water is in a liquid state and because of that $\Psi_{ice\text{-}fw} = 0$.

From 1.50th h to 11.50th h, the icing degree $\Psi_{ice\text{-}fw}$ increases almost linearly from 0 to 1 and remains 1 until the end of the 30 h log freezing process (Figure 4).

The calculation of the average mass icing degree of the log, $\Psi_{ice\text{-}bw}$, is carried out according to the following equation, obtained in (Deliiski and Tumbarkova, 2017):

$$\psi^{n}_{ice\text{-}bw} = \frac{1}{S_w}\iint_{S_w} \frac{u^{272.15}_{fsp} - \left\{0.12 + (u^{272.15}_{fsp} - 0.12)\cdot \exp[0.0567(T^{n}_{i,k} - 272.15)]\right\}}{u^{272.15}_{fsp}} dS_w \quad (18)$$

Where $T^{n}_{i\,k}$ is the current temperature in the knot with coordinates *i* along *r* and *k* along *z*, K;

S_w – area of ¼ of the longitudinal section of the log subjected to freezing, m².

The fiber saturation point at T = 272.15 K, $u^{272.15}_{fsp}$, used in Eq. 18, can be calculated according to the equation (Stamm, 1964; Deliiski, 2013a)

$$u^{272.15}_{fsp} = u^{293.15}_{fsp} + 0.021, \quad (19)$$

Where $u^{293.15}_{fsp}$ is the standardized value of the fiber saturation point of wood species at 293.15 K, i.e. at 20 °C, kg/kg.

The gradual change in $N_{ice\text{-}bw}$ causes a curvilinear increase of $\Psi_{ice\text{-}bw}$ from 0 before 2.50th h until reaching 0.502 at the end of 30 h freezing (Figure 4). This value of $\Psi_{ice\text{-}bw}$ means that 1 - 0.502 = 0.498 relative parts (i.e. 49.8 %) of the bound water in the studied log remains in a liquid state in the cell walls at the end of 30th h of freezing when the calculated average log mass temperature is -29.6 °C.

The change in the derivatives $d\Psi_{ice\text{-}fw}/d\tau$ and $d\Psi_{ice\text{-}bw}/d\tau$ during 30 h freezing of the log is presented in Figure 5. To reduce the fluctuations in the values of these derivatives, their calculation was done with an interval of $150\cdot\Delta\tau$ = 900 s = 0.25 h. The fluctuations are caused by the uneven increase of the number of knots $N_{ice\text{-}fw}$ and $N_{ice\text{-}bw}$ during the freezing process of the log, which determines an uneven change in $d\Psi_{ice\text{-}fw}/d\tau$ and $d\Psi_{ice\text{-}bw}/d\tau$.

When $0 \le \Psi_{ice\text{-}fw} \le 1$, the derivative $d\Psi_{ice\text{-}fw}/d\tau$ fluctuates between $0.139\cdot10^{-5}$ s^{-1} and $5.28\cdot10^{-5}$ s^{-1}. When $\Psi_{ice\text{-}fw}$ becomes equal to 1 at 11.50th h, the derivative $d\Psi_{ice\text{-}fw}/d\tau$ obtains the value of $2.34\cdot10^{-5}$ s^{-1}. That derivative is equal to 0 when $\Psi_{ice\text{-}fw} = 0$ or $\Psi_{ice\text{-}fw} = 1$.

Before reaching the inflexion point of the curve $\Psi_{ice\text{-}bw} = f(\tau)$, the derivative $d\Psi_{ice\text{-}bw}/d\tau$ increases with smaller fluctuations than $d\Psi_{ice\text{-}fw}/d\tau$. When the inflexion point of $\Psi_{ice\text{-}bw} = f(\tau)$ reaches 14.50th h, that derivative obtains its maximum value equal to $0.96\cdot10^{-5}$ s^{-1}.

After reaching the maximum value, the derivative $d\Psi_{ice\text{-}bw}/d\tau$ decreases gradually and reaches a value

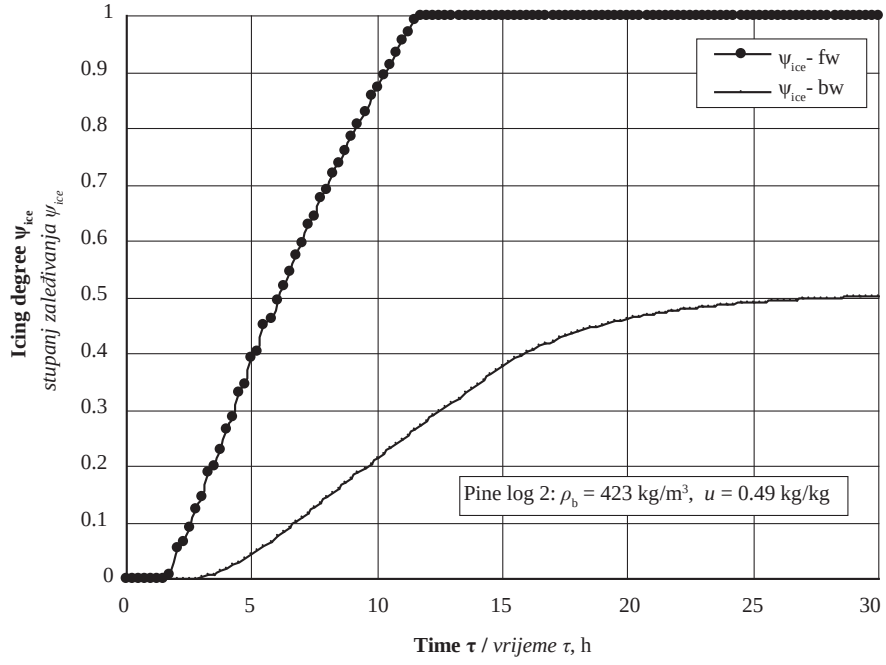

Figure 4 Change in $\Psi_{ice\text{-}fw}$ and $\Psi_{ice\text{-}bw}$ during log freezing
Slika 4. Promjene $\Psi_{ice\text{-}fw}$ i $\Psi_{ice\text{-}bw}$ tijekom zamrzavanja istraživanog trupca

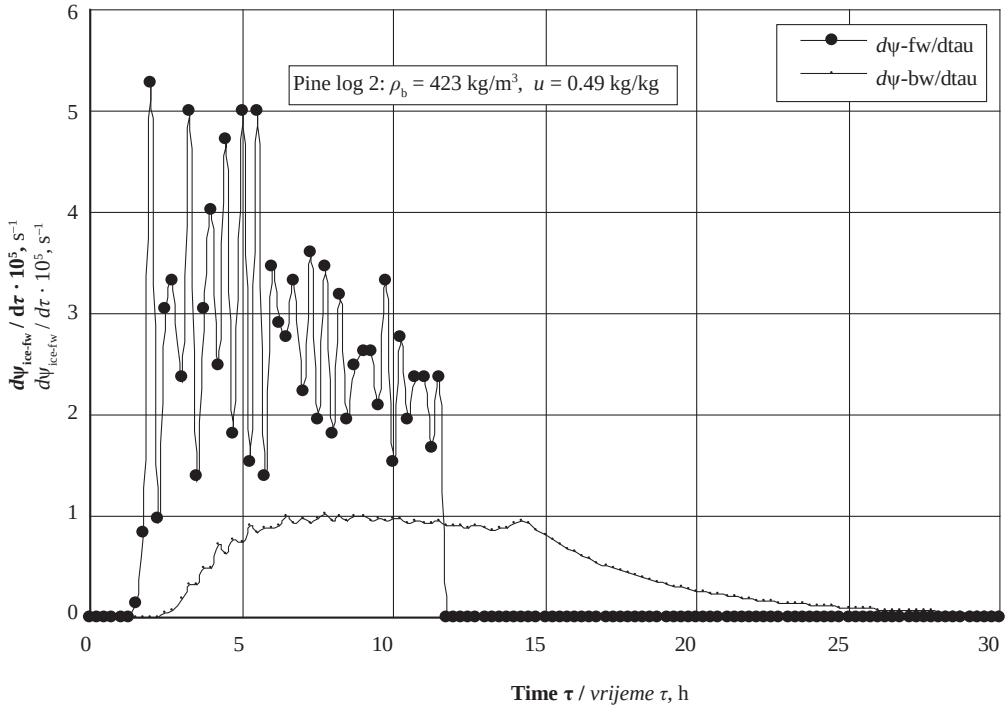

Figure 5 Change in $d\Psi_{ice\text{-}fw}/d\tau$ *and* $d\Psi_{ice\text{-}bw}/d\tau$ during log freezing
Slika 5. Promjene $d\Psi_{ice\text{-}fw}/d\tau$ i $d\Psi_{ice\text{-}bw}/d\tau$ tijekom zamrzavanja istraživanog trupca

of $0.040 \cdot 10^{-5}$ s^{-1} at the end of 30 h freezing. Derivative $d\Psi_{ice\text{-}bw}/d\tau$ is equal to 0 only at the beginning of the freezing process when $N_{ice\text{-}bw} = 0$ and $\Psi_{ice\text{-}bw} = 0$.

3.5 Change of specific latent heat fluxes $q_{LHv\text{-}fw}$ and $q_{LHv\text{-}bw}$

3.5. Promjena specifičnih latentnih tokova topline $q_{LHv\text{-}fw}$ i $q_{LHv\text{-}bw}$

Figure 6 presents the change of the specific latent heat fluxes $q_{LHv\text{-}fw}$ and $q_{LHv\text{-}bw}$ calculated according to Eq. 11 and 12 during 30 h freezing of the studied pine log. It can be seen that, during the log freezing, the heat fluxes $q_{LHv\text{-}fw}$ and $q_{LHv\text{-}bw}$ change according to three interconnected sections, as follows:

• change of heat flux $q_{LHv\text{-}fw}$:

1. During the first 1.50 h of the log cooling process, the entire quantity of the free and bound water in the log is in a liquid state and because of that $q_{LHv\text{-}fw} = 0$ kW/m^3.

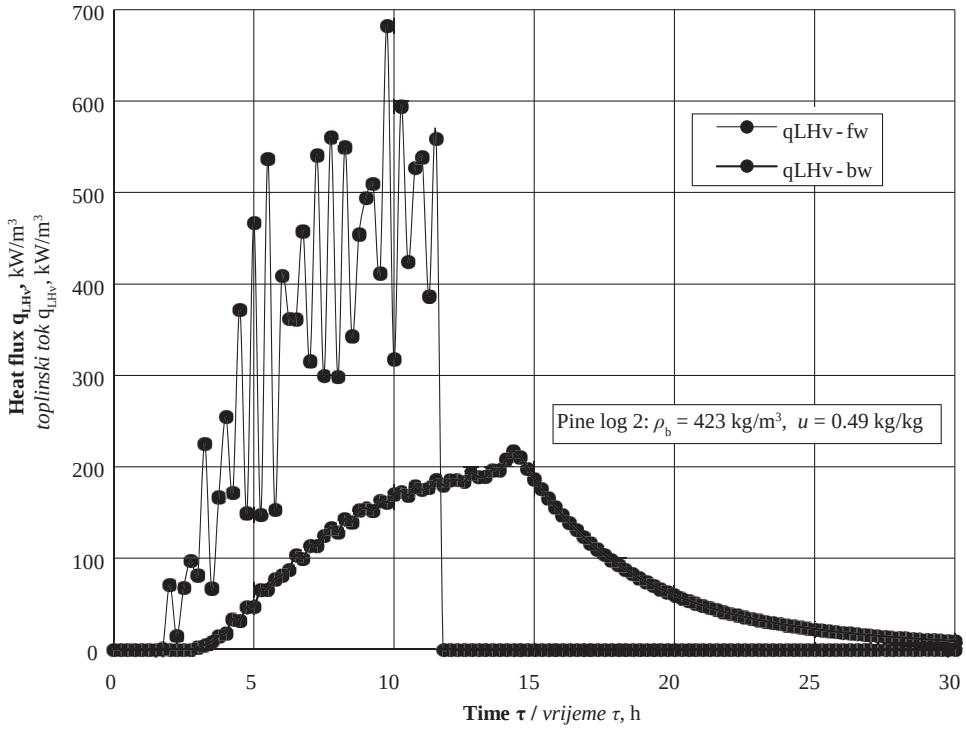

Figure 6 Change in $q_{LHv\text{-}fw}$ *and* $q_{LHv\text{-}bw}$ during log freezing
Slika 6. Promjene $q_{LHv\text{-}fw}$ i $q_{LHv\text{-}bw}$ tijekom zamrzavanja istraživanog trupca

2. From 1.50th h of the log freezing process, the free water crystallization starts. Then the heat flux $q_{LHv\text{-}fw}$ begins to increase with fluctuations from the value of 0 until reaching the value of 4.934 kW/m^3 at 11.50th h when the number of knots $N_{ice\text{-}fw}$ becomes equal to N_{total} = 800. The fluctuations in $q_{LHv\text{-}fw}$ are caused by the fluctuations of the derivative $d\Psi_{ice\text{-}fw}/d\tau$, used in Eq. 11.

3. After 11.50th h, the icing degree $\Psi_{ice\text{-}fw}$ becomes equal to 1. Then the heat flux $q_{LHv\text{-}fw}$ obtains a value of 0 kW/m^3, and it remains unchanged until the end of the 30 h freezing.

• change of heat flux $q_{LHv\text{-}bw}$:

1. During the first 2.50 h of the freezing process, the whole amount of the bound water in the log is in a liquid state and because of that $q_{LHv\text{-}bw}$ = 0 kW/m^3.

2. From 2.50th h, the crystallization of the bound water in the log starts. Then the heat flux $q_{LHv\text{-}bw}$ begins to increase from the value of 0 until reaching its maximum value of 2.012 kW/m^3 at 14.25th h.

3. After 14.25th h, the derivative $d\Psi_{ice\text{-}bw}/d\tau$ decreases in comparison with its maximum value and this causes a decrease in the heat flux $q_{LHv\text{-}bw}$. At the end of 30th h of log freezing, when the calculated average log mass temperature is equal to -29.6 °C, the flux $q_{LHv\text{-}bw}$ obtains the value of 0.085 kW/m^3.

4 CONCLUSIONS
4. ZAKLJUČAK

This paper presents a methodology for mathematical modeling and research of two interconnected problems: 2D non-stationary temperature distribution in logs subjected to freezing and change in the specific latent heat fluxes of the free and bound water in the logs during the freezing process.

The paper gives mathematical descriptions of the latent heat fluxes $q_{LHv\text{-}fw}$ and $q_{LHv\text{-}bw}$, which are formed in logs during the freezing of the free water in the range from 0 °C to -1 °C, and of the bound water below -1 °C, respectively. These descriptions are introduced in our own 2D non-linear mathematical model of the 2D temperature distribution in logs during their freezing.

A software program for the solution of the model and computation of the specific latent heat fluxes $q_{LHv\text{-}fw}$ and $q_{LHv\text{-}bw}$ was prepared in FORTRAN, and it was input in the calculation environment of Visual FORTRAN Professional developed by Microsoft.

With the help of the program, computations for the determination of the heat fluxes $q_{LHv\text{-}fw}$ and $q_{LHv\text{-}bw}$ were completed as an example for the case of a pine log with D = 0.24 m, L = 0.48 m, t_{w0} = 11.1 °C, ρ_b = 423 kg/m^3, and u = 0.49 kg/kg subjected to 30 h freezing in a freezer at approximately -30 °C.

It was determined that the values of the specific latent heat fluxes $q_{LHv\text{-}fw}$ and $q_{LHv\text{-}bw}$ of the studied log change according to complex relationships, as follows:

– the heat flux $q_{LHv\text{-}fw}$, which is only formed by the freezing of the free water in the wood, changes from 0 to 4.934 kW/m^3 during the time from 1.50th h to 11.50th h of the freezing process;

– the heat flux $q_{LHv\text{-}bw}$, which is formed by the freezing of a portion of the bound water in the wood, changes from 0 to 2.012 kW/m^3 during the time from 2.50th h to 14.25th h of the freezing process. After the 14.25th h, the flux decreases and at the end of 30 h freezing, it reaches a value of 0.085 kW/m^3.

By applying the mathematical descriptions of $q_{LHv\text{-}fw}$ and $q_{LHv\text{-}bw}$ during our simulations with the mathematical model, we observed good conformity between the calculated and experimentally determined changes in the temperature field during the freezing of logs of different wood species with different moisture contents. The overall *RMSE* for the studied four characteristic points in the logs does not exceed 5 % of the temperature ranges between the initial and final temperatures of the logs subjected to freezing. This proves the suitability of the model as well as the correctness of the suggested mathematical descriptions of the studied latent heat fluxes.

Accuracy of the model and good correlation with the results of our comprehensive experimental studies provide the basis for using the model for carrying out various calculations related to the non-stationary temperature distribution and energy characteristics of logs of different wood species during their freezing. The mathematical model, after being connected with other models of the log defrosting process, could be input into the software of programmable controllers for providing optimized model-based automatic control (Deliiski, 2004; Deliiski and Dzurenda, 2010; Hadjiski *et al*., 2018) of thermal treatment of frozen logs in the production of veneer.

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Symbols:

c – specific heat capacity, J/(kgK)
D – diameter, m
E – exponent
L – specific latent heat, J/kg, or length, m
N – number of knots of the calculation mesh
q – specific heat flux, W/m^3
R – radius, m
r – radial coordinate: $0 \le r \le R$, m
S – area of ¼ of log longitudinal section, m^2
T – temperature, K: $T = t + 273.15$
t – temperature, °C: $t = T - 273.15$
u – moisture content, kg·kg^{-1} = %/100
z – longitudinal coordinate: $0 \le z \le L/2$, m
α – heat transfer coefficients between log surfaces and the surrounding air medium, W/(m^2·K)
λ – thermal conductivity, W/(m·K)
ρ – density, kg/m^3
σ – root mean square error, °C

τ – time, s
Δr – step along the coordinates r and z for solving the model, m
$\Delta\tau$ – step along the time coordinate for solving the model, s
Ψ – relative icing degree of logs or relative degree of solidification of metal

Subscripts:
avg – average (for root mean square error)
b – basic (for wood density)
bw – bound water
cr – crystallization
fr – freezing
fsp – fiber saturation point
fw – free water
ice – ice (for logs' icing degrees or for number of knots of the calculation mesh)
i – point of the calculation mesh in the direction along the logs' radius: i = 1, 2, 3,…, 21
k – point of the calculation mesh in longitudinal direction of the logs: k = 1, 2, 3, …, 41
LH – latent heat
m – medium (for cooling substance)
M – metal
Ms – metal in solid state
Mv – volume of the metal
0 – initial
p – parallel to wood fibers
r – radial direction
total – total (for number of knots of the calculation mesh)
v – volume
w – wood
we – wood effective (for specific heat capacity)
wS – wood containing solid state water (ice)
ψ – relative icing degree of logs

Superscripts:
n – time level during model solving: n = 0, 1, 2, …

272.15 – at 272.15 K, i.e. at -1 °C
293.15 – at 293.15 K, i.e. at 20 °C

5 REFERENCES
5. LITERATURA

1. Chudinov, B. S., 1966: Theoretical Research of Thermo Physical Properties and Thermal Treatment of Wood. Dissertation for Dr.Sc., SibLTI, Krasnojarsk, USSR (in Russian).
2. Chudinov, B. S., 1968: Theory of Thermal Treatment of Wood. Nauka, Moscow, 255 p. (in Russian).
3. Chudinov, B. S., 1984: Water in Wood. Nauka, Moscow (in Russian).
4. Dantzig, J., 1989: Modelling Liquid-solid Phase Changes with Melt Convection. International Journal for Numerical Methods in Engineering, 28 (8): 1769-1785. http://doi.org/10.1002/nme.1620280805.
5. Deliiski, N., 2004: Modelling and Automatic Control of Heat Energy Consumption Required for Thermal Treatment of Logs. Drvna industrija, 55 (4): 181-199.
6. Deliiski, N., 2009: Computation of the 2-dimensional Transient Temperature Distribution and Heat Energy Consumption of Frozen and Non-frozen Logs. Wood Research, 54 (3): 67-78.
7. Deliiski, N., 2011: Transient Heat Conduction in Capillary Porous Bodies. In: Ahsan A. (ed.): Convection and Conduction Heat Transfer. InTech Publishing House, Rijeka: 149-176. http://doi.org/10.5772/21424.
8. Deliiski, N., 2013a: Computation of the Wood Thermal Conductivity during Defrosting of the Wood. Wood Research, 58 (4): 637-650.
9. Deliiski, N., 2013b: Modelling of the Energy Needed for Heating of Capillary Porous Bodies in Frozen and Non-frozen States. Lambert Academic Publishing, Scholars' Press, Saarbrücken, Germany, 116 p.
10. Deliiski, N., 2013c: 3D Modeling and Visualization of the Non-stationary Temperature Distribution during Heating of Frozen Wood. Drvna industrija, 64 (4): 293-303. http://doi.org/10.5552/drind.2013.1306.
11. Deliiski, N.; Dzurenda, L., 2010: Modelling of the Thermal Processes in the Technologies for Wood Thermal Treatment. TU Zvolen, Slovakia, 224 p. (in Russian).
12. Deliiski, N.; Dzurenda, L.; Tumbarkova, N.; Angelski, D., 2015: Computation of the Temperature Conductivity of Frozen Wood during its Defrosting. Drvna industrija, 66 (2): 87-96. http://doi.org/10.5552/drind.2015.1351.
13. Deliiski, N.; Tumbarkova, N., 2016: A Methodology for Experimental Research of the Freezing Process of Logs. Acta Silvatica et Lignaria Hungarica, 12 (2): 145-156. http://doi.org/10.1515/aslh-2016-0013.
14. Deliiski, N.; Tumbarkova, N., 2017: An Approach and an Algorithm for Computation of the Unsteady Icing Degrees of Logs Subjected to Freezing. Acta Facultatis Xilologiae Zvolen, 59 (2): 91-104.
15. Deliiski, N.; Tumbarkova, N., 2018: An Approach for Computing the Heat Sources in Logs Subjected to Freezing. Acta Silvatica et Lignaria Hungarica, 14 (1): 35-49, https://doi.org/10.2478/aslh-2018-0002.
16. Efimov, S. N., 1985: Temperature Dependence of the Heat of Water Crystallization. Engineering-Physical Journal of the Institute of Physic-Technical Problems of the Nord, Siberian Department of the Academy of Sciences of USSR, Yakutsk, 49 (4): 658-664 (in Russian).
17. Hadjiski, M.; Deliiski, N., 2015: Cost Oriented Suboptimal Control of the Thermal Treatment of Wood Materials. IFAC-PapersOnLine 48-24 (2015): 54-59. http://doi.org/10.1016/j.ifacol.2015.12.056.
18. Hadjiski, M.; Deliiski, N., 2016: Advanced Control of the Wood Thermal Treatment Processing. Cybernetics and Information Technologies, Bulgarian Academy of Sciences, 16 (2): 179-197. http://doi.org/10.1515/cait-2016-0029.
19. Hadjiski, M.; Deliiski, N.; Grancharova, A., 2018: Spatiotemporal Parameter Estimation of Thermal Treatment Process via Initial Condition Reconstruction Using Neural Networks: 51-80. In: Intuitionistic Fuzziness and Other Intelligent Theories and Their Applications, Springer International Publishing, 193 p.
20. Hrčka, R., 2017: Model in Free Water in Wood. Wood Research, 62 (6): 831-837.
21. Hu, H.; Argyropoulos, S., 1996: Mathematical Modelling of Solidification and Melting: A Review. Modelling and Simulation in Materials Science and Engineering, 4: 371-396. http://doi.org/10.1088/0965-0393/4/4/004.
22. Khattabi, A.; Steinhagen, H. P., 1992: Numerical Solution to Two-dimensional Heating of Logs. Holz als Roh- und Werkstoff, 50 (7-8): 308-312. http://doi.org/10.1007/BF02615359.
23. Khattabi, A.; Steinhagen, H. P., 1993: Analysis of Transient Non-linear Heat Conduction in Wood Using Finite-

difference Solutions. Holz als Roh- und Werkstoff, 51 (4): 272-278. http://doi.org/10.1007/BF02629373.
24. Khattabi, A.; Steinhagen, H. P., 1995: Update of "Numerical Solution to Two-dimensional Heating of Logs". Holz als Roh- und Werkstoff, 53 (1): 93-94. http://doi.org/10.1007/BF02716399.
25. Kollmann F. F.; Côté, W. A. Jr., 1984: Principles of Wood Science and Technology. I. Solid Wood. Springer-Verlag, Berlin, Heidelberg, New York, 592 p.
26. Mihailov, E.; Petkov, V., 2010: Cooling Parameters and Heat Quantity of the Metal During Continuous Casting of Blooms. Int. Review of Mechanical Engineering, 4 (2): 176-184.
27. Nikolov, S.; Videlov, Ch., 1987: Manual for Wood Drying. Zemizdat, Sofia, 394 p. (in Bulgarian).
28. Pahi, S., 2010: Understanding specific latent heat. Lesson 4.3 – Understanding thermal latent heat. Bidang Sains dan Matematik.
29. Pervan, S., 2009: Technology for Treatment of Wood with Water Steam. University in Zagreb (in Croatian).
30. Požgaj, A.; Chovanec, D.; Kurjatko, S.; Babiak, M., 1997: Structure and Properties of Wood. 2nd ed. Priroda a.s., Bratislava, 485 p. (in Slovak).
31. Rogers, R. R.; Yau, M. K., 1989: A short Course in Cloud Physics (3rd ed.). Pergamon Press, ISBN 0-7506-3215-1.
32. Salcudean, M.; Abdullah, Z., 1988: On the Numerical Modelling of Heat Transfer during Solidification Processes. International journal for numerical methods in engineering, 25: 445-473. http://doi.org/10.1002/nme.1620250212.
33. Shubin, G. S., 1990: Drying and Thermal Treatment of Wood. Lesnaya Promyshlennost, Moscow, URSS, 337 p. (in Russian).
34. Stamm, A. J., 1964: Wood and Cellulose Science. Ronald Press, New York.
35. Steinhagen, H. P., 1986: Computerized Finite-difference Method to Calculate Transient Heat Conduction with Thawing. Wood Fiber Science, 18 (3): 460-467.
36. Steinhagen, H. P., 1991: Heat Transfer Computation for a Long, Frozen Log Heated in Agitated Water or Steam – A Practical Recipe. Holz als Roh- und Werkstoff, 49 (7-8): 287-290. http://doi.org/10.1007/BF02663790.
37. Steinhagen, H. P.; Lee, H. W., 1988: Enthalpy Method to Compute Radial Heating and Thawing of Logs. Wood Fiber Science, 20 (4): 415-421.
38. Telegin, A. S.; Shvidkiy, B. S.; Yaroshenko, U. G., 2002: Heat- and Mass Transfer. Akademkniga, Moscow, 455 p. (in Russian).
39. Trebula, P.; Klement, I., 2002: Drying and Hydro-thermal Treatment of Wood. Technical University in Zvolen, Slovakia, 449 p. (in Slovak).
40. Videlov, Ch., 2003: Drying and Thermal Treatment of Wood. University of Forestry in Sofia, Sofia, 335 p. (in Bulgarian).

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HRVATSKA KOMORA
INŽENJERA ŠUMARSTVA
I DRVNE TEHNOLOGIJE

HRVATSKA KOMORA INŽENJERA ŠUMARSTVA I DRVNE TEHNOLOGIJE

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Comparison of Birch and Beech Wood in Terms of Economic and Technological Properties for Plywood Manufacturing

Usporedba ekonomskih i tehnoloških svojstava brezovine i bukovine za proizvodnju furnirske ploče

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ABSTRACT • *The aim of this study was to investigate the use of birch wood, one of the most important wood species used in the plywood industry, especially in Europe, the Nordic countries, Poland, Belarus and Russia as an alternative to beech wood. For this purpose, comparison was made of their economic and technological properties. In five-ply plywood manufacturing, beech (Fagus orientalis Lipsky) and birch (Betula pendula) veneer sheets were used with melamine urea formaldehyde (MUF) and urea formaldehiyde (UF) resins. Some mechanical properties such as shear strength, bending strength and modulus of elasticity of plywood panels were conducted according to EN 314-1 and EN 310, respectively. Mean mechanical strength obtained for birch plywood panels was quite above the limit values specified in the related standards. When taking into consideration the annual increment of beech and birch trees in 1 ha and the time they need to reach suitable diameters for the manufacturing of rotary cut veneers, it was calculated that birch trees provide 2.46 times more physical harvesting than beech trees.*

Keywords: *birch, beech, economic comparison, technological properties, plywood*

SAŽETAK • *U radu je istraživana uporaba brezovine kao jedne od najvažnijih vrsta drva koja se upotrebljava kao alternativa bukovini za proizvodnju furnirskih ploča, posebice u Europi, u nordijskim zemljama, Poljskoj, Bjelorusiji i Rusiji. Za potrebe rada uspoređivana su njihova ekonomska i tehnološka svojstva. U proizvodnji furnirske ploče od pet slojeva upotrijebljeni su listovi furnira od bukovine (Fagus orientalis Lipsky) i brezovine (Betula pendula), koji su slijepljeni ljepilom na bazi melamin-urea-formaldehidnih (MUF) i urea-formaldehidnih (UF) smola. Ispitana su mehanička svojstva furnirskih ploča prema normi EN 314-1 i EN 310, i to čvrstoća na smicanje, čvrstoća na savijanje i modul elastičnosti. Dobivene srednje vrijednosti čvrstoće brezovih i bukovih furnirskih ploča bile su znatno iznad graničnih vrijednosti navedenih u normama. Kada se u obzir uzme godišnji prirast bukve i breze na 1 ha šume i vrijeme potrebno za postizanje odgovarajućih promjera za proizvodnju ljuštenih furnira, izračunano je da breza osigurava 2,46 puta više raspoložive količine za sječu od bukve.*

Ključne riječi: *breza, bukva, ekonomska usporedba, tehnološka svojstva, furnirska ploča*

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1 INTRODUCTION
1. UVOD

Plywood is a wood composite with good physical and mechanical properties and can be used in construction and furniture industry. Its production in the world and Europe in 2016 exceeded 159 and 8 million cubic meters, respectively (FAO, 2018). European Union (EU) imports of panels (mainly plywood) increased by 9 % to Euro 2.79 billion in 2017. This follows a 3 % rise in 2016 and an 11 % increase in 2015. Most of this gain was due to a rise in plywood imports from Russia and other Eastern European countries. The value of EU plywood imports from China and tropical countries was generally stable or declining in 2017 (Industry News and Markets, 2018).

Wood species are an important factor for technological properties and sale price of plywood panels. Beech wood is the most widely used wood species for plywood manufacturing in Turkey. Beech forests indigenously grow in central Europe, in the Balkan peninsula, from Greece and Bulgaria up to the Caucasus along the Black Sea Region and Turkey. As a matter of fact, beech wood is one of the most important commercial hardwood species in Southeastern Europe (Skarvelis *et al*., 2013). Beech wood is classified as a medium density hardwood; it is heavy, hard, strong, high in resistance to shock, and highly suitable for steam bending (Bektas *et al*., 2002).

Birch (*Betula pendula*), a hardwood species, is the most significant deciduous tree species in Europe, the Nordic countries, Poland, Belarus and Russia. Birch wood is mainly used for plywood production and for indoor applications due to its low dimensional stability (Hill 2006; Biziks *et al*., 2013). Birch plywood production in Russia has demonstrated constant growth in recent years, producing nearly 3.5 million cubic meters in 2016. This industry is heavily export-oriented, with more than half of the volume being sold to lucrative markets in Europe, North America and the Middle East & North Africa (MENA). The total value of exported Russian birch plywood amounted to almost 1 billion dollars in 2016 (Hanninen, 2017).

The quality and production costs of beech plywood panels are affected by the formation of red heartwood and difficulties in wood preservation and log storage. It was stated that the diameter of the logs used in plywood manufacturing needed to be at least 35 cm (Lutz, 1978). Beech trees in the existing forests in Turkey reach this diameter in 120 years (Toksoy *et al.*, 2006). For birch trees, this growth is slow in the first years and followed by rapid growth. Growth ceases after 50 years (Cakiroglu and Aydin, 2012).

In this study, comparison was made between the economic and technological benefits of the use of birch wood instead of beech wood as a raw material in plywood manufacturing process. For this purpose, some technological properties of plywood manufactured from beech and birch logs were determined and then compared with the values specified in related standards. On the other hand, the quantity of birch and beech logs that can be obtained from the same area in the existing forests of Turkey was determined by using increment and rotation age values. Afterwards, the prices of beech and birch logs were also taken into consideration and the costs of these logs were discussed.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Beech (*Fagus orientalis* Lipsky) logs with 45 cm diameter obtained from the Ordu region, which is located on the north cost of Turkey, and birch logs with 35 cm diameter obtained from Ukraine were used in this study. Veneer sheets with 1.5 mm thickness were obtained by rotary cutting under laboratory conditions after the steaming of beech and birch logs at the temperature of 70 °C - 90 °C for 12 hours. The horizontal opening (distance from the leading edge of pressure bar to a plane extended from the ground surface of the knife) was 85 % of the veneer thickness and the vertical opening was 0.5 mm in the rotary peeling process.

The veneers obtained were dried to 6-8 % moisture content by using a veneer dryer. Five-ply plywood panels with the dimensions of 60 cm x 60 cm and thickness of 7 mm were manufactured. Two types of resins were used as adhesive, melamine-urea formaldehyde (MUF) and urea formaldehyde (UF) resins with 55 % solid content. MUF and UF resin solutions used in plywood manufacturing were composed of 100 parts MUF and UF resins, 30 parts wheat flour and 10 parts NH_4Cl (with 15 % concentration) as hardener, by weight. Technical specifications of UF and MUF resins supplied by the producers of resins are given in Table 1.

The glue mixture was applied at a rate of 160 g per square meter to individual surfaces of veneers with a four-roller glue spreader. Three different plywood drafts were formed for each resin as completely beech veneers in all layers, completely birch veneers in all layers and as

Table 1 Technical specifications of urea formaldehyde and melamine-urea formaldehyde resins
Tablica 1. Tehnička svojstva urea-formaldehidne i melamin-urea-formaldehidne smole

Specifications / *Svojstva*	**Urea Formaldehyde (UF)** *Urea-formaldehidna smola*	**Melamine-Urea Formaldehyde (MUF)** *Melamin-urea-formaldehidna smola*
Solid content / *sadržaj suhe tvari*, %	54-56	54-56
Density / *gustoća*, g/cm^3 *pri* 20 °C	1.22-1.23	1.225-1.240
Viscosity / *viskoznost*, cP·s *pri* 20 °C	100-200	90-150
Gelation time / *vrijeme želiranja*, s	15-25	70-110
Flow rate / *vrijeme istjecanja pri* 20 °C	25-45	20-40
Free formaldehyde / *slobodni formaldehid*, %	max. 0.8	max 0.16
pH, at 20 °C	7.5-8.5	8.5-9.5

mixed panel (beech-birch-beech-birch-beech). Hot press time and temperature were 7 minutes and 110 °C, respectively, while press pressure was 12 kg/cm^2. Two replicate plywood panels were manufactured for each test group. Test samples were conditioned to achieve equilibrium moisture content at 20 °C temperature and 65 % relative humidity prior to testing.

The bonding strength of plywood panels was determined according to EN 314-1 (1998) standard with a universal testing machine. Samples manufactured with MUF and UF resins were tested after immersion in water at 20 °C for 24 h. Twenty-five specimens were used for the evaluation of shear strength tests. Bending strength and modulus of elasticity tests were conducted according to EN 310 (1993) standard on a universal testing machine. Eighteen test samples (9 transverse and 9 longitudinal test pieces) of all test groups were prepared for bending strength and MOE tests and arithmetic mean values of the test results were used.

Multifactor analysis of variance was performed for the statistical evaluation of changes in mechanical properties depending on the wood species and glue types. After multifactor analysis of variance, Student-Newman-Keuls test at the confidence level of 95 % was used to compare the mean values of variance sources.

3 RESULTS
3. REZULTATI

3.1 Mechanical properties of panels
3.1. Mehanička svojstva ploča

The mean values of shear strength, bending strength and modulus of elasticity of plywood panels are given in Table 2, and the results of the multifactor analysis of variance related to these mechanical properties are given in Table 3.

Student-Newman-Keuls test at the confidence level of 95 % was used to compare the mean values of variance sources, and the results of statistical evaluation are given in Table 4.

According to Table 2, the values of mechanical properties of beech plywood panels for UF resin were higher than those obtained for birch and mixed plywood. However, the highest bending strength and modulus of elasticity values for MUF resin were found for birch plywood panels. The results of multifactor analysis of variances also proved that the difference between plywood panels manufactured from beech, birch and mixed veneers was significant. The effect of veneer wood species and glue types on modulus of elasticity and shear strength was significant with error

Table 2 Mean values of bending strength, modulus elasticity and shear strength of beech and birch plywood
Tablica 2. Srednje vrijednosti čvrstoće na savijanje, modula elastičnosti i čvrstoće na smicanje bukove i brezove furnirske ploče

Glue type *Vrsta ljepila*		**Bending strength** *Čvrstoća na savijanje*, N/mm^2			**Modulus of elasticity** *Modul elastičnosti*, N/mm^2			**Shear strength** *Čvrstoća na smicanje*, N/mm^2		
		Beech	Birch	Mixed	Beech	Birch	Mixed	Beech	Birch	Mixed
UF	*X*	104.58	94.34	92.26	7269.6	6044.9	6007.5	3.26	2.89	2.57
	S	5.90	9.90	5.06	313	570	757	0.39	0.35	0.30
MUF	*X*	94.69	100.88	97.41	6899.1	7096.9	6498.4	3.87	3.06	2.96
	S	8.73	10.41	12.86	437	533	465	0.19	0.46	0.38

X: Arithmetic mean values / *X - aritmetička sredina*
S: Standard deviation / *S - standardna devijacija*

Table 3 The effect of sources of variation on bending strength, modulus of elasticity and shear strength of plywood panels
Tablica 3. Utjecaj uzroka odstupanja na čvrstoću na savijanje, modul elastičnosti i čvrstoću na smicanje furnirskih ploča

Mechanical properties *Mehanička svojstva*	**Source of variation** *Uzroci odstupanja*	**Sum of squares** *Zbroj kvadrata*	**Degrees of freedom** *Stupnjevi slobode*	**Mean squares** *Srednja vrijednost kvadrata*	**F-value** *F-vrijednost*	**Sig. level** *Stupanj značajnosti*
Bending strength *čvrstoća na savijanje*	Wood species / *vrsta drva*	418.132	2	209.07	2.064	NS
	Glue type / *vrsta ljepila*	9.782	1	9.782	0.097	NS
	Interactions: Wood species - Glue type / *međudjelovanje: vrsta drva - vrsta ljepila*	1494.183	2	747.092	7.377	***
Modulus of elasticity *modul elastičnosti*	Wood species / *vrsta drva*	1.27	2	6335558.01	22.508	***
	Glue type / *vrsta ljepila*	4122830.609	1	4122830.609	14.647	***
	Interactions: Wood species - Glue type / *međudjelovanje: vrsta drva - vrsta ljepila*	9241163.061	2	4620581.531	16.415	***
Shear strength *čvrstoća na smicanje*	Wood species / *vrsta drva*	17.336	2	8.668	67.881	***
	Glue type / *vrsta ljepila*	5.704	1	5.704	44.668	***
	Interactions: Wood species - Glue type / *međudjelovanje: vrsta drva - vrsta ljepila*	1.208	2	0.604	4.730	**

NS: Non-significant / *NS - nije značajno*
***Significant at the 0.001 level / *značajno na razini 0,001*

Table 4 Newman-Keuls table related to the effect of wood species and glue types on the variance sources on bending strength, shear strength and modulus of elasticity of plywood panels ($p \leq 0.01$)
Tablica 4. Newman-Keulsova tablica vezano uz utjecaj vrste drva i vrste ljepila na uzroke odstupanja čvrstoće na savijanje, čvrstoće na smicanje i modula elastičnosti furnirskih ploča ($p \leq 0,01$)

Source of variation *Uzroci odstupanja*		***N***	**Shear strength** *Čvrstoća na smicanje,* N/mm²		***N***	**Bending strength** *Čvrstoća na savijanje,* N/mm²		***N***	**Modulus of elasticity** *Modul elastičnosti,* N/mm²	
Wood species *vrsta drva*	Beech	50	3.57	a*	36	99.64	a	36	7084	a
	Birch	50	2.98	b	36	97.61	a	36	6571	b
	Mixed	50	2.76	c	36	94.84	a	36	6253	c
Glue types *vrsta ljepila*	MUF	75	3.30	a	54	97.66	a	54	6831	a
	UF	75	2.91	b	54	97.06	a	54	6441	b

*Different letters indicate statistically significant difference. / **Različita slova označavaju statistički značajnu razliku.*

probabilities of 0.001. However, the effect of wood species and glue types on bending strength was not significant as shown in Table 3.

As can be seen in Table 4, the effects of wood species and glue types on mechanical properties were found statistically significant. The values of shear strength and modulus of elasticity of beech plywood panels were determined higher than those of birch and mixed plywood panels. The reason may lie in the fact that the density of beech wood was higher compared to birch wood. Oven-dry density values of beech (*Fagus orieantalis* Lipsky) and birch (*Betula pendula*) wood were stated as 0.64 g/cm³ and 0.52 g/cm³, respectively (Malkocoglu, 1994; Herajarvi, 2002). It was concluded in the literature that the shear strength of wood increases with increasing density (Chow and Chunsi, 1979; Namara and Waters, 1970). Therefore, it was not a surprising result that the values of shear strength and modulus of elasticity of beech plywood panels were higher than those of birch plywood. Toksoy *et al*. (2006) reported in their studies regarding the use of alder (*Alnus glutinosa* subsp. barbata) wood as an alternative to beech wood that the values of bending strength, modulus of elasticity and shear strength of alder plywood were found as 79 N/mm², 6499 N/mm² and 2.75 N/mm², respectively. Similarly, the values of bending strength, modulus of elasticity and shear strength of plane (*Platanus orientalis*) plywood were found as 70 N/mm², 3960 N/mm² and 1.77 N/mm², respectively (Demirkir *et al.*, 2013). MUF resin was used as adhesive in both studies mentioned above. In the present study, the values of mechanical properties of birch plywood were 101 N/mm², 7096 N/mm² and 3.06 N/mm², respectively. According to these results, birch wood can be stated as a better alternative to beech wood when compared to alder and plane wood.

Also, the MUF-bonded plywood panels generally have higher values of shear strength and modulus of elasticity than those of UF-bonded plywood panel groups. Gindl and Gupta (2002) stated that the treatment of wood with melamine–formaldehyde resin showed a considerable potential to improve mechanical properties. However, as can be seen in Table 4, the effects of wood species and glue types on the bending strength of all groups were not found statistically significant in the present study.

Mean values of shear strength obtained from the samples of all plywood panels manufactured from birch logs were above the limit value (1.0 N/mm²) specified in EN 314-2 (1998) standard. Mean values obtained for bending strength of plywood panels were also higher than the limit values for structural purpose plywood panels (40 N/mm²) specified in DIN 68705-3 (1981). It has been specified in DIN 68792 (2016) that bending strength values parallel to the grain direction of plywood panels, with thicknesses up to 6 mm, need to be at least 75 N/mm², if the panels are used for concrete mould. Modulus of elasticity values of plywood were limited with 8500 N/mm² up to 6 mm thickness and 5000 N/mm² for panels with thickness of 6-12 mm. According to the results, all plywood panels manufactured in this study had satisfactory bonding for indoor applications.

3.2 Economic analysis
3.2. Ekonomska analiza

A few studies of birch plantations in Baltic countries (Liepiņš, 2011) and in naturally regenerated birch stands (Aosaar *et al*., 2016) covering an age range from 15 to 20 years, report birch MAI (Mean Annual Increment) around 10 m³ ha-1 yr-1 (Lutter, 2017). However, the mean annual increment of beech and birch in 1 ha is 2.3 and 3 m³, respectively, in the existing forests in Turkey (State Planning Organization, 2001). When these values are taken into consideration, increment coefficient *X* is found as (1),

$$X = \frac{2.3\ (\text{beech})}{3\ (\text{birch})} = 0.77 \qquad (1)$$

The time required to reach sufficient log diameter for veneer production by rotary peeling is 120 years for beech (Kiris, 2002). Economic studies on birch on fertile forestland and on abandoned agricultural land show that the financial maturity age of birch is around 35 to 40 years (mean 37.5 years), to produce plywood, saw logs and pulpwood (Korjus *et al*., 2011; Tullus *et al*., 2012).

Accordingly, the harvesting time *coefficient Y* is determined as (2),

$$X = \frac{120\ (\text{beech})}{37.5\ (\text{birch})} = 3.2 \qquad (2)$$

The yield is mostly dependent on the log diameter in plywood production. As it was considered that beech and birch trees have the same log diameter at the end of the harvesting season, the productivity coefficient according to log diameter was assumed as *Z*=1 when in-

crement quantity per hectare and the required time to reach sufficient log diameter for veneer production were taken into consideration. The difference between birch and beech was calculated by the following equations.

1 birch = ($X \times Y \times Z$) beech

1 birch = ($0.77 \times 3.2 \times 1$) beech

1 birch = 2.464 beech

Birch was calculated to provide 2.46 times more physical harvesting than beech by considering the present conditions of the forests in Turkey. In addition to this, the prices of birch and beech logs should be evaluated. The price of any product is generally determined by its supply and demand. Changes in supply and demand cause the change in price, too. Therefore, it is very difficult to estimate changes connected with price that include long periods. In addition, the price of any material can change depending on many factors, such as inflation, exchange rate, substitute goods, complement goods, interest and quality (Toksoy *et al*., 2006). The average market price of logs in Turkey was 105 $/m^3 for birch and 163 $/m^3 for beech in 2018. When birch logs are used for plywood production instead of beech logs, raw material cost can be reduced at a rate of 35 % according to the market prices.

4 CONCLUSIONS
4. ZAKLJUČAK

Although the use of beech, which is one of the most important wood species, is appropriate for general purpose plywood production in terms of veneer production technology, such production leads to a significant loss in terms of country economy. As known, general purpose plywood does not require high quality properties in the place of use. Suitable technologies should be developed for the use of fast-growing native wood species in general purpose plywood production. It is important to evaluate high-quality beech logs in the furniture industry in terms of ease of processing and technological properties. Birch plywood is produced in some small capacity plywood factories in our region, instead of beech plywood. The present study showed that birch plywood panels are good enough for general purpose use. Birch wood is cheaper than beech wood, and it has suitable density and colour. It has been concluded that the mechanical strength of birch plywood panels was almost the same as that of beech plywood. Therefore, birch wood can be used in all areas where beech wood has been traditionally used. Birch logs are also recommended for plywood production instead of beech logs and this can lead to the decrease in plywood manufacturing costs.

5 REFERENCES
5. LITERATURA

1. Aosaar, J.; Mander, Ü.; Varik, M.; Becker, H.; Morozov, G.; Maddison, M.; Uri, V., 2016: Biomass production and nitrogen balance of naturally afforested silver birch (*Betula pendula* Roth.) stand in Estonia. Silva Fennica, 50: 1-19. http://doi.org/10.14214/sf.1628.
2. Bektas, I.; Guler, C.; Basturk, M. A., 2002: Principal mechanical properties of Eastern beech wood (*Fagus orientali*s Lipsky) naturally grown in Andırın Northeastern Mediterranean region of Turkey. Turkish Journal of Agriculture and Forestry, 26 (3): 147-154.
3. Biziks, V.; Andersons, B.; Beļkova, Ļ.; Kapača, E.; Militz, H., 2013: Changes in the microstructure of birch wood after hydrothermal treatment. Wood Science and Technology, 47 (4): 717-735. https://doi.org/10.1007/s00226-013-0531-1.
4. Chow, S.; Chunsi, K. S., 1979: Adhesion strength and wood failure relationship in wood-glue bonds. Mokuzai Gakkaishi, 25 (2): 125-131.
5. Cakiroglu, E. O.; Aydin, I., 2012: The usage of birch wood in plywood manufacturing as alternative to beech wood. Kahramanmaraş Sütçü İmam University Journal of Engineering Sciences, Special issue, 50-55.
6. Demirkir, C.; Colakoglu, G.; Colak, S.; Aydin, I., 2013: Utilization of sycamore tree as an alternative wood specie in plywood manufacturing. Duzce Forestry Journal, 9 (2): 9-13.
7. Gindl, W.; Gupta, H. S., 2002: Cell-wall hardness and young's modulus of melamine- modified spruce wood by nano-ındentation, composites, Part A: Applied Science and Manufacturing, 33 (8): 1141-1145. https://doi.org/10.1016/S1359-835X(02)00080-5.
8. Hanninen, V., 2017: Possible Export Ban of Russian Birch Logs on the Horizon. Technical reports, Indufor Group, Finland.
9. Heräjärvi, H., 2002: Properties of birch (*Betula pendula*, B. pubescens) for sawmilling and further processing in Finland. The finnish Forest Research Institute, Research Papers 871.52p + Five Appendices.
10. Hill, C. A. S., 2006: Wood Modification: Chemical, Thermal and Other Processes. John Wiley & Sons, p. 239, ISBN: 0-470-02172-1.
11. Kiris, R., 2002: Regulations on forest management. Ankara, Turkey: Ministry of Forestry of Turkish Republic.
12. Korjus, H.; Põllumäe, P.; Rool, S., 2011: Profitability analysis of short rotations in Scots pine, Norway spruce and silver birch stands. Forestry Studies, 54: 28-36.
13. Liepiņš, K., 2011: Growth of silver birch (*Betula pendula* Roth) in plantations on farmlands in Latvia. Mežzinātne, 23: 3-14 (in Latvian with English summary).
14. Lutter, R., 2017: Growth development and ecology of midterm hybrid aspen and silver birch plantations on former agricultural lands. PhD Thesis, Estonian University of Life Sciences, Estonia.
15. Lutz, J. F., 1978: Wood veneer: log selection, cutting, and drying. US Department of Agriculture, Technical bulletin no.1577.
16. Malkoçoğlu, A., 1994: Technological properties of beech (*Fagus orientalis* Lipsky) wood. PhD Thesis, Karadeniz Technical University, Trabzon, Turkey.
17. Namara, U. S.; Waters, O., 1970: Comparison of the rate of glueline strength development for oak and maple. Forest Product Journal, 20 (3): 34-35.
18. Skarvelis, M.; Mantanis, G., 2013: Physical and mechanical properties of beech wood harvested in the Greek public forests. Wood Research, 58 (1): 123-130.
19. Toksoy, D.; Çolakoğlu, G.; Aydin, I.; Çolak, S.; Demirkir, C., 2006: Technological and economic comparison of the usage of beech and alder wood in plywood and laminated veneer lumber manufacturing. Building and Environment, 41 (7): 872-876. https://doi.org/10.1016/j.buildenv.2005.04.012.
20. Tullus, A.; Lukason, O.; Vares, A.; Padari, A.; Lutter, R.; Tullus, T.; Karoles, K.; Tullus, H., 2012: Economics of

hybrid aspen (*Populus tremula* L. × *P. tremuloides* Michx.) and silver birch *(Betula pendula* Roth) plantations on abandoned agricultural lands in Estonia. Baltic Forestry, 18: 288-298.
21. ***1981: DIN 68705-3. Plywood; building-veneer plywood. German Institute for Standardization, Germany.
22. ***1993: EN 310. Wood based panels. Determination of modulus of elasticity in bending and of bending strength. European Standard.
23. ***1998: EN 314-1. Plywood–bonding quality–Part1: test methods, European Standard.
24. ***2018: Industry News and Markets. Wood Products Prices in Europe The International Tropical Timber Organization (ITTO) Tropical Timber Market Report, U.S.
25. ***2001: State Planning Organization. VIII. Five year development plan (2001 – 2005). Forestry special experts commission report, State Planning Organization, Pub. No. 2531, Ankara, Turkey.
26. ***2016: DIN 68705-3. Large area shuttering panels of veneer plywood for concrete and reinforced concrete. German Institute for Standardization, Germany.
27. ***2018: The Food and Agriculture Organization (FAO). FAOSTAT-FAO Statics Division – Production Quantity/ Plywood. http://faostat3.fao.org/browse/F/FO/E.

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Compliance of Preschool Chair Dimensions

Usklađenost dimenzija stolica za djecu predškolske dobi

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ABSTRACT • *The proper growth and development of children is conditioned by many factors. One of the most overlooked prerequisite is the proper posture of the body in a seated position, which could be disrupted by the incorrectly dimensioned chairs used in kindergartens. To authenticate dimensions of preschool chairs in relation with contemporary European Standard 1729-1:2015, the research has been conducted in 14 public kindergartens in three European countries: Republic of Croatia, Republic of North Macedonia and Republic of Bulgaria. The results lead to the conclusion that a small number of chairs fulfil dimensional requirements. From the obtained data of the analysed chairs used by preschool children certain deficiencies can be identified. The stated findings could be the basis for new suggestions and improvements of outdated furniture design with the aim to improve relevant regulations, standards and guidelines in order to present new preschool furniture quality parameters related to contemporary needs of children in kindergartens to the local authorities, furniture manufacturers and investors.*

Keywords: *preschool furniture, kindergartens, EN 1729-1, functional dimensions of furniture*

SAŽETAK • *Pravilan rast i razvoj djece uvjetovani su mnogim čimbenicima. Jedan od često previđanih preduvjeta pravilnog razvoja jest ispravno držanje tijela u sjedećem položaju, što može dovesti do pogrešnog dimenzioniranja stolica na kojima djeca sjede u dječjim vrtićima. Kako bi se dokazala usklađenost dimenzija stolica namijenjenih djeci predškolske dobi sa suvremenom europskom normom EN 1729-1:2015, istraživanja su provedena u 14 javnih dječjih vrtića u tri europske države: Republici Hrvatskoj, Republici Sjevernoj Makedoniji i Republici Bugarskoj. Rezultati upućuju na zaključak da samo mali broj stolica u cijelosti ispunjava dimenzijske zahtjeve. Iz dobivenih podataka analiziranih stolica kojima se koriste djeca predškolske dobi mogu se identificirati određeni nedostatci. Navedeni zaključci mogu biti osnova za nove prijedloge i poboljšanja dizajna zastarjelog namještaja te bi trebali biti usmjereni na poboljšanje relevantnih propisa, standarda i smjernica kako bi se lokalnim vlastima, proizvođačima namještaja i investitorima predstavili novi parametri kvalitete namještaja za djecu predškolske dobi, što se ponajprije odnosi na suvremene potrebe djece u vrtićima.*

Ključne riječi: *namještaj za djecu predškolske dobi, vrtići, EN 1729-1, funkcionalne dimenzije namještaja*

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1 INTRODUCTION
1. UVOD

Today's children aged from 1 to 7 years (in some countries from 6 months to 7.5 years) spend in kindergartens six to eight hours a day, mostly playing, learning, sleeping or eating. All these activities are usually taken in sitting, standing or lying positions of the body (Domljan *et al*., 2015). The playrooms, in which almost all the activities during the day are carried out, should be adapted to different children's needs and susceptible to easy changes, transformations and adaptations (Dudek, 2005). Adequate design of equipment and furniture as well as proper spatial organization could improve or aggravate children's social, mental, cognitive and physical behaviour and development (Bajbutović, 1983; Prebeg and Prebeg, 1985; Pisareva, 1999; Auf-Franić *et al*., 2003; Iliev, 2011; Domljan, 2011).

In order to design adequate furniture and other equipment in kindergartens and enable proper growth and development of preschool children, there are some contemporary problems and aspects that have to be pointed out when equipping of kindergartens:
- children's anthropometry and furniture dimensions
- posture of children's body while sitting, and
- furniture procurement and production.

This research deals with the analysis of compliance of the observed preschool chair with relevant standards, in three different countries and their capital cities: Zagreb (Republic of Croatia), Skopje (Republic of North Macedonia) and Sofia (Republic of Bulgaria).

The aim of the research was to investigate whether the dimensions of the chairs used in observed preschool institutions are in compliance with the standard EN 1729-1:2015 Furniture – Chairs and tables for educational institutions – Part 1: Functional dimensions (2015).

1.1 Children's anthropometry and furniture dimensions
1.1. Antropometrija djece i dimenzije namještaja

The main requirement in designing children's furniture is to pay attention to the children's anthropometry (Iliev and Domljan, 2016). Anthropometric data of the children's body has to be used respecting the age and sex of the child (Iliev *et al*., 2018). In the earliest years of childhood, the spinal column, as all other bones, are not sufficiently formed (Prebeg and Prebeg, 1985). If the chair is designed according to the shapes of the children's body, it is expected that the body will be developed properly (Domljan, 2011). The second aspect is the size (dimensions) of the furniture, especially chairs and tables that are most widely used. The surveys showed a mismatch between dimensions of furniture in educational institutions and anthropometric dimensions of children (Hedge and Lueder, 2007; Domljan *et al*., 2008; Iliev and Domljan, 2017). Inappropriate furniture, which is not compatible with the children's body dimensions, could be one of the key factors for musculoskeletal disorders and back pain in the future (MSD/BP) (Hedge and Lueder, 2007; Domljan *et al*., 2010a).

1.2 Posture of children's body while sitting
1.2. Držanje tijela djece pri sjedenju

One of the key requirements for the psychophysical development of children is the proper way of sitting and performing tasks in a sitting position (Knight and Noyes, 1999; Troussier *et al*., 1999). The chair is one of the furniture elements that is compulsory when equipping kindergartens (Domljan *et al*., 2015). Although a number of considerations and researches proved that the chair will never be enough comfortable for sitting (Cranz, 1998), children already in kindergarten learn "proper" sitting and "correct" posture when sitting. The anatomy of the child's body, the dimension of individual body variables, and the position of the body that the child takes in each activity in the kindergarten have a great influence on the design and construction of the chair for preschool upbringing. For now, unfortunately, the child's body has to adjust to the shape and curves of the chair when sitting, and not the other way round (Domljan *et al*., 2010b).

1.3 Furniture production and procurement
1.3. Proizvodnja i nabava namještaja

There are a few problems in production and procurement of preschool furniture, such as: the low price of the equipment procured through public tendering, low quality of the furniture mostly because of the low price, scarce number of references, standards and guidelines for designing contemporary furniture, etc.

Furniture used in public preschool institutions is always procured through public procurement (Domljan *et al*., 2015). Until recently, free choice in procurement and equipping public preschool institutions used to be limited by insufficient specifications directed towards only one criterion: the lowest price of the furniture and other equipment. This means that the financial factor was decisive for the procurement, while all others (e.g. ergonomic, quality or contemporary methods in education process) were neglected (Vlaović *et al*., 2003). As each municipality does not have the same financial resources, the differences are more prominent. Private kindergartens usually do not have such financial issues, but they also lack the proper knowledge for furnishing kindergartens with quality furniture (Domljan *et al*., 2015).

There are a few relevant documents in the Republic of Croatia (National Pedagogical Standard for Pre-School Education, 2008), in the Republic of North Macedonia (Regulations of Activities in Children's Educational Institutions, 2009) and in the Republic of Bulgaria (Ordinance No. 3 on Health Requirements for Kindergartens, 2007), which superficially describe the procedures in equipping kindergartens, types and number of furniture, and give information about how interiors and exteriors of kindergartens should look like. Unfortunately, the appearance and descriptions of the furniture, prescribed in those public regulations, are very much general. As the details are not defined, it leads to a great diversity in the design process among investors, producers and other subjects involved in the process. One of the problems in educational institu-

tions is the lack of investments for quality furniture. Neither the city government nor the local authorities want to invest a much more significant amount of money into design, production or procurement of quality furniture. Kindergartens and schools are sometimes equipped with the furniture older than 50 years (Domljan *et al*., 2015).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Polygons
2.1. Poligoni

The research was performed in three countries in their capital towns in 14 public kindergartens (polygons), from March to September 2017 (Table 1).
The polygons were selected by the following criteria:

i. Geographical position and public regulations of kindergartens:

The kindergartens in all three polygons covered either the central or suburban areas of each city. Depending on the city regulations, analysed kindergartens have different administrative and procurement regulations. For instance, in Skopje each kindergarten belongs to different municipalities in the city with different administrative units. In Zagreb and Sofia kindergartens are under the competence of the city government with the same administrative regulations of the local authority. In terms of different criteria arranged from i to vi, polygons were selected as presented in Table 2:

ii. Architecture style:
A – facilities intended for carrying out preschool activities only
B – facilities repurposed into preschool institutions
iii. Age of facility:
C – facilities from the 20th century and older than 20 years
D – new modern facilities build in the last 20 years
iv. Size of kindergarten group:
SG – small group (less than 15 children in the group)
NG – normal group (16 to 30 children in the group)
LG – large group (30 to 45 children in the group)
v. Children's age in kindergarten group:
HE – heterogeneous group (different age of children (from 3 to 7 years)
HO – homogeneous group (similar age of children (+/- 1 year)
vi. Age of furniture used in kindergartens:
O – old (older than 30 years)
CT – contemporary (from 30 to 5 years old)
N – new (no older than 5 years)

2.2 Samples
2.2. Uzorci

The samples were preschool chairs, used by the children at the polygons. The samples were observed and analysed in all three polygon groups. The main characteristics of the selected types of chairs are stated below, with the code given to each type of chair.
Polygon group I:
B – material: solid beech wood (legs, armrests), beech veneer plywood (seat, backrest), plywood thickness:

Table 1 Polygons
Tablica 1. Poligoni

Polygon group *Grupa poligona*	**State** / *Država*	**City** / *Grad*	**Number of polygons** *Broj poligona*
I	Republic of North Macedonia	Skopje	8
II	Republic of Croatia	Zagreb	3
III	Republic of Bulgaria	Sofia	3
Total number of polygons / *Ukupan broj poligona*			14

Table 2 Polygons and their descriptions
Tablica 2. Poligoni i njihovi opisi

Polygon group *Grupa poligona*	**Kindergarten code** *Oznaka vrtića*	**Name of kindergarten, municipality, address** *Ime vrtića, općina, adresa*	**Facility style** *Stil zgrade*	**Age of facility** *Starost zgrade*	**Group size** *Veličina grupe*	**Age of children** *Starost djece*	**Age of furniture** *Starost namještaja*
I	1	*Majski cvet* / Mun. Karposh	A	C	NG	HO	O/N
	2	*11-ti Oktomvri* / Mun. Butel	A	C	NG	HE	O
	3	*Koco Racin* / Mun. Center	A	D	NG	HO	N
	4	*Tashko Karadža* / Mun. Butel	A	C	NG	HO	O
	5	*13-ti Noemvri* / Mun. Center	A	C	LG	HO	N
	6	*Park* / Municipality Center	A	C	NG	HO	CT
	7	*Buba Mara* / Mun. Aerodrom	A	C	NG	HO	O/CT
	8	*Sonce* / Municipality Aerodrom	A	D	NG	HO	N
II	9	*Različak* /Petrinjska str.	A	C	NG	HO	O/CT
	10	*Različak* / Jurišićeva str.	A	C	NG	HE	O/CT
	11	*Različak* / Amruševa str.	A	C	NG	HE	O/CT
III	12	*Bratja Mormarevi* / Vrbacha str.	B	C	LG	HO	O/CT
	13	*Bratja Mormarevi* / Pobeda str.	A	D	NG	HE	O/N
	14	*Mojot svet* / Tsar Simeon str.	A	C	NG	HO	O/CT

seat - 7 mm / backrest 6 mm; surface: PU colourless vanish, visible screws; rounded front of the seat; backrest without a pronounced lumbar support; inclination of backrest 10°; negative seat slope; armrest as constructional part of legs; stackable chair.
C – material: solid beech wood (legs, backrest), beech veneer plywood (seat); surface: stained wood, PU vanish; turned legs and backrest carriers; visible screws; backrest without a pronounced lumbar support, inclination 0°; curved seat; non stackable chair.
D – material: solid beech wood (legs), beech veneer plywood (seat and backrest), plywood thickness: seat - 7 mm / backrest 6 mm; surface: red coloured plywood, PU colourless vanish; visible screws; rounded front of the seat; backrest without a pronounced lumbar support; inclination of backrest 5°; negative seat slope; non stackable chair.
F – material: moulded plastic; surface: slippery, shinny, green coloured; rounded edges; seat inclination 0°; backrest inclination 0°, without a pronounced lumbar support; adaptable sitting height (plastic caps at the bottom of legs); stackable chair.
H – material: solid beech wood (legs, armrest), beech upholstered plywood (seat, backrest); chipboard (working top); surface: PU colourless vanish, laminated chipboard; vinyl upholstery; seat and backrest inclination 0°; visible screws; non stackable chair.
Polygon group II:
K – material: solid beech wood (legs, armrests), beech veneer plywood (seat, backrest), plywood thickness seat - 7 mm / backrest 6 mm; surface: PU colourless vanish; rounded front of the seat; backrest without a pronounced lumbar support; inclination of backrest 5°-7°; negative seat slope; visible screws; non stackable chair.
L – material: solid beech wood (legs, armrests), beech veneer plywood (seat, backrest), plywood thickness seat - 7 mm / backrest 6 mm; surface: PU colourless vanish; rounded front of the seat; backrest without a pronounced lumbar support; inclination of backrest 15°; negative seat slope; visible screws; stackable chair.
Polygon group III:
N – material: moulded plastic; surface: slippery, shinny, red coloured; rounded edges; seat inclination 0°; backrest inclination 10°, without a pronounced lumbar support; stackable chair.
P – material: solid fir wood (seat, legs, backrest); surface: stained wood, PU colourless vanish; non rounded front of the seat; backrest without a pronounced lumbar support; seat and backrest inclination 0° inclination of backrest and seat 0°; visible screws (wooden construction with tenon and groove); non stackable chair.
Q – material: solid beech wood (legs), beech veneer plywood (seat, backrest), plywood thickness seat - 10 mm / backrest 8 mm; surface: PU colourless vanish (legs), painted floral motifs (seat, backrest); rounded edges 10 mm; backrest without a pronounced lumbar support; inclination of backrest 10°; seat slope 0°; non visible screws; (wooden construction with tenon and groove); non stackable chair.

2.3 Methods
2.3. Metode

Two main types of methods have been used in the research:
- objective method of direct measurement of the samples, and
- method of observing, recording and photographing the samples

The samples have been selected, analysed and measured directly at the polygons (Table 2). Nine variables have been measured according to EN 1729-1:2015 (Table 3).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Most kindergartens in one polygon have the same or similar chairs, depending on manufacturers and procurement regulations in the city. Regardless of those similarities, large differences were found in each kindergarten with respect to types, shape and construction, functionality, dimensions, materials and colours of chairs.

It was found that a total of 20 different types of chairs were used by children in polygons. Generally, all types of chairs were made in two sizes:
- the higher chair, used in all kindergarten groups (children aged 3 to 7 years)
- the lower chair, used in nursery groups (children aged 6 months to 3 years)

Among all 20 types, only 10 types of chairs were selected for future analysis and measurement. These 10 types were in the group of armchairs or chairs made from foams and could not be observed and measured in accordance with EN 1729-1:2015. Also, the reason for the selection was the measuring procedure. Namely,

Table 3 Variables measured on the samples, according to EN 1729-1:2015
Tablica 3. Varijable izmjerene na uzorcima, prema EN 1729-1:2015

Symbol / *Oznaka*	**Description** / *Opis*
h8	seat height / *visina sjedala*
b3	seat width / *širina sjedala*
t4	effective depth of seat / *efektivna dubina sjedala*
b4	backrest width / *širina naslona*
h7	height to highest point of backrest / *visina do najviše točke naslona*
α	inclination of (single-sloped) seat, degrees / *nagib sjedala u stupnjevima*
γ	angle between seat and backrest / *kut između sjedala i naslona*
p	height of armrest above seat / *visina naslonā za ruke iznad sjedala*
r	width between armrests / *razmak između naslonā za ruke*

Table 4 Results of functional dimensions of samples
Tablica 4. Rezultati funkcionalnih dimenzija uzoraka

Polygon group *Grupa poligona*	**Chair code** *Šifra stolice*	**Dimensions** / *Dimenzije*, mm								
		h8	*b3*	*t4*	*b4*	*h7*	α	γ	*p*	*r*
I	B	270	300	280	320	125	5°	100°	1,5	300
	C	290	330	300	290	40	(-)5°	95°	/	/
	D	290	300	300	320	120	3°	95°	/	/
	F	270	300	300	300	130	0°	93°	/	/
	H	240	300	250	300	270	0°	105°	130	300
II	K	290	290	270	305	150	0°	113°	110	290
	L	270	300	266	310	270	(-)3°	95°	133	310
III	N	300	310	250	310	300	0°	105°	/	/
	P	305	240	290	220	40	0°	90°	/	/
	Q	285	280	290	320	130	0°	100°	/	/

according to EN 1729-1:2015, Annex F, furniture sizes 3 to 7 have to be measured with special equipment, like SCMD (School Chair Measuring Device), which was not used in kindergartens.

The size of the selected 10 chairs was 0, 1 and 2, marked with letters B to Q, as described in chapter 2.2. The results of measured functional dimensions of chairs are given in Table 4.

3.1 Comparison of samples dimensions and requirements of EN 1729-1:2015
3.1. Usporedba dimenzija uzoraka sa zahtjevima norme EN 1729-1:2015

The European Standard EN 1729-1:2015 *Furniture – Chairs and tables for educational institutions – Part 1: Functional dimensions* (***, 2015) is applied by the national technical committee in all three countries considered in this study. Thanks to this fact, it was possible to compare the analysed samples in all polygons.

The results of the measured variables and the relation with the standard are shown in Table 5.

The inconsistency and deviation from the standard are indicated with **bold-underlined** or marked with *minus* sign (-).

The comparison is aimed to determine whether the measured dimensions correspond to the standard, whether the furniture is correctly marked, whether the instructions for use are provided and whether the differences in children's height are taken into consideration.

Besides the applicable but not mandatory standard EN 1729-1, each country has its own regulations / guidelines / normatives for equipping preschool institutions.

The problem with the regulations or guidelines mostly lies in very short and cursory descriptions of detailed product design. For example, the applicable *Regulations of Activities in Children's Educational Institutions* (2009) in the Republic of North Macedonia describe the furniture as follows: "Equipment and furniture in kindergartens should be functional, portable, stable, made of quality material, preferably natural one, easy to maintain and with aesthetic appearance and adjusted for the children's age".

The meaning of "quality material" or "aesthetic appearance" is not clear enough. In the Republic of Croatia, the currently applicable *National Pedagogical Standard for Pre-School Education* (2008) has almost the same description.

In the Republic of Bulgaria, the description for chairs is given in the *Ordinance No. 3* (2007) related to health requirements in kindergartens. It reads as follows: "The playroom is equipped with tables and chairs adapted to the anatomical and physiological features of children of the respective age group. A dining corner shall be set up with tables and chairs adapted to the anatomical and physiological characteristics of children of the respective age group".

Similarly as above, the meaning of "adapted to the anatomical and physiological characteristics" is not quite clear.

The comparison of the samples used in all three polygons shows wide deviations. The main problem is that majority of chairs in some polygons are older than 30 years. It belongs to the time when EN 1729 did not even exist.

Based on three analysed groups of chairs (size marks 0, 1 and 2), it can be concluded that only three types of chairs fit the prescribed dimensions *h8* and *b3* (chair code B, L and M). Other dimensions, such as effective depth of seat (*t4*), backrest width (*b4*), seat inclination (α), angle between seat and backrest (γ), height of armrest above seat (*p*), width between arms (*r*), to mention only a few, are not in accordance with the European Standard for size marks 0, 1 and 2. Therefore, it is necessary to make extensive anthropometric analyses and researches of children of preschool age in order to resolve the diversity of furniture dimensions.

Some samples (chair codes C, D, H, K, P and Q) fulfil neither the dimensions *h8* (height of the seat) nor *b3* (seat width) prescribed in the standard. The largest differences were observed in the dimension of the seat height of all chairs.

It should be pointed out that the dimensions prescribed in the standard are not fully respected.

Regarding the dimensions, two main sizes of chairs, high and low, are found in all preschool facilities. The higher chairs are commonly used by children aged from 3 to 7 in kindergarten groups (except in North Macedonia, where according to the public law, children aged from 2 to 3 years belong to the kinder-

Table 5 Deviations of measured sample variables in relation to EN 1729-1:2015
Tablica 5. Odstupanja mjerenih varijabli uzoraka od norme EN 1729-1:2015

Chair code *Šifra stolice*		 B	 C	 D	 F	 H	 K	 L	 N	 P	 Q
Size (colour) according to EN 1729-1 / *Veličina (boja) prema EN 1729-1*		2 (violet)	2 (violet)	2 (violet)	1 (orange)	1 (orange)	2 (violet)	1 (orange)	2 (violet)	2 (violet)	1 (orange)
Dimensions, mm *dimenzije,* mm	*h8*	+ (-10)	- **(-20)**	- **(-20)**	+ (+10)	- **(-20)**	- **(+20)**	+ (+10)	+ (-10)	+ (+5)	- **(-15)**
	b3	+ (+60)	+ (+90)	+ (+20)	+ (+60)	+ (+20)	+ (+50)	+ (+60)	+ (+30)	+ **(-40)**	±
	h7	+	+	+	+	+	+	+	+	+	+
	t4, b4, α, γ, p, r	n/a (not applicable)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Marking *označivanje*	Colouring or size marking according to EN 1729-1 / *obojeno ili označeno prema EN 1729-1*	no (nature wood)	no (nature wood)	no (red)	no (green)	no (nature wood)	no (nature wood)	no (nature wood)	no (orange)	no (nature wood)	no (colorful)
	Manufacturer and year / *proizvođač i godina proizvodnje*	n/a (not available)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

garten group, and not nursery group as in other countries). The lower type of chairs is used in nursery groups. In some preschool facilities, there is no the lower type of chairs, so kids only use chairs of one size.

In all polygons, it was found that children were divided into two main types of age groups: homogeneous (HO) and heterogeneous (HE). Homogeneous (HO) groups included children of the same age, and were divided into the following groups: a) children from 2 to 3 years old; b) children from 3 to 4 years old; c) children from 4 to 5 years old, d) children from 5 to 6 years old, and e) mostly 7 or 7,5 years old kids (school age). Accordingly, children who actively use chairs could be divided into four or maximum five age groups. The situation was different in heterogeneous (HE) groups, where children aged from 3 to 7 years were staying in one playroom. According to most kindergarten educators, heterogeneous groups are a very good solution from pedagogical point of view – e.g. small kids learn from the older, the older kids learn how to be attentive. There is, however, the problem of the chair size. Almost all kids have been using only one size chair, which is not in accordance with the requirements of their healthy physical growth.

According to the results of this research, the chairs should be dimensioned according to children's anthropometric dimensions and growth, regardless of whether the children were in homogenous or heterogeneous type of group.

The usual procedure in furnishing kindergartens is to provide two-size furniture (Domljan *et al.*, 2015). This procedure should be changed in accordance with EN standards, which recommend to purchase at least four size marks (size 0 to 3). No matter what age the child belongs to, the dimensions of the furniture should be adapted to the anthropometric dimensions of each child.

To obtain the size of the chairs, comprehensive anthropometric research needs to be done to compare and match children's body dimensions with the size of the furniture. On the other hand, EN 1729-1:2015 can be used in the section for chairs for preschool children, which is divided into four sizes from 0 to 3. In order to distinguish one type of the chair from another, the colours prescribed in the European standard can be used.

4 CONCLUSIONS
4. ZAKLJUČAK

Based on the results of the analysed types of chairs, as well as the comparison with the current standard EN 1729-1:2015, deviations and mismatches in functional dimensions and marks were found in all three polygons. The following conclusions and recommendations could be pointed out:

Generally, the analysed chairs do not correspond at all to the applicable standard for individual kindergarten groups in all polygons (chair codes C, D, H, K, P and Q).

Particularly, some chairs do not fulfil the requirements related to the seat height (chair codes C, D, H, K and Q), some samples do not fulfil the requirements related to the seat width (chair code N), and chairs are not marked correctly as prescribed in the standard (all chairs).

The biggest problem regarding the dimensions of the chair and its comparison to children's dimensions prescribed in the same standard is that they are not compatible. Namely, according to the EN 1729-1:2015, each size group of the chair is prescribed for certain height group of children, regardless of age. The children are divided into some groups by age, not by their body dimensions. Children of the same age and gender grow unevenly, which depends on numerous factors. Regardless of the group that a child is attending in a kindergarten due to his/her age, it does not have to mean that the child's height belongs to his/her kindergarten group. Therefore, in one kindergarten group, it is possible to notice large differences in the children's height.

Each kindergarten group should have several chair dimensions, ranging from 0 to 2, and for older groups, it has to be size 3 (and even 4) according to the standard. This should precede the anthropometric survey of children in kindergarten at the beginning of the new season (every September), so that a selection of required chairs can be made by groups. Only in this way, the dimensions of furniture that comply with the standard can be consistent with the anthropometrics of children in each kindergarten group.

Some state regulations and guidelines for equipping preschool institutions are too general in describing furniture and equipment. By a comprehensive analysis that would include interdisciplinary teams of experts, the regulations should be improved and provide detailed technical descriptions and sketches, before starting the process of procurement. Although in the Republic of Croatia such a manual already exists (Domljan *et al.*, 2015), relevant users should take it into account.

The process of equipping preschool institutions is carried out in a procedure regulated by state law and public procurement, where the "most economically advantageous tender" (which sometimes includes even the lowest price) are mostly the basic criterion for procurement, and not the quality of the furniture or the dimensions of children who are attending the corresponding (age) group in kindergartens. This has to be changed by new laws.

The findings in this paper could make a new basis for proposing solutions aimed at reducing the detected mismatches and improving the process of designing preschool furniture and procurement system of equipping preschool facilities. It has to be adapted to the up-to-date anthropometrics and children's dimensions in kindergartens.

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5 REFERENCES
5. LITERATURA

1. Auf-Franić, H.; Oluić, V.; Žarnić, T.; Bertina, M.; Korlaet, L.; Rister, V.; Roth-Čerina, M., 2003: Nurseries and kindergartens – guidelines for programming, planning and designing, University of Zagreb – Faculty of Architecture, Zagreb, Acta Architectonica, Croatia.
2. Bajbutović, Z., 1983: Arhitektura školske zgrade. Svjetlost, OOUR Zavod za udžbenike i nastavna sredstva, Sarajevo.
3. Cranz, G., 1998: The Chair: Rethinking Culture, Body and Design. W.W. Norton & Company, UK.
4. Domljan, D.; Grbac, I.; Hađina, J., 2008: Classroom furniture design – compliance of pupils' and chairs' dimensions. Collegium Antropologicum, 32 (1): 257-265. PMID: 18494212.
5. Domljan, D.; Vlaović, Z.; Grbac, I., 2010a: Musculoskeletal deformities and back pain in schoolchildren. In: Proceedings of 4th International ergonomics conference – Ergonomics 2010. Mijović, B. (ed.). Croatian society of ergonomics, Stubičke Toplice/Zagreb, Croatia, pp. 227-236.
6. Domljan, D.; Grbac, I; Vlaović, Z., 2010b: Pupils' working postures in primary school classrooms. Periodicum biologorum, 112 (1): 39-45.
7. Domljan, D., 2011: The Design of Contemporary School Furniture as a Prerequisite for Maintainance of Pupils' Health. Doctoral thesis. University of Zagreb Faculty of Forestry, Zagreb, Croatia.
8. Domljan, D.; Grbac, I.; Jirouš Rajković, V.; Vlaović, Z.; Živković, V.; Župčić, I., 2015: Quality and technical descriptions of wooden products, vol. 1 – equipping educational facilities. Domljan, D. and Vlaović, Z. (eds). University of Zagreb Faculty of Forestry, Croatian Chamber of Economy, Zagreb, Croatia.
9. Dudek, M., 2005: Children Spaces. Architectural Press, An imprint of Elsevier, Oxford, Burlington, UK.
10. Hedge, A; Lueder, R., 2007: School furniture. In: Ergonomics for Children: Designing Products and Places for Toddlers to Teens (Chapter 21), Rani Lueder, R. and Berg Rice, V. J. (eds.). CRC Press, pp. 721-450.
11. Iliev, B., 2011: Comparative analysis for the pre-school institutions in Municipality of Centar with modern tendencies in designing and articulations of specific interventions in space as a result of the psycho-physical needs by the children. Master thesis. Ss. Cyril and Methodius University, Skopje, North Macedonia.
12. Iliev, B.; Domljan, D.; Vlaović, Z., 2018: Importance of anthropometric data in design of preschool furniture. In: Proceedings of the 7th International Ergonomics Conference Ergonomics – Emphasis on Wellbeing, Sumpor, D. (ed.). Croatian Ergonomics Society, Zadar, Croatia, pp. 141-148.
13. Iliev, B.; Domljan, D., 2017: Comparison between preschool tables used in kindergarten in Croatia, Macedonia and Bulgaria. In: Proceeding of the 28th International Conference on Wood Modification and Technology: Implementation of wood science in woodworking sector, Grbac, I. (ed.). Faculty of Forestry, University of Zagreb, Zagreb, Croatia, pp. 207-214.
14. Iliev, B.; Domljan, D., 2016: Anthropometric analysis as an important method for designing furniture for preschool children. In: Proceeding of the 27th International Conference on Wood Modification and Technology: Implementation of wood science in woodworking sector, Grbac, I. (ed.). Faculty of Forestry, University of Zagreb, Zagreb, Croatia, pp. 83-88.
15. Knight, G.; Noyes, J., 1999: Children's behaviour and the design of school furniture. Ergonomics, 42 (5): 747-760. https://doi.org/10.1080/001401399185423.
16. Prebeg, Ž.; Prebeg, Ž., 1985: Higijena i škola, 5. izd. Školska knjiga, Zagreb.
17. Troussier, B.; Tesniere, C.; Fauconnier, J.; Grisons, J.; Juvin, R.; Phelip, X., 1999: Comparative study of two different kinds of school furniture among children. Ergonomics 42: 516-526. https://doi.org/10.1080/001401399185612.
18. Pisareva, E., 1999: Equipping of the public building. University of Forestry, Sofia, Bulgaria.
19. Vlaović, Z.; Horvat, S.; Domljan, D.; Tkalec, S., 2003: Design and construction of the office and school furniture according to the European standards. In: Proceedings of the 17th international conference: Furniture industry adjustment to European standards. Faculty of Forestry, University of Zagreb, Zagreb, Croatia, pp. 67-76.
20. *** 2007: Ordinance No. 3 on a health requirements for kindergartens (online), Issued by the Ministry of Health., 5 February 2007, Official Gazette of the Republic of Bulgaria 64/2012. http://www.mh.government.bg/media/filer_public/2015/04/17/naredba3-ot-05-02-2007g-zdravni-iziskvania-detski-gradini.pdf (Accessed May 4, 2018).
21. *** 2008: National pedagogical standard for pre-school education (online), NN 63/2008, URL: http://narodne-novine.nn.hr/clanci/sluzbeni/2008_06_63_2128.html (Accessed April 12, 2018).
22. *** 2009: Rulebook of performing the activity for institutions for children (online). Ministry of Labor and Social Policy of the Republic of Macedonia, Official Gazette of the Republic of Macedonia 35/2009 http://www.slvesnik.com.mk/Issues/E7498D-8218F4744E921F6E0AB12270C5.pdf (Accessed April 15, 2018).
23. *** 2015: EN 1729-1:2015. Chairs and tables for educational institutions – Part 1: Functional dimensions.

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Insect Species Damaging Industrial Wood in Western Black Sea Region of Turkey

Vrste kukaca koje oštećuju industrijsko drvo u Zapadnoj crnomorskoj regiji u Turskoj

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ABSTRACT • *Insect species collected in log depots in Western Black Sea Region of Turkey were identified. The study covered two years, 2015 and 2016, in 21 log depots in seven provinces (Duzce, Bolu, Zonguldak, Bartin, Karabuk, Kastamonu and Sinop). The study area was divided into three sub regions and each sub region was analyzed for insect species, their prevalence and intensities. Overall, four orders, 22 families, 74 genera and 57 species were described in log depots of the study area. Sub region 1 (Düzce-Bolu) showed the highest diversity in terms of insect species and sub region 2 (Zonguldak-Bartin) had the lowest diversity. Dorcus parallelipipedus Linnaeus, 1758 (Coleoptera: Lucanidae) and Rhagium inquisitor Linnaeus, 1758 (Coleoptera: Cerambycidae) were found in all provinces studied. Based on wood species analysis, Scots pine wood had the highest diversity in insect species, followed by fir, oak and beech. The study also described some important wood-destroying insect species from the families Anobiidae, Buprestidae and Cerambycidae. Buprestis dalmatina (Mannerheim, 1837) (Coleoptera: Buprestidae), Leptura aurulenta (Fabricius, 1792) (Coleoptera: Cerambycidae) and Stictoleptura scutellata (Fabricius, 1781) (Coleoptera: Cerambycidae), all wood-destroying insect species, were identified for the first time in the Western Black Sea Region of Turkey.*

Keywords: *log depots, Turkey, Western Black Sea Region, wood-destroying insects, wood species*

SAŽETAK • *U sklopu istraživanja identificirane su vrste kukaca koje su prikupljene na stovarištima trupaca u Zapadnoj crnomorskoj regiji u Turskoj. Studija se provodila tijekom dvije godine, 2015. i 2016., na 21 stovarištu u sedam pokrajina (Duzce, Bolu, Zonguldak, Bartin, Karabuk, Kastamonu and Sinop). Područje istraživanja bilo je podijeljeno u tri podregije u kojima su analizirane vrste kukaca, njihova prevalencija i intenzitet. U skladištima trupaca na istraživanom su području ukupno opisana četiri reda, 22 porodice, 74 roda i 57 vrsta kukaca. U podregiji 1. (Düzce-Bolu) primijećena je najveća raznolikost vrsta kukaca, a u podregiji 2. (Zonguldak-Bartin) zabilježena je najmanja raznolikost. U svim istraživanim pokrajinama pronađeni su Dorcus parallelipipedus Linnaeus, 1758 (Coleoptera: Lucanidae) i Rhagium inquisitor Linnaeus, 1758 (Coleoptera: Cerambycidae). Na temelju analize različitih vrsta drva zaključeno je da je borovina imala najveću raznolikost vrsta kukaca, a slijedile su jelovina, hrastovina i bukovina. U studiji su također opisane neke važne vrste kukaca koji razaraju drvo, a pripadaju porodicama Anobiidae, Buprestidae and Cerambycidae. Kukci vrsta Buprestis dalmatina (Mannerheim, 1837) (Coleoptera: Buprestidae), Leptura aurulenta (Fabricius, 1792) (Coleoptera: Cerambycidae) i Stictoleptura scutellata (Fabricius, 1781) (Coleoptera: Cerambycidae) također razaraju drvo i prvi su put zabilježeni u Zapadnoj crnomorskoj regiji u Turskoj.*

Ključne riječi: *stovarište trupaca, Turska, Zapadna crnomorska regija, kukci koji razaraju drvo, vrste drva*

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1 INTRODUCTION
1. UVOD

Trees and forests, which are essential for the future of human kind, are under threat of many pest species. Among them, insects can be considered the most important. Insects, with the greatest number of species on earth, either have contact with living trees or during the service life of forest product after harvest. These insect species consume wood as food sources or use it as shelter for their larvae. As a result, they can reduce physical, chemical and technological properties of wood within very short time. They cause tremendous economic loss if the necessary precautions are not taken. Each year, the loss of about 500 million USD is reported due to activities of insects, fungi and marine organisms in US alone (FAO, 2010a). Furthermore, each year plants produced on about 35 million ha worldwide are damaged by insects (FAO, 2010b).

Coleoptera can be considered as one of the most important insect orders. The Coleopteran insects feed on almost all plant species and their different parts (Lodos and Tezcan, 1995). They are often found in wood. The most important wood-damaging insect families of this order are Anobiidae, Buprestidae, Cerambycidae, Curculionidae, Elateridae, Lucanidae, Scarabaeidae, Curculionidae/Scolytinae, and Tenebrionidae.

Members of Anobiidae, Buprestidae (Çanakçıoğlu and Mol, 1998; Kaygın, 2007), Cerambycidae and Curculionidae (Brockerhoff *et al*., 2006) are considered as the most invasive species of wood. One fifth of Cerambycids are somewhat related to the timber industry or wood species used in timber industry (Hellrigl, 1974). They are extremely harmful to barked softwood and hardwood logs in field and sawmill depots (Komut *et al*., 2010). Insect from this family can be found on almost all tree species (Gokturk, 2002). It was reported recently that populations of insects from the Cerambycidae and other saproxylic beetles has been decreased (Nieto and Alexander, 2010).

Harvested logs are transferred and stockpiled in field depots until sold and shipped to buyers. This raw material is prone to insect and fungal attack, and its economic value of wood and efficiency of the wood industry are significantly reduced (Komut *et al*., 2010).

The Western Black Sea Region of Turkey has an important role in the country's industrial wood production. The Western Black Sea Region covers 33.764 km^2, 27.6 % of the whole Black Sea Region and 4.3 % of the country. According to the General Directory of Forestry, in Turkey a total of 21.537.091 ha is covered with forest land. An important portion of the forest land, about 13 % (2.441.699 ha), lies in the Western Black Sea Region (GDF, 2012).

As of 2012, 2.735.000 m^3 of softwood and 4.190.000 m^3 of hardwood were produced from this region. This amount accounts for 31 % of the industrial wood production of Turkey, which is around 13.400.000 m^3 (GDF, 2012). In addition, saw mill industry, wood-based panel production and furniture industry have been actively established in this region, accounting for 14, 10, 14, 12, 27, 17 and 7 % of the total industrial activity in Bartin, Bolu, Duzce, Karabuk, Kastamonu, Sinop and Zonguldak, respectively.

The purpose of the current study was to identify wood-destroying insect species in logs stored in field depots in the Western Black Sea Region of Turkey. So far, the literature has covered insect species on living trees and forested lands in this region but there is limited information on insect species in log depots. The current study can be considered the first such investigation for the Western Black Sea Region.

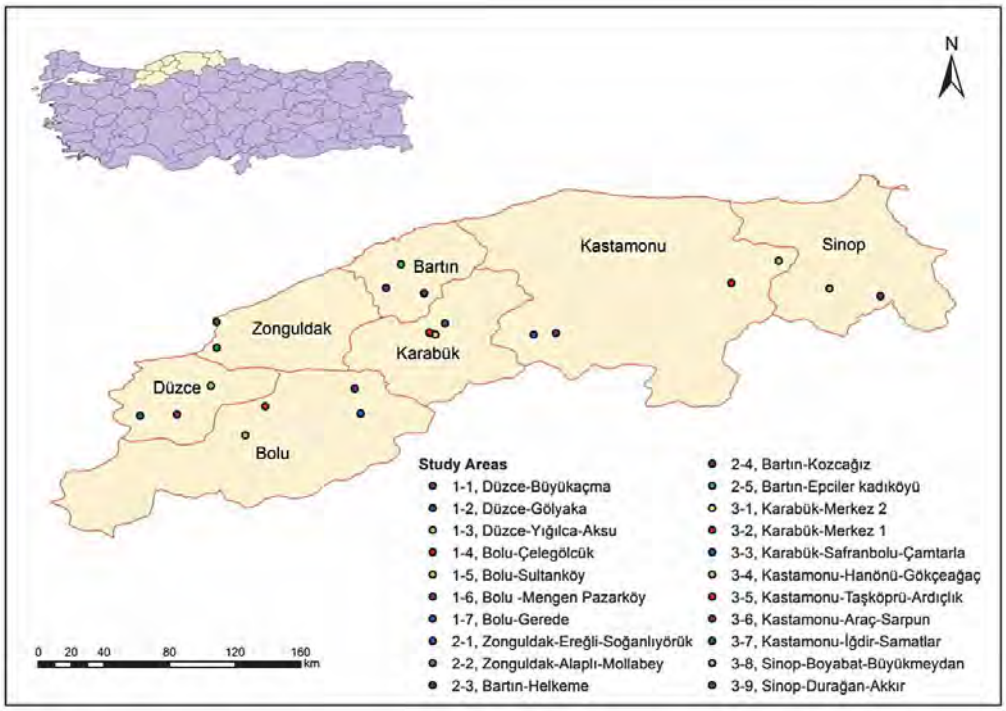

Figure 1 Locations of log depots in the research area
Slika 1. Mjesta skladišta trupaca na istraživanom području

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Study areas
2.1. Područja istraživanja

This study covered 21 log depots in different provinces of the Western Black Sea Region (Figure 1). The study area was divided into three sub regions: 1, Duzce-Bolu; 2, Zonguldak-Bartin; and 3, Karabuk-Kastamonu-Sinop, based on the distribution of the forest regional directorates in Turkey. The log depots were selected based on their annual production capacity. The highest production log depots were intentionally chosen. Data loggers were placed in each log depot to record temperature and relative humidity data. Figure 1 shows details of the study area.

2.2 Collection of insects and their transfer to the laboratory
2.2. Prikupljanje kukaca i njihov transport do laboratorija

The log depots were visited by the research team of Duzce University every 20 days between April 2015 and October 2016, totaling 16 study visits for each location. Wood species were first identified in each log depot (Table 1). Subsequently a sampling quadrant (20 x 50 cm) was established on selected logs to observe

Table 1 Wood species stored in log depots
Tablica 1. Vrste drva uskladištene na stovarištu trupaca

Name of study area *Ime istraživanog područja*	**Study area (log depot) code** *Oznaka istraživanog područja (stovarište trupaca)*	**Wood species in the study area** *Vrsta drva u istraživanom području*
Duzce - Buyukacma	1-1	Beech (*Fagus orientalis*), oak (*Quercus* sp), poplar (*Populus* sp), Scots pine (*Pinus sylvestris*), Red pine (*Pinus brutia*), fir (*Abies nordmanniana*) hornbeam (*Carpinus betulus*)
Duzce - Golyaka	1-2	Linden (*Tilia* sp), cherry (*Prunus avium*), fir (*Prunus avium*), beech (*Fagus orientalis*), sycamore (*Platanus orientalis*), poplar (*Populus* sp), ash (*Fraxinus angustifolia*)
Duzce - Yigilca - Aksu	1-3	Hornbeam (*Carpinus betulus*), beech (*Fagus orientalis*), oak (*Quercus* sp), fir (*Abies nordmanniana*), chestnut (*Castanea sativa*)
Bolu - Celegolcuk	1-4	Scots pine (*Pinus sylvestris*), fir (*Abies nordmanniana*), beech (*Fagus orientalis*)
Bolu - Sultankoy	1-5	Fir (*Abies nordmanniana*), Scots pine (*Pinus sylvestris*), beech (*Fagus orientalis*), oak (*Quercus* sp)
Bolu - Mengen - Pazarkoy	1-6	Fir (*Abies nordmanniana*), pine (*Pinus* sp)
Bolu-Gerede	1-7	Pine (*Pinus* sp)
Zonguldak - Eregli - Soganliyoruk	2-1	Linden (*Tilia* sp), beech (*Fagus orientalis*), hornbeam (*Carpinus betulus*), oak (*Quercus* sp), alder (*Alnus glutinosa*), chestnut (*Castanea sativa*), red pine (*Pinus brutia*)
Zonguldak - Alapli - Mollabey	2-2	Beech (*Fagus orientalis*), pine (*Pinus* sp), chestnut (*Castanea sativa*), fir (*Abies nordmanniana*), Linden (*Tilia* sp)
Bartin - Helkeme	2-3	Fir (*Abies nordmanniana*)
Bartin - Kozcagiz	2-4	Scots pine (*Pinus sylvestris*), fir (*Abies nordmanniana*), oak (*Quercus* sp)
Bartin - Epciler Kadikoy	2-5	Beech (*Fagus orientalis*), oak (*Quercus* sp), poplar (*Populus* sp), Scots pine (*Pinus sylvestris*), fir (*Abies nordmanniana*)
Karabuk - Merkez - 1	3-1	Hornbeam (*Carpinus betulus*), alder (*Alnus glutinosa*), pine (*Pinus* sp), oak (*Quercus* sp), fir (*Abies nordmanniana*)
Karabuk - Merkez - 2	3-2	Pine (*Pinus* sp), oak (*Quercus* sp), fir (*Abies nordmanniana*), hornbeam (*Carpinus betulus*)
Karabuk - Safranbolu - Camtarla	3-3	Scots pine (*Pinus sylvestris*), black pine (*Pinus nigra*), oak (*Quercus* sp)
Kastamonu - Gokceagac	3-4	Oak (*Quercus* sp)
Kastamonu - Taskopru - Ardiclik	3-5	Pine (*Pinus* sp), oak (*Quercus* sp)
Kartamonu - Arac - Sarpun	3-6	Fir (*Abies nordmanniana*), pine (*Pinus* sp)
Kastamonu - Igdir -Samatlar	3-7	Pine (*Pinus* sp), fir (*Abies nordmanniana*), oak (*Quercus* sp)
Sinop - Boyabat - Buyuk Meydan	3-8	Scots pine (*Pinus sylvestris*), black pine (*Pinus nigra*), oak (*Quercus* sp)
Sinop - Duragan - Akkir	3-9	Scotch pine (*Pinus sylvestris*), beech (*Fagus orientalis*), oak (*Quercus* sp)

Table 2 Determinations for sub region 1, Duzce-Bolu
Tablica 2. Obilježja podregije 1., Duzce-Bolu

Order / Family *Red / porodica*	**Insect species** *Vrsta kukca*	**Log depots** *Stovarište trupaca*	**Dates (Months)** *Datumi (mjeseci)*	**Wood species** *Vrsta drva*	**Wood part** *Dio drva*	**Insect life stage** *Razvojni stadij kukca*	**Total insect number** *Ukupan broj kukaca*
Coleoptera							
Tenebrionidae	*Uloma cypraea* Kraatz, 1873	1-1, 1-2, 1-6	4, 5	F	SW, HW	$A^{4,5}$, L^{4}	21
	Uloma sp.	1-2	4	F	SW	L^{4}	1
	Helops caeruleus Linnaeus, 1758	1-1	8	B*	SW	A^{8}	1
	Menephilus cylindricus Herbst, 1784	1-3, 1-4, 1-5, 1-6	4, 5, 6, 7, 9	F, B, Yp	SW	$L^{4,9}$, $P^{4,6}$, $A^{4,5,6,7,9}$	23
	Euboeus mimonti Boieldieu, 1865	1-1	4	B	SW	L^{4}	1
Elateridae	*Ampedus* sp. Dejean, 1833	1-1, 1-4	4, 5, 8	F, B	SW, B**	L^{4}, P^{5}, $A^{4,8}$	15
	Lacon punctatus Herbst, 1779	1-2,-1-4, 1-5	4	F, C	SW, HW	L^{4}, P^{4}	6
	Lacon sp. Laporte de Castelnau, 1836	1-4	4	C	SW	L^{4}	1
	Ampedus nigroflavus Goeze, 1777	1, 1	4	F	SW	A^{4}	3
	Synaptus filiformis Fabricius, 1781	1-5	4	Yp	SW	L^{4}	1
	Agriotes sp. Eschscholtz, 1829	1-1	5	B	SW	L^{5}	2
Scarabaeidae	*Valgus hemipterus* Linnaeus, 1758	1-2	4, 5	C, F	SW	L^{4}, P^{5}, A^{5}	5
	Cetonia aurata Linnaeus, 1758	1-2, 1-5	5, 8	F	SW	L^{5}, A^{8}	10
	Valgus sp. Scriba, 1790	1-2	4	F	SW	L^{4}, P^{4}	2
Cerambycidae	*Rhagium inquisitor* Linnaeus, 1758	1-1, 1-4, 1-6, 1-7	3, 4	YP, B	SW, B	L^{4}, P^{4}, A^{4}	37
	Stictoleptura scutellata Fabricius, 1781	1-3	5	B	SW	L^{5}, A^{5}	2
	Monochamus galloprovincialis Olivier, 1795	1-4	8	Yp	SW	A^{8}	5
	Ergates faber Linnaeus, 1761	1-5	4	F	SW	L^{4}	1
	Hylotrupes bajulus Linnaeus, 1758	1-1, 1-4, 1-5	6	Yp	SW	L^{6}, A^{6}	25
	Phymatodes testaceus Linnaeus, 1758	1-5	6	Yp	SW	A^{6}	1
	Anastrangalia sanguinolenta Linnaeus, 1761	1-6	4, 6	Bp, F	SW	L^{4}, A^{6}	5
Buprestidae	*Chalcophora detrita* Klug, 1829	1-4	4, 5	F	SW	$L^{4,5}$	2
	Chalcophora mariana Linnaeus, 1758	1-4	6, 9	F, Bp	SW	L^{6}, P^{6}, A^{8}	4
Curculionidae	*Rhyncolus ater* Linnaeus, 1758	1-5, 1-6	3, 4, 5, 6, 10	Bp, F	SW	$A^{3,4,5,6,10}$	34
	Rhyncolus sp. Germar, 1817	1-5	4, 8	F	SW	$L^{4,8}$, P^{8}	4
	Rhyncolus elongates Gyllenhal, 1827	1-6	3	F	SW	A^{3}	34
	Xyleborus sp. Eichhoff, 1864	1-6	3	F	B	L^{3}	1
	Ips sexdentatus Boerner, 1776	1-4	4, 6	Yp	B	$L^{4,6}$, A^{6}	38
Lucanidae	*Dorcus parallelipipedus* Linnaeus, 1758	1-1, 1-2, 1-3, 1-4, 1-5, 1-6	4, 5, 8	F, B, L, O, C, P	SW, HW	$L^{4,5}$, $P^{4,5}$, $A^{4,5}$	80
	Sinodendron cylindricum Linnaeus, 1758	1-4	2	B	SW	L^{2}	20
Cleridae	*Thanasimus formicarius* Linnaeus, 1758	1-4	4	O, Bp	B	A^{4}	5
	Clerus mutillarius Fabricius, 1775	1-4	8	O	B	A^{8}	1
Anobiidae	*Anobium punctatum* De Geer, 1774	1-1, 1-4	6	O	SW, HW	L^{6}	26
	Ptilinus fuscus Geoffroy & Fourcroy, 1785	1-2, 1-6	5, 6	P*	SW	$A^{5,6}$	6
Trogossitidae	*Ostoma ferruginea* Linnaeus, 1758	1-4, 1-5, 1-6	4, 5, 6, 10	F, Bp, Yp	SW	$A^{4,5,6,10}$	54
Cantharidae	*Cantharis fusca* Linnaeus, 1758	1-3	5	Yp	B	A^{5}	1
	Cantharis livida Linnaeus, 1758	1-4	3	Yp	SW	L^{3}	2
Lycidae	*Lygistopterus sanguineus* Linnaeus, 1758	1-1	5	O	SW	L^{5}	1
Hymenoptera							
Formicidae	*Camponotus vagus* Scopoli, 1763	1-1, 1-2, 1-3, 1-4	4, 5, 8, 9	Yp, B, O	HW	L^{4}, $A^{5,8,9}$	98
	Lasius sp. Fabricius, 1804	1-5	4	O	HW	A^{4}	1

Wood species: B - beech; Bp - black pine; C - Cherry; F - fir; L - linden; O - Oak; P - poplar; Yp - yellow pine. / *Vrste drva: B - bukovina; Bp - drvo crnog bora; C - trešnjevina; F - jelovina; L - lipovina; O - hrastovina; Yp - drvo žutog bora.*
Wood part: B - between bark and cambium; HW - heartwood; SW - sapwood. / *Dio drva: B - između kore i kambija; HW - srž; SW - bjeljika.*
Insect life stage: A - adult; L - larvae; P - pupae. */ Razvojni stadij kukca: A - odrasli kukac; L - ličinka; P - kukuljica.*
*Superscripted numbers are the month of collection. / **Brojevi u superskriptu označavaju mjesece tijekom kojih su kukci prikupljeni.*

and collect larvae, pupae and adult insects. Several types of knifes, saws and axes were used during the study visits, and small plastic containers with perforated lids were used for collecting the live specimens. Each plastic container was labeled with a number, area, code, date of collection, form of organism (larvae, pupae or adult) and wood species.

Species collected as larvae or pupae were either kept in the piece of wood in which they were found or transferred to fine moist sawdust prepared from the same wood species. The purpose was to make it easier to identify the species of larvae or pupae.

2.3 Species identification
2.3. Identifikacija vrsta kukaca

The live specimens collected were kept in individual containers to keep their body intact for easy and reliable identification. Insect species were identified by experts using a stereo microscope. Adult insect was directly determined, whereas larvae and pupae forms were stored in conditioning rooms under appropriate conditions (20-22 °C and 60-70 % RH) until they reached adulthood (Akbulut *et al.*, 2008). Some species of larvae and pupae were described by using the methods of Cherepanov (1991). Several identification keys (Acatay, 1961) and related books (Freude *et al*., 1981, Freude *et al*., 1983; Bevan, 1987; Borror *et al*., 1989; Bense, 1995; Cherepanov, 1991; Creffield, 1996; Canakcioglu and Mol, 1998; Kaygin, 2007) were used for the classification. After identification, the samples were preserved/mounted for future reference.

2.4 Wood species in study areas
2.4. Vrste drva na istraživanom području

Table 1 lists the wood species of logs stored in the depots in the study areas. The range of wood species varied between depots, with a total of 14 species identified. Almost all species were present in each sub regions. The most abundant tree species (7) were present at the Buyukacma in Duzce and Soganliyoruk in Zonguldak.

3 RESULTS
3. REZULTATI

In the current study, insects were collected in three sub regions recording the species, collection date, wood species, location in wood substrate, and insect life stage and population in sampling quadrants.

Table 2 lists species collected in seven log depots in sub region 1 (Duzce-Bolu). Two orders, 13 families, 42 genera, and 33 species were recorded. Almost all insect species belong to the Coleoptera with the highest diversity in species found in the Cerambycidae. *Cam-*

Table 3 Determinations for sub region 2, Zonguldak-Bartin
Tablica 3. Obilježja podregije 2., Zonguldak-Bartin

Order / Family *Red / porodica*	**Insect species** *Vrsta kukca*	**Log depots** *Stovarište trupaca*	**Dates (Months)** *Datumi (mjeseci)*	**Wood species** *Vrsta drva*	**Wood part** *Dio drva*	**Insect life stage** *Razvojni stadij kukca*	**Total insect number** *Ukupan broj kukaca*
Coleoptera							
Tenebrionidae	*Uloma cypraea* Kraatz, 1873	2-1, 2-2, 2-5	4, 5	O, L, B*	SW	$A^{4,5}$	6
Elateridae	*Ampedus pomorum* Herbst, 1784	2-5	5	B	SW	A^{5}	1
Scarabaeidae	*Valgus hemipterus* Linnaeus, 1758	2-2	4	B	HW	L^{4}	1
Cerambycidae	*Rhagium inquisitor* Linnaeus, 1758	2-2, 2-4	3, 6	Yp	SW	$L^{3,6}$, P^{3}	9
	Hylotrupes bajulus Linnaeus, 1758	2-1, 2,4	3, 4	Yp, Bp	SW	$L^{3,4}$	2
	Aegosoma scabricorne Scopoli, 1763	2-2	4	L	SW	L^{4}	4
	Rhagium sp. Fabricius, 1775	2-2	4	O	SW	L^{4}	1
	Leptura quadrifasciata Scopoli, 1763	2-1	4	L	SW	L^{4}, P^{4}, A^{4}	39
	Leptura aurulenta Fabricius, 1792	2-1	4	L	SW	L^{4}, P^{4}, A^{4}	22
	Arhopalus rusticus Linnaeus, 1758	2-1, 2-2	4, 6	Yp, Bp	SW	L^{4}, P^{6}, A^{6}	3
	Saperda sp. Fabricius, 1775	2-1	4	L	SW	L^{4}	13
	Plagionotus sp. Mulsant, 1842	2-1	4	O	SW	L^{4}	2
Cantharidae	*Cantharis rufa* Linnaeus, 1758	2-4	3	Yp	SW	L^{3}	1
Curculionidae	*Rhyncolus ater* Linnaeus, 1758	2-3	9	F	SW	A^{9}	7
	Ips sexdentatus Boerner, 1776	2-2	4, 6	Yp, L	SW, B**	$A^{4,6}$	4
Lucanidae	*Dorcus parallelipipedus* Linnaeus, 1758	2-1, 2-2, 2-4, 2-5	3, 4, 5, 8	F, L, B	SW, HW	$L^{3,4,5}$, P^{4} $A^{3,4,8}$	42
Cleridae	*Trichodes apiaries* Linnaeus, 1758	2-5	9	Yp	B	A^{9}	1
Colydiidae	*Dechomus sulcicollis* Germar, 1824	2-2	4	Yp	SW	L^{4}, E^{4}	148
Lymexylidae	*Lymexylon* sp. Fabricius, 1775	2-4	3	Yp	SW	L^{3}	2
Hymenoptera							
Formicidae	*Camponotus vagus* Scopoli, 1763	2-5	5	B	HW	A^{5}	1

Wood species: B - beech; Bp - black pine; C - Cherry; F - fir; L - linden; O - Oak; P - poplar; Yp - yellow pine. / *Vrste drva: B - bukovina; Bp - drvo crnog bora; C - trešnjevina; F - jelovina; L - lipovina; O - hrastovina; Yp - drvo žutog bora.*
Wood part: B - between bark and cambium; HW - heartwood; SW - sapwood. / *Dio drva: B - između kore i kambija; HW - srž; SW - bjeljika.*

Table 4 Determinations for sub region 3, Karabuk-Kastamonu-Sinop
Tablica 4. Obilježja podregije 3., Karabuk-Kastamonu-Sinop

Order / Family *Red / porodica*	**Insect species** *Vrsta kukca*	**Log depots** *Stovarište trupaca*	**Dates (Months)** *Datumi (mjeseci)*	**Wood species** *Vrsta drva*	Wood part *Dio drva*	**Insect life stage** *Razvojni stadij kukca*	**Total insect number** *Ukupan broj kukaca*
Coleoptera							
Tenebrionidae	*Menephilus cylindricus* Herbst, 1784	3-1	3	F, Yp	SW	A^{3}	3
	Corticeus sp. Pillar & Mitterpacher, 1783.	3-6	8	O	B	A^{8}	2
	Opatrum sabulosum Linnaeus, 1761	3-5	5	Yp	SW	L^{5}, A^{5}	2
	Neatus sp. Le Conte, 1862	3-1	3	Bp, Yp	SW	L^{3}, A^{3}	4
	Corticeus pini Panzer, 1799	3-6	3, 6	Bp, Yp	SW	$A^{3,6}$	10
Elateridae	*Ampedus* sp. Dejean, 1833	3-5, 3-6	5	F, O	SW	A^{5}	3
	Lacon punctatus Herbst, 1779	3-7, 3-9	3, 5, 8	F, Rp	SW	$L^{3,5,8}$, A^{3}	5
	Ampedus elegantulus Schönherr, 1817	3-7	3	F	SW	A^{3}	1
Scarabidae	*Trichius sexualis* Bedel, 1906	3-4	5	O	SW	L^{5}	1
Cerambycidae	*Rhagium inquisitor* Linnaeus, 1758	3-3, 3-6, 3-7	3, 5	Bp, Yp	SW	$L^{3,5}$, A^{5}	9
	Hylotrupes bajulus Linnaeus, 1758	3-5, 3-6	3	Yp	SW	A^{3}	3
	Aegosoma scabricorne Scopoli, 1763	3-5	5	Yp	SW	L^{5}	2
	Rhagium bifasciatum Fabricius, 1775	3-5, 3-6	3, 5	Yp	SW	L^{3}, A^{5}	2
	Clytus arietis Linnaeus, 1758	3-2	5	H	SW	A^{5}	4
Buprestidae	*Chalcophora detrita* Klug, 1829	3-9	3	Rp	SW	L^{3}	2
	Buprestis dalmatina Mannerheim, 1837	3-9	5	Yp	SW	L^{5}	1
	Buprestis octoguttata, Linnaeus, 1758	3-9	3	F	SW	L^{3}	2
Curculionidae	*Rhyncolus ater* Linnaeus, 1758	3-1, 3-2	5	Yp	SW	A^{5}	1
	Rhyncolus elongates Gyllenhal, 1827	3-2	5	Yp	SW	A^{5}	1
	Xyleborus sp. Eichhoff, 1864	3-7	5	O	B	A^{5}	2
	Ips sexdentatus Boerner, 1776	3-4, 3-5, 3-7, 3-8, 3-9	3, 6	F, Yp	B, SW	L^{6}, $P^{,6}$ $A^{3,6}$	51
	Hylastes sp. Erichson, 1836	3-7	3	F	B	L^{3}	3
	Xyleborus eurygraphus Ratzeburg, 1837	3-3	3	O, Bp	B	L^{3}, A^{3}	4
	Orthotomicus erosus Wollaston, 1857	3-3	5	Bp	B	L^{5}	3
Lucanidae	*Dorcus parallelipipedus* Linnaeus, 1758	3-4, 3-6	3, 5	B, Yp, O	SW	$L^{3,5}$, P^{8}	3
Anobiidae	*Anobium punctatum* De Geer, 1774	3-7	3	Yp	SW	L^{3}	4
Trogossitidae	*Temnochila caerulea* Olivier, 1790	3-6	5	B	B	A^{5}	1
Rhysodidae	*Rhysodes sulcatus* Fabricius, 1787	3-2	3	Yp	SW	A^{3}	1
Melandrydae	*Rushia parreyssi* Mulsant, 1856	3-1, 3-2	3	Yp	SW	A^{3}	2
Dasytidae	*Aplocnemus alpestris* Kiesenwetter, 1861	3-5	5	Yp	SW	A^{5}	1
Silvanidae	*Uleiota planata* Linneaus, 1761	3-9	8	Bp	B^{**}	A^{8}	1
Lepidoptera							
Cossidae	*Zeuzera pyrina* Linnaeus, 1761	3-9	3	B^{*}	SW	L^{3}	1
Blattodea							
Rhinotermitidae	*Reticulitermes* sp. Holmgren, 1913	3-9	6	Yp	SW	A	60

Wood species: B - beech; Bp - black pine; C - Cherry; F - fir; L - linden; O - Oak; P - poplar; Yp - yellow pine. / *Vrste drva: B - bukovina; Bp - drvo crnog bora; C - trešnjevina; F - jelovina; L - lipovina; O - hrastovina; Yp - drvo žutog bora.*
Wood part: B - between bark and cambium; HW - heartwood; SW - sapwood. / *Dio drva: B - između kore i kambija; HW - srž; SW - bjeljika.*

Table 5 Correlation coefficients for ecological factors and insect species diversity and density
Tablica 5. Koeficijenti korelacije za ekološke čimbenike, raznolikost i gustoću vrste kukaca

		Insect species diversity *Gustoća vrste kukaca*	**Mean insect density** *Srednja gustoća kukaca*	**Total insect density** *Ukupna gustoća kukaca*	**Altitude** *Visina*	**Mean temperature** *Srednja temperatura*	**Mean relative humidity** *Srednja relativna vlažnost zraka*
Insect species diversity *Gustoća vrste kukaca*	R^2	1	**0.840****	**0.904****	0.042	-0.443	**0.575***
	P		0.000	0.000	0.865	0.058	0.010
Total insect density *Ukupna gustoća kukaca*	R^2	**0.904****	**0.920****	1	-0.070	-0.312	**0.574***
	P	0.000	0.000		0.775	0.193	0.010

ponotus vagus, while *D. parallelipipedus* had the greatest population and distribution. *Agriotes sp., A. sanguinolenta, E. faber, E. mimonti, S. filiformis, S. cylindricum* and *S. scutellata* were found only in this sub region.

Table 3 lists species collected in five log depots in sub region 2 (Zonguldak-Bartin). Three orders, 12 families, 21 genera and 15 species were recorded. Again, the highest diversity in terms of species was found in the Cerambycidae. *Dorcus parallelipipedus* had the highest population, and *A. scabricorne, L. quadrifasciata* and *Lymexylon sp.* were only found in this sub region.

Table 4 lists species collected in nine log depots in sub region 3 (Karabuk-Kastamonu-Sinop). Three orders, 15 families, 33 genera and 27 species were recorded. Ips sexdentatus was the most common and widely distributed species. *Aplocnemus alpestris, C. arietis, B. octoguttata, O. sabulosum, R. parreyssi, R. sulcatus, Reticulitermes* sp., *U. planata, Xyleborus* sp. and *Z. pyrina* were only found in this sub region.

Correlation analysis was performed based on insect diversity and density, temperatures and relative humidity of study areas and altitude from the sea level. Based on the current findings, a positive relationship was detected between insect diversity and density and relative humidity (Table 5). Insect diversity and density increased with the increase of relative humidity of the study area. On the other hand, effects of temperature and altitude from the sea level on insect diversity and density were found insignificant.

4 DISCUSSION
4. RASPRAVA

Bolu Province had the highest diversity with 20 species, whereas Sinop Province had the lowest diversity with only six species. Several reasons might account for this difference, including the range of wood species and the quantity of logs in depots (Irmler *et al.*, 1996; Okland *et al.*, 1996). Sinop Province had four wood species, while Bolu Province had five (Table 1) and the quantity of wood held in depots in Bolu was higher than in Sinop.

Akbulut *et al.* (2008) studied wood-destroying insects in forest depots in Duzce Province. In their study, insects were categorized as detrimental or not detrimental, with *A. punctatum, H. bajulus* and *Xestobium rufovillosum* (De Geer, 1774) being considered economically important insect species for wood. They also found some insect species, which were also found in our study, including *A. punctatum, I. sexdentatus, H. bajulus, M. galloprovincialis, P. curvidens, T. formicarius, V. hemipterus* and *Xyleborus* sp. However, in our study, some insect species, namely *C. vagus, D. parallelipipedus, P. fuscus, S. scutellate* and *U. cypraea*, were not found in Duzce Province.

Unal *et al.* (2008) studied wood-destroying insects in old historical Ottoman houses in Kastamonu Province. They found *A. punctatum* and *H. bajulus* as wood-destroying insects. In Yildiz (2012), 23 bark beetle species were determined in Bartin and Karabuk provinces, and *O. erosus* bark beetle was reported for the first time in Bartin province.

Larvae, pupae and adults of some insect species were detected in all or most of the study areas. *Dorcus parallelipipedus* and *R. inquisitor* were recorded in the seven provinces studied, with *D. parallelipipedus* detected in 12 log depots and *R. inquisitor* in nine log depots. These species belong to the Lucanidae and Cerambycidae, respectively. *Rhagium inquisitor*, in particular, has been reported to be common in the region due to extensive hardwood (oak, beech and birch) and softwood (spruce, fir and pine) production (Bily and Mehl, 1989; Kolk and Starzyk, 1996). Previous studies also found that and *D. parallelipipedus* and *R. inquisitor* are common species in Turkey (Kaygin, 2007; Ozdikmen and Turgut, 2010).

Furthermore, *C. vagus* (three provinces and six log depots), *H. bajulus* (five provinces and seven log depots), *I. sexdentatus* (four provinces and seven log depots) and *L. punctatus* (four provinces and five log depots) can be considered as extensively distributed. While there is no common reason for the abundance of these species in the region, the density and number of pine species might affect *H. bajulus* population, and the storage of fire wood and pine wood with bark might contribute to *I. sexdentatus* numbers. The sizable populations of *S. rubra* might attract its predator *L. punctatus* (Canakcioglu and Mol, 1998; Kaygin, 2007; Merkl *et al.*, 2010).

Insects were also evaluated for wood preference. Beech, fir, oak and Scotch pine occurred in almost all log depots studied (Table 1). Other wood species varied between locations. The highest insect species diversity was found on Scots pine with 32 species, followed by fir, oak and beech with 23, 17 and four species, respectively. Wood species preference of in-

sects depends on extractive substances of wood species and their toxic and anti-insecticide effects (Moore, 1979; Klepzig *et al*., 1995; Tascioglu *et al*., 2013). The sapwood ratio of woods is also an important factor in wood preference, since sapwood and starch are positively related in most wood species (Sivrikaya, 2008). The results of the current study suggest that most destruction due to insects occurs in the sapwood of logs (Tables 2-4). In addition, it is thought that insect species diversity and density found in Scots pine, fir, oak and beech wood occurred because these species are present in almost all log depots in the region and are stored for long periods.

When wood insect species and wood species relationship are evaluated, the main reasons for insect to invade wood are considered to feed and shelter (Jonsson *et al*., 2005). Especially predator insects tunnel into wood to feed on their prey species, usually other harmful insect species (Drees *et al.,* 2017). Even though these insect species are not directly feeding on wood, their tunneling causes damage (Wermelinger *et al*., 2013).

When evaluating wood preferences of insects, *D. parallelipipedus* species were determined on seven wood species including both hardwoods and softwoods. Predator species, like *Ampedus* sp., *L. punctatus* and *O. ferruginea*, were collected from three wood species. This phenomenon could not be explained by the chemical and physiological features of wood but rather by wood preference of the prey insect.

According to previous reports, *L. aurulenta* was observed in Gumushane Province (Alkan and Eroglu, 2001) and in Istanbul Province (Turgut *et al.,* 2010; Albayati *et al.*, 2016), and *B. dalmatina* and *S. scutellata* were found in Sakarya and Istanbul Provinces, respectively (Sakalian, 2003; Albayati *et al*., 2016), so these are the first records for the Western Black Sea Region.

Jaworski and Hilszczanski (2013) indicated that certain increases in temperatures and relative humidity in the area would result in an increase in insect diversity and density. However, the present study only supported the effect of relative humidity, while the effect of temperature was not found significant.

Members of the Elateridae and Tenebrionidae are generally known to be predator insects (Sarikaya and Avci, 2009; Andersson *et al.,* 2015). Species of these predator families were observed tunneling in both bark and wood during their pupa, larva or adult stage causing major damage to the technological features of wood (Tables 2-4). Especially *C. vagus* and *Lasius* sp. make galleries and nests in wood. Although these species do not use wood as a food source, they feed on wood-destroying insects within the wood.

In conclusion, four orders, 22 families, 74 genera and 57 species of insects were determined in the Western Black Sea Region. Some of these species, namely, *A. rusticus, H. bajulus and M. galloprovincialis in the Cerambycidae, C. detrita, B. dalmatina,* and *B. octoguttata* in the Buprestidae, and A. punctatum in the Anobiidae, are considered to be leading wood destroyers.

Also, *B. dalmatina, L. aurulenta* and *S. scutellata* were recorded for the first time in the Western Black Sea Region.

Dorcus parallelipipedus and *R. inquisitor* were found widely spread in the region. *Ampedus* sp., *D. parallelipipedus, L. punctatus O. ferruginea* and *V. hemipterus* were found in a wide range of wood species. The highest insect diversity and density was found in Duzce-Bolu with 42 genera and 40 species. Most insect species were observed in wood stored in field depots for 2 years or more, indicating that storage time is an important contributor to insect diversity and population density. Thus, logs should be processed as soon as possible without extended periods of storage time to prevent spread and infestation of pest species.

Storing newly harvested wood together with old logs stored for extended periods due to legal problems represents a major problem. This storage practice can help spread some insect species from older material to newly harvested raw material. The best solution would be to improve procedures to have older raw material sold and removed as soon as possible.

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5 REFERENCES
5. LITERATURA

1. Acatay, A., 1961: Zararlı Orman Böcekleri Teşhis Anahtarı. [*Identification key of Forest Destroying Insects*] 1 st ed. Istanbul, Istanbul University Publications. Turkish.
2. Akbulut, S.; Keten, A.; Yüksel, B., 2008: Wood destroying insects in Düzce province. Turkish Journal Zoology, 32: 343-350.
3. Albayati, M. M. I.; Ozdikmen, H.; Ayberk, H., 2016: Longhorned beetles of Belgrad forest in Istanbul province with new records to Europe, European Turkey, Marmara region of Turkey and Istanbul province (Coleoptera: Cerambycidae). Munis Entomology and Zoology, 11: 661-667.
4. Alkan, H.; Eroglu, M., 2001: A contribution to the knowledge of Cerambycidae (Insecta: Coleoptera) species of the Eastern Black Sea region in Turkey. Turkish Journal of Entomology, 25: 243-255.
5. Andersson, J.; Hjalten, J.; Dynesius, M., 2015: Wood-inhabiting beetles in low stumps, high stumps and logs on boreal clear-cuts: implications for dead wood management. PLoS One, 10 (3), e0118896. https://doi.org/10.1371/journal.pone.0127220.
6. Bense, U., 1995: Longhorn beetles: Illustrated key to the Cerambycidae and Vesperidae of Europe. Weikersheim, Margraf Verlag.
7. Bevan, D., 1987: Forest Insects, Forest Commission Handbook. 1. A guide to insects feeding on trees in Britain, pp. 153.
8. Bily, S.; Mehl, O., 1989: Longhorn Beetles (Coleoptera, Cerambycidae) of Fennoscandia and Denmark: Fauna Entomologica Scandinavica. Leiden, Netherlands: Brill.

9. Borror, D. J.; Triplehorn, C. A.; Johnson, N. F., 1989: An introduction to study of insects. Sixth edition, California, Saunders College Publishing.
10. Brockerhoff, E. G.; Jones, D. C.; Kimberley, M. O.; Suckling, D. M.; Donaldson, T., 2006: Nationwide survey for invasive wood-boring and bark beetles (Coleoptera) using traps baited with pheromones and kairomones. Forest Ecology and Management, 228: 234-240.
11. Canakcioglu, H.; Mol, T., 1998: Orman Entomolojisi: Zararlı ve Yararlı Böcekler. Istanbul, ISBN: 9754044872. [*Forest Entomology: Harmful and Useful Insects*], Istanbul University Publication. Turkish.
12. Cherepanov, A. I., 1991: Cerambycidae of Northern Asia, Lieden, Brill.
13. Creffield, J. W., 1996: Wood-destroying insects: wood borers and termites. CSIRO Publishing.
14. Drees, B. M.; Jackman, J. A.; Merchant, M. E., 2017: House and landscape beetles. Texas Agricultural Extension Service.
15. FAO, 2010a: Global Forest Resources Assessment Main Report. FAO Forestry Paper No. 163, Rome.
16. FAO, 2010b: World Forest Inventories. Importance of wood preservation in tropical countries.
17. Freude, H.; Harde, K. W.; Lohse, G. A., 1981: Die Käfer Mitteleuropas, Band 10. Krefeld, Goecke and Evers Verlag.
18. Freude, H.; Harde, K. W.; Lohse, G. A., 1983: Die Käfer Mitteleuropas, Band 11. Krefeld, Goecke and Evers Verlag, German.
19. GDF, 2012: General Directory of Forestry. Forestry Statistics, Ankara.
20. Gokturk, T., 2002: Coleoptera species and it's predators and parasitoids living in forest trees in Artvin. [dissertation]. Trabzon, Karadeniz Technical University.
21. Hellrigl, K. G., 1974: Cerambycidae, Bockkäfer. Longhorned Beetles, Longicornia. 130-202. In: Schwenke W. (ed.). Die Forstschädlinge Europas, Hamburg und Berlin, Verlag Paul Parey.
22. Irmler, U.; Heller, K.; Warning, J., 1996: Age and tree species as factors influencing the populations of insects living in dead wood (Coleoptera, Diptera: Sciaridae, Mycetophilidae). Pedobiologia, 40: 134-148.
23. Jaworski, T.; Hilszczanski, J., 2013: The effect of temperature and humidity changes on insects development their impact on forest ecosystems in the expected climate change. Leśne Prace Badawcze, 74: 345-355.
24. Jonsson, B. G.; Kruys, N.; Ranius, T., 2005: Ecology of species living on dead wood – Lessons for dead wood management. Silva Fennica, 39: 289-309.
25. Kaygın, A. T., 2007: Endüstriyel Odun Zararlıları [Industrial Wood Borers]. Ankara, Science and Biology Publications Series. Turkish.
26. Klepzig, K. D.; Kruger, E. L.; Smalley, E. B.; Raffa, K. F., 1995: Effects of biotic and abiotic stress on induced accumulation of terpenes and phenolics in red pines inoculated with bark beetle-vectored fungus. Journal of Chemical Ecology, 21: 601-626.
27. Kolk, A.; Starzyk, J. R., 1996: The Atlas of Forest Insect Pests. The Polish Forest Research Institute, Multico Warszawa.
28. Komut, O.; Imamoğlu, S.; Oztürk, A., 2010: The effective damage in forestry enterprises selling storage and precautions. III. National Black Sea Forestry Congress, Artvin, Turkey, 20-22 May, 270-278.
29. Lodos, N.; Tezcan, S., 1995: Turkish Entomology V. Buprestidae (General, Applied and Faunistic). Izmir, Entomology association publications.
30. Moore, H. B., 1979: Wood-inhabiting insects in houses: Their identification, biology, prevention and control. USDA Forest Service and Department of Housing and Urban Development, 133.
31. Nieto, A.; Alexander, K. N. A., 2010: European Red List of Saproxylic Beetles. Luxembourg: Publications Office of the European Union.
32. Okland, B.; Bakke, A.; Hagvar, S.; Kvamme, T., 1996: What factors influence the diversity of saproxylic beetles? A multiscaled study from a spruce forest in southern Norway. Biodiversity and Conservation, 5: 75-100.
33. Ozdikmen, H.; Turgut, S., 2010: A synopsis of Turkish Rhagium F., 1775 with zoogeographical remarks (Coleoptera: Cerambycidae: Lepturinae). Munis Entomology and Zoology, 5: 964-976.
34. Sakalian, V., 2003: New data for the distribution of jewel beetles (Coleoptera: Buprestidae) in Turkey. Acta Zoologica Bulgarica, 55: 5-10.
35. Sarikaya, O.; Avci M., 2009: Predators of Scolytinae (Coleoptera: Curculionidae) species of the coniferous forests in the Western Mediterranean Region, Turkey. Turkish Journal Entomology, 33: 253-264.
36. Sivrikaya, S., 2008: Factors effecting natural durability in wood. Journal of Bartın Faculty of Forestry, 10: 66-70.
37. Tascioglu, C.; Yalcin, M.; Sen, S.; Akcay, C., 2013: Antifungal properties of some plant extracts used as wood preservatives. International Biodeterioration and Biodegradation, 85: 23-28.
38. Turgut, S.; Ozdikmen, H.; Cebeci, H., 2010: *Oxymirus cursor* and *Leptura aurulenta* (Coleoptera: Cerambycidae): first records for Turkey. Florida entomologist, 93: 516-518.
39. Wermelinger, B.; Lachat, T.; Muller, J., 2013: Forest insects and their habitat requirements. In Focus-Managing Forest in Europe.

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LABORATORY FOR HYDROTHERMAL PROCESSING OF WOOD AND WOODEN MATERIALS

Testing of hydrothermal processes of wood and wooden materials

Thermography measurement in hydrothermal processes

Standard and nonstandard determination of moisture content in wood

Determination of climate and microclimate conditions in air drying and storage of wood, organization of lumber storage

Project and development of conventional and unconventional drying systems

Steaming chamber projects

Establishing and modification of kiln drying schedules

Consulting in selection of kiln drying technology

Introduction of drying quality standards

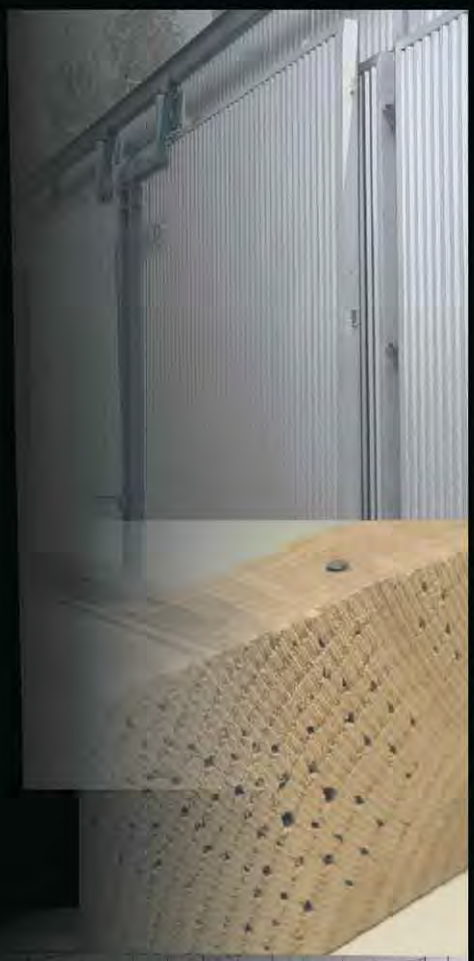
Determination of wood bending parameters

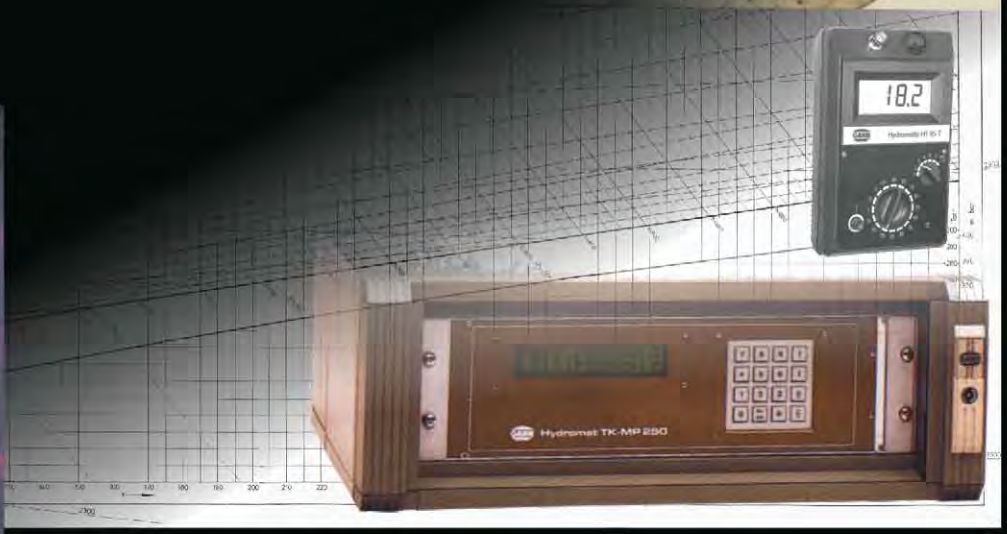
Detection and reducing of hydrothermal processes wood defects

Reducing of kiln drying time

Drying costs calculation

Kiln dryer capacity calculation





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Improving the Performance and Quality of Processes by Applying and Implementing Six Sigma Methodology in Furniture Manufacturing Process

Poboljšanje izvedbe i kvalitete procesa proizvodnje namještaja primjenom metodologije *Six Sigma*

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ABSTRACT • *The main aim of this paper is to illustrate the application of selected methods and procedures in the implementation of the Six Sigma Methodology in the furniture manufacturing processes, specifically in the wood veneer pressing, to verify the application and to evaluate the benefits of using selected methods and procedures through a series of step DMAIC process improvement. The application of selected methods and tools within the Six Sigma Methodology, such as DPMO, efficiency and sigma levels, project charter, histogram of mistakes caused by the application of the adhesive, the SIPOC plot mapping process, reaction plans, Ishikawa diagram and control diagrams bring the system and clarity of measurable results into project management for process improvement and process change. The benefits of their use are the cost savings and performance improvement processes.*

Keywords: *process, quality, Six Sigma Methodology, DMAIC, statistical regulation, process performance, furniture manufacturing*

SAŽETAK • *Glavni je cilj ovog rada prikazati provedbu odabranih metoda i postupaka pri primjeni Six Sigma metodologije u proizvodnji namještaja. To se posebice odnosi na provjeru primjene i procjenu prednosti korištenja odabranih metoda i postupaka pri prešanju furnira unutar niz koraka za poboljšanje DMAIC procesa. Primjena odabranih metoda i alata u sklopu metodologije Six Sigma, kao što su DPMO, učinkovitost i sigma razine, projektna povelja, histogram grešaka uzrokovanih primjenom ljepila, proces mapiranja SIPOC, reakcijski planovi, Ishikawa dijagram i kontrolni dijagrami, uvodi sustav i jasnoću mjerljivih rezultata u upravljanje projektima radi poboljšanja i promjene procesa. Prednosti njihove uporabe jesu smanjenje troškova i poboljšanje proizvodnog procesa.*

Ključne riječi: *proces, kvaliteta, metodologija Six Sigma, DMAIC, statistički propis, svojstva procesa, proizvodnja namještaja*

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1 INTRODUCTION
1. UVOD

Business and business activities are the decisive driving force behind economic activity in the market economy. The successful operation of businesses in strong competition is determined by well-functioning management. In the process of quality assurance in companies, decision-making based on an analysis of the situation with the appropriate use of operational management and quality improvement tools and methods plays an important role. The actual management decisions on issues of quality improvement can be based on qualitative or quantitative data. It is precisely these data that play an important role in the appropriate choice of tools. To ensure and improve process quality, Six Sigma Methodology is used to achieve, maintain and maximize profits, increase business performance, and focus on customers. The implementation of Six Sigma, mainly in the engineering, automotive, electrical and electronics industries, as well as in providing services, has achieved enormous cost savings.

Six Sigma originated in the 1980s as a corporate strategy containing a set of techniques for the improvement of manufacturing processes and elimination of defects in the Motorola company. The main goal of the strategy was to minimize the dispersion of the characteristics critical for the quality of manufactured products and performed processes, and set the average values approaching the target values defined by the customers. The application of Six Sigma Methodology – SSM brought about changes within a short time, leading to the reduction of defects in the products using the same labor, technology, and design, at less cost. Thanks to the strategy, Motorola gained the leading position in the area of quality and was awarded the Malcom National Quality Award. Many worldwide companies like Toyota, Ford, BMW, Hilti, Allied Signal, Xerox, Kodak, Shell, General Electric, Honeywell International, Caterpillar, Raytheon, and Merril Lynch have successfully applied this methodology, as presented by Khumar, 2006; Chapman, 2005 and Al-Agha *et al*., 2015.

According to Gibbons, 2010, by applying Six Sigma in a well-known manufacturing company in the United Kingdom, overall equipment effectiveness improved significantly from 40 % to 85 %. General Electric was one of the first companies adopting the SSM from Motorola and in the three years since introduction they calculated that the method had saved them $750 million, net, after subtracting all costs, including the cost of the method.

Six Sigma processes show a proven approach for businesses and organizations to improve their performance, and that sustainability programs are in need of this operational approach and discipline. Six Sigma helps a business leader design a sustainable program for value creation as stated by Kadri, 2013.

Based on a case study done by Sujová *et al*. (2016) „Experience of Slovak and Czech companies has proven that, for example, processes in manufacturing companies in the automobile industry with an already established quality assurance system are at an average level of around 3.5 to 4 sigma. In this case, an improvement in the company's processes by 0.2 sigma represents economic benefits in the amount of 1 % of company income". Six Sigma concept on the corporate performance are used for example in Volkswagen, Slovak Telecom, U.S. Steel, T-Mobile, Allianz, Kooperatíva, Jungheinrich and Kaufland.

Six Sigma is defined as "a well-established approach that seeks to identify and eliminate defects, mistakes or failures in business processes or systems by focusing on those process performance characteristics that are of critical importance to customers" (Antony, 2008).

The designation of the Six Sigma Methodology is based on statistics. Sigma in mathematical statistics represents the standard deviation, denoted by the Greek alphabet σ, which represents the value of the amount of difference of a particular process. If the sigma is larger than the mean value, it is more variable in the resulting product (Khumar, 2006).

Six Sigma is a statistical methodology that aims to reduce variation in any process (Chakravorty and Shah, 2012; Näslund, 2008), reduce costs in manufacturing and services, make savings to the bottom line, increase customer satisfaction (Stamatis, 2004; Drohomeretski *et al*., 2013; Kollár, 2013; Manville *et al*., 2012; Näslund, 2008; Schroeder, 2006) measure defects, improve product quality, and reduce defects to 3.4 parts per million opportunities in an organization (Lee and Wei, 2009; Chen and Lyu, 2009).

The characteristics of the Six Sigma Methodology are described in the works of several authors (Pande *et al*., 2002; Janetka, 2006; Töpfer *et al*., 2008; Linderman, 2003; Joglekar, 2003; Tošenovský, 2003; Gejdoš, 2006, 2014). Based on the study of individual authors' views on the Six Sigma Methodology, it can be concluded that Six Sigma Methodology is an approach or system that combines the use of statistical methods, understanding customer requirements and reducing process variability to improve processes and increase the level of perfection expressed by the maximum number of errors per millionth opportunity, and this value should be around the number of 3.4 errors. The Six Sigma strategy credo reads: "Work smarter, not harder".

Töpfer *et al*. (2008), Mateides *et al*. (2006), Simanová (2015), George (2002) and many other authors agree on the most common application of the standard DMAIC approach to project solving, which is characterized by the following five steps:

D – Defining opportunities for improvement,
M – Identifying measurement of the level of success,
A – Identifying and analyzing causes of problems,
I – Proposal for potential improvements by Six Sigma methods,
C – Determining a control plan.

The application of statistical methods that are part of the statistical process management was dividied by Mateides *et al*., 2006 into three areas: Statistical

Process Control, Statistical Survey and Process Capability.

The statistical regulation of the process can be based on the views of the authors Nenadal and Plura (2008), Nolan and Provost (1990), Montgomery (1997) and Terek and Hrnčiarová (2004), who characterize it as an instrument of process variability analysis that reveals the process, its shortcomings and their causes, their repeatability and their impact on the process.

Horálek (2004), Terek and Hrnčiarová (2004), Plura (2001), Nenadál and Plura (2008), Mateides *et al*. (2006) and Škorp (2001) recommend using the following regulatory diagrams for statistical process control by measuring:

- $\bar{x}$, R – chart of arithmetic mean and variation range
- $\bar{x}$, s – chart of arithmetic mean and standard deviation
- Me, R – chart of median and variation range
- $\bar{x}$, $\overline{MR}$ – chart for individual values and a slide chart.

The value $\bar{x}$ represents the selection mean of the values obtained from small subgroups and it is the process location. The R value is the range of values in each subgroup and it is the degree of process scattering. In all control diagram applications by measurement, it is assumed that within the selection, the quality trace is normal (Gaussian) distribution. Derogations from this assumption affect the efficiency of diagrams (Hrubec *et al*., 2009).

Control charts are the most frequently used tool in the statistical regulation of processes. They allow more accurate distinguishing of random from systematic causes of fluctuations in the value of a mark of quality, i.e. they facilitate regulation and improvement in the quality of the process. Control charts are used in monitoring processes and when ascertaining the need for corrections or changes in the process, in order to achieve a better mean value of the process or in order to reduce variability in the process. In control charts, the horizontal axis contains the times when statistical sampling of regulated values took place, and the vertical axis contains calculated values of the appropriate sample characteristics (Závadský, 2006). Interpretation of control diagrams is simple. We assume that while processes remain within the regulatory boundaries, variability arises from common causes. However, if observation proves the opposite, it is necessary to pay more attention to the observation to discover the causes of the deviations.

Based on recommendations of different authors (Plura, 2001; Töpfer, 2008; Terek and Hrnčiarová, 2004; Linczényi and Nováková, 2001), process capability analysis involves the selection of process characters, collection of measurable data, statistical assessment of the process by means of control chart, verification of the normality values for the process capability analysis and calculation of capability indexes. In order to evaluate the process capability, histograms were used as a visual synthesis of frequency distribution. Expression of process capability by a number (pointer) has led to the development of process capability indexes. In quality assurance with Six Sigma, great emphasis is put on various variants of competence coefficients and statistical models and procedures. Securing and improving process quality can be determined by other qualitative indicators such as the C_p and C_{pk} indexes.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Methodology of the research
2.1. Metodologija istraživanja

Application and implementation of Six Sigma using some DMAIC tools is briefly illustrated in a case study of a furniture company that has an integrated and certified quality management system - QMS according to ISO 9001:2000 standard.

2.1.1 D – Defining opportunities for improvement
2.1.1. D – Definiranje mogućnosti poboljšanja

The following tools and methods were used in the phase of defining: DPMO calculation, sigma efficiency and sigma, project charter, error histogram for glue application and SIPOC mapping process. Based on the analysis of non-conforming products, a problem was identified that had to be addressed in the project. In the project charter, the project goal was formulated in precise numbers, and the deadlines for implementation of the solution and the expected duration of the phases were determined. A specific breakdown of the performance of the team members, deadlines for their implementation, checks and revisions, as well as a breakdown of the implementation of corrective actions were proposed in the preliminary draft plan. According to Nenadál and Plura (2008), Defects per Million Opportunities (DPMO) represents the number of defects that occur per million opportunities in product manufacturing. As one of the main criteria of Six Sigma, it was calculated according to the following equation (1):

$$\text{DPMO} = \frac{(\text{number of defect products})}{(\text{total number of products} \times \text{number of opportunities per defect})} \times 10^6 \quad (1)$$

The effectivity calculation was carried out by defining the equation:

$$(1 - \text{DPMO}/1000000) \times 100 \quad (2)$$

The level of sigma calculation was carried out by defining the equation:

$$\text{V Normal } (1\text{-DPMO}/1000000;\ 1;\ 5;\ 1) \quad (3)$$

Calculations were carried out using Excel and STATISTICA Cz (***Stat Soft. Inc., 2013).

2.1.2 M – Measurement parameters and critical process selection
2.1.2. M – Mjerni parametri i odabir kritičnog procesa

Important answers to the questions about the essence of measurement are *What will we measure* and *What we want to measure.* The evaluation of the obtained values results in the selection of the critical process. The aim of the measurement was to reduce the variability of the pressing process - the operation of gluing with the output of quality parts and low occur-

rence of misalignments. The second step was to define a specific quality mark, namely the weight of the adhesive coating on one side of the piece in g, which was subsequently calculated as g/m^2. The nominal value of the quality mark according to the technical conditions and the processing scheme for the oak veneer was 52 g/m^2 with a tolerance of ± 4 g/m^2. Upper control value USL = 56 g/m^2 and lower LSL = 48 g/m^2. The pressing process was performed on a synchronized line. The production equipment, whose competence was examined, was the adhesive application. Most misfits were found on the machine. In the application design and implementation of the Six Sigma Methodology, the values of the glue weights were used to determine the variability of the pressing process - the application of the adhesive through the coefficients of capability. In the calculation of the indexes, the process is generally assumed to be stable, the observations are statistically independent and have a normal distribution. In our experiment, we have used indexes of competence, which are considered as first generation indexes.

Capability index C_p is an indicator of the potential capability of the process and characterizes the dispersion of the process. Generally, it is the ability of the process to achieve values with lower variability relative to the tolerance interval. To calculate C_p index, we used the equation (4):

$$C_p = \frac{USL - LSL}{6\sigma} \quad (4)$$

Where
USL – upper tolerance limit
LSL – lower tolerance limit
σ – standard deviation
6σ – 3σ on the left and 3σ on the right on the target value T

In practice, C_p = 1.33 can be considered as the minimum admissible value, because there is always a certain fluctuation, and the measurement process is never in a perfectly matched state. Boundary 1.33 should be considered earlier for the measurement process. This criterion corresponds to approximately three discrepancies on one tolerance limit for the production of 100,000 pieces. For the newly introduced process, the required index values are higher (e.g., C_p = 1.50). At C_p = 1.67), and virtually zero percentage of nonconforming products is expected. The C_p limit value for comparison was set at C_p = 1.33.

Critical capability index C_{pk} is an indicator of the actual, real capability of the process. This index is characterized not only by the variability of the quality trace, but also by its position in relation to the defined tolerance area (tolerance field), i.e. the distance of the upper or lower limit from the mean value.

$$C_{pkUSL} = \frac{USL - \overline{\overline{X}}}{3\sigma} \qquad C_{pkLSL} = \frac{\overline{\overline{X}} - LSL}{3\sigma} \quad (5)$$

Where
USL –upper tolerance limit
LSL –lower tolerance limit
$\overline{\overline{X}}$ – average mean value in subgroups, overall selective mean
σ – standard deviation

Capability index always considers the lower value:

$$C_{pk} = \min (C_{pkUSL}, C_{pkLSL}) \quad (6)$$

2.1.3 A – Analysis of measured data
2.1.3. A – Analiza izmjerenih podataka

On the basis of conclusions from the Measure phase, the Analysis phase emphasized the identification of the main problem, identification of possible causes and identification of the mistakes that caused the variability of the pressing process - the application of the adhesive. The brainstorming method was used to interpret the analyzed measurement data, to identify a particular problem, to arrange the possible causes of the problem, and to form the Ishikawa chart.

2.1.4 I – Improve phase
2.1.4. I – Poboljšanje

The main objective of the Improve phase is the elaboration and implementation of the design of the reaction plan for the pressing process - application of the adhesive. The response plan includes a graphical representation of the location of the glue weight values in the individual bands of the flowchart, and the procedure to be followed by the operator in setting, measuring, checking and transmitting information. On the basis of the instructions given in the reaction plan, measurements were carried out with the time gap in the verification of the measures to reduce the misalignment due to the poor application of the adhesive in the critical pressing - gluing process. In the Improve phase, the following tools and methods were used: brainstorming, Ishikawa diagram, C_p and C_{pk} process capability indexes, sigma process, histogram, industrial statistics & Sigma. In the furniture manufacturing process, it was essential to achieve a glue coating according to the 52 g/m^2 technology with a deviation of ± 4 g/m^2, which in our case was a regulated quantity.

2.1.5 C – Control phase
2.1.5. C – Kontrola

Since the controlled variables were measured on a continuous scale, we used control in the Control phase to illustrate a pair of control charts. One graph characterizes the position of the controlled variable - the mean value (diameter) and the second is used to regulate the variability of the controlled variable by means of the regulation of the span and standard deviation. The control count determined the number of subgroups, the number of selections k = 20. The control interval (constant time interval between two consecutive selections) was determined based on technological limitations every 20 minutes. The range of sub-groups was determined, the selection size n = 5, which represented the number of controlled products in one subgroup k. Overall, 100 measurements were taken. In the process, the necessary conditions for regulation were provided, namely the immediacy of all known effects, as well as the equipment of the workplace and the training of employees. Descriptive Statistics module and Industrial Statistics and Sigma module - Quality Management Plans were used for the calculations.

Control chart - $\bar{X}$, *R* is the most commonly used control chart. It allows you to track the entire distribution, making it easier to find a source of significant impact. This is a combination of two charts. One is the arithmetic average $\bar{X}$, with drawings control limits $UCL_{\bar{X}}$ and $LCL_{\bar{X}}$. In the second chart, the selection range *R* draws the regulatory limit UCL_R and LCL_R. The values of the relevant indicators $\bar{X}$ and *R* are determined for each selection. The average values obtained $\bar{x}_1$, $\bar{x}_2$, $\bar{x}_3$, ... $\bar{x}_n$, are used to calculate the diameter (7). The values R_1, R_2, R_3, ... R_n obtained by (9) are used to calculate the average of the range (9):

$$\bar{x} = \frac{1}{k}(\bar{x}_1 + \bar{x}_2 + ...\bar{x}_n) = \frac{1}{k}\sum_{i=1}^{n} x_i \quad (7)$$

$$R = xmin_{\max} \quad (8)$$

$$\bar{R} = \frac{1}{k}(R_1 + R_2 + ...R_n) = \frac{1}{k}\sum_{i=1}^{n} R_i \quad (9)$$

For the calculation of control limits UCL and LCL for control charts, values $\bar{x}$, R and conversion coefficients A_2, D_3 and D_4 are used for the average and range within a subgroup n = 25, in accordance with the norm Shewhart regulatory charts STN ISO 8258.

The control limits are calculated to determine the width of the field in which the diameters ($\bar{X}$) oscillated in a range (R_i). The control chart parameters for the average and range are calculated by Hrubec *et al.* (2009) and Terek and Hrnčiarová (2004) as follows:

The upper control limit for the average

$$UCL_{\bar{X}} = \bar{\bar{X}} + A_2 \cdot \bar{R} \quad (10)$$

The lower control limit for average

$$LCL_{\bar{X}} = \bar{\bar{X}} - A_2 \cdot \bar{R} \quad (11)$$

The central line for average

$$CL = \bar{\bar{X}} \quad (12)$$

The upper control limit for range

$$UCL_R = D_4 \cdot \bar{R} \quad (13)$$

The lower control limit for range

$$LCL_R = D_3 \cdot \bar{R} \quad (14)$$

The central line for range

$$CL = \bar{R} \quad (15)$$

Control chart - $\bar{X}$, *s*

The control chart parameters $\bar{X}$ are calculated according to Eq 13-15. Parameters for the control chart according to Terek and Hrnčiarová (2004) are calculated as follows:

The upper control limit for standard deviation

$$UCL_S = B_4 \cdot \bar{s} \quad (16)$$

The lower control limit for standard deviation

$$LCL_S = B_3 \cdot \bar{s} \quad (17)$$

The central line for standard deviation

$$CL = \bar{s} \quad (18)$$

Conversion coefficients B_3 and B_4 are for the different ranges of subgroups n listed in the Shewhart regulatory charts STN ISO 8258.

Control chart - $\overline{MR}$, s

In the case of the individual variability control chart, the variability of the process varies as the control procedure uses the selective sliding range of the two subsequent measurements and is defined as follows:

$$MR_i = | X_i - X_{i-1} | \quad (19)$$

which is understood as the selection range *R* in the absolute value for the selection range *n* = 2. The average sliding range is calculated according to the equation:

$$\overline{MR} = \frac{MR_1 + MR_2 + \ldots MR_m}{m} \quad (20)$$

The control chart parameters ($\overline{MR}$, s) are calculated according to Eq. 21-23. According to Terek and Hrnčiarová (2004), the parameters for the control charts are calculated as follows:

The upper control limit for the sliding range

$$UCL_{MR} = D_4 \cdot \overline{MR} \quad (21)$$

The lower control limit for the sliding range

$$LCL_{MR} = 0 \quad (22)$$

The central line for standard deviation

$$CL = \overline{MR} \quad (23)$$

According to Shewhart regulatory charts STN ISO 8258, conversion coefficients D_4 are used for different ranges of subgroups n (***STN ISO 8258).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The analysis of source data in the production of 437,781 pieces revealed the resulting average DPMO values, efficiency and sigma level of selected company processes such as pressing, gluing of side surfaces of furniture parts, surface treatment, joining and manipulation. Worst values were reached in the pressing process, according to DPMO, which accounted for 107,536.58 defects per million opportunities; the output yield of the pressing process was expressed by an average efficiency of 89.27 % and an average sigma level of 2.7. The pressing process was based on the analysis identified as critical. Other processes showed efficiency over 99 % and sigma levels from 4.1 to 4.7. The company gives priority to saving the cost of disagreements by 10 % and increasing the level of sigma critical process from 2.75 to 2.85. Reducing the number of disagreements and thus increasing the customer satisfaction was considered a priority benefit.

In the measurement phase, values are measured by weight of the adhesive coating. The average adhesive weights in 12 sets of measurements and 576 samples ranged from 51.44 g/m^2 to 53.23 g/m^2. As a measure, the minimum adhesion value of the adhesive was

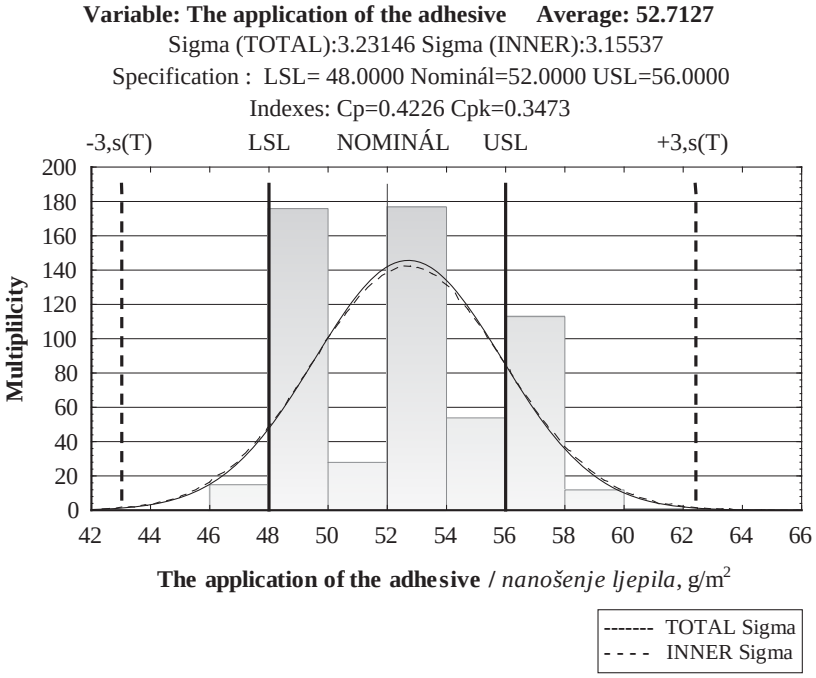

Figure 1 Histogram of weight distribution in adhesive application
Slika 1. Histogram raspodjele mase pri nanošenju ljepila

46.26 g/m^2 and the maximum value was 60.50 g/m^2. The lower tolerance limit of 48 g/m^2 was exceeded in 16 cases, ranging from 46-48 g/m^2. For example, the weights exceeded the range of 56 to 58 g/m^2 above the tolerance limit in 138 cases. The upper tolerance limit was exceeded in a range of 58 – 60 g/m^2 in 15 cases and in one case in the range of 60 - 62 g/m^2. For illustration, the output modules of statistics to measure the weight of adhesive application are presented (Figure 1).

The ridge shape of the histogram indicates that the variability of the process was high and was not due to the natural variation/variability in the process. Index capability values were also low, the total C_p index was 0.4226 and the critical index C_{pk} = 0.3473. Both coefficients were less than 1.33, so it was possible to conclude on the basis of aggregate results **that the production process is inappropriate**. Furthermore, it was important to point out that the coefficient $C_p > C_{pk}$, which means that the process was not positioned at the center of the tolerance interval and responded to the deflection of the actual mean value of the process μ from the center of the tolerance interval. On the basis of the above, it was possible to conclude that there were definite, systematic causes in the process.

In the analysis phase, attention has to be paid to checking the technical parameters of the adhesive -

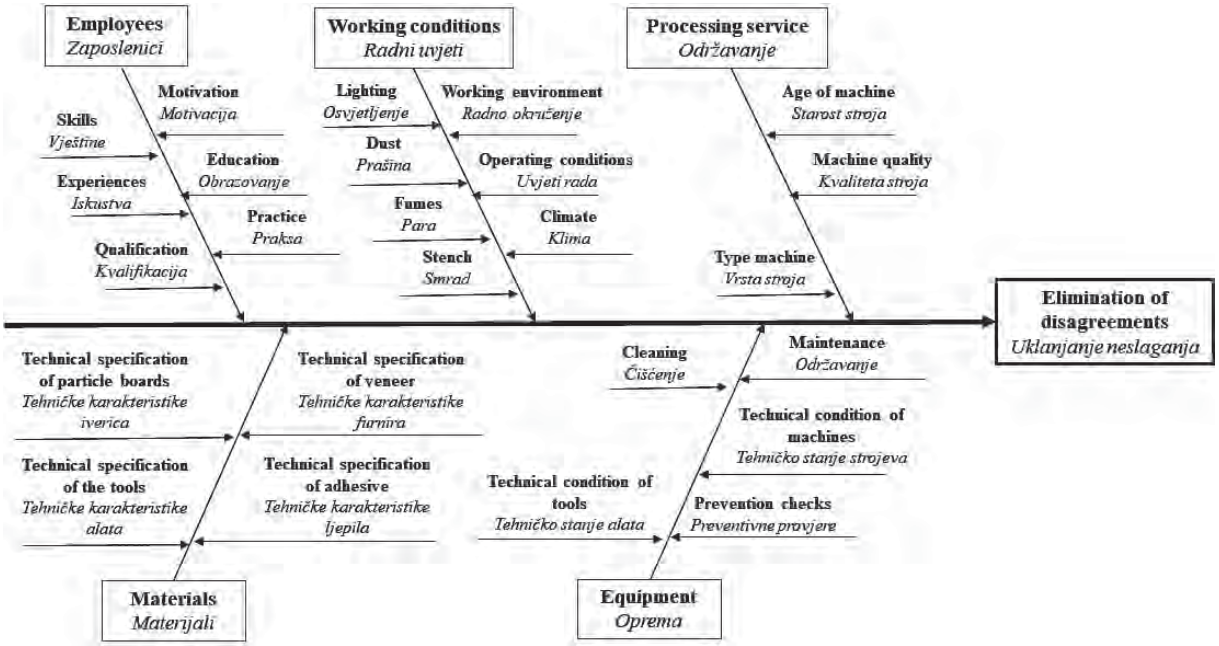

Figure 2 Ishikawa diagram of decomposition of elimination of disagreements
Slika 2. *Ishikawa* dijagram dekompozicije uklanjanja neslaganja

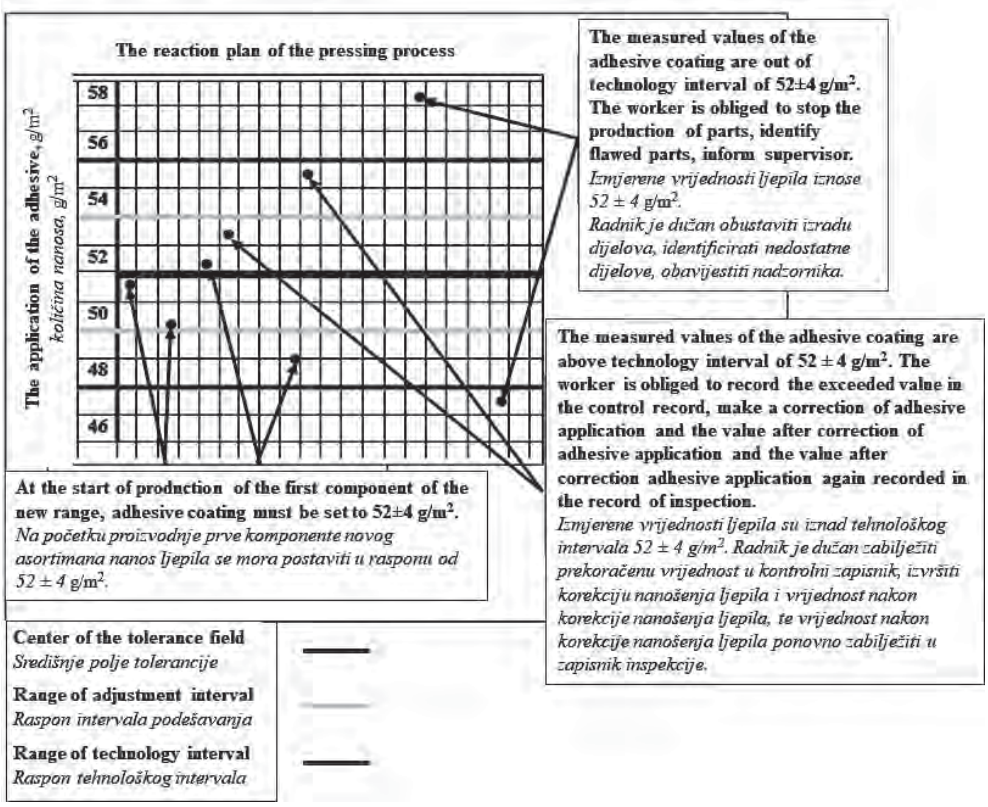

Figure 3 Draft of the reaction plan for pressing
Slika 3. Nacrt reakcijskog plana prešanja

such as temperature and viscosity. These parameters had a primary effect on the weight of the adhesive coating applied on the chipboard parts to which the oak veneers were glued. The impact of non-compliance with the chipboard and veneer technical parameters did not materialize significantly during the measurement. The form of disagreement was found defective with respect to technological discipline by the operator of

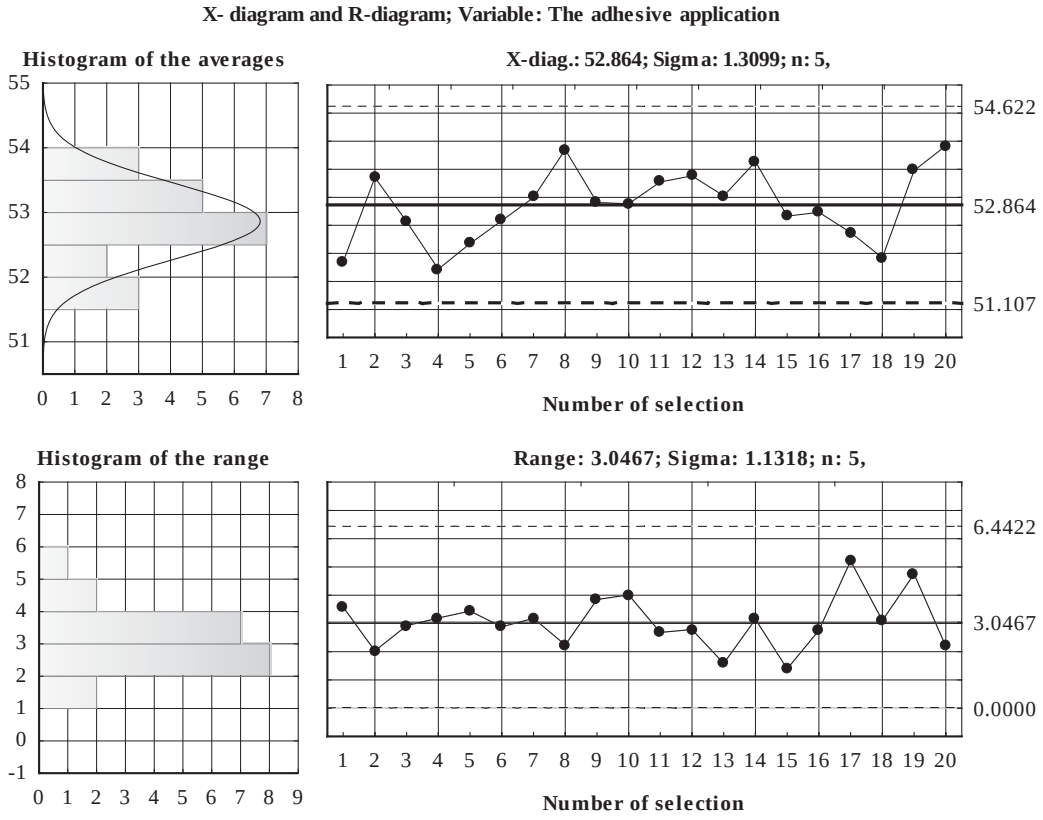

Figure 4 Control charts and histograms of averages and range for the adhesive application
Slika 4. Kontrolni dijagrami i histogrami prosjeka i raspona nanosa ljepila

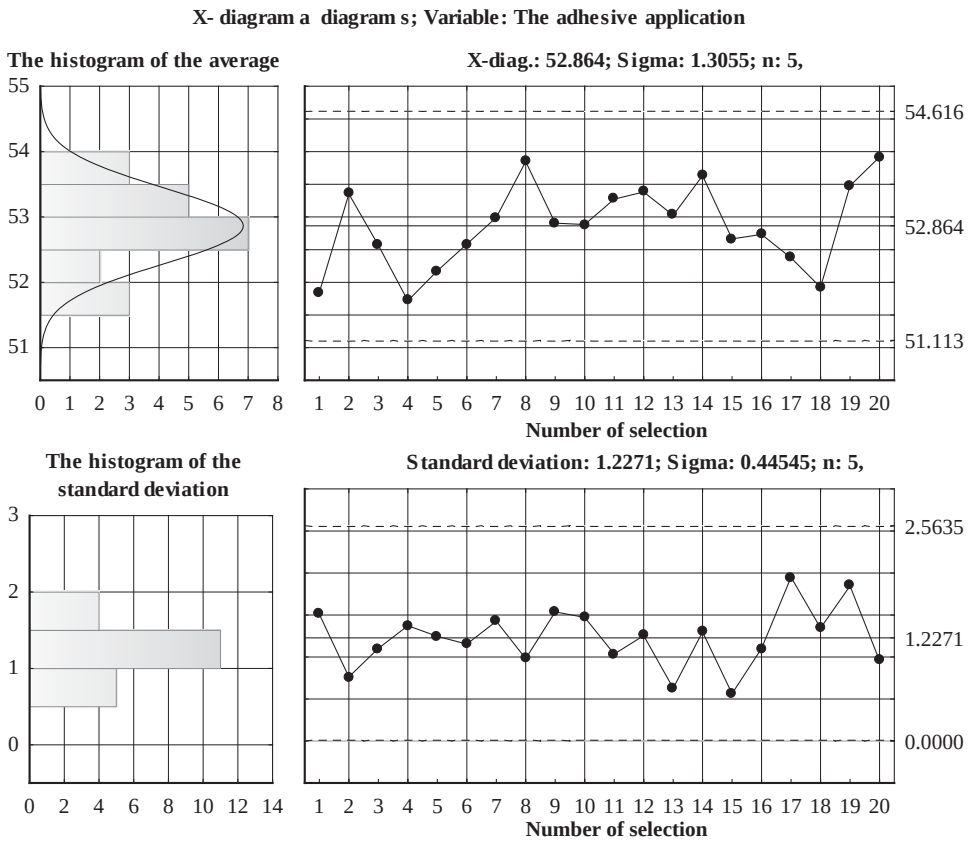

Figure 5 Control charts of average and standard deviation for the adhesive application
Slika 5. Kontrolni dijagrami i histogrami prosjeka i standardne devijacije nanosa ljepila

the adhesive application, particularly when setting the adhesive coating. Low adhesion of the adhesive resulted in dry places. In order to avoid this error when applying the adhesive, the operator adjusted the adhesion of the adhesive that exceeded the upper limit. Problems also arose due to the change in the type of adhesive. The foaming was used to reduce the weight of 82 g/m^2 to 52 g/m^2. The Ishikawa diagram design, which depicts the decomposition of the causes of the first stage to the causes of the second and third stage, is shown in Figure 2.

In the Improve phase, the reaction plan was developed as measures to eliminate the disagreements in the process. The draft of the reaction plan for the pressing is shown in Figure 3.

Control was performed in the Control phase. From the control diagrams of the averages and the range for the controlled variable - the adhesion of the adhesive showed that the measured values were not outside the control limits of the respective control diagram. In this case, it was possible to assume that the process was stable and that the calculated control limits could be used in the statistical regulation of the given variable as shown in Figure 4.

The control charts of the standard deviation presented in Figure 5 show that the average value of the standard deviation is 1.2271 and the other values range from 0.5-2 and do not exceed the control limits. This confirms the assumption that common causes are present in this process.

For a more detailed assessment of the situation, a selection range of n = 1 was chosen as well as the possibility of using a control chart for individual measurements as shown in Figure 6. In this case, the flowchart of individual values with a control chart of moving ranges was used. From the control chart of the moving range as the difference between the results of two successive measurements, it can be seen that the average value is 1.7827 and the largest group ranges between 0-1. This diagram would be better used if automated control and measurement were applied in the process, and if the measured quantity were measured for each product. This would be economical and time-saving.

The economic evaluation of the implementation and application of selected methods and tools within Six Sigma

Basic data for the economic evaluation of the proposal were the number of non-conforming parts of defects broken down by type. After the implementation of the Six Sigma tools, disagreements in the pressing process decreased by 20.89 % compared to the original state. The total amount of non-conforming parts in the pressing process was reduced as shown in Table 1. We can say that following the implementation of the proposed Six Sigma Quality Improvement, the cost savings of 16.47 % were achieved. The goal stated in the project charter, namely to reduce the cost of complaints and non-conforming products by at least 10 %, was achieved.

The improvement was observed in a reduction of DPMO and increase of efficiency. The sigma level increased from 2.75 to 2.95. One of the goals set in the project charter was to increase the sigma level from

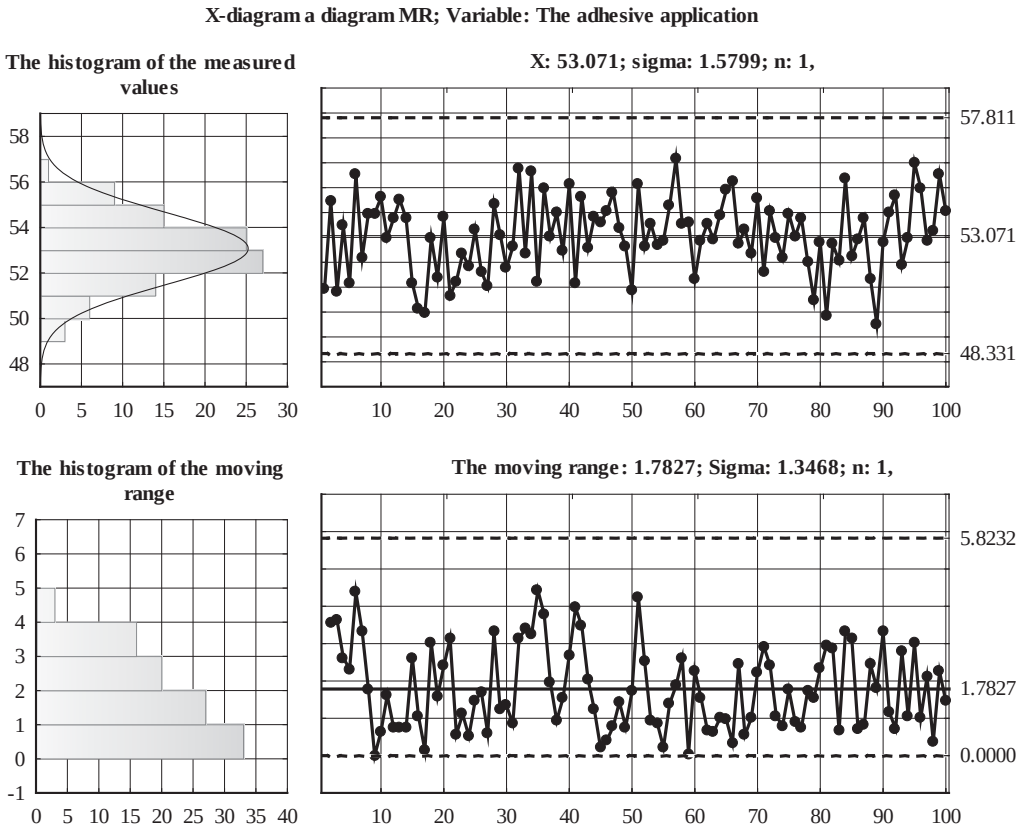

Figure 6 Control charts of the measured values and moving range for the adhesive application
Slika 6. Kontrolni dijagrami izmjerenih vrijednosti i raspona nanosa ljepila

Table 1 Economic evaluation of the draft changes in the pressing process
Tablica 1. Ekonomska procjena nacrta promjena u postupku prešanja

Situation *Položaj*	**Number of non-conforming parts, pcs** *Broj nesukladnih dijelova, kom.*	**Price per piece, €** *Cijena komada, €*	**Total amount, €** *Ukupna cijena, €*
Before the change / *prije promjene*	5,879.00	9.24	54,321.96
After the change / *nakon promjene*	4,911.00	9.24	45,377.24

2.75 to 2.85. Based on the above analysis, it can be stated that the charter goal regarding the pressing process has been fulfilled.

4 CONCLUSIONS
4. ZAKLJUČAK

Based on the above-mentioned theoretical knowledge and practical experience verified directly in furniture manufacturing processes, it can be stated that Six Sigma Methodology is appropriate for improving the quality and process performance in furniture manufacturing processes. Six Sigma application and implementation, using DMAIC steps, provides a system for defining, measuring, analyzing, improving and managing processes, by choosing methods that are not strictly prescribed, which can be chosen by the implementation team according to the needs and type of problems considered. The results of the case study presented in this paper have shown that, after the implementation of the selected tools of Six Sigma, non-conforming parts in the pressing process were reduced by 968 pieces, which represents 8,944.72 euros of cost savings. Specific outcomes of the case study provide guidance for the selection of methods and tools within the Six Sigma Methodology related to project management for process improvement and implementation of changes in processes. The woodworking industry and specific furniture industry represent a perspective industry whose advancement and growth of competitiveness stems from the use of new management methods, traditional and modern methods and procedures considered in this paper.

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5 REFERENCES
5. LITERATURA

1. Al-agha, O.; Alzubaidi, A. J.; Al-agha, M. I., 2015: Implementing Six Sigma Methodology in Industrial Control Systems. Int. J. Comput. Appl. Technologie.
2. Antony, J., 2008: Reflective practice: can Six Sigma be effectively implemented in SMEs? International Journal

of Productivity and Performance Management, 57 (5): 420-423.
3. Drohomeretski, E.; Gouvea Da Costa, S.; Pinheiro De Lima, E.; Andrea Da Rosa, P., 2013: Lean, Six Sigma and Lean Six Sigma: an analysis based on operations strategy. International Journal of Production Research, 52 (3): 804-824. http://doi.org/10.1080/00207543.2013.842015.
4. Gejdoš, P., 2006: Method Six Sigma – Flexibile system for improving business performance. (Metóda Six Sigma – flexibilný systém zdokonaľovania podnikovej výkonnosti). Acta facultatis xylologiae, 2: 103-111.
5. Gejdoš, P., 2014: Building and certification of quality management systems in theory and practice. (Budovanie a certifikácia systémov manažérstva kvality v teórii a praxi). Zvolen: TU Zvolen.
6. George, M. L., 2002: Lean Six Sigma. USA: The McGraw-Hill.
7. Gibbons, P. M., 2010: Incorporating six sigma thinking and asset management strategy performance indicators into the overall equipment effectiveness measure. In Proceedings of the second European Research Conference on Continuous Improvement and Lean Six Sigma, Bristol, UK.
8. Horálek, V., 2004: Simply tools for quality management (Jednoduché nástroje řízení jakosti I.). Národní informační středisko pro jakost, Praha: 63-74.
9. Hrubec, J.; Virčíková, E., 2009: Integrated management system 1. (Integrovaný manažérsky systém. 1. vydanie). Nitra: 542.
10. Chakravorty, S. S.; Shah, A. D., 2012: Lean Six Sigma (LSS): an implementation experience. European Journal of Industrial Engineering. 6 (1): 118-137. http://doi.org/10.1504/EJIE.2012.044813.
11. Chapman, A., 2005: Six sigma training, history, definitions. http://www.businessballs.com/sixsigma.htm
12. Chen, M.; Lyu, J., 2009: A Lean Six-Sigma approach to touch panel quality improvement. Production Planning and Control, 20 (5): 445-454. http://doi.org/10.1080/09537280902946343.
13. Janetka, P., 2006: Six Sigma for small and medium businesses. Modern management (Six Sigma i pro malé a střední podniky. Moderní řízení), 41 (7): 44.
14. Joglekar, A. M., 2003: Statistical Methods for Six Sigma in R&D and Manufacturing. USA: J. Wiley and Sons: 321.
15. Kadri, S., 2013: Six Sigma Methodology for the Environment Sustainable Development. In Mechanism Design for Sustainability, 1st ed. Luo, Z. (ed.). Springer: Berline, Germany: 61-76. http://doi.org/10.1007/978-94-007-5995-4_4.
16. Khumar, D., 2006: Six Sigma Best Practices. Fort Lauderdale: J. Ross Publishing, Inc.
17. Kollár, V., 2013. The Quality Management. Bratislava.
18. Lee, L.; Wei, C., 2009: Reducing mold changing time by implementing Lean Six Sigma. Quality and Reliability Engineering International, 26 (4): 387-395. http://doi.org/10.1002/qre.1069.
19. Linczényi, A.; Nováková, R., 2001: The management of quality (Manažérstvo kvality). 1. vyd. Bratislava: STU v Bratislave: 299.
20. Linderman, K.; Schroeder, R. G.; Zaheer, S.; Choo, A. S., 2003: Six Sigma: A Goal-theoretic Perspective. Journal of Operations Management, 21 (2): 193-203.
21. Manville, G.; Greatbanks, R.; Krishnasamy, R.; Parker, D. W., 2012: Critical success factors for Lean Six Sigma programmes: a view from middle management. International Journal of Quality and Reliability Management, 29(1): 7-20. http://doi.org/10.1108/02656711211190846.
22. Mateides, A., 2006: Quality management history, concepts, methods (Manažérstvo kvality história, koncepty, metódy). University Matej Bel: 443, 449-445.
23. Montgomery, D. C., 1997: Introduction to Statistical Quality Control. New York, J. Wilex.
24. Näslund, D., 2008: Lean, six sigma and lean sigma: fads or real process improvement methods? Business Process Management Journal, 14 (3): 269-287.
25. Nolan, T. W., Provost, L. P., 1990: Understanding Variation. Quallity Progress: 287.
26. Pande, P. S.; Neumann, P. R.; Cavanagh, R. R., 2002: We are introducing the Six Sigma method (Zavádíme metodu Six Sigma). TwinsCom, Brno.
27. Plura, J., 2001: Planning and continual improvement of quality (Plánovaní a neustálé zlepšováni jakosti). Computer Pres, Praha.
28. Schroeder, R. A., 2006: Six Sigma: The Breakthrough Management Strategy Revolutionizing the World's Top Corporations. Sydney: Currency: 9.
29. Simanová, Ľ., 2015: Specific Proposal of the Application and Implementation Six Sigma in Selected Processes of the Furniture Manufacturing. In Procedia Economics Finance, 34: 268-275. http://doi.org/10.1016/S2212-5671(15)01629-9.
30. Stamatis, D. H., 2004: Six Sigma Fundamentals: A Complete Guide to the System, Methods, and Tools. New York: Productivity Press.
31. Škorp, M., 2001: From control diagrams to Six sigma. Quality management (OD regulačních diagramu k Six sigma. Řízení jakosti): 7-8.
32. Sujová, A.; Simanová, Ľ.; Marcineková, K., 2016: Sustainable process performance by application of Six Sigma concepts: the research study of two industrial cases. Sustainability, 8 (3): 260. http://doi.org/10.3390/su8030260.
33. Terek, M.; Hrnčiarová, Ľ., 2004: Statistical Quality Management (Štatistické riadenie kvality). Bratislava: IURA EDITION: 234.
34. Töpfer, A., 2008: Six Sigma., Computer Press a.s. Brno.
35. Tošenovský, J., 2003: Evaluation process capability in problem situations (Hodnocení zpusobilosti procesu v problémových situacích). VŠB TU, Ostrava.
36. Závadský, J., 2006: Methods, tools and techniques of quality management (Metódy, nástroje a techniky manažérstva kvality). Banská Bystrica: Univerzita Mateja Bela, Ekonomická fakulta v Banskej Bystrici: 180.
37. ***Shewhart regulatory charts STN ISO 8258:1995.
38. ***Stat Soft. Inc. (2013). STATISTICA (data analysis software system), version 12. www.statsoft.com.

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Pinus palustris Mill.

NAZIVI

Pinus palustris Mill. naziv je drva botaničke vrste iz porodice *Pinaceae.* Trgovački su nazivi te vrste također: american pitch pine (SAD, Velika Britanija); longleaf pine, southern yellow pine (SAD); sumpfkiefer, amerikanische Terpentin kiefer, pitch pine, echte pechkiefer (Njemačka), pin des marais, pitchpin américain, pin de Boston (Francuska); pino palustre, pino pece, pino grasso, pino giallo (Italija); amerikaanse pitchpine (Nizozemska) i sördens gultall (Švedska).

NALAZIŠTE

Stabla *Pinus palustris* Mill. rastu u Sjevernoj i Srednjoj Americi, na jugoistočnoj obali SAD-a te u Gvatemali, Hondurasu, Nikaragvi i drugim zemljama Srednje Amerike.

Niskih su zahtjeva glede vrste tla te podnose i krupnozrnato pjeskovito tlo, ali uglavnom rastu u klimama s blagim zimama. U Sjevernoj Americi nalazimo ih u listopadnim šumama, a u Srednjoj Americi rastu unutar tropskih šuma četinjača.

STABLO

Visina stabla doseže 30 – 40 m. Čisto deblo dugo je 10 – 18 m, a prsni mu je promjer od 0,4 do 0,7 m. Debla su isključivo valjkastog oblika. Kora drva je svjetlonarančasta do smeđa. Puca u oveće tanke ljuske.

DRVO

Makroskopska obilježja

Drvo ima smolenice, koje su u kasnom drvu dobro vidjive golim okom. Bjeljika je bijelosiva do žućkastobijela, široka 5 – 10 cm. Srž drva je žutocrvena do crvenkastosmeđa. Tekstura drva je jednolična i manje više ukrasna. Granica goda je uočljiva. Prijelaz iz ranoga u kasno drvo nagao je. Kasno drvo znatno je tamnije od ranoga. Drvni traci i traheide ranoga drva golim su okom nevidljivi.

Mikroskopska obilježja

Traheide su radijalno raspoređene i u kasnoga su drva izrazito debelostjene. Debljina staničnih stijenki traheida ranoga drva iznosi 1,8...2,8...4,2 mikrometara, a u kasnoga drva ta debljina iznosi 6,4...8,1...11,4 mikrometara. Promjer lumena traheida ranoga drva je 16,1...40,3...60,3 mikrometara, a promjer lumena traheida kasnoga drva iznosi 12,8...19,0...29,7 mikrometara. Dugačke su 1600...4900...6900 mikrometara. Volumni je udio traheida oko 90,8 %. Drvni su traci heterocelularni, nepravilnoga rasporeda. Jednoredni su drvni traci visoki 140...210...310 mikrometara (do osam stanica), a široki su 22...29...39 mikrometara. Višeredni drvni traci sa smolenicama visoki su 250...690...800 mikrometara (do 12 stanica), a široki su od dvije do četiri stanice. Gustoća drvnih trakova je 9...11 na 1 mm, a njihov volumni udio iznosi oko 8,4 %.

Fizička svojstva

Gustoća apsolutno suhog drva, ρ_o	450...620...870 kg/m^3
Gustoća prosušenog drva, $\rho_{12\text{-}15}$	490...670...900 kg/m^3
Gustoća sirovog drva, ρ_s	850...950 kg/m^3
Poroznost	oko 60 %
Radijalno utezanje, β_r	4,0...5,3 %
Tangentno utezanje, β_t	7,1...7,7 %
Volumno utezanje, β_v	11,3...13,2 %

Mehanička svojstva

Čvrstoća na tlak	42...60 MPa
Čvrstoća na vlak, okomito na vlakanca	oko 3,3 MPa
Čvrstoća na savijanje	76...104 MPa
Čvrstoća na smik	9,2...12,6 MPa
Tvrdoća prema Brinellu, paralelno s vlakancima	32...42 MPa
Tvrdoća prema Brinellu, okomito na vlakanca	28...39 MPa
Modul elastičnosti	10,0...13,2...14,0 GPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Drvo se dobro pili, lijepi, blanja, brusi, buši, čavla i vijča. Prilikom obrade smola iz drva može se lijepiti za alate, odnosno puniti brusno sredstvo, što otežava površinsku i finalnu obradu drva. Bruševina drva može uzrokovati iritaciju kože i/ili dišne probleme.

Sušenje

Drvo se dobro i polako suši, a sklonost promjeni oblika i raspucavanju malena je.

Trajnost i zaštita

Prema normi HRN 350-2, 2005, srž drva *Pinus palustris* Mill. slabo je otporna na gljive uzročnice truleži (razred otpornosti 3) i osjetljivo je na napad termita (razred otpornosti M-S). Srž je slabo permeabilna (razred 3-4). Po trajnosti pripada razredu 2 i stoga se može upotrebljavati u interijeru. Za primjenu na otvorenim prostorima drvo je potrebno prethodno impregnirati zaštitnim sredstvom.

Uporaba

Drvo se upotrebljava za izradu konstrukcija kao što su mostovi, grede, stupovi, željeznički pragovi i dr. Od njega se također izrađuju šperploče, drvena pulpa, furnir i parket. Sporedni se proizvodi dobivaju smolarenjem i destilacijom drva.

Sirovina

Drvo se isporučuje u obliku trupaca dužine 3,0 do 6,0 m, odnosno kao piljena građa debljine 26...80 mm i širine 100 do 300 mm.

Napomena

Drvo se može rabiti kao zamjena za duglazijevinu i arišević. Za sada nije na popisu ugroženih vrsta međunarodne organizacije CITES, ali je na popisu međunarodne organizacije IUCN označena kao ugrožena vrsta drva. Drvo sličnih svojstava imaju i ove vrste: *Pinus caribaea* Morelet, *P. echinata* Mill., *P. elliottii* Engelm., *P. oocarpa* Schiede. *P. rigida* Mill., *P. taeda* L., *P. contorta* Dougl., *P. resinosa* Ait., *P. ponderosa* Dougl., *P. lambertiana* Dougl., *P. monticola* Dougl.

Literatura

1. ***HRN EN 350-2, 2005: Trajnost drva i proizvoda na osnovi drva – Prirodna trajnost masivnog drva, 2. dio.
2. Rendle, B. J., 1969: World Timbers, North & South America, London: Ernest Benn limited, University of Toronto press, pp. 64-65.
3. Wagenführ, R.; Scheiber, C., 2006: HOLZATLAS, VEB Fachbuchverlag, Leipzig, pp. 632-634.
4. ***1964: Wood dictionary, Elsevier publishing company Amsterdam, pp. 479.
5. http://www.wood-database.com/wood-articles/restricted-and-endangered-wood-species/ (preuzeto 14. veljače 2019.).

prof. dr. sc. Jelena Trajković
izv. prof. dr. sc. Bogoslav Šefc

Upute autorima

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Upute

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Znanstveni i stručni radovi moraju biti sažeti i precizni. Osnovna poglavlja trebaju biti označena odgovarajućim podnaslovima. Napomene se ispisuju na dnu pripadajuće stranice, a obrojčavaju se susljedno. One koje se odnose na naslov označuju se zvjezdicom, a ostale uzdignutim arapskim brojkama. Napomene koje se odnose na tablice pišu se ispod tablica, a označavaju se uzdignutim malim pisanim slovima, abecednim redom.

Latinska imena trebaju biti pisana kosim slovima (italicom), a ako je cijeli tekst pisan kosim slovima, latinska imena trebaju biti podcrtana.

U uvodu treba definirati problem i, koliko je moguće, predočiti granice postojećih spoznaja, tako da se čitateljima koji se ne bave područjem o kojemu je riječ omogući razumijevanje ciljeva rada.

Materijal i metode trebaju biti što preciznije opisane da omoguće drugim znanstvenicima ponavljanje pokusa. Glavni eksperimentalni podaci trebaju biti dvojezično navedeni.

Rezultati trebaju obuhvatiti samo materijal koji se izravno odnosi na predmet. Obvezatna je primjena metričkog sustava. Preporučuje se upotreba SI jedinica. Rječe rabljene fizikalne vrijednosti, simboli i jedinice trebaju biti objašnjeni pri njihovu prvom spominjanju u tekstu. Za pisanje formula valja se koristiti Equation Editorom (programom za pisanje formula u MS Wordu). Jedinice se pišu normalnim (uspravnim) slovima, a fizikalni simboli i faktori kosima (italicom). Formule se susljedno obrojčavaju arapskim brojkama u zagradama, npr. (1) na kraju retka.

Broj slika mora biti ograničen samo na one koje su prijeko potrebne za objašnjenje teksta. Isti podaci ne smiju biti navedeni i u tablici i na slici. Slike i tablice trebaju biti zasebno obrojčane, arapskim brojkama, a u tekstu se na njih upućuje jasnim naznakama (“tablica 1” ili “slika 1”). Naslovi, zaglavlja, legende i sav ostali tekst u slikama i tablicama treba biti napisan hrvatskim i engleskim jezikom.

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Primjer

Kärki, T., 2001: Variation of wood density and shrinkage in European aspen (*Populus tremula*). Holz als Roh- und Werkstoff, 59: 79-84. http://dx.doi.org/10.1007/s001070050479.

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Primjeri

Krpan, J., 1970: Tehnologija furnira i ploča. Drugo izdanje. Zagreb, Tehnička knjiga.

Wilson, J. W.; Wellwood, R. W., 1965: Intra-increment chemical properties of certain western Canadian coniferous species. U: W. A.
Cote, Jr. (Ed.): Cellular Ultrastructure of Woody Plants. Syracuse, N.Y., Syracuse Univ. Press, pp. 551- 559.

Ostale publikacije (brošure, studije itd.)

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Web stranice

***1997: “Guide to Punctuation” (online), University of Sussex, www.informatics.sussex.ac.uk/department/docs/punctuation/node 00.html. First published 1997 (pristupljeno 27. siječnja 2010).

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