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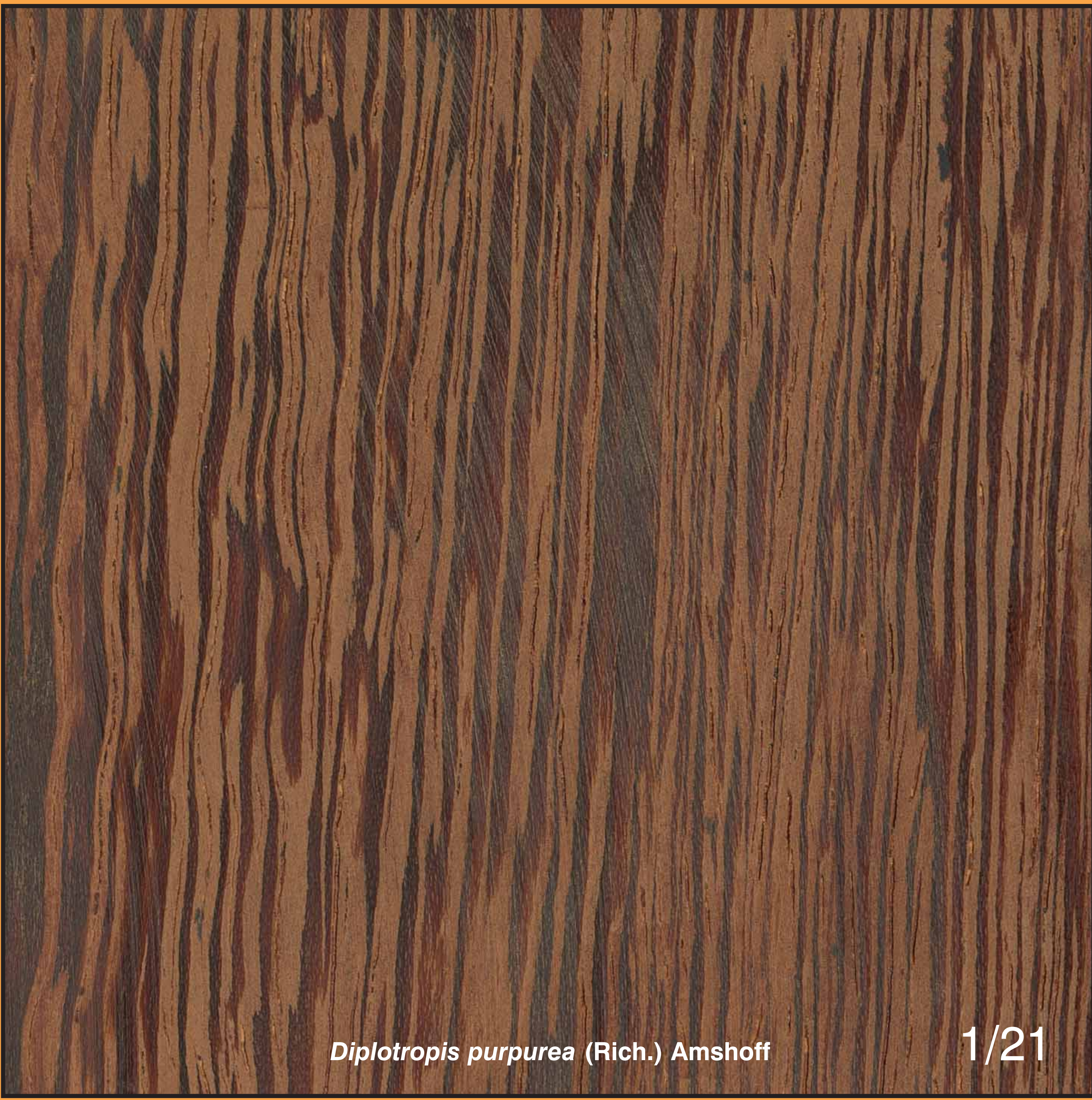

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Sadržaj
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Bending Characteristics of Laminated Wood Composites Made of Poplar Wood and GFRP

Savojna svojstva lameliranog drva izrađenoga od topolovine i GFRP-a

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ABSTRACT • *In this study, 4 layers of 5 mm thick slats obtained by sawing method from poplar wood were used. Plain woven GRFP with low density and grammage of 100 g/m² (Type 1) and plain woven GRFP with high density and grammage of 200 g/m² (Type 2) were placed and glued between each layer. Polyvinyl acetate (PVAc-D4), Polyurethane (PU) and dual-component Epoxy (L285-resin and H285-hardener) adhesives were used for gluing the layers. Strength values (bending and modulus of elasticity) between the obtained layers were investigated. As a result of the study, it was determined that epoxy glue has higher strength than polyurethane and polyvinyl acetate glues; Type 2 plain woven fabric has higher strength than Type 1 plain woven fabric; and parallel load to the glue line results in higher performance than perpendicular load to the glue line.*

Keywords: *poplar; wood laminate; bending strength; modulus of elasticity*

SAŽETAK • *U radu se prikazuje istraživanje lameliranog drva izrađenoga od piljenjem proizvedenih topolovih platica debljine 5 mm složenih u četiri sloja. Između svakog sloja zalijepljena je plošno tkana GRFP tkanina male gustoće i površinske mase 100 g/m² (tip 1) i plošno tkana GRFP tkanina velike gustoće i površinske mase 200 g/m² (tip 2). Za lijepljenje drva i tkanine upotrijebljena su ova ljepila: polivinilacetatno (PVAc-D4), poliuretansko (PU) i dvokomponentno epoksidno (L285-mola i H285-otvrdnjivač). Istražene su vrijednosti čvrstoće (savijanje i modul elastičnosti) te je utvrđeno da epoksidno ljepilo ima veću čvrstoću nego poliuretansko i polivinilacetatno ljepilo. Nadalje, tkanina tipa 2 ima veću čvrstoću od tkanine tipa 1, a djelovanjem sile paralelno sa sljubnicom dobivena su bolja svojstva nego pri djelovanju sile okomito na sljubnicu.*

Ključne riječi: *topolovina, drvni laminati, čvrstoća na savijanje, modul elastičnosti*

1 INTRODUCTION
1. UVOD

The value of forest products is also increasing due to the continuous decrease in forest resources and the increase of costs in the world. Due to the increase in furniture consumption, it will be possible to meet the demand for forest products by processing the forests in accordance with the scientific principles and to use the cut trees most efficiently. Lamination technique is used for efficient use of wood materials, removal of defects and formation of diagonal fibers in curved formations. With the developing technology, it is used as glued

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laminated timber material, which has an important place in today's design world as a contemporary material that allows to reach the smallest part of the wood by applying small pieces of wood with the help of glue, allowing wider openings and any desired shape.

Regarding solid wood materials, laminated wood materials, which are superior in terms of aesthetic, economic, and technological properties, have been suggested to be preferred in skeletal elements that require strength, particularly in LVL (Laminated Veneer Lumber) furniture production (Eckelman, 1993). Laminated wood materials are used in columns and beams as building elements, and in furniture which is exposed to high static and dynamic forces, in particular by sticking the plaque coating plates hot or cold under prestress under high pressure, flat or inclined (Dongel, 1999).

There are many reports available in the literature on the effects of laminated layer thickness on mechanical properties (Braun and Moody, 1977; Moody, 1981; Youngquıst *et al.,* 1984; Keskin, 2001; Altınok *et al.,* 2009; Percin *et al.,* 2009) and glue type (Senay, 1996; Eren, 1998; Dongel, 1999; Guray *et al.,* 2003) and different press pressure (Franklin Glue Comp, 1989; Dilik, 1997; Ulupınar, 1998;).

Tests with glass fiber reinforced materials were first carried out by Wangaard (1964) and Biblis (1965). In these initial experiments, both researchers made experiments using epoxy resin-treated one-way glass fiber on different types of solid wood materials. The first experiment on laminated beams was carried out by Theakson (1965). Experiments were carried out using water-based adhesive and epoxy adhesive with glass fiber woven, glass fiber felt and one-way untreated glass fiber in various shapes. The highest performance was achieved with one-way glass fiber. In recent years, some researches have been carried out on mechanical reinforcement of glass fiber and wood based structural materials (Pidaparti and Johnson, 1996; Hallström and Grenestedt, 1997; Fiorelli and Dias, 2006; Akgul *et al.,* 2009; Ozalp *et al.,* 2009; Riberio *et al.,* 2009; Basterra *et al.,* 2012; Borri *et al.,* 2013; Mıstak, 2013; Bal 2014a and 2014b; Osmannezhad *et al.,* 2014; Bal, 2015; Bal and Ozyurt, 2015; Guntekin, 2015).

The elements (beams) under the influence of the bending force are divided into two groups as "horizontal laminar elements" and "vertical laminar elements" according to the applied force direction (Baird and Ozelton, 1990). When the load is applied perpendicular to the glue line, it is called horizontal, and when the load is applied parallel to the glue line it is called vertical element. Examples of horizontal and vertical laminar elements are given in Figure 1.

The aim of this study was to bond and thicken layers between 5 mm thick *Populus nigra* slats using polyvinyl acetate (PVAc-D4), polyurethane (PU-D4) and dual-component epoxy resin (L285-resin and H285-hardener) to determine the bending strength and modulus of elasticity of laminated wood materials produced in 4 layers by placing low-density and high density glass fiber fabric (GFRP) in order to strengthen the layers.

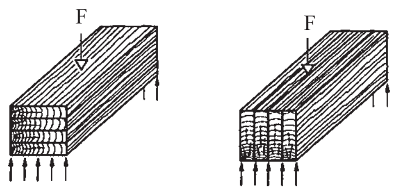

Figure 1 Examples of load perpendicular to glue line and parallel to glue line
Slika 1. Primjeri djelovanja sile okomito i paralelno na sljubnicu

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Wood material
2.1. Drvni materijal

The black poplar wood (*Populus nigra*) used as a solid wood in the preparation of the test specimens was obtained entirely randomly from lumber mills in Usak province. The choice of wood material was to ensure perfect timber, smooth fibers, without knots, with normal growth, no reaction wood, and no fungus and pest damage. The slats were cut from black poplar by a circular sawing machine with the dimension of 5 mm × 70 × mm × 1000 mm. The slats were stored until reaching a moisture content of 12 % in an air conditioning room with a temperature of (20 ± 2) °C and a relative humidity of (65 ± 5) %.

2.2 Glass fiber fabric (GFRP)
2.2. Tkanina ojačana staklenim vlaknima (GFRP)

It is produced from glass fiber materials such as fiberglass, silica, colemanite, aluminum oxide, soda. Glass fiber is the most known and used among fiber reinforced composites (Dost Kimya, 2017). Plain woven GFRP with low density and grammage of 100 g/m^2 (Type 1) and plain woven GFRP with high density and grammage of 200 g/m^2 (Type 2) were used between slats to improve the mechanical properties of timber structural elements and are shown in Figure 2.

2.3 Glue
2.3. Ljepilo

Polyvinyl acetate (PVAc-D4), Polyurethane (PU-D4) and Epoxy (L285 resin + H285-hardener) adhesives were used for bonding slats. Polyvinyl acetate adhesive (PVAc-D4) is an adhesive with advantageous properties such as odorless, easy application, quick curing, cold application and non-flammability (Polisan Ltd. Şti., 2017). Polyurethane adhesive (PU-D4) is a one component, polyurethane based, fast and

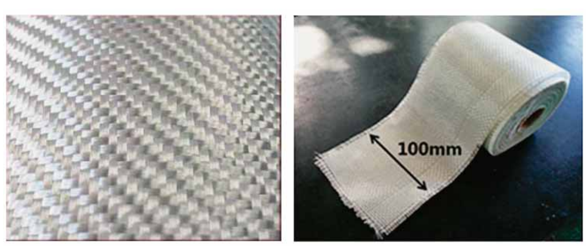

Figure 2 Glass Fiber Fabrics (GFRP)
Slika 2. Tkanina ojačana staklenim vlaknima (GFRP)

moisture curing adhesive for indoor use (Polisan Ltd. Şti. 2017) and Epoxy (L285-resin+H285-hardener) is a polyurethane based (PU) dual component adhesive, which provides excellent adhesion to wood materials and achieves the desired mechanical strength (Dost Kimya, 2017).

2.4 Preparation of experimental samples
2.4. Priprema eksperimentalnih uzoraka

The test specimens were prepared according to the standard "TS EN 408:2010 + A1:2014-04 Timber and Glued Laminates - Determination of Some Physical and Mechanical Properties". During the production of the test specimens from air-dried 5 mm thick solid materials, 4 solid layers of PVAc-D4, PU-D and Epoxy glues and plain woven GFPR with low and high density interlayer materials and samples without interlayer (as a control) were produced. For interlayer samples, 3 layers of glass fiber material were used for intermediate support between solid layers. In the lamination process, the dimensions of slats are 5×100×1000 mm and 4 layers are bonded. In the case of samples of interlayer materials, the glue solution was applied to the solid bonding surfaces with a brush and glue spread of 180-200 gr/m². In the bonding process, the surfaces are glued and kept for 5-6 minutes (open time). The cold laminating process was carried out by setting the pressure to 1.2 N/mm², cold in the hydraulic press with a pressure gauge suitable for hot and cold preseason for 8 hours (closed time).The laminated material obtained after pressing is prepared with woodworking machines according to the standard. The prepared samples are shown in Figure 3.

By using 2 plain woven types (control, Type 1 and Type 2), 3 glue types (PVAc-D4, PU-D4, and epoxy), 1 wood type (poplar) and 2 load types (bending strength and modulus of elasticity), a total of 90 samples (3×3×1×2×5) were prepared with 5 replicates for each parameter. Prior to testing, all specimens were stored in a conditioning room maintained at (20±2 °C) and 65 % RH until moisture equilibrium was achieved.

2.5 Methods
2.5. Metode

2.5.1 Bending strength
2.5.1. Čvrstoća na savijanje

The prepared test samples were tested, according to the 4-point bending principle, in parallel and perpendicular direction to the glue line using the SHIMADZU universal testing machine placed in the laboratory of Karabuk University Safranbolu Vocational School.

The loading speed of the test machine is 5mm/min. The bending strength, modulus of elasticity and load carrying capacity of the specimens placed with the

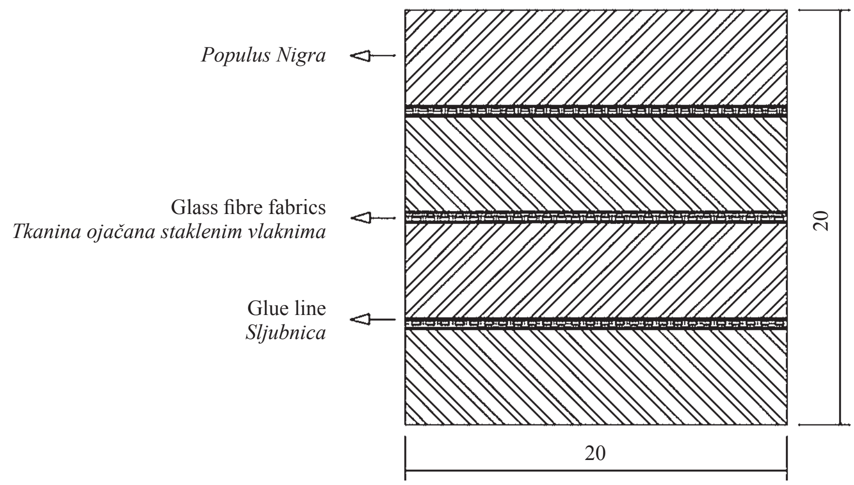

Figure 3 Test Samples of GFRP + Glue + Wood
Slika 3. Ispitni uzorci: GFRP + ljepilo + drvo

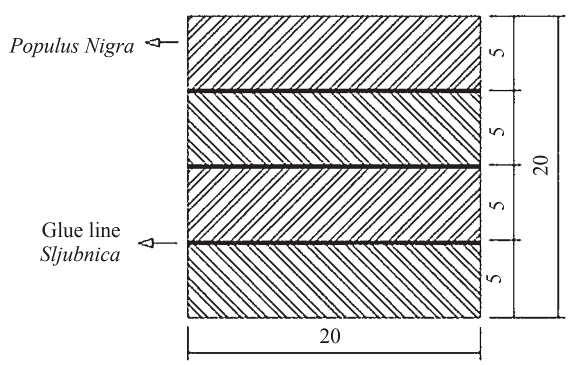

Figure 4 Test Samples of Glue + Wood
Slika 4. Ispitni uzorci: ljepilo + drvo

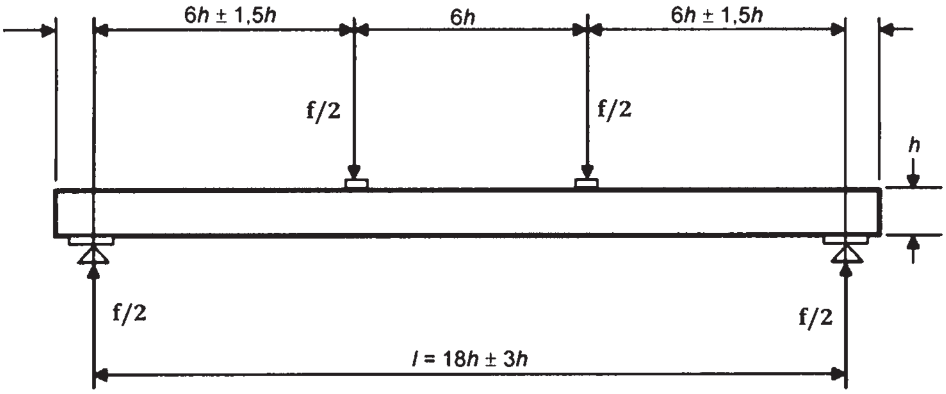

Figure 5 4-point bending principle
Slika 5. Načelo savijanja u četiri točke

base points of 360 (mm) are calculated. The 4-point bending strength was determined as (Eq. 1.):

$$\sigma_{E4} = \frac{F \cdot L}{b \cdot h^2} \tag{1}$$

Where is bending strength (N/mm²), *F* is the maximum load (N), *L* is span (mm), *b* is width (mm) and *h* is thickness (mm).

2.5.2 Modulus of elasticity
2.5.2. Modul elastičnosti

The modulus of elasticity was determined as (Eq. 2.):

$$E_{m \cdot g4} = \frac{\lambda^3 \cdot (F_2 - F_1)}{b_1 \cdot h_1^3 \cdot (W_2 - W_1)} \cdot \left[\left(\frac{3a}{4\lambda} \right) - \left(\frac{a}{\lambda} \right)^3 \right] \tag{2}$$

Where $E_{m \cdot g4}$ is modulus of elasticity (N/mm²), λ is length measured for identification of the modulus of elasticity, b_1 is width – dimension in tangential direction (cm), h_1 is height – dimension in radial direction (cm), *a* is distance between loading point and nearest spam (mm), $F_2 - F_1$ is increase of the load ratio on the correct line of the load-deflection curve (N), and $W_2 - W_1$ is increase in deformation corresponding to $F_2 - F_1$ (mm).

2.6 Evaluation of data
2.6. Evaluacija podataka

Statistical results (arithmetic mean *X*, standard deviation *SS* and coefficient of variation *%V*) of the data obtained in the experiments were calculated. In order to determine the test results, multiple variance analysis (ANOVA) was used to determine the effect of factors on the values obtained for all groups. The Duncan test was used to indicate the significance level of the interaction of the factors ($p < 0.05$) with 5 % error. Under the name of homogeneity group (HG), groups that differ were designated as A, B, C, etc.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Bending strength of parallel to glue line
3.1. Čvrstoća na savijanje paralelno sa sljubnicom

According to the normality analysis test result, the regions show normal distribution. The statistical evaluation results of bending strength of laminated composite material and solid wood materials are given in Table 1 and results of multiple variance analysis are given in Table 2.

The effect of glue type and glass fiber fabric type on the bending strength parallel to the glue line was significant ($p < 0.05$). The double interaction of the glue type and glass fiber fabric type ($p < 0.05$) was negligible with respect to the error. Duncan test results applied to determine which groups are different are given in Table 3 by glue type and Table 4 by glass fiber fabric type.

According to Table 4, the highest bending strength was obtained from Type 2, while the lowest bending strength sample was obtained from control samples.

Table 1 Bending strength values parallel to glue line (N/mm²)
Tablica 1. Vrijednosti čvrstoće na savijanje paralelno sa sljubnicom (N/mm²)

Glue type *Vrsta ljepila*	GFRP	*X*min	*X*max	*X*	*SS*	*%V*
PVAc-D4	Control	40.52	46.13	43.32	2.32	5.355
	Type 1	47.02	52.64	49.83	2.67	5.358
	Type 2	62.96	68.58	65.77	3.52	5.351
PU-D4	Control	36.58	42.20	39.39	2.11	5.356
	Type 1	42.49	48.11	45.30	2.43	5.364
	Type 2	56.98	62.60	59.79	3.20	5.352
Epoxy	Control	52.64	58.26	55.45	2.97	5.356
	Type 1	60.97	66.59	63.78	3.42	5.362
	Type 2	81.38	87.00	84.19	4.50	5.345

SS – standard deviation / *standardna devijacija*; *V* – coefficient of variation / *koeficijent varijacije*

Table 2 Variance analysis results of the effects of glue type and glass fiber fabric type on bending strength values parallel to glue line
Tablica 2. Rezultati analize varijance utjecaja vrste ljepila i vrste tkanine ojačane staklenim vlaknima na čvrstoću na savijanje paralelno sa sljubnicom

Source of variance *Izvor varijance*	**Sum of square** *Zbroj kvadrata*	***df***	**Mean square** *Prosječni kvadrat*	***F* ratio** *F-omjer*	**Level of significance** *Razina značajnosti*
Glue type (A) / *vrsta ljepila (A)*	3146.130	2	1573.065	164.012	.000
Plain woven type (B) *vrsta plošno pletene tkanine (B)*	4522.027	2	2261.014	235.740	.000
A x B	99.787	4	24.947	2.601	.062
Residual / *ostatak*	345.281	36	9.591		
Total / *ukupno*	150810.086	45			

Table 3 Duncan test results (N/mm²) of the effect of bending strength parallel to glue line by glue type
Tablica 3. Duncanov test čvrstoće na savijanje (N/mm²) paralelno sa sljubnicom s obzirom na vrstu ljepila

Glue type / *Vrsta ljepila*	***X***	**HG**
Epoxy	67.81	A
Polyvinyl Acetate (PVAc-D4)	52.97	B
Polyurethane (PU-D4)	48.16	C

Table 4 Duncan test results of the effect of bending strength (N/mm²) parallel to glue line by glass fiber fabric type
Tablica 4. Duncanov test čvrstoće na savijanje (N/mm²) paralelno sa sljubnicom s obzirom na vrstu tkanine ojačane staklenim vlaknima

GFRP	***X***	**HG**
Type 2 / *tip 2*	69.92	A
Type 1 / *tip 1*	52.97	B
Control / *kontrola*	46.05	C

3.2 Bending strength perpendicular to glue line
3.2. Čvrstoća na savijanje okomito na sljubnicu

The statistical evaluation results of bending strength of laminated wood material and solid wood are given in Table 5, and the results of multiple variance analysis are given in Table 6.

The effect of the type of glue and glass fiber fabric type on the vertical bending strength of the glue line was significant ($p < 0.05$). The double interaction of the glue type and glass fiber fabric type ($p < 0.05$) was negligible with respect to the error. Duncan test results applied to determine which groups are different are given in Table 7 by glue type and Table 8 by glass fiber fabric type.

According to Table 7, the highest bending strength was obtained from epoxy glue, while the lowest bending strength was obtained from polyurethane glue (PU-D4).

Table 5 Bending strength values perpendicular to glue line (N/mm²)
Tablica 5. Vrijednosti čvrstoće na savijanje okomito na sljubnicu (N/mm²)

Glue type / *Vrsta ljepila*	**GFRP**	***X*min**	***X*max**	***X***	***SS***	**%*V***
PVAc-D4	Control	38.49	43.83	41.16	2.20	5.344
	Type 1	44.67	50.01	47.34	2.54	5.365
	Type 2	59.81	65.15	62.48	3.34	5.345
PU-D4	Control	34.75	40.09	37.42	2.00	5.344
	Type 1	40.36	45.70	43.03	2.31	5.368
	Type 2	54.13	59.47	56.80	3.04	5.352
Epoxy	Control	50.01	55.35	52.68	2.82	5.353
	Type 1	57.92	63.26	60.59	3.25	5.363
	Type 2	77.31	82.65	79.98	4.28	5.351

SS – standard deviation / *standardna devijacija*; *V* – coefficient of variation / *koeficijent varijacije*

Table 6 Variance analysis results of the effects of glue type and glass fiber fabric type on bending strength values perpendicular to glue line
Tablica 6. Rezultati analize varijance utjecaja vrste ljepila i vrste tkanine ojačane staklenim vlaknima na čvrstoću na savijanje okomito na sljubnicu

Source of variance *Izvor varijance*	**Sum of square** *Zbroj kvadrata*	***df***	**Mean square** *Prosječni kvadrat*	***F* ratio** *F-omjer*	**Level of significance** *Razina značajnosti*
Glue type (A) / *vrsta ljepila (A)*	2839.409	2	1419.705	163.998	0.000
Plain woven type (B) *vrsta plošno pletene tkanine (B)*	4080.998	2	2040.499	235.710	0.000
A x B	89.964	4	22.491	2.598	0.057
Residual / *ostatak*	311.646	36	8.657		
Total / *ukupno*	136106.147	45			

Table 7 Duncan test results (N/mm²) of the effect of bending strength perpendicular to glue line by glue type
Tablica 7. Duncanov test (N/mm²) čvrstoće na savijanje okomito na sljubnicu s obzirom na vrstu ljepila

Glue type / *Vrsta ljepila*	***X***	**HG**
Epoxy	64.42	A
Polyvinyl Acetate (PVAc-D4)	50.32	B
Polyurethane (PU-D4)	45.75	C

Table 8 Duncan test results (N/mm²) on the effect of bending strength perpendicular to glue line by glass fiber fabric type
Tablica 8. Duncanov test (N/mm²) čvrstoće na savijanje okomito na sljubnicu s obzirom na vrstu tkanine ojačane staklenim vlaknima

GFRP	***X***	**HG**
Type 2 / *tip 2*	66.42	A
Type 1 / *tip 1*	50.32	B
Control / *kontrola*	43.75	C

According to Table 8, the highest bending strength was obtained from Type 2 glass fiber fabric samples, followed by Type 1 glass fiber fabric and control samples.

3.3 Modulus of elasticity parallel to glue line
3.3. Modul elastičnosti paralelno sa sljubnicom

The statistical evaluation of the results of laminated wood material and modulus of elasticity parallel to glue line is given in Table 9, and the results of multiple variance analysis are given in Table 10.

The effect of the type of glue and glass fiber fabric type was significant with the margin of error (p <0.05) in the modulus of elasticity parallel to the glue line. The double interaction of the glue type and glass fiber fabric type (p <0.05) was negligible with respect to the error. Duncan test results applied to determine which groups are different are given in Table 11 by glue type and Table 12 by glass fiber fabric type.

According to Table 11, the highest modulus of elasticity was obtained from epoxy glue and the lowest modulus of elasticity value was obtained from polyurethane (PU-D4) glue.

According to Table 12, it can be seen that the highest modulus of elasticity was obtained from Type 2 glass fiber fabric samples, while the lowest value was obtained from control samples.

Table 11 Duncan test results of the effect of modulus of elasticity (N/mm²) parallel to glue line by glue type
Tablica 11. Duncanov test modula elastičnosti (N/mm²) paralelno sa sljubnicom s obzirom na vrstu ljepila

Glue type / *Vrsta ljepila*	***X***	**HG**
Epoxy	5072	A
Polyvinyl Acetate (PVAc-D4)	3785	B
Polyurethane (PU-D4)	3775	B

Table 12 Duncan test results of the effect of modulus of elasticity (N/mm²) perpendicular to glue line by glass fiber fabric type
Tablica 12. Duncanov test modula elastičnosti (N/mm²) paralelno sa sljubnicom s obzirom na vrstu tkanine ojačane staklenim vlaknima

GRFP	***X***	**HG**
Type 2 / *tip 2*	5099	A
Type 1 / *tip 1*	4034	B
Control / *kontrola*	3499	C

Table 9 Modulus of elasticity parallel to glue line (N/mm²)
Tablica 9. Modul elastičnosti paralelno sa sljubnicom (N/mm²)

Glue type / *Vrsta ljepila*	**GFRP**	***X*min**	***X*max**	***X***	***SS***	**%*V***
PVAc-D4	Control	2785	3127	2956	154.34	5.200
	Type 1	3052	3393	3223	79.22	2.400
	Type 2	4148	4489	4318	106.22	2.400
PU-D4	Control	3878	4220	4049	175.98	4.300
	Type 1	3270	3612	3441	60.11	1.700
	Type 2	4440	4782	4611	80.84	1.700
Epoxy	Control	4150	4492	4321	159.39	3.600
	Type 1	4520	4862	4691	275.14	5.800
	Type 2	6115	6457	6286	368.42	5.800

SS – standard deviation / *standardna devijacija*; *V* – coefficient of variation / *koeficijent varijacije*

Table 10 Variance analysis results of the effects of glue type and glass fiber fabric type on modulus of elasticity values parallel to glue line
Tablica 10. Rezultati analize varijance utjecaja vrste ljepila i vrste tkanine ojačane staklenim vlaknima na modul elastičnosti paralelno sa sljubnicom

Source of variance *Izvor varijance*	**Sum of square** *Zbroj kvadrata*	***df***	**Mean square** *Prosječni kvadrat*	***F* ratio** *F-omjer*	**Level of significance** *Razina značajnosti*
Glue type (A) / *vrsta ljepila (A)*	10053593.200	2	5026796.600	1752.657	0.000
Plain woven type (B) *vrsta plošno pletene tkanine (B)*	713831.733	2	3569158.867	1244.433	0.000
A × B	216240.267	4	54060.067	18.849	0.053
Residual / *ostatak*	103251.600	36	2868.100		
Total / *ukupno*	348988507.000	45			

Table 13 Modulus of elasticity perpendicular to glue line (N/mm²)
Tablica 13. Modul elastičnosti okomito na sljubnicu (N/mm²)

Glue type / *Vrsta ljepila*	**GFRP**	***X*min**	***X*max**	***X***	***SS***	**%*V***
PVAc-D4	Control	2772	3014	2893	81.11	2.800
	Type 1	2613	2855	2734	177.34	6.400
	Type 2	3726	3968	3847	108.49	2.800
PU-D4	Control	3671	3912	3791	73.00	1.900
	Type 1	3427	3669	3548	191.16	5.300
	Type 2	4921	5163	5042	96.72	1.900
Epoxy	Control	4033	4275	4154	53.38	1.200
	Type 1	4055	4296	4175	225.89	5.400
	Type 2	5403	5645	5524	70.79	1.200

SS – standard deviation / *standardna devijacija*; *V* – coefficient of variation / *koeficijent varijacije*

Table 14 Variance analysis results of the effects of glue type and glass fiber fabric type on modulus of elasticity values perpendicular to glue line
Tablica 14. Rezultati analize varijance utjecaja vrste ljepila i vrste tkanine ojačane staklenim vlaknima na modul elastičnosti okomito na sljubnicu

Source of variance *Izvor varijance*	**Sum of square** *Zbroj kvadrata*	***df***	**Mean square** *Prosječni kvadrat*	***F* ratio** *F-omjer*	**Level of significance** *Razina značajnosti*
Glue type (A) / *vrsta ljepila (A)*	9120065.644	2	4560032.822	1754.189	0.000
Plain woven type (B) *vrsta plošno pletene tkanine (B)*	6474541.111	2	3237270.556	1245.338	0.000
A × B	196258.622	4	49064.656	18.875	0.052
Residual / *ostatak*	93582.400	36	2599.511		
Total / *ukupno*	316532875.000	45			

3.4 Modulus of elasticity perpendicular to glue line
3.4. Modul elastičnosti okomito na sljubnicu

The statistical evaluation results of modulus of elasticity of laminated wood material and solid wood are given in Table 13, and the results of multiple variance analysis are given in Table 14.

The effect of the type of glue and glass fiber fabric type was significant with the margin of error ($p<0.05$) in the modulus of elasticity perpendicular to the glue line. The double interaction of the glue type and glass fiber fabric type ($p<0.05$) was negligible with respect to the error. Duncan test results applied to determine which groups are different are given in Table 11 by glue type and Table 12 by glass fiber fabric type. Duncan test results applied to determine which groups are different are given in Table 15 by glue type and Table 16 by glass fiber fabric type.

The highest modulus of elasticity value was obtained with epoxy glue, followed by polyvinyl acetate grafted (PVAc-D4) and polyurethane grafted (PU-D4), respectively.

According to Table 16, it can be seen that the highest modulus of elasticity was obtained from Type 2, while the lowest value was obtained from control samples.

As a result, it was determined that epoxy glue has higher strength than polyurethane and polyvinyl acetate glues; Type 2 plain weaving woven fabric has higher strength than Type 1 plain weaving woven fabric; and laminates parallel to the glue line have higher performance than those perpendicular to the glue line. In recent years, some research has been carried out on the mechanical reinforcement of glass fiber and wood-based structural materials (Basterra *et al*., 2012; Mıstak, 2013; Bal and Ozyurt, 2015; Guntekin 2015). In these studies, the researchers generally made experiments on the bending properties and adhesion strength of the reinforced material. Premrov *et al*., (2003) investigated the mechanical strengths of wooden structural elements reinforced with carbon fiber, and they obtained a 50 % higher strength in the bending strength of laminated elements. Gaff and Gaffrik (2015) also examined the effect of bending strength of laminated beech wood on densification. As a result, the bending strength value was found to

Table 15 Duncan test results of the effect of modulus of elasticity (N/mm²) perpendicular to glue line by glue type
Tablica 15. Duncanov test modula elastičnosti (N/mm²) okomito na sljubnicu s obzirom na vrstu ljepila

Glue type / *Vrsta ljepila*	***X***	**HG**
Epoxy	4805	A
Polyvinyl Acetate (PVAc-D4)	3613	B
Polyurethane (PU-D4)	3486	C

Table 16 Duncan test results of the effect of modulus of elasticity (N/mm²) perpendicular to glue line by glass fiber fabric type
Tablica 16. Duncanov test modula elastičnosti (N/mm²) okomito na sljubnicu s obzirom na vrstu tkanine ojačane staklenim vlaknima

GFRP	***X***	**HG**
Type 2 / *tip 2*	4618	A
Type 1 / *tip 1*	4127	B
Control / *kontrola*	3158	C

be 17 % higher than the control sample. Muratoglu (2011) achieved high strength with carbon fiber reinforced strip rod (CFRP) and double component epoxy adhesive in reinforcement processes in the restoration of historical buildings.

4 CONCLUSIONS
4. ZAKLJUČAK

In this study, the modulus of elasticity of the laminated wood material supported by various glass fiber materials was investigated from 4 aspects. To this purpose (*Populus nigra*.) wood, which is widely used in the manufacture of furniture and building elements in our country, was made of 4 layers of glass fiber elements placed in porous structure between slats and bonded with epoxy, polyvinyl acetate (PVAc-D4) and polyurethane (PU-D4). As a result of the test, control samples and samples supported by glass fiber fabric were statistically evaluated according to the glue type, glass fiber type and load type. Based on the results, epoxy adhesive showed the highest bending strength parallel and perpendicular to the glue line, while polyurethane (PU-D4) glue showed the lowest bending strength. According to the glass reinforcing fiber type, Type 2 showed the highest bending strength, while the control samples showed the lowest bending strength. Epoxy + Type 2 showed the highest bending strength combined with glue type and glass reinforcing fiber type. Epoxy adhesive showed the highest modulus of elasticity strength parallel and perpendicular to the glue line, while polyurethane (PU-D4) glue showed the lowest bending strength. Regarding the type of glue, epoxy adhesive showed the highest modulus of elasticity perpendicular to the glue line, while polyurethane (PU-D4) glue showed the lowest modulus of elasticity value. Epoxy + Type 2 showed the highest modulus of elasticity combined with glue type and glass reinforcing fiber type.

Based on the experimental results obtained, it was determined that the bending strength and the modulus of elasticity increased the strength of the support materials as compared to the control example. Since there is a significant increase in the strength properties of the material when using the intermediate filler material in the laminated materials, its use may be preferred in furniture and building properties. In the literature, it is stated that the performance will increase as a result of the increase of layer thickness in pine samples. As a continuation of this study, researchers are recommended to focus on different layer symmetry and testing of laminated samples with different filling materials.

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Determining the Competencies Necessary for Exporting in Furniture Industry with Decision Tree Models

Određivanje izvoznih kompetencija u industriji namještaja uz pomoć modela stabla odlučivanja

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ABSTRACT • *In order to increase the competitiveness of companies, there are factors that need to be considered both in the domestic and foreign markets. In particular, companies that want to maintain their presence in the foreign market must differentiate from other companies in the industry and gain significant advantages over their competitors in order to maintain this continuity. If companies pay more attention to the factors that are effective in export, they can be predicted to be successful in competition and especially in export. The aim of this study was to determine the factors and issues affecting export performance in furniture industry and to determine the effect of these factors and issues on exports. In this context, the application data were obtained from the survey of 182 managers of companies operating in the furniture industry in Turkey. The scenarios produced in the study were made with J48 algorithm-decision trees modeling, which is one of the data mining methods. Thanks to these scenarios, road maps were drawn to give ideas to the companies and managers planning to export. As a result of this study, the "staff status" factor, the "manager's overseas experience" and "the legal form of the company" were identified as the main determinants of export.*

Keywords: *export determinants; furniture industry; data mining; decision trees*

SAŽETAK • *Kako bi se povećala konkurentnost tvrtke, potrebno je uzeti u obzir čimbenike koji utječu na domaće i inozemno tržište. Tvrtke koje žele biti kontinuirano zastupljene na inozemnom tržištu moraju se izdvajati od ostalih tvrtki i imati znatne prednosti pred konkurentskim tvrtkama. Ako tvrtke više pozornosti pridaju čimbenicima koji utječu na izvoz, može se očekivati da će biti konkurentne u izvozu svojih proizvoda. Cilj ovog istraživanja bio je utvrditi čimbenike i probleme koji u industriji namještaja utječu na izvoz i procijeniti njihov utjecaj na izvoznu uspješnost. U tu su svrhu anketirana 182 voditelja tvrtki za proizvodnju namještaja koje posluju u Turskoj. Scenariji prikazani u ovom istraživanju načinjeni su uz pomoću algoritma J48 – modela stabla odlučivanja, što je jedna od metoda rudarenja podataka. Zahvaljujući tim scenarijima, izrađeni su hodogrami koji mogu pomoći tvrtkama i voditeljima u planiranju izvoza. Rezultati ovog istraživanja pokazali su da su glavne odrednice izvoza status osoblja, inozemno iskustvo voditelja tvrtke i pravni oblik tvrtke.*

Ključne riječi: *odrednice izvoza; industrija namještaja; rudarenje podataka; stablo odlučivanja*

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1 INTRODUCTION
1. UVOD

Furniture industry is an important foreign trade area in the world. The furniture industry is an important economic factor in the world with its rapidly increasing growth and an annual value of approximately 437 billion dollars. In the furniture industry, which was once dominated by European countries, China has been the leading world industry with a 35 % share in recent years. Although Asia and the Pacific continue to be the fastest growing regions, it is noteworthy that in 2016 China's exports in furniture decreased, while Vietnam became the fastest growing furniture industry. In the last 5 years, the increase in furniture imports in the USA increased from 23 billion dollars to 32 billion dollars and became the main source of growth in this industry (TRADEMAP, 2019). Figure 1 presents the leading exporters in the furniture industry in the world.

In terms of exports, being successful in world trade is possible by following a competitive policy at a global level. In this case, it is possible to measure the foreign trade ability of a country and an industry by determining the factors affecting the export performance.

It has been observed that scientific studies related to export performance are mostly conducted in non-furniture industries. In the scientific studies related to the furniture industry, subjects other than export performance have been addressed. In this context, this study is original.

The motivations of this paper can be listed as follows: (1) no academic studies observed the determinants of exporting performance of companies on the world furniture market, which is fast growing based on decision tree approach; (2) almost no assumptions are needed in decision tree modelling such as in regression models; (3) the question whether there are any different determinants in furniture export industry with respect to other industries and other countries. Accordingly, researching these items can be considered as highlights of the study.

In the literature on export performance, the following models were widely used: Export Performance and Determinant Model (Aaby and Slater, 1989), Export Performance Model (Dhanaraj and Beamish, 2003), Determining Models of Export Performance (Madsen, 1989), Theoretical Model (Gemunden, 1991) and Export Performance Model (Zou and Stan, 1998). In addition, in many studies, it can be found that the factors affecting export performance are divided into two groups, both internal and external factors, and economic and non-economic factors.

When the literature is examined in detail, it can be observed that many researchers divide the variables used into internal and external variables. Internal variables used in scientific studies are divided into titles as management characteristics and perceptions, organizational capabilities, knowledge-based factors, relational factors and company characteristics. The variables under these main headings and the researchers using these variables are given in Table 1.

The external variables used in the measurement of export performance in the literature are given under two main headings: domestic market characteristics and characteristics of export market. The external variables used under these main headings are given in Table 2.

On the other hand, many scientists working on export performance categorized the factors that are effective in performance measurement in two sub-headings as economic factors and non-economic factors. The factors that are economic are related to sales and market relations (Table 3).

Non-economic factors are evaluated under two headings as "General" and "Other". These factors and the studies using these factors are given in Table 4.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

In the questionnaire prepared to be used in the analysis of the study, opinions about the characteris-

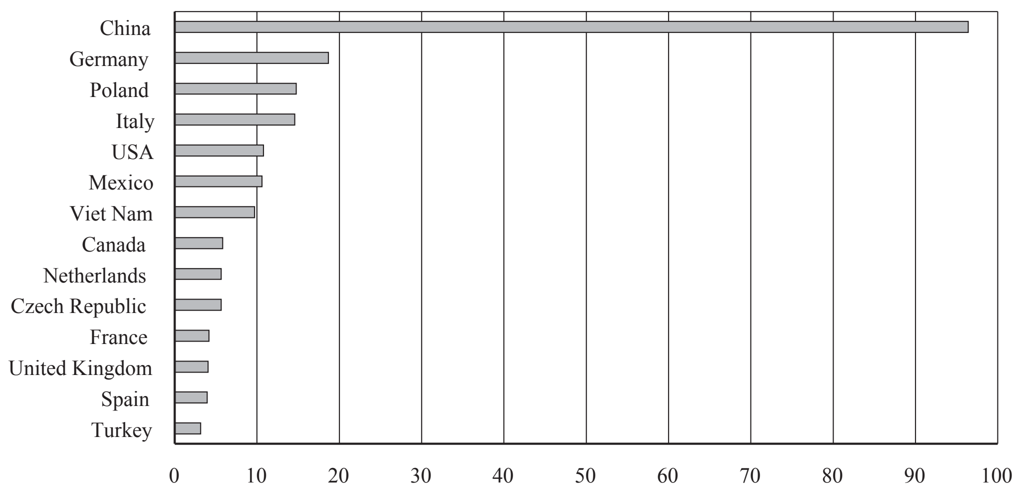

Figure 1 Exports in wood furniture of major countries in world furniture exports in 2018, in billion $ (TRADEMAP, 2019)
Slika 1. Izvoz drvenog namještaja vodećih zemalja u izvozu namještaja u svijetu u 2018. (u mlrd. USD) (TRADEMAP, 2019.)

Table 1 Internal variables used in measurement of export performance
Tablica 1. Unutarnje varijable upotrijebljene u procjeni odrednica izvoza

Internal variables / *Unutarnje varijable*	**References** / *Literatura*
Management features and perceptions / *Značajke i percepcije upravljanja* Export commitment and support / *izvozna predanost i potpora* International experience / *međunarodno iskustvo* International orientation / *međunarodna orijentacija* Export motivation / *motivacija za izvoz* Perception of export advantages / *percepcija prednosti izvoza* Age, Education / *dob, obrazovanje*	Reid, 1983; Çavuşgil, 1984; Aaby and Slater, 1989; Rocha *et al*., 1990; Dichtl, Koeglmayr and Müller, 1990; Holzmüller and Stöttinger, 1996; Czinkota and Ursic, 1991; Oviatt and McDougall, 1994; Çavuşgil and Zou, 1994; Roth, 1995; White *et al*., 1998; Zou and Stan, 1998; Beamish *et al*., 1999; Jones, 2001; Styles and Ambler, 2000; Dean *et al*., 2000; Katsikeas *et al*., 2006; Stöttinger and Holzmüller, 2001; Gençtürk and Kotabe, 2001; Ibeh and Young, 2001; O'Cass and Julian, 2003; Ibeh, 2003; Alvarez, 2002; Contractor *et al*., 2003; Lages and Montgomery, 2004; Ibeh and Wheeler, 2005; Brouthers and Nakos, 2005; Cadogan *et al*., 2005; Lejpras, 2019
Organization capabilities / *Mogućnosti organizacije* Advanced technology / *napredna tehnologija* Product - service quality / *kvaliteta proizvoda/usluge*	Madsen 1989; Çavuşgil *et al*., 1993; Chetty and Hamilton, 1993; Styles and Ambler, 1994; Thirkell and Dau, 1998; Piercy *et al*., 1998; Robertson and Chetty, 2000; Prasad *et al*., 2001; Shoham *et al*., 2002; Balabanis and Katsikea, 2003; O'Cass and Julian, 2003; Yeoh, 2004; Alvarez, 2004; Contractor *et al*., 2003; Haahti *et al*., 2005; Lopez-Rodriguez and Rodriguez, 2005; Lejpras, 2019
Export strategy / *strategija izvoza* Export planning / *planiranje izvoza* Export organization / *organizacija izvoza* Market expansion / *širenje tržišta* Service strategy / *strategija usluge* Risk taking, Control, Process / *preuzimanje rizika, kontrola, postupak*	White *et al*., 1998; Hoang, 1998; Zou and Stan, 1998; Piercy *et al*., 1998; Aaby and Slater, 1989; Shoham, 1999a; Robertson and Chetty, 2000; Baldauf *et al*., 2000; Dean *et al*., 2000; Francis and Collins-Dodd, 2004; Li and Ogunmokun, 2001; Shoham *et al*., 2002; Solberg, 2002; Balabanis and Katsikea, 2003; Deng *et al*., 2002; Dhanaraj and Beamish, 2003; Julien and Ramangalahy, 2008; Chung, 2003; Chen *et al*., 2004; Li, 2004; Haahti *et al*., 2005; Ibeh and Wheeler, 2005; Brouthers and Nakos, 2005; Contractor *et al*., 2003
Marketing Mix / *marketinški miks* Product strategy / *strategija proizvoda* Price strategy / *strategija cijena* Promotional strategy / *promidžbena strategija* Distribution strategy / *strategija distribucije*	Amine and Çavuşgil, 1986; Madsen, 1989; Fraser and Hite, 1990; Louter *et al*., 1991; Dominguez and Sequeira, 1993; Beamish *et al*., 1993; Styles and Ambler, 1994; Çavuşgil and Zou, 1994; Thirkell and Dau, 1998; Piercy *et al*., 1998; Hoang, 1998; Samiee and Anckar, 1998; Shoham, 1999b; Myers, 1999; Robertson and Chetty, 2000; Gençtürk and Kotabe, 2001; Albaum and Tse, 2001; Li and Ogunmokun, 2001; Brouthers and Xu, 2002; Shoham *et al*., 2002; Chung, 2003; O'Cass and Julian, 2003; Morgan *et al*., 2004; Lee and Griffith, 2004; Chen *et al*., 2004; Lages and Montgomery, 2004; Brouthers and Nakos, 2005
Knowledge-based factors / *Čimbenici utemeljeni na znanju* Export expertise / *izvozna ekspertiza* International experience / *međunarodno iskustvo*	Hoang, 1998; Baldauf *et al*., 2000; Dean *et al*., 2000; Francis and Collins-Dodd, 2004; Li, 2004; Li and Ogunmokun, 2001; Prasad *et al*., 2001; Brouthers and Xu, 2002; Solberg, 2002; Deng *et al*., 2002; O'Cass and Julian, 2003; Chen *et al*., 2004; Contractor *et al*., 2003; Brouthers and Nakos, 2005; Lejpras, 2019
Export information, Market research, Customer information, Market information, Competitor information, Supply chain channel information *informacije o izvozu, istraživanje tržišta; podatci o kupcima; podatci o tržištu; podatci o konkurentima; podatci o kanalu lanca opskrbe*	Kogut and Zander, 1992; Grant, 1996; Teece *et al*., 1997; Hart and Tzokas, 1999; Yeoh, 2004; Richey and Myers, 2001; Solberg, 2002; Morgan *et al*., 2003; Li, 2004
Relational factors / *Relacijski čimbenici* Business and corporate relations, Distribution channel relationship, Customer relationship, Supplier relationship, Partnership relationship, Membership in registered and unregistered commercial networks, Government and other corporate relations *poslovni i korporativni odnosi; odnos distribucijskih kanala; odnos s kupcima; odnos s dobavljačima; partnerski odnos; članstvo u registriranim i neregistriranim komercijalnim mrežama; vladini i drugi korporativni odnosi*	Coviello and Munro, 1997; Zou and Stan, 1998; Styles and Ambler, 2000; Crick and Jones, 2000; Li and Ogunmokun, 2001; Cadogan *et al*., 2005; Ibeh and Wheeler, 2005; Styles *et al*., 2008

Table 1 Internal variables used in measurement of export performance (continuation)
Tablica 1. Unutarnje varijable upotrijebljene u procjeni odrednica izvoza (nastavak)

Internal variables / *Unutarnje varijable*	**References** / *Literatura*
Company characteristics / *Obilježja tvrtke* Company size / *veličina tvrtke* Degree of internationalization / *stupanj internacionalizacije* Company age / *starost tvrtke* Industry sector - product type / *industrijski sektor - vrsta proizvoda* Organization culture / *kultura organizacije* Financial resources / *financijska sredstva* Ownership structure / *vlasnička struktura*	Çulpan, 1989; Beamish *et al*. 1993; Hoang, 1998; Thirkell and Dau, 1998; White *et al*., 1998; Piercy *et al*., 1998; Andersen and Moen, 1999; Myers, 1999; Beamish *et al*., 1999; Shoham, 1999a; Shoham, 1999b; Baldauf *et al*., 2000; Robertson and Chetty, 2000; Styles and Ambler, 2000; Dean *et al*., 2000; Wolff and Pett, 2000; Francis and Collins-Dodd, 2004; Gençtürk and Kotabe, 2001; Stöttinger and Holzmüller, 2001; Richey and Myers, 2001; Albaum and Tse, 2001; Li and Ogunmokun, 2001; Brouthers and Xu, 2002; Solberg, 2002; O'Cass and Julian, 2003; Prasad *et al*., 2001; Rose and Shoham, 2002; Shoham *et al*., 2002; Cadogan *et al*., 2005; Akyol and Akehurst, 2003; Balabanis and Katsikea, 2003; Deng *et al*., 2002; Chung, 2003; Dhanaraj and Beamish, 2003; Julien and Ramangalahy, 2008; Morgan *et al*., 2004; Alvarez, 2004; Li, 2004; Chen *et al*., 2004; Francis and Collins-Dodd, 2004; Lee and Griffith, 2004; Yeoh, 2004; Haahti *et al*., 2005; Cadogan *et al*., 2005; Brouthers and Nakos, 2005; Contractor *et al*., 2007; Bekteshi, 2020

Table 2 External variables used in measurement of export performance
Tablica 2. Vanjske varijable primijenjene za mjerenje obilježja izvoza

External variables / *Vanjske varijable*	**References** / *Reference*
Characteristics of export market / *Obilježja izvoznog tržišta* Legal and political, Cultural similarity Market competitiveness, Environmental competitiveness, Economic similarity, Channel accessibility Customer exposure *zakoni i politika; sličnost kultura; tržišna konkurentnost; okolišna konkurentnost; gospodarska sličnost; dostupnost kanala; izloženost kupaca*	White *et al*., 1998; Baldauf *et al*., 2000; Dean *et al*., 2000; Robertson and Chetty, 2000; Brouthers and Xu, 2002; Rose and Shoham, 2002; O'Cass and Julian, 2003; Balabanis and Katsikea, 2003; Chen *et al*., 2004; Lee and Griffith, 2004; Morgan *et al*., 2004; Cadogan *et al*., 2005; Lages and Montgomery, 2004
Domestic market features / *Obilježja domaćeg tržišta* Domestic market conditions, Export support/ *uvjeti na domaćem tržištu; potpora izvozu*	Robertson and Chetty, 2000; Gençtürk and Kotabe, 2001; Stöttinger and Holzmüller, 2001; Francis and Collins-Dodd, 2004; Alvarez, 2002; Lages and Montgomery, 2004

Table 3 Economic factors used in measurement of export performance
Tablica 3. Ekonomski čimbenici primijenjeni u procjeni obilježja izvoza

Economic factors / *Ekonomski čimbenici*	**References** / *Literatura*
Sales related / *Vezani za prodaju* Export density / *gustoća izvoza* Increase in export density / *povećanje gustoće izvoza* Export sales efficiency / *učinkovitost izvozne prodaje* Export sales growth / *rast izvozne prodaje* Export growth compared to competitors / *rast izvoza u usporedbi s konkurentima* Return on investment in export sales / *povrat ulaganja u izvoznu prodaju* Export sales volume / *opseg izvozne prodaje* Export sales volume compared to competitors / *izvozna prodaja u usporedbi s konkurentima*	Czinkota and Ronkainen, 1995; Çavuşgil, 1984; Cooper and Kleinschmidt, 1985; Reid, 1983; Schlegelmilch and Ross, 1987; Çulpan, 1989; Madsen, 1989; Walters and Samiee 1990; Axinn and Thach 1990; Louter *et al*., 1991; Czinkota and Ursic, 1991; Chan, 1992; Ito and Pucik, 1993; Walters, 1993; Kaynak and Kuan, 1993; Beamish *et al*., 1993; Bodur, 1994; Crick and Jones, 2000; Akyol and Akehurst 2003; Lim, Sharkey and Kim, 1996; Katsikeas *et al*., 2000; Thirkell and Dau, 1998; Hoang, 1998; Wakelin, 1998; Piercy *et al*., 1998; Styles *et al*., 2008; White *et al*., 1998; Shoham, 1999a; Hart and Tzokas, 1999; Shoham 1999b; Myers, 1999; Beamish *et al*., 1999; Andersen and Moen, 1999; Dean *et al*., 2000; Wolff and Pett, 2000; Francis and Collins-Dodd, 2004; Baldauf *et al*., 2000; Stewart and McAuley, 2000; Yeoh, 2004; Styles and Ambler, 2000; Robertson and Chetty, 2000; Gençtürk and Kotabe, 2001; Richey and Myers, 2001; Stöttinger and Holzmüller, 2001; Li and Ogunmokun, 2001; Prasad *et al*., 2001; Brouthers and Xu, 2002; Shoham et.al., 2002; Patterson, Cicic and Shoham, 1997; Rose and Shoham, 2002; Solberg, 2002; Roper and Love, 2002; Cadogan *et al*., 2005; Dhanaraj and Beamish, 2003; Balabanis and Katsikea 2003; Lages and Montgomery, 2004; Morgan *et al*., 2004.

Table 3 Economic factors used in measurement of export performance (continuation)
Tablica 3. Ekonomski čimbenici primijenjeni u procjeni obilježja izvoza (nastavak)

Market related / *Vezani za tržište* Export market share / *udio u izvoznom tržištu* Export market share by competitors / *udio konkurenata u izvoznom tržištu* Export market share growth / *rast udjela na izvoznom tržištu* Export market share growth compared to competitors, Market solidarity Market diversification, Entry rate to new markets, Entry rate to new markets compared to competitors *rast udjela izvoznog tržišta u usporedbi s konkurentima; tržišna solidarnost; diversifikacija tržišta; stopa ulaska na nova tržišta; stopa ulaska na nova tržišta u usporedbi s konkurentima*	Çavuşgil and Zou, 1994; Thirkell and Dau, 1998; White *et al*., 1998; Piercy *et al*., 1998; Shoham, 1999a; Andersen and Moen, 1999; Myers, 1999; Robertson and Chetty, 2000; Albaum and Tse, 2001; Richey and Myers, 2001; Prasad *et al*., 2001; Baldauf *et al*., 2000; Brouthers and Xu, 2002; Cadogan *et al*., 2005; Rose and Shoham, 2002; Solberg, 2002; Dhanaraj and Beamish, 2003; Akyol and Akehurst, 2003; Lages and Montgomery, 2004; Morgan *et al*., 2004.

Table 4 Non-economic factors used in measurement of export performance
Tablica 4. Neekonomski čimbenici primijenjeni za mjerenje obilježja izvoza

Non-economic factors / *Neekonomski čimbenici*	**References** / *Literatura*
General / *Općenito* Export success / *uspjeh izvoza* Rating of export performance compared to competitors / *ocjena provedbe izvoza u usporedbi s konkurentima* Overall export performance / *ukupni izvozni učinak* Overall export performance compared to competitors / *ukupni izvozni učinak u usporedbi s konkurentima* Strategic export performance / *strateška provedba izvoza*	Seifert and Ford, 1989; Raven, McCullogh and Tansuhaj, 1994; Singer and Czinkota 1994; Katsikeas *et al*., 1996; Patterson, Cicic and Shoham, 1997; Styles *et al*., 2008; White *et al*., 1998; Thirkell and Dau, 1998; Anderson and McAuley, 1999; Andersen and Moen, 1999; Myers, 1999; Styles and Ambler, 2000; Robertson and Chetty, 2000; Stewart and McAuley, 2000; Crick and Jones, 2000; Gençtürk and Kotabe, 2001; Li and Ogunmokun, 2001; Prasad *et al*., 2001; Shoham *et al*., 2002; Solberg, 2002; Brouthers and Xu, 2002; O'Cass and Julian, 2003; Akyol and Akehurst, 2003; Balabanis and Katsikea, 2003; Lages and Montgomery, 2004; Manzanares, 2019; Imran *et al*. 2020
Others / *Drugi čimbenici* Achieving targets related to reaction to competition pressure, Awareness and image creation in export market, Contribution of export to the growth of the company and the contribution of the management quality of the company Customer satisfaction, New technology - expertise, Product-service quality Quality of customer relations, Quality of distributor relations, Reputation of the company *postizanje ciljeva vezanih za reakciju na pritisak konkurencije; svjesnost i stvaranje dojma na izvoznom tržištu; doprinos izvoza rastu poduzeća i doprinos kvalitete upravljanja; zadovoljstvo kupaca; nova tehnologija/stručnost; kvaliteta proizvoda/usluga; kvaliteta odnosa s kupcima; kvaliteta odnosa s distributerima; ugled tvrtke*	Thirkell and Dau, 1998; Myers, 1999; Prasad *et al*., 2001; Gençtürk and Kotabe, 2001; Morgan *et al*., 2004; Manzanares, 2019; Imran *et al*. 2020

tics, attitudes, and strategies of the companies were collected by a total of 95 questions, 51 items of which are in 7 points likert scale, and 32 of which consist of mostly open-ended, ratio scale and some nominal scale questions on the characteristics of companies.

The 1-7 interval scale is used, 1 referring to "strongly disagree", 4 referring to "not agree/disagree", and 7 referring to "strongly agree".

As the random process was not used in sampling, the evaluations obtained from the analysis represent the properties and attitudes of 182 companies. Based on the literature research, it was decided to examine all the influential variables in determining the exporting of the furniture industry; accordingly the attitudes/trends of the companies in terms of 51 items and eight factors listed below were measured, in order to determine the effective items/factors in exporting (Table 5).

The listed items, evaluated in the following tables are selected according to conducted factor analyses for each dimension, separately. The scores of 51 items selected out of 63 items are the arithmetic means of the item attitude scores attributed by companies, and

Table 5 List of variables used in the study
Tablica 5. Popis varijabli primijenjenih u istraživanju

1. Factor: Brand-advertisement-packaging *1. čimbenik: brend/reklama/pakiranje*		**5. Factor: Environmental and economic** *5. čimbenik: okoliš i gospodarstvo*
The importance of internet sites in promotion / *važnost internetskih stranica u promociji* Congress fair participation / *sudjelovanje na kongresima* Promotion of new product in short time / *promocija novog proizvoda u kratkom vremenu* Advertisement promotion activities / *promotivne aktivnosti putem oglašavanja* Giving importance to packaging / *pridavanje važnosti pakiranju* Being a brand of every product / *težnja da svaki proizvod bude brend* Being a recognized brand / *biti priznati brend* Not having a marketing problem / *nema marketinških problema*		Internal market shrinkage / *smanjenje unutarnjeg tržišta* Export to EU countries / *izvoz u zemlje EU-a* Distance to market / *udaljenost od tržišta* Cultural similarity with market / *kulturološka sličnost s tržištem* Attention to demographic characteristics / *briga o demografskim obilježjima* Change in exchange rates / *promjena tečaja* Effect of interest rates / ***učinak kamatnih stopa***
2. Factor: Customer satisfaction *2. čimbenik: zadovoljstvo kupaca*		**6. Factor: Management style and format** *6. čimbenik: način i format upravljanja*
Complaint for product / *prigovor na proizvod* On-time delivery / *pravodobna dostava* Compliance with technical requirements / *sukladnost s tehničkim zahtjevima* Customer expectation in new product / ***očekivanj****a kupaca vezana za novi proizvod* Quality based satisfaction / *zadovoljstvo kvalitetom* Price based satisfaction / *zadovoljstvo cijenom* Design based satisfaction / *zadovoljstvo dizajnom* Technical team for customer satisfaction / *tehnički tim zadužen za zadovoljstvo kupaca* Satisfying warranty period / *zadovoljavajući jamstveni rok*		Compliance with export / *usklađenost s izvozom* Desire and support for exporting / *želja za izvozom i potpora izvozu* Appreciating export opportunities / *poštovanje izvoznih mogućnosti* Having export motivation / *postojanje motivacije za izvoz*
3. Factor: Competition status *3. čimbenik: status konkurencije*		**7. Factor: Research and development activities** *7. čimbenik: istraživačke i razvojne aktivnosti*
Fast adaptation to demand / *brza prilagodba potražnji* Not worrying about the new competition / *suvišnost brige o novoj konkurenciji* Determination of sales price by competitors / *određivanje prodajne cijene ovisno o konkurenciji* Taking the quality document easily / *jednostavno preuzimanje dokumenata o kvaliteti* New market research being pioneer in price determination / *novo istraživanje tržišta kao pionirski korak u određivanju cijena* Ensuring price advantage / *osiguranje cjenovne prednosti* Possessing competitive power in the industry / *posjedovanje konkurentske moći u industriji* Developing different strategies for different products / *razvijanje različitih strategija za različite proizvode*		Pioneer in new product / *pionirska uloga u razvoju novih proizvoda* Eco-friendly / *ekološka prihvatljivost* Innovative in ARGE / *inovativnost u ARGE-u* Having detailed information about the market / *posjedovanje detaljnih informacija* ***o tržištu*** Following technology / *praćenje tehnologije*
4. Factor: Export structure *4. čimbenik: struktura izvoza*		**8. Factor: Personnel status** *8. čimbenik: status osoblja*
Pioneering in exporting / *pionirski izvoz* Having an export strategy / *posjedovanje izvozne strategije* Having an export organization / *postojanje organizacije izvoza* Receiving professional support in the export strategy / *primanje stručne potpore u izvoznoj strategiji* Export agreement period / *razdoblje ugovora o izvozu* Making export in the last 5 years / *izvoz u posljednjih pet godina*		In-service training / *stručno usavršavanje* Provision of qualified personnel / *osiguranje kvalificiranog osoblja* Employee ambience satisfaction / *zadovoljstvo korisnika sredinom*

factor scores of these eight factors are the means of the item scores of the factor members.

The variables obtained from 32 open-ended questions are:

- Equity ($)
- Management Type (Individual/Family Company, Corporate Company)
- Advertising Expenditure ($)
- Manager's Experience Abroad (year)
- Legal Form of the Company (Ordinary, Joint Stock or Limited Liability, Limited Partnership, Collective)
- Automation Utilization Rate (%)

Scenarios were produced with the help of algorithms called J48 and decision trees were formed with the variables that were more effective in these scenarios. All of the analyses were done with the software called WEKA. WEKA is a Data Mining application development program that started as a project and today it is used by many people around the world. WEKA is an open code program developed on the Java platform.

2.1 Decision trees and pruning
2.1. Stabla odlučivanja i obrezivanje

Decision trees are an important machine learning algorithm used in many areas. The J48 algorithm is a decision tree classification algorithm. Decision trees are widely used because they are easy to evaluate and perceive, and they do not need to satisfy as much assumptions as the regression models. The J48 algorithm consists of two steps. The first is the process of forming the structure of the tree and the second is pruning (Gümüşçü *et al*., 2016). In this study, J48 classification algorithm developed by J. Ross Quinlan was used.

Decision trees consist of a root, nodes, branches and leaves. The top part of the tree is called root and the bottom part is called leaf. Each attribute in the data set represents the nodes. The parts that provide the connection between the nodes are called branches.

The most important process step in forming decision trees is to decide which branching will take place according to quality value (Kavzaoğlu and Çölkesen, 2010). Knowledge gain (Equation 1), gini index (Equation 2) and towing rule (Eq. 3) are commonly used as decision-making criteria (Gümüşçü *et al*., 2016).

Assuming that if the number of classes is h and these class values are repeated as *T*, then the probability value of a class is as in Eq. 1.

$$P_i = \frac{C_i}{|T|} \quad (1)$$

C_i represents the number of class values in a class. If the entropy value of this class is $H(T)$, it is as in Eq. 2.

$$H(T) = -\sum_{i=1}^{n} P_i \log_2 P_i \quad (2)$$

Considering that *T* class values are subdivided into T_1, T_2 ..., T_n according to *Y* attribute values in the data set, the information gain that can be obtained by dividing the *T* class values by using *Y* attribute values is as in Eq. 3.

$$IG(Y,T) = H(T) - \sum_{i=1}^{n} \frac{|T_i|}{|T|} H(T_i) \quad (3)$$

In calculating the value of the attribute, the dissociation information is calculated as in Eq. 4.

$$SI(Y) = -\sum_{i=1}^{n} \frac{|T_i|}{|T|} \log_2 \left(\frac{|T_i|}{T} \right) \quad (4)$$

The amount of information gain is obtained by the ratio of the information gain to the dissociation information (Equation 4). In this way, the tree structure is created according to the quality with the highest earnings information by finding earnings information for each attribute (Gümüşçü *et al*., 2016).

In addition to obtaining the structure of decision trees, pruning is another important process. Pruning can be done in two ways. When the tree structure is obtained, the process of stopping the division to prevent the tree to grow further is called pre-pruning. As another method, after the tree structure is completely formed, the nodes considered to be excessive are removed. This pruning process is known as the last pruning (Quinlan, 1999).

2.2 Evaluation of classification result
2.2. Evaluacija rezultata klasifikacije

To measure the success of the classification, it is not enough to look at the accuracy rate. The recall and precision values of the classification process also provide information about the success of the classification.

Accuracy Ratio: The ratio of the number of correctly classified samples to the total number of samples.

$$Accuracy = \frac{TP + TN}{Total\,Sample\,Count} \quad (5)$$

TP (True positive): It means that it does export for export company.

FP (False positive): It means that it does export for non-exporting company.

TN (True negative): It means that it does not export to the non-exporting company.

FN (False negative): It means that it does not export to the exporting company.

In this case, the confusion matrix is formed as follows (Table 6):

Recall: The rate of correct detection of non-export.

$$Recall = \frac{TP}{TP + FN} \quad (6)$$

Precision: The ratio of those who cannot actually export and those who cannot export.

$$Precision = \frac{TP}{TP + NP} \quad (7)$$

There is a conflict between the two important scales. To eliminate this, the F score is measured. The F score uses the harmonic mean to be able to ignore extreme values.

$$F_{Score} = 2 \times \frac{Precision \times Recall}{Precision + Recall} \quad (8)$$

Table 6 Confusion matrix
Tablica 6. Matrica konfuzije

Actual / *Stvaran*			
Positive / *Pozitivan*	**Negative** / *Negativan*		
True positive *stvarno pozitivan*	False negative *lažno negativan*	Positive *pozitivan*	Prediction *predviđanje*
False negative *lažno negativan*	True negative *stvarno negativan*	Negative *negativan*	

2.3 ROC curve (Receiver Operating Characteristic Curve)
2.3. ROC krivulja (karakteristična krivulja rada prijamnika)

ROC Curve is used frequently in the success calculations of classification models. It is basically calculated over two values.

TPR (True Positive Ratio): It means the sensitivity ratio in detecting exporting companies.

$$TPR = \frac{TP}{TP + FN} \tag{9}$$

FPR (False Positive Ratio): It is the rate of determining that means “it does export” to non-exporting companies.

$$FPR = \frac{FP}{FP + FN} \tag{10}$$

When these two values are placed on the x and y axes, the area under the line (AUC) is calculated and the TPR and FPR ratios are determined against the limit values falling along the curve. For each limit value, precision and recall values are calculated and the limits that make the F score maximum are selected. In fact, the larger the area below the line, the higher the success rate of the model. The higher the *F* score, the higher is the area under the line (Şık, 2014; Aydemir, 2017, Langloisa and Frank; 2011).

Sensitivity (Recall or True positive rate): Sensitivity is calculated as the number of correct positive predictions divided by the total number of positives. It is also called recall (REC) or true positive rate (TPR). The best sensitivity is 1.0, whereas the worst is 0.0. Sensitivity is calculated as the number of correct positive predictions (TP) divided by the total number of positives (P = TP + FN) (Langloisa and Frank; 2011).

Kappa statistic: Kappa statistic is called the accuracy measure of the prediction. Kappa takes a value between 0 and 1. If kappa is between 0.4 and 0.6, a moderate fit is achieved. If the Kappa value is between 0.6 and 0.8, it means that there is a good level of prediction. A very good level of harmony is achieved between Kappa 0.8 and 1 (Landis and Koch, 1977).

3 RESULTS
3. REZULTATI

The variables used in this section have been determined through the regression and logistic regression analyses, which are more effective in exporting, taking into account the findings obtained above. In order to create healthy models in the scenarios, these preliminary analyses were performed in order to find the variables that might have the ability of representation in the model. These variables are modeled with decision trees on the basis of WEKA with different scenarios.

3.1 Scenario 1 and findings
3.1. Scenarij 1. i zaključci

The first model included variables such as Shareholders’ Equity, Management Type, Legal Form of the Company, Sales Revenues, Partnership Status, Percentage of Automation Usage, Advertising Expenditures, Product Development Expenditures. In order to reach a more accurate result, surveys that did not include the Equity and Advertising Expenditures data were excluded from the evaluation. In this case, a total of 68 companies were evaluated. As a result of J48 algorithm, the number of correctly classified data is 66 and the number of incorrectly classified data is 2. The model is classified with an accuracy of 97.1 %.

As a result of the evaluation of J48 decision tree algorithm, it was seen that the variables of Equity, Management Type and Advertising Expenditures, which were initially included in the model, had more meaningful explanations. Since the equity variable has the highest entropy, the decision tree started branching with this variable. It was concluded that furniture companies with equity higher than $77,000 can export.

According to Figure 2, the second-high entropy Management Type variable leads the decision tree for companies whose equity capital is below $ 77,000. According to this variable, the management style of the companies shows that they can export even if their equity is below $ 77,000. However, for companies managed as Family Business, the Advertising spending variable is the final decision maker of the decision tree. Accordingly, it is seen that the companies that are family companies and that allocate more than $ 10,000 for Advertising Expenditures can export. Finally, it was concluded that the companies that allocate $ 10,000 or less budget for advertising expenditures cannot export.

In this Scenario, the following conditions are necessary for a company to export;

1. If the equity is more than $ 77,000,
2. Although the equity is less than $ 77,000, if the firm is managed as a corporate company,
3. If it is a family owned company with an equity capital of less than $ 77,000, it can export if it allocates more than $ 10,000 to the advertising expenditure.

In the decision tree model obtained by using J48 algorithm in WEKA program, the number of leaves was 4 and the length of the tree was 7. It was found that the variables included in the model accounted for 97 % of the structure of the decision tree. This result shows that the model is descriptive. When talking about the success of a model, it was only mentioned in the method part of this paper that the accuracy rate alone would not make sense. Accuracy value and recall value were found to be 0.971. The ROC area value was calculated as 0.907 and the F score was 0.971, so the model was very successful. The accuracy measure of the prediction, kappa statistic, was found to be 0.817 and proved that the prediction showed a very good level of fit.

3.2 Scenario 2 and findings
3.2. Scenarij 2. i zaključci

In Scenario 2 established with WEKA, all the factors, the manager’s experience abroad and the legal form of the company were used as input. The Export Structure Factor was the first node of the decision tree.

According to this scenario, it is seen that no company without a score for the Export Structure factor

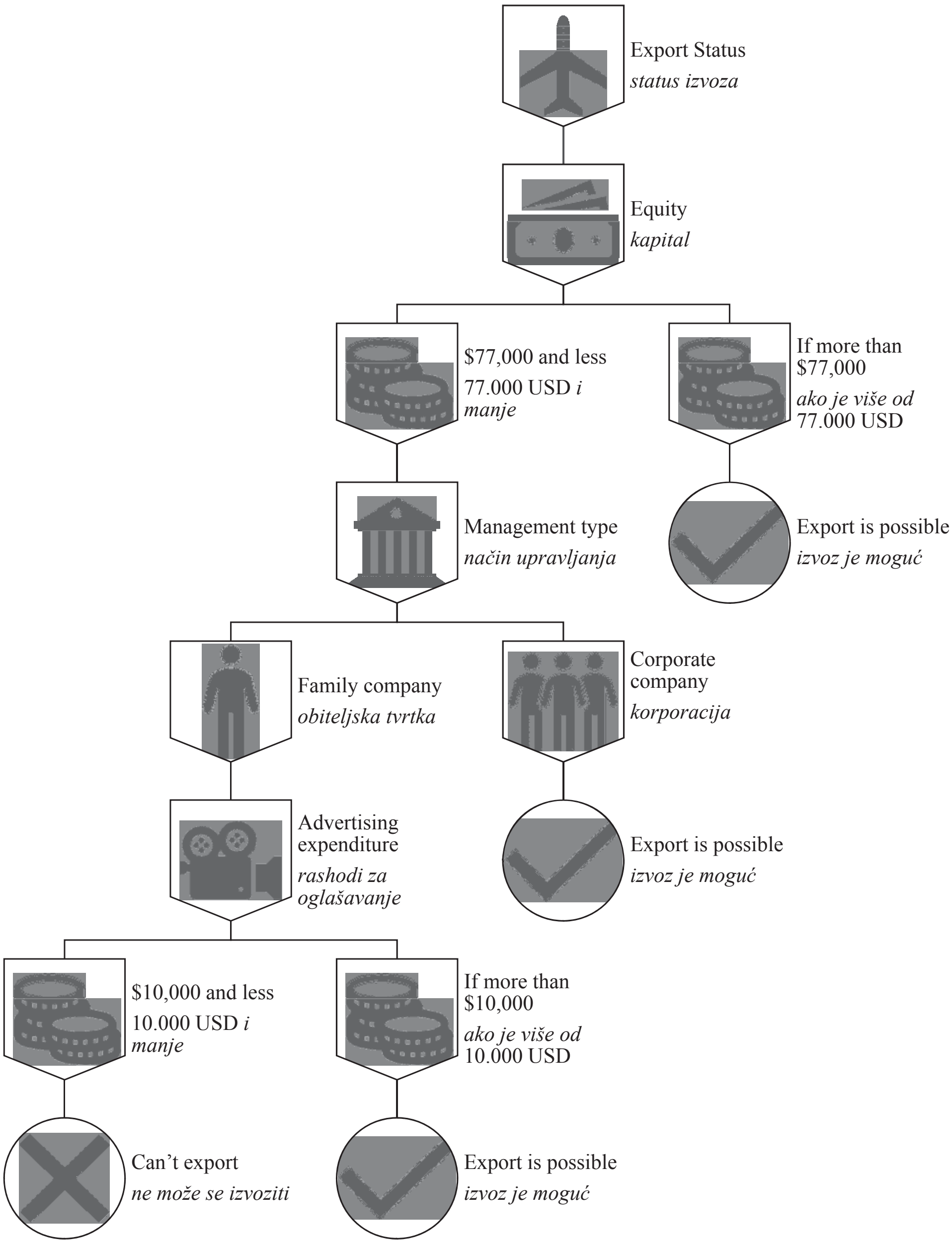

Figure 2 Decision tree model for Scenario 1
Slika 2. Model stabla odlučivanja za 1. scenarij

can export (Figure 3). This factor in the decision tree should not be taken into account in the comments, as this Export Structure factor is only taken into account in exporting companies. Since this Scenario included the manager's experience abroad at a critical level of 4 years, the interpretation of the scenario was considered original. If the Export Structure factor is higher than zero, the overseas experience of the Manager plays an important role in the decision tree. Accordingly, if the manager has overseas experience for more than 4 years, it can be said that this company exports easily. If it is a company with a manager who has less than 4 years of experience abroad, it can export only if it is a Joint Stock Company or a Limited Company.

If the firm is a common, limited partnership or a collective company, the Competitiveness factor appears to be prominent. Accordingly, if the Competitive Status factor score is above 5.5, the fact that the company manager has more than 2 years of experience means that the company can export. However, if the manager has 2 years or less experience abroad, this company cannot export.

If the Company's Competitiveness factor has a value of 5.5 or less, the Staff Situation factor comes into play. It is not possible for a company whose personnel situation score is zero to export. It is determined that if the value of Personnel Situation factor is higher than 0 and if the Competitive Status factor is less than 5.5, this company can export.

In this scenario, the following conditions are necessary for a company to export;

1. If the Export Structure factor score is greater than zero and the manager's overseas experience is more than 4 years,
2. If the Export Structure factor is greater than zero and the manager's overseas experience is 4 years or less,

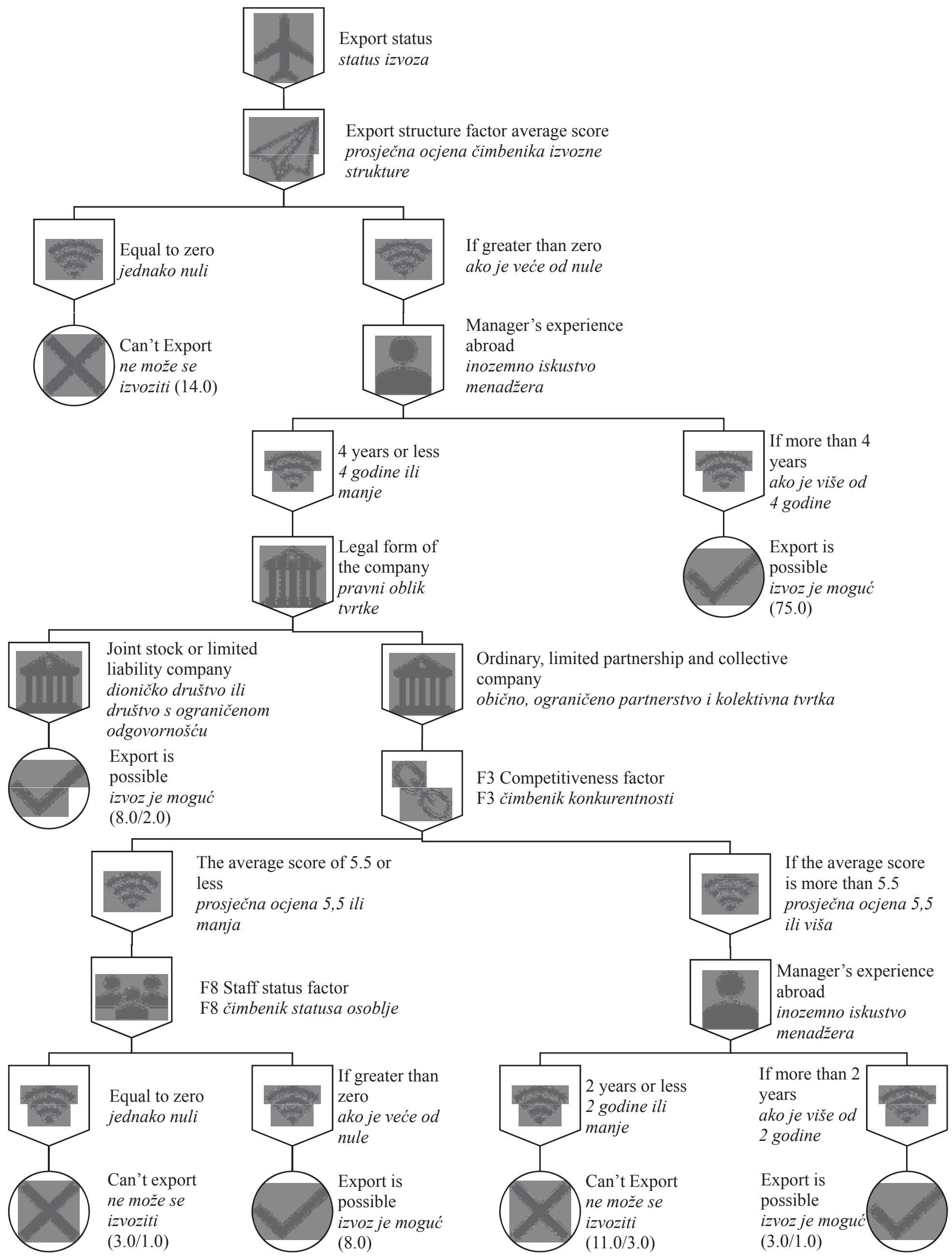

Figure 3 Decision tree model for Scenario 2
Slika 3. Model stabla odlučivanja za 2. scenarij

provided the legal form of the firm is limited or joint-stock company,

3. If the Export Structure factor is greater than zero, the manager's overseas experience is less than 4 years and the Competition Status score is less than 5.5, and the Staff Situation score is greater than zero,
4. If the Export Structure factor is greater than zero, the manager's overseas experience is less than 4 years and the Competition Status score is more than 5.5 and if the manager's overseas experience is between 2 and 4 years.

The accuracy of the scenario was found to be 94.5 %. This means that only 10 out of 182 companies were misclassified. Accuracy value was calculated as 0.945 and recall value was calculated as 0.945. The ROC Area value was 0.968 and the F score was 0.945. These values mean that the model is quite successful. The accuracy measure of the prediction, kappa statistic, was found to be 0.836 and proved that the prediction showed a very good level of fit.

3.3 Scenario 3 and findings
3.3. Scenarij 3. i zaključci

The variables used in Scenario 3 were Competitiveness, Export Structure, Personnel Situation, Manager's overseas experience, logarithm of this variable, Equity, Legal Structure of the Company, Automation Utilization Rate and Advertising Expenditures. According to these variables, for the scenario in Figure 4, the experience of the manager abroad is the most important factor for a company to export. If the manager has any overseas experience, even for a very short time, it means that the company he works for can easily export (131 companies). However, if the

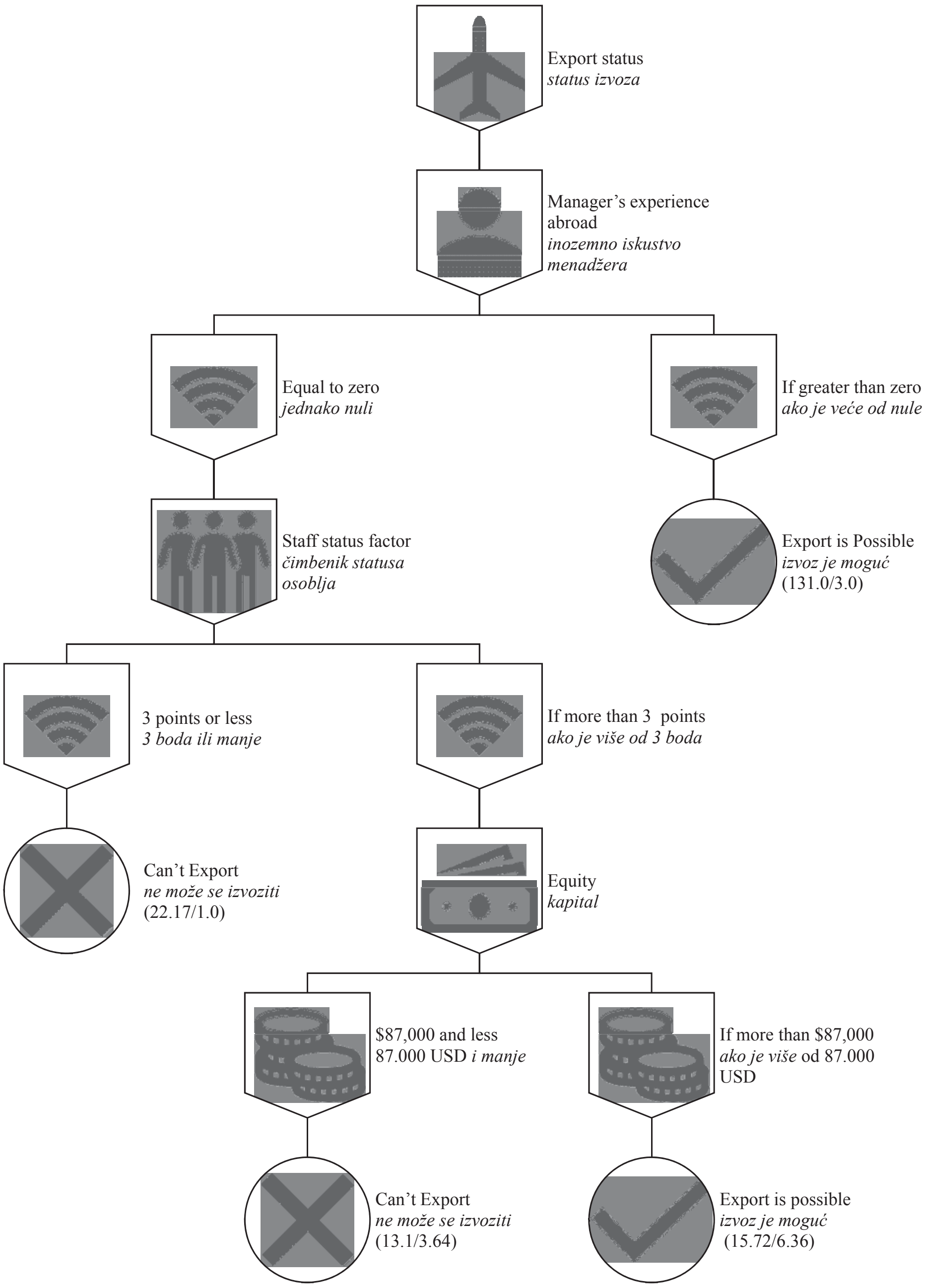

Figure 4 Decision tree model for Scenario 3
Slika 4. Model stabla odlučivanja za 3. scenarij

manager has no experience abroad, the most important factor in the decision tree is the staff situation. Accordingly, it is concluded that companies whose average score is 3 or less cannot export. However, it is possible to decide whether the companies whose Staff Situation factor is higher than 3 can export by looking at the third important issue, equity. Accordingly, it was concluded that companies with an equity capital of $ 87,000 and below could not export and companies with an equity of $ 87,000 or more could export.

In this Scenario, the following conditions are necessary for a company to export;

1. If the Manager has overseas experience,
2. If the Manager has no overseas experience, the firm can export if the Staff Situation factor score is greater than 3 and the Equity is greater than $ 87,000.

The accuracy rate of the Scenario was found to be 92.9 %. This means that only 13 out of 182 companies were misclassified. Accuracy value was calculated as 0.932 and recall value was calculated as 0.929. ROC Area value was 0.947 and F score was 0.930. These values mean that the model is quite successful. The accuracy measure of the prediction, kappa statistic, was found to be 0.801 and proved that the prediction showed a very good level of fit.

3.4 Scenario 4 and findings
3.4. Scenarij 4. i zaključci

This Scenario that resulted from another model used the following variables: Competitive Status, Export Structure, Personnel Situation, Manager's overseas experience, Equity, Advertising Expenditures, Legal Structure of the Company, and Automation

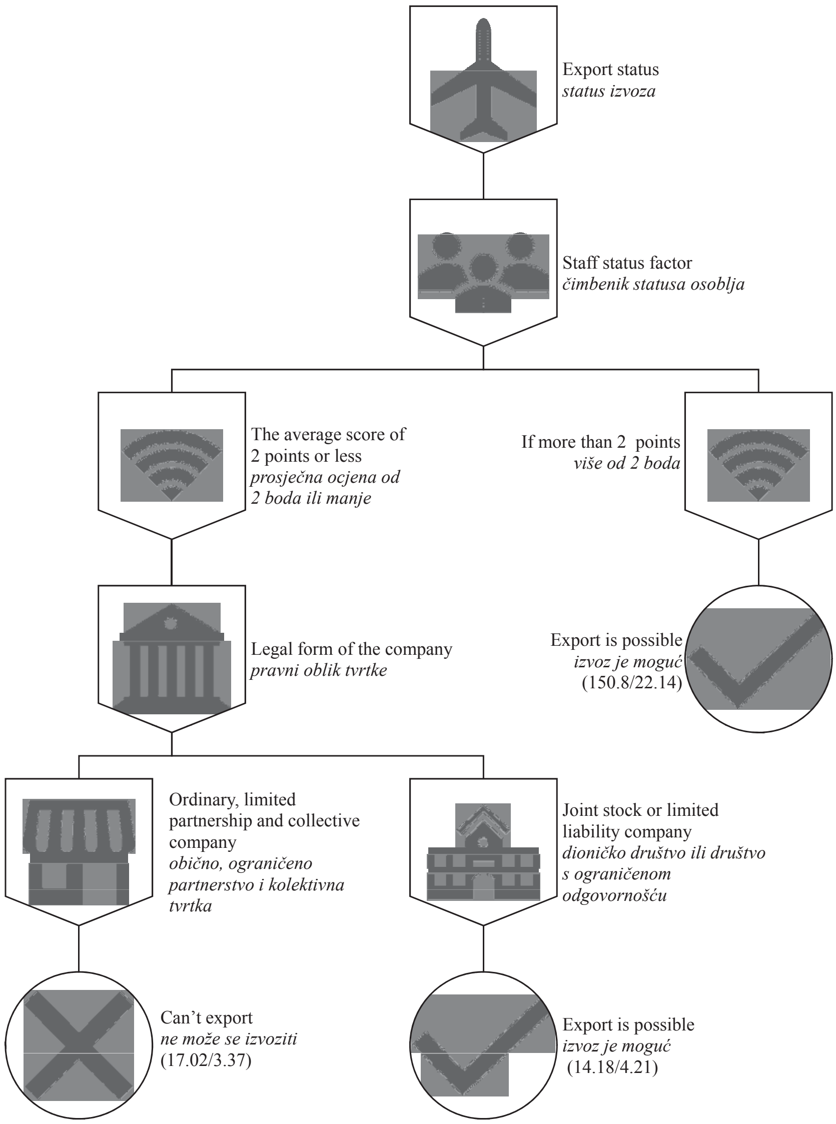

Figure 5 Decision tree model for Scenario 4
Slika 5. Model stabla odlučivanja za 4. scenarij

Utilization Rates. In this Scenario, Staff Situation, Qualified Personnel Procurement, In-Service Training and Personnel Environment Satisfaction are the most important factors. Accordingly, it is seen that companies with an average value of more than 2 can export. If the Staff Situation factor is less than 2 or 3, the Firm's Legal Form plays an important role in the decision tree. Accordingly, although the Staff Situation is less than 2, it is seen that companies with limited or joint stock status can export. However, if the legal form of the firm is Ordinary Company, Limited Partnership, Shared Limited Partnership or Collective Company, export is not possible.

According to this Scenario, in order for a firm to export, the Staff Situation factor score must be greater than 2 (Figure 5). If the Staff Situation factor score is 2 or less, the legal form of the firm should be Limited or Joint Stock Company. It was concluded that the Staff Situation factor score was 2 or less and the firm could not export if the legal form of the firm was ordinary, limited partnership or collective company.

In this Scenario, the following conditions are necessary for a firm to export;

1. If the Staff Situation factor score is greater than 2,
2. If the Staff Situation factor score is less than 2, the firm may export if the legal form is limited liability or joint stock.

The accuracy rate of the scenario was found to be 92.9 %. This means that only 13 out of 182 companies were misclassified. Accuracy value was calculated as 0.932 and recall value was calculated as 0.929. ROC Area value was 0.947 and F score was 0.930. These values mean that the model is quite successful. The accuracy measure of the prediction, kappa statistic, was found to be 0.801 and proved that the prediction showed a very good level of fit.

3.5 Scenario 5 and findings
3.5. Scenarij 5. i zaključci

The variables used as inputs in this Scenario are Brand-Advertisement-Packaging, Competition Status, Export Structure, Economic and Environmental Factors, Management Style and Style, R & D Activities, Staff Situation, Manager's overseas experience, legal form of the company, automation and advertising expenditures.

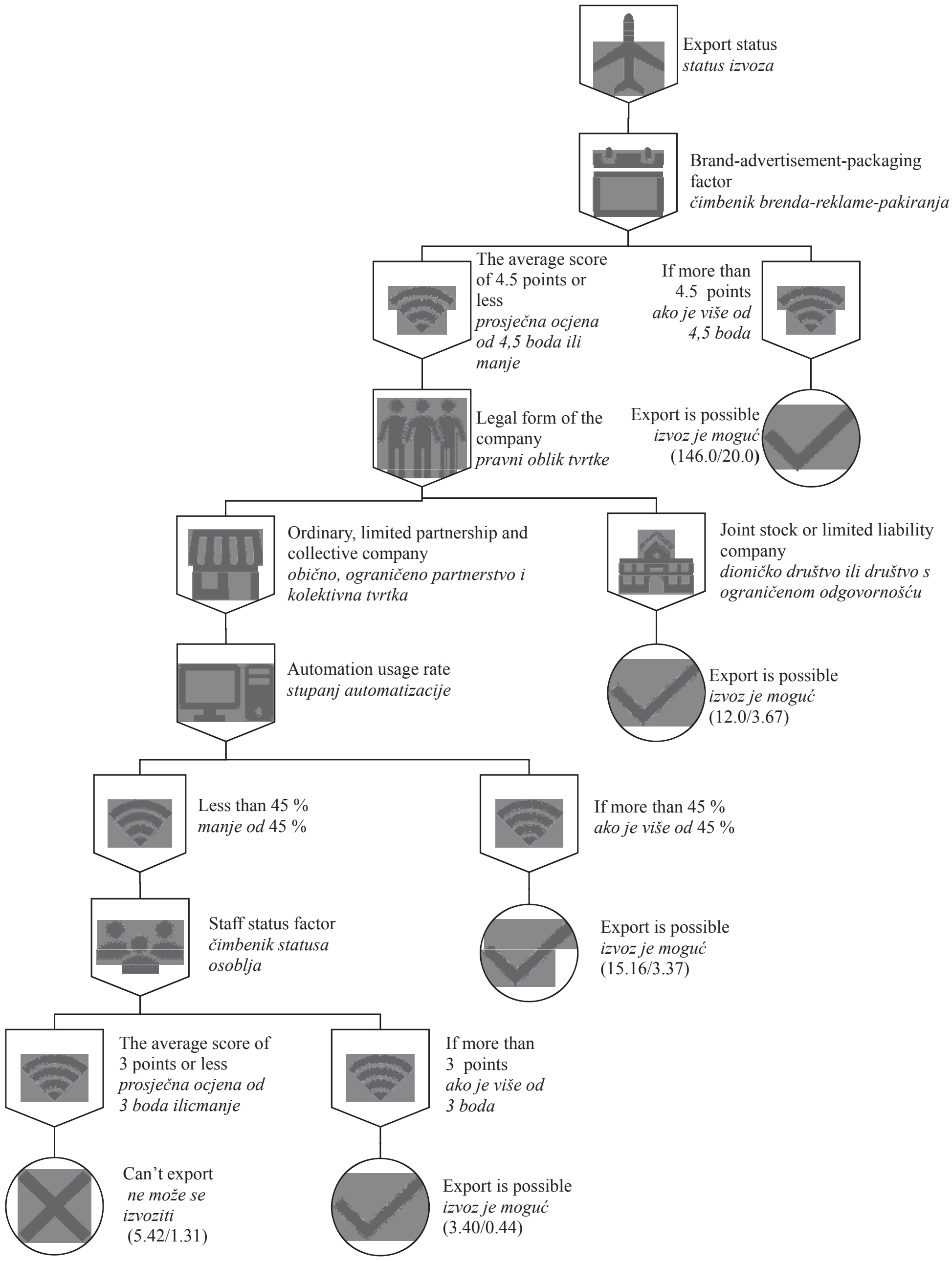

Figure 6 Decision tree model for Scenario 5
Slika 6. Model stabla odlučivanja za 5. scenarij

In this scenario, the knots of the decision tree are Brand-Advertisement-Packaging factor, Legal structure of the company, Automation usage rate and Staff Situation factor.

According to this Scenario, a company must meet the following conditions in order to export (Figure 6):

1. Brand-Packaging-Advertising factor score should be higher than 4.5,
2. If Brand-Packaging-Advertising factor score is 4.5 or less, Legal Form should be Joint Stock or Limited Liability,
3. If the brand-packaging-advertising factor score is 4.5 or less and the legal form is ordinary, limited partnership or collective company, the automation usage rate should be more than 45 %,
4. If the Brand-Packaging-Advertising factor score is 4.5 or less and the legal form is ordinary, limited or collective company and the automation rate is less than 45 %, the Staff Situation factor score should be higher than 3.

If the above conditions are not fulfilled, it is concluded that a company cannot export under this Scenario.

The accuracy rate of the Scenario was found to be 84.6 %. This means that 28 out of 182 data were misclassified. Accuracy value was calculated as 0.842 and recall value was calculated as 0.946. ROC Area value was 0.720 and F score was 0.835. These values mean that the model is successful. The accuracy measure of the prediction, i.e. kappa statistic, is found to be 0.476, proving that the prediction shows a moderate fit.

3.6 Overview of scenarios
3.6. Pregled scenarija

In order to examine the scenarios as a whole, all the factors used and the subjects that cause branching in the scenarios are discussed. The expressions shown in Scenario 1 (S1) to Scenario 5 (S5) show the scenario numbers and alternative ways to export in each scenario.

Consequently, there are 2 alternative routes in S3 and S4, 3 alternative routes in S1 and S2, and 4 alternative routes in S5.

In examining the findings of the scenarios, it can be seen that the staff situation factor comes to the fore in 4 scenarios. This is followed by the legal form of the company. Whether the legal form of the company is Joint Stock Company or Limited Company has been decisive in 3 scenarios. Overseas experience of the manager and equity have been identified as effective in 3 scenarios.

These findings show that the determination of the factors affecting the export, which constitutes the main subject of the study, is correct.

4 DISCUSSION AND CONCLUSIONS
4. RASPRAVA I ZAKLJUČAK

Export is an important opportunity that increases the welfare and competitiveness of countries. Thanks to exports, companies increase their sales, profits, capacity utilization, competitiveness, employment in the country, share in world markets and reduce foreign trade deficit.

In the last 5 years, the furniture industry has become an important economic industry with an annual value of 376 billion dollars. Socio-economic aspects of employment are also of considerable importance. In terms of furniture production and trade, EU countries have developed considerably compared to many regions of the world. Especially Germany and Italy are ahead of other European countries in terms of production, import and consumption. China has been a leader in furniture production in the world and has been leading the industry for the last five years. There is a significant potential for development and growth of the furniture industry in Turkey. When the furniture industry in Turkey is examined, it can be seen that the furniture companies aim to increase the export share by more than 2 % (Anadolu Agency, 2017).

Export performance is generally defined as the success of a company in international sales. Despite many studies to determine the determinants of export performance, there is no consensus on these determinants (Aaby and Slater, 1989; Madsen, 1989; Shoham, 1999a; Zou and Stan 1998). In various studies, it is seen that different export performance indicators and different measurements are used. This situation causes difficulties in the comparison of the studies. Therefore, in this study, efforts were made to identify common indicators that can evaluate export performance and measurements related to the issues affecting export.

In order to identify the factors affecting the export performance of the furniture industry in Turkey, a comprehensive literature study was carried out on companies engaged in the production of furniture by combining the factors and issues obtained in a survey of 182 furniture firms. The aim is to convey the findings to the executives, investors, decision makers and even academicians interested in the export industry.

In the study, efforts were made to draw meaningful results from the data obtained using data mining. Decision tree models, one of the data mining techniques, and J48 algorithm have been studied in 5 different scenarios.

In addition to these factors, the most important issues in the scenarios were found to be the corporate structure of the company, equity capital, overseas experience of managers, automation usage rates and advertising expenditures, and it was observed that these issues were effective in many scenarios. The determination of these issues was one of the important results obtained from the study.

The other important result and suggestion of our study is decision tree modeling should be conducted by using logistic regression findings of determinants / variables in order to produce more significant results. In case of so many variables, a decision tree may not give successful or clean modeling. Since pre-modeling by logistic regression may eliminate most of the relatively insignificant variables, this logistic regression promoted decision tree approach is recommended for future decision tree studies.

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The Effect of Using Pumice Powder and Plasticizer on Physico-Mechanical and Thermal Properties of Cement-Bonded Particleboards

Utjecaj praha plovućca i plastifikatora na fizičko-mehanička i toplinska svojstva cementom vezanih iverica

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ABSTRACT • *In this study, the effect of using pumice powder and plasticizer on some properties of cement-bonded particleboards (CBPBs) was investigated. Therefore, CBPBs were produced using 0 %, 10 %, 20 % and 30 % pumice powder and 0 %, 0.4 %, 0.8 %, 1.2% plasticizer. Based on test results, it was found that using pumice powder had an important positive effect on water absorption and thickness swelling, but no effect on density. The amount of thickness swelling decreased by 15 % with the use of 30 % pumice powder. The modulus of elasticity and internal bond strength were generally increased by 20 % with the use of pumice powder, while modulus of rupture and thermal insulation properties were decreased. The use of 0.4 % and 0.8 % plasticizers positively affected the properties of board properties. The use of plasticizer had a positive effect on thermal properties. The thermal conductivity values decreased by 18 % as the amount of plasticizer increased to 1.2 %. In this regard, the use of plasticizers in CBPBs production is an option in terms of improving thermal properties.*

Keywords: *cement-bonded particleboard (CBPBs); pumice; plasticizer; physical and mechanical properties; thermal conductivity*

SAŽETAK • *U radu je opisano istraživanje utjecaja praha plovućca i plastifikatora na neka svojstva cementom vezanih iverica (CBPB). Stoga su CBPB proizvedeni upotrebom 0, 10, 20 i 30 % praha plovućca te 0, 0,4, 0,8 i 1,2 % plastifikatora. Na temelju rezultata ispitivanja utvrđeno je da je prah plovućca imao znatan pozitivni učinak na upijanje vode i debljinsko bubrenje ploča, dok se gustoća ploča nije mijenjala. Upotrebom 30 % praha plovućca debljinsko se bubrenje ploča smanjilo za 15 %. Modul elastičnosti i međuslojna čvrstoća proizvedenih ploča uz upo-*

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trebu praha plovućca povećali su se za 20 %, dok su se modul loma i toplinska izolacija smanjili. Upotreba 0,4 i 0,8 % plastifikatora pozitivno je utjecala na svojstva ploča. Primjena plastifikatora pozitivno je utjecala i na toplinska svojstva ploča. Pri povećanju količine plastifikatora na 1,2 %, vrijednosti toplinske vodljivosti smanjile su se za 18 %. Stoga je upotreba plastifikatora u proizvodnji CBPB-a jedna od opcija za poboljšanje toplinskih svojstava tih ploča.

Ključne riječi: *cementom vezana iverica (CBPB); plovućac; plastifikator; fizička i mehanička svojstva; toplinska vodljivost*

1 INTRODUCTION
1. UVOD

Today, the concept of waste management has gained substantial impetus due to limited natural resources and increasing world population. This concept is a leading research topic for renewable chemical resources and converting waste into raw materials to be used for value-added products (Dziurka, 2013; Cavdar *et al.*, 2013). To cope with the scarcity of timber production, it is necessary to develop new solutions. One of the solutions provided by engineering technology that can be implemented today is that the lesser known wood species or timber waste can be converted into wood products such as particleboard, fiberboard, oriented strand board (OSB), wood-cement board or other wood composite materials (Gunawan, 2012).

One of the composite materials produced from wooden materials is cement-bonded particleboards (CBPBs). CBPBs are made of particles, fiber or strands of wood mixed with Portland cement and small quantities of additives manufactured into panels, tiles, bricks, wall elements and other products used in the construction and building industry (Okino *et al.*, 2004; Ashori *et al.*, 2012). CBPBs have a great number of advantages compared to panels produced with organic resins: fire resistance, high resistance to fungal and insect attack, dimensional stability against external weather conditions (Quiroga *et al.*, 2016). The wood composite panels, such as fiberboard and particleboard composites, can be degraded by biological factors and environmental conditions (Reinprecht, 2016).

Pumice has been a well-known lightweight aggregate for over 2000 years due to its resistance and durability. Pumice aggregates, blended with Portland cement and water, can be used in manufacturing of different engineered materials such as insulating structural floor decks, lightweight thermal and sound insulating panels, fire-resistant lightweight concrete for roof decks, lightweight floor fills, shear wall systems, masonry blocks and a variety of other permanent insulating practices (Failla, 1982; Gunduz, 2008). There are about 18 billion tons of pumice deposits in the world. Pumice deposits in Turkey are approximately 15.8 of the total world deposits (Elmastas, 2012). With the use of pumice powder in the cement, it provides heat and sound insulation due to its porous structure. In addition, it increases the resistance properties (El-Gamal and Hashem, 2017).

Normal plasticizers are generally based on lingosulphonate. This is a natural water-soluble organic polymer found in wood and extracted as a waste stream during paper pulp processing. It can be used to give the product higher resistance, to reduce water content for increased strength and reduced permeability, improved durability in order to reduce the amount of cement required to produce a concrete of specified strength and durability and as a cement dispersant at the same water content to increase consistence and workability retention (Akman, 1996).

Pumice powder (PuP) and normal plasticizers (NoP) are important production components for concrete producers. However, there is no comprehensive study related to their effects on the properties of CBPBs. The objective of this study is to investigate the effect of PuP and NoP on some physical and mechanical properties of CBPBs, such as density (D), water absorption (WA), thickness swelling (TS), thermal conductivity (TC), modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond strength (IB).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Spruce (*Picea orientalis* L.) planer shavings were supplied by a commercial forest products plant in Trabzon, Turkey. In this study, fresh type CEM I 42,5R Portland cement was used as the binding agent. Aluminium sulfate [$Al_2(SO_4)_3.18H_2O$] and sodium silicate (Na_2SiO_2) were used as cement curing accelerator. Pumice powder with grain size of 10 μm was purchased from BEKTAS mining, Co, Turkey. PLASTIBERG-4000BV Normal plasticizer, provided by Bauberg Co, Germany, was used as the plasticizer. The technical specifications of the plasticizer used are given in Table 1.

2.2 Methods
2.2. Metode

2.2.1 Manufacture of boards
2.2.1. Proizvodnja ploča

Planer shavings were converted into particles using a drum knife flaking machine. Then, they were categorized by means of a horizontal screen shaker. The particles that remained between 3-1.5 mm sieves and

Table 1 Technical specifications of plasticizer
Tablica 1. Tehnička svojstva plastifikatora

Structure of material *Struktura materijala*	Lignin-based *na bazi lignina*
Color / *Boja*	Brown / *smeđa*
Density / *Gustoća*	1.13 - 1.16 kg/m^3
Chlorine (Cl_2) content *Sadržaj klora* (Cl_2)	<0.1 %
Alkali content / *Alkalni sadržaj*	<10 %

between 1.5-0.5 mm sieves were operated in the core and surface sections of the panels, respectively. NoP of 0 %, 0.4 %, 0.8 %, and 1.2 % were used as substitutes for cement, and PuP of 0 %, 10 %, 20 %, and 30 % were used as substitutes for particles. A mass ratio of 1/2.75 for wood-cement, and a mass ratio of 1/1.64 for water-cement (the amount of water in the wood strands was included) were used for all the boards. Based on cement weight, 1.5 % aluminium sulfate and 1.75 % sodium silicate were used as additive. Sodium silicate (water-glass) is added to the mixture to accelerate the setting of Portland cement and reduce the volume changes in wood. They penetrate into the capillaries of the wood, where in the course of chemical reactions they turn into insoluble compounds and build up in the wood. This makes access to water more difficult and improves the resistance to swelling and absorbability.

The particles were placed in the mixing vessel and then the calculated amounts of additives and water were added and thoroughly mixed. After that, Portland cement was added and mixing continued until uniformity was obtained. Hand-made board mats with dimensions of 550 mm × 550 mm × 10 mm were hot pressed for 8 h and cold pressed for 16 h to achieve a target board density of 1.200 g/cm^3. Pressing pressure and temperature were selected as 1.8-2 N/mm^2 and 60 °C, respectively. All the boards were designed to have a particle ratio of 40 % at the surface layers and 60 % at the core layer. A total of sixteen experimental panels were manufactured. After pressing, the boards were further stored in a climate room for 28 days at 25 °C and 65 % RH.

2.2.2 Physical and mechanical properties
2.2.2. Fizička i mehanička svojstva ploča

Physical properties including D, WA and TS were determined according to EN 323:1993, ASTM D1037:1998, EN 317:1993, respectively. Mechanical properties including MOR, MOE, and IB were determined according to EN 310:1993, EN 319:1993, respectively using a Zwick 10KN Universal Testing Machine (Zwick Inc. Germany). The results obtained were evaluated according to EN 634-2:2009.

2.2.3 Thermal conductivity
2.2.3. Toplinska vodljivost

TC analysis of the samples was performed according to ASTM C1113-99:2004 standard by using a thermal conductivity meter (QTM 500-Kyoto Electronic). Thermal conductivity (λ) was calculated using the following Eq. 1:

$$\lambda = \frac{q \cdot ln(t_2 / t_1)}{4 \cdot \pi \cdot (T_2 - T_1)} \quad (1)$$

Where λ is the thermal conductivity coefficient (W/mK), q is the heat transfer rate (cal), t_2 / t_1 is the time interval (s) and $T_2 - T_1$ is the temperature difference between the ends (°C).

2.2.4 Statistical analysis
2.2.4. Statistička analiza

The result of each cement-bonded particleboard was analyzed with ANOVA test using SPSS 13.0 software. The significance (p<0.05) between the treatments was compared with DUNCAN homogeneity groups.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Physical properties
3.1. Fizička svojstva

The evulation results of physical properties for all the board groups, including homogeneity group values, are shown in Figure 1 and Table 2. Utilization of PuP and NoP were found to be effective on the amount of WA. Using a PuP of 30 % provided a 12 % reduction in WA values compared to the control group. Based on EN standards, cement-bonded particleboards should have a maximum TS value of 1.5 %, for 24 hours immersion (EN 634-2, 2009). Generally, an increasing amount of PuP resulted in a decrease in WA and TS values. This decrease may be attributed to the fact that PuP has a lesser hydrophilic character than wood raw material. Sarıışık and Sarıışık (2010) reported that the pumice water absorption rate was determined as 34 %. Kılıç and Hafızoglu (2002) determined that WA values of poplar, fir, pine and alder were 95 %, 139 %, 100 %, and 81 % in their study on a variety of wood samples to determine the rate of water uptake of wood species kept in water for 48 hours, respectively. So, a decrease in the use of wood chips has increased the water resistance of the boards.

The amount of plasticizer affected WA and TS values of the boards. Using 0.4 % and 0.8 % plasticizer

Table 2 Homogeneity groups of properties depending on pumice powder and plasticizer amount
Tablica 2. Homogenost grupa svojstava ovisno o količini praha plovućca i plastifikatora

Source of parameter *Izvor parametra*	**Content** *Sadržaj*	***D*** g/cm^3	***WA*** %	***TS*** %	***TC*** W/mK	***MOR*** N/mm^2	***MOE*** N/mm^2	***IB*** N/mm^2
PuP (%)		HG	HG	HG	HG	HG	HG	HG
	0	A*	A	A	A	A	A	A
	10	A	B	A	A	AB	B	B
	20	A	C	B	A	B	C	C
	30	A	D	C	B	B	D	D
NoP (%)	0	A	A	A	A	A	A	A
	0.4	A	B	B	A	B	B	B
	0.8	A	B	B	B	A	C	C
	0.12	A	C	C	B	C	D	D

*Different letters mean that there is a significant difference. / *Različito slovo označava postojanje značajne razlike.*

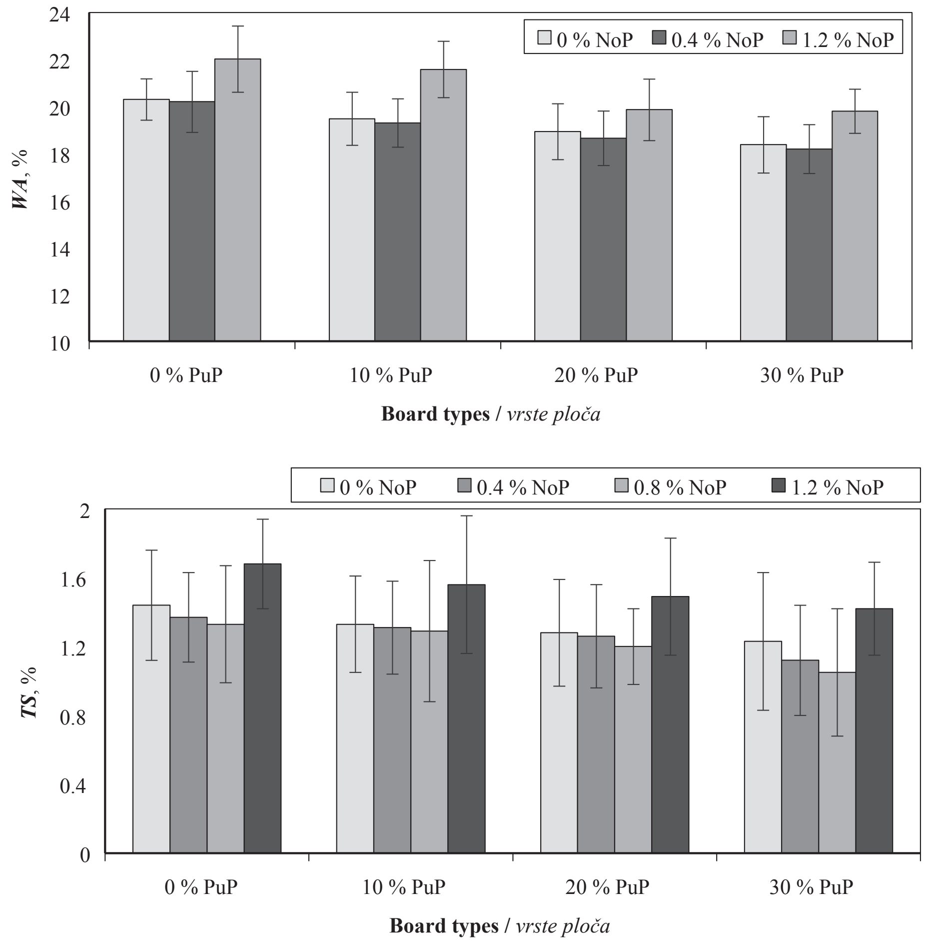


Figure 1 The effect of the amount of PuP and NoP on dimensional stability of boards
Slika 1. Utjecaj količine PuP-a i NoP-a na dimenzijsku stabilnost ploča

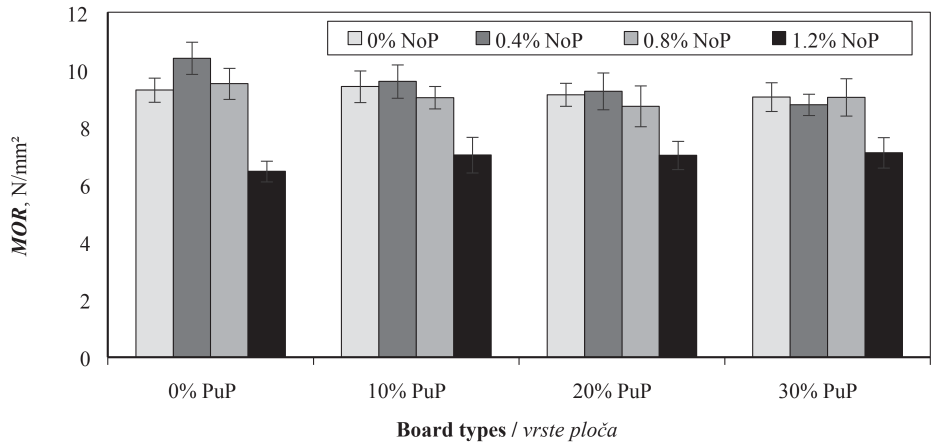
increased the resistance of the boards to water. The plasticizers act as an air-entraining agent in the concrete. In addition, they prevent cement grains from sticking together and caking (Uyan and Akman, 1985). This increases the impact strength and toughness properties of the boards. On the other hand, using 1.2 % plasticizer decreased the water resistance of the boards. This is caused by the failure of holding together the mixture of solid particles. Thus, the concrete loses stability, and separations occur (Turkel and Felekoglu, 2004). Therefore, the excessive use of plasticizer adversely affected the board properties.

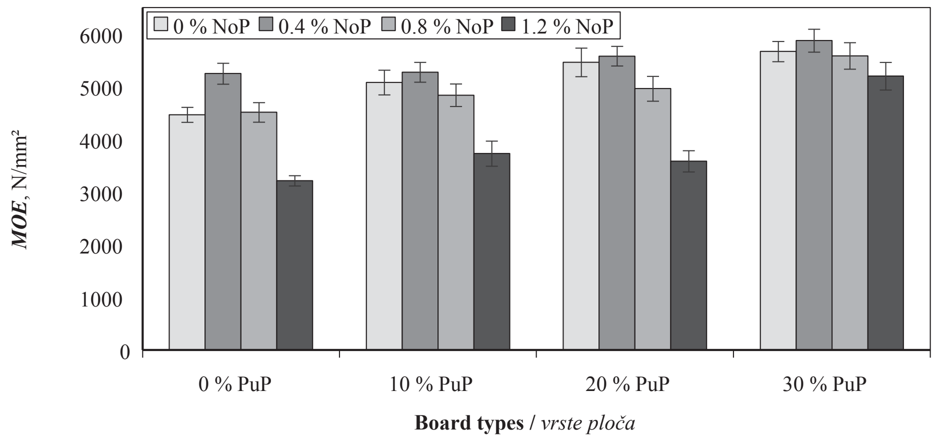
3.2 Mechanical properties
3.2. Mehanička svojstva

The results of mechanical properties for all the board groups, including homogeneity group values, are shown in Figure 2 and Table 2. The mechanical properties of the boards gave results in accordance with the standard EN 634-2 (2009), except for those using 1.2 % NoP. The use of 1.2 % NoP resulted in a reduction of 5 % in MOR compared to the control group. Moslemi and Prifister (1987) stated that there is a significant relationship between wood-cement ratio and bending resistance. Suitable ratios for high bending resistance values are between 1/2 and 1/3. The wood-cement ratio increased to 1/4 when a PuP of 30 % was used. Thus, reducing the amount of wood may have caused the bending resistance to decrease. The applied force spreads over a larger area with the increase in the amount of wood. This leads to a decrease in tension and has a positive effect on bending resistance (Papadopoulos *et al.*, 2006).

The use of over-plasticizer reduced the MOR values. There is a certain dosage range for the use of the plasticizer. The use of plasticizers in excess of this range can cause some problems such as delay and shortening of the cement setting, early reduction and decomposition (Ferraris, 1999; Halim *et al.*, 2017). The plasticizer dosage range according to the concrete institute varies between 0.25 % and 0.45 % (CI, 2013). Especially, the chemical structure and physical properties of the cement used in production have a significant impact on the utilization rate (Tkaczewska *et al.*, 2014). Besides, the addition of wood particles in the cement paste may have affected this rate.

When the effect of the amount of pumice powder on MOE was examined, the result showed that it had a negative linear relationship with MOE. Adding a PuP of 30 % to the board leads to an improvement of 20 % in its MOE values. Decrease in wood-cement ratio leads to an increase in MOE (Frybort *et al.*, 2008). Papadopoulos *et al.* (2008) reported that a change in the wood-cement ratio from 1/3 to 1/4 decreased MOR by approximately 20 %, while it increased MOE by about 15 %. The highest MOE values were obtained with the





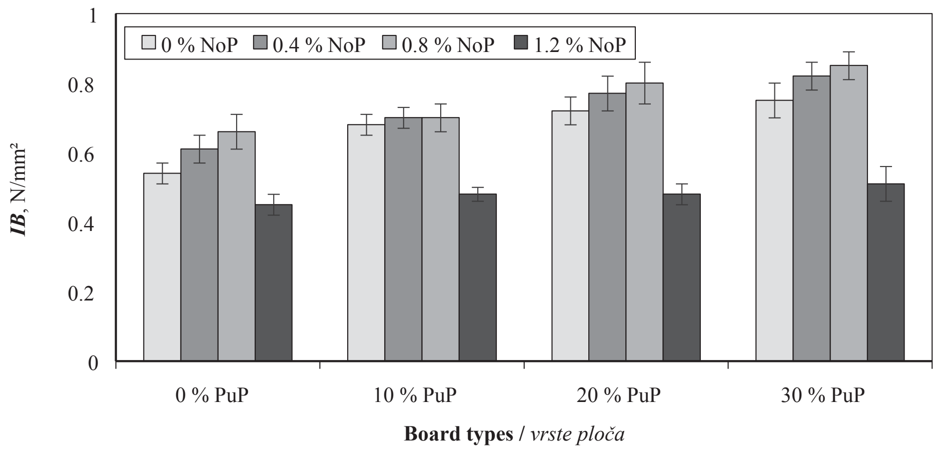


Figure 2 The effect of the amount of PuP and NoP on mechanical properties of boards
Slika 2. Utjecaj količine PuP-a i NoP-a na mehanička svojstva ploča

use of 4 % plasticizer. Studies have shown that the use of plasticizers improves the consistency and performance of concrete (Burgos *et al.*, 2012, Topcu *et al.*, 2016).

The results demonstrated that using a PuP of 30 % provided an improvement of 20 % in the IB strength of the boards. PuP shows pozzolan properties due to the high content of amorphous silica. The inhibited effect of wood extractives is reduced by adding pozzolanic additives in cement based wood composites (Vaickelionis and Vaickelioniene, 2006). PuP contributed to a reduction in the concentration of water and alkaline soluble components, which inhibited the hydration reaction of cement, in wood-cement paste because it was used instead of wood. This may have positively affected the hydration of cement.

3.3 Thermal conductivity
3.3. Toplinska vodljivost

The results of thermal conductivity for all the board groups, with homogeneity group values, are shown in Figure 4 and Table 2. According to the results, the boards produced cannot be accepted as thermal insulation materials. Nonetheless, the positive effects on the insulation of the construction can be examined.

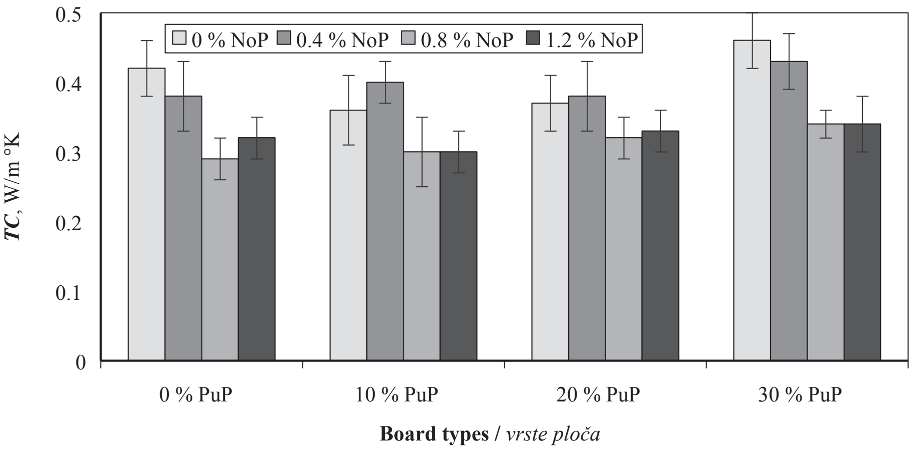


Figure 3 The effect of the amount of PuP and NoP on thermal conductivity of boards
Slika 3. Utjecaj količine PuP-a i NoP-a na toplinsku vodljivost ploča

The TC values increased by 15 % as the amount of PuP increased only up to 30 %. It can be said that the amount of voids decreased and heat transfer increased due to the reduction in particle size. Therefore, the decrease in the amount of wood use increased the heat transfer coefficient because wood is a good heat insulation material since it contains empty spaces (Ross, 2010). Bederina and Quéneudec (2010) reported that the addition of wood shavings in concrete improves its thermal insulation properties. The increase in the amount of NoP leads to a decrease in the heat-conducting properties of the boards. The TC values decreased by 18 % as the amount of NoP increased to 1.2 %. It can be said that the use of plasticizers also improves the thermal insulation properties due to the positive effect on the flow and placement of cement. The use of plasticizers increases both the fluidity of the cement paste and the amount of adsorption to the cement fraction of the plasticizer (Zhang *et al.*, 2016).

4 CONCLUSIONS
4. ZAKLJUČAK

In this study, the effects of PuP and NoP on the physico-mechanical properties and thermal conductivity of CBPBs were investigated. In general, 0.4 % and 0.8 % NoP improved the dimensional stability and mechanical resistance properties of the boards. On the contrary, when 1.2 % NoP were used, mechanical resistance properties were negatively affected due to the corruption in the structure of the board. On the other hand, PuP increased the dimensional stability, MOR and IB properties of the boards. However, PuP reduced the bending resistance of the boards. Although the TC values of the boards are compatible with the studies conducted under similar conditions, it has been determined that they will not be used as thermal insulation material. Even though 1.2 % NoP decreased the strength properties of the boards, it reduced the thermal conductivity coefficient. It was concluded that the use of PuP and NoP at the appropriate dosage improved the strength properties of CBPBs. Additionally, there is potential in the use of planer shavings as an alternative to wood material as reinforcement in wood cement composites for building construction helping in reducing waste disposal costs.

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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

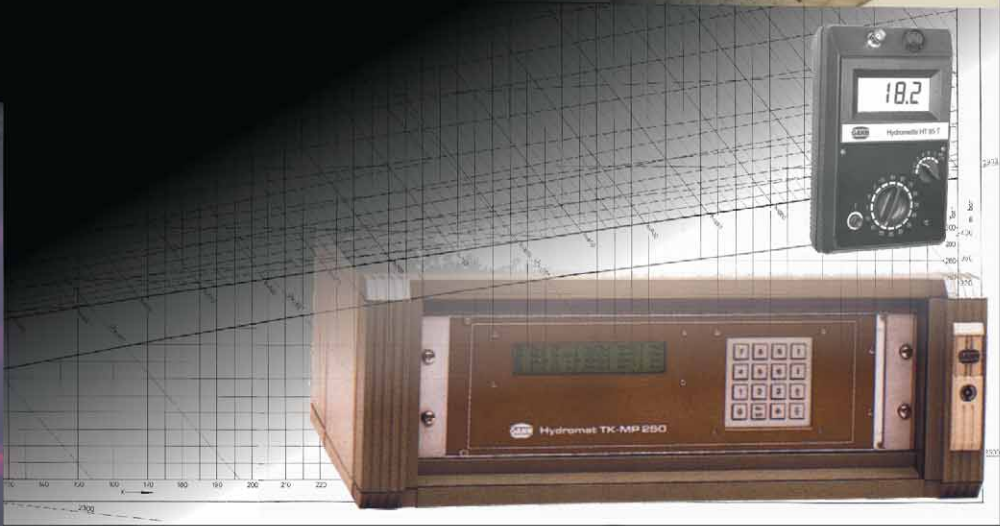
Determination of wood bending parameters

Detection and reducing of hydrothermal processes wood defects

Reducing of kiln drying time

Drying costs calculation

Kiln dryer capacity calculation



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An Assessment of Environmental Impact on Glued Wood Building Elements

Procjena utjecaja okolišnih uvjeta na lijepljene drvne elemente u graditeljstvu

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ABSTRACT • *The research investigated the impact of environmental factors (temperature and humidity) on pine glulam, oak glulam, and laminated veneer lumber (LVL) elements, all of which can be used in building structures. Elements underwent freezing, heating, drying, and wetting processes in different modes, thereby simulating different environmental conditions that could be encountered during the service period of the materials. Their mechanical properties (modulus of elasticity - MOE and coefficient of damping) were recorded at each stage. It was determined that, in the case of dry construction elements (where a moisture content was between 7.0 and 14.0 %), the MOE increases by a few percentage points with decreasing temperature and humidity levels, and decreases with increasing temperature and humidity levels. The coefficient of damping varied by 20 % - in most cases, when the modulus of elasticity increased, this decreased, and vice versa. Under extreme environmental changes (with the elements being soaked, frozen at -25 °C, and dried at 40 °C), the MOE of the glued timber decreased by 16 % when this parameter of LVL decreased by about 10 %. Alterations in viscous properties produced similar results (the coefficient of damping increased by 50 % for the glued timber and by 66 % for the LVL). This is explained by the partial destruction of the element structure, the occurrence of cracks, and the decreased anisotropy of the LVL structure.*

Keywords: *glued wood (glulam); laminated veneer lumber; modulus of elasticity; coefficient of damping; wood defects*

SAŽETAK • *U radu je istraživan utjecaj okolišnih čimbenika (temperature i vlage) na elemente lameliranih nosača izrađenih od borovine i hrastovine te na elemente lamelirane furnirske građe (LVL), koji se često rabe u graditeljstvu. Elementi su bili na različite načine podvrgnuti smrzavanju, zagrijavanju, sušenju i vlaženju kako bi se simulirali različiti okolišni uvjeti koji bi se mogli pojaviti tijekom uporabe tih materijala. U svakoj su fazi ispitivanja bilježena mehanička svojstva promatranih drvnih elemenata (modul elastičnosti – MOE i koeficijent prigušenja). Utvrđeno je da se u suhih građevinskih elemenata (sadržaj vode između 7,0 i 14,0 %) s padom temperature i vlage MOE povećava za nekoliko postotnih bodova, a smanjuje se s porastom temperature i vlage. Koeficijent prigušenja u većini je ispitivanja varirao za 20 %: kako se modul elastičnosti povećavao, koeficijent prigušenja se smanjivao, i obrnuto. Pri ekstremnim promjenama okolišnih uvjeta (potapanjem elemenata, smrzavanjem na –25 °C i sušenjem na 40 °C) MOE lameliranih nosača se smanjio za 16 %, a LVL-a za oko 10 %. Glede promjena viskoelastičnih svojstava, zabilježeni su slični rezultati (koeficijent prigušenja lameliranih nosača povećao se za 50 %, a LVL-a za 66 %). To se objašnjava djelomičnom razgradnjom strukture drvnih elemenata, pojavom pukotina i smanjenom anizotropijom strukture LVL-a.*

Ključne riječi: *lamelirani drvni nosači; lamelirana furnirska građa; modul elastičnosti; koeficijent prigušenja; greške drva*

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1 INTRODUCTION
1. UVOD

Timber and timber elements are widely used in building structures (Rindler *et al*., 2018; Sanscartier Pilon *et al*., 2019; Žlahtič-Zupanc *et al*., 2018; Risse *et al*., 2019; Subhani *et al*., 2017; Gilbert *et al*., 2017; Markström *et al*., 2018; Hildebrandt *et al*., 2017; Musselman *et al*., 2018). The production of various timber articles (laminated timber) has a purpose both in economic and ecological terms. In order to reduce emissions it is appropriate to use timber materials instead of concrete and steel structures. The demand for these materials is projected to continuously increase (Risse *et al*., 2019, Hildebrandt *et al*., 2017). The construction of buildings with more than two floors is one of the latest trends in which more timber products could be used (Markström *et al*., 2018).

Constructions that are made using glued timber materials, such as laminated veneer lumber (LVL) and cross laminated timber (CLT), can be used to reinforce concrete and steel structures and ensure better protection levels against earthquakes (Sanscartier Pilon *et al*., 2019).

More lately, identifying, improving, and forecasting the properties of timber structures has become a topical subject. It is already known that, in most cases, timber becomes wet or dry when in service under the changing ambient temperature and humidity levels. Alterations in timber moisture content may result in alterations in terms of dimensions and shape of timber materials, or the occurrence of various defects and changes in mechanical properties (Wood Handbook, 2010). It has already been established that an increase in temperature from -30 °C to +30 °C will decrease the *MOE* in timber materials (Ayrilmis *et al*., 2010).

The impact of different factors on alterations in the moisture content of timber materials under ambient conditions was also something that has previously been investigated. The absorption properties of timber materials can be altered by applying thermal modifications, along with wax, oil, and biocide treatments (Žlahtič-Zupanc *et al*., 2018). It has been determined that the moisture content of glued timber materials - which changes under the influence of the ambient temperature - also alters its mechanical properties. In addition, the change in these properties also depends on the glue that has been used (Rindler *et al*., 2018). The mechanical properties of one of the most commonly used construction materials - LVL - can be improved by using other materials, such as polymeric options (Subhani *et al*., 2017). Thanks to the digital model developed, it is possible to predict the LVL mechanical properties in various directions and to produce beams of the desired mechanical properties (Gilbert *et al*., 2017). Building structures often require holes to be made in the materials. It has been determined that both the diameter of those holes and, especially, their location affect the strength properties and durability of LVL beams (Musselman *et al*., 2018).

The aim of the study is to evaluate the impact of environment factors on the mechanical properties of glulam beams in both oak and pine, as well as LVL beams.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The research study used glued oak and pine glulam beams (each glued segment consisting of five planks) and LVL beams (the thickness of the layer was about 3 mm) with the dimensions of 1200 mm × 75 mm ×100 mm, a humidity level was between 10.5-14.0 %, and the density was accordingly within the limits of 740-780 kg/m^3, 520-550 kg/m^3, and 590-670 kg/m^3, respectively. The glulam beams were glued by using water-resistant polyurethane glues, and the LVL specimens were glued by using formaldehyde-based glues. There were 10 beams of each type. A schematic for specimen cross-sections is provided in Figure 1.

In order to simulate changes in environmental parameters, the climatic conditions were modelled in the climatic chamber (the appropriate air temperature and relative humidity are determined in the chamber, all samples are stacked in chamber and the change in their mechanical properties is recorded every 7 days). In the chamber, the temperature was maintained within an accuracy level of 1 °C, and the relative humidity level was maintained within an accuracy level of 2 %. The length of the specimens was measured using a tape measure within an accuracy of 1 mm, while the width and thickness were measured using sliding callipers within an accuracy of 0.05 mm, and the mass was measured using a balance within an accuracy of 0.1 g. The moisture content for the specimens was measured with an electric resistance moisture meter.

4 cycles were simulated: “cold” - samples frozen in air at -25 °C, “dry” - samples kept at 40 °C at 40 % relative humidity, “wet” - samples irrigated at 20 °C at 85 % humidity and “extreme” - the samples were soaked in water at 20 °C, frozen in air at -25 °C and dried at 40 °C and 40 % relative humidity.

Before carrying out the research study, all specimens were conditioned in a climatic chamber for a total of fourteen days at 20 °C and with a relative air

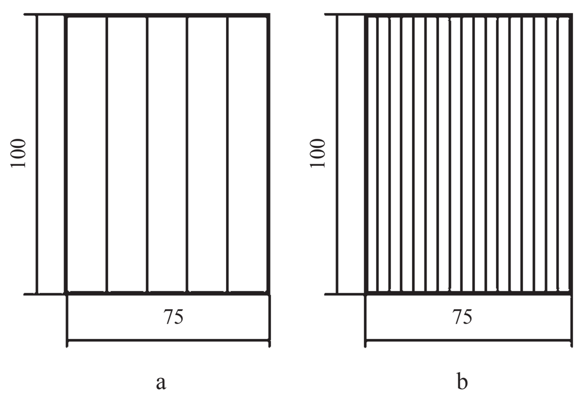

Figure 1 A schematic of specimen cross-sections: a) oak and pine glulam beams; b) LVL beams
Slika 1. Shema poprečnog presjeka uzoraka: a) lamelirani nosači od hrastovine i borovine; b) nosači od lamelirane furnirske građe

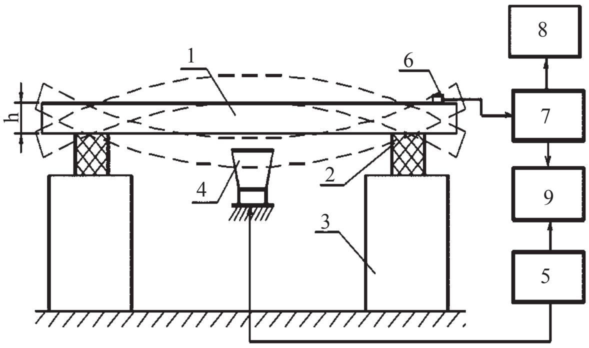

Figure 2 Scheme of the test stand:1 - specimen; 2 - vibration damping material (foam rubber); 3 - massive supports; 4 - loudspeaker; 5 - vibration generator; 6 - sensor; 7 - measuring instrument; 8 - oscilloscope; 9 - phase meter

Slika 2. Shema ispitnog postolja: 1 – uzorak; 2 – materijal za prigušivanje vibracija (spužvasta guma); 3 – masivni nosači; 4 – zvučnik; 5 – generator vibracija; 6 – senzor; 7 – mjerni uređaj; 8 – osciloskop; 9 – mjerač faze

humidity of 60 %. After completing the conditioning process, the moisture content of the specimens was measured at between 11.0-12.5 %.

The special test stand (Figure 2) was used to determine the *MOE* and the coefficient of damping on the basis of the non-destructive testing (transverse resonant vibrations) method, which also allowed assessing the mechanical properties of the specimens (Albrektas and Vobolis, 2003; Albrektas and Vobolis, 2004; Timoshenko *et al*., 1985). The studies were performed at a frequency of 20-2000 Hz.

The *MOE* was calculated based on the following Eq. 1 (Timoshenko *et al*., 1985):

$$E = \frac{f_{\text{rez}}^2 \cdot 4 \cdot \pi^2 \cdot \rho \cdot s \cdot l^4}{I \cdot A^2} \qquad (1)$$

Where: E–modulus of elasticity, f_{rez} – frequency of transverse vibrations, ρ –density of wood, s – cross-sectional area, l – beam length, I – cross-sectional moment of inertia, A – method of fastening represented by a coefficient

The viscous properties of studied specimens were evaluated based on the following Eq. 2

$$tg\delta \approx \frac{\Delta f}{f_{\text{rez}}} \qquad (2)$$

Where: f_{rez}– frequency of transverse vibrations, Δf – frequency bandwidth when amplitude of vibrations decreases by 0.7 times.

The *MOE* and the coefficient of damping for each specimen were determined in two directions: with the glue joints on the specimens orientated as shown in Figure 1 and the specimen turned at an angle of 90°. For example, the oak glulam beam that falls within code 'O1', should be coded 'O1.1' when placed on a test stand as shown in Figure 1, and 'O1.2' when turned at an angle of 90°. The average values for all ten oak timber beams are marked as 'OX.1' and 'OX.2', respectively. Meanwhile, the groups into which the pine glulam beams have been organised are marked as 'PX.1' and 'PX.2', respectively, and the LVL specimens are marked as 'LX.1' and 'LX.2', respectively.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The measurements for the *MOE* and the coefficient of damping for the specimens was carried out after completing the conditioning process. These values are displayed in Table 1.

It was estimated that the *MOE* of oak glulam beams altered within the limits of 11500-14200 MPa, and for pine glulam beams it was within the limits of 11000-13400 MPa, while the LVL altered within the limits of 12900-14900 MPa. The coefficient of damping for all specimens remained within the limits of 0.0085-0.0145 r.u. These values correspond to the values that are given in the available literature (Albrektas and Vobolis, 2003; Wagenführ, 2000; Wood Handbook, 2010; Albrektas *et al*., 2019).

It should be noted that the *MOE* of the LVL specimens is slightly higher, although it corresponds to the *MOE* of natural wood. In addition, having carried out a statistical analysis of the *MOE* and coefficient of damping values for each group, it was found that the coefficient of variation for the *MOE* values in the LVL specimens was approximately 2 %, and the coefficient of variation of the coefficient of damping was approximately 5 %. These coefficients of variation for oak and pine specimens altered within the limits of 6-8 %.

In order to simulate the various operating conditions of their structures, the specimens underwent a freezing phase at -25 °C and were observed for changes in their mechanical properties. Variations in the *MOE* are displayed in Figure 3.

The results show that, during a freezing phase, the *MOE* increased for all specimens. The most significant increase was recorded after the first seven days. For the oak specimens the increase amounted to 1.5 %, for the pine specimens it was 4.9 %, and for the LVL specimens it was 5.5 %. After a period of 21 days, the *MOE* for the oak specimens increased by 3.1 %, for the pine specimens by 5.5 %, and for the LVL by 6.6 % in comparison to the original value. In all cases the increase in the *MOE* for group '1' is higher than that of

Table 1 Average values for *MOE* and coefficient of damping for specimens
Tablica 1. Srednje vrijednosti *MOE*-a i koeficijenta prigušenja za ispitivane uzorke

Group of specimens	Oak / *Hrastovina*		Pine / *Borovina*		LVL	
Grupa uzoraka	*MOE*, MPa	Coef. of damping, r.u. *Koeficijent prigušenja, r.u.*	*MOE*, MPa	Coef. of damping, r.u. *Koeficijent prigušenja, r.u.*	*MOE*, MPa	Coef. of damping, r.u. *Koeficijent prigušenja, r.u.*
X1	12420	0.0100	11530	0.0115	14510	0.0113
X2	13470	0.0121	12110	0.0110	13160	0.0118

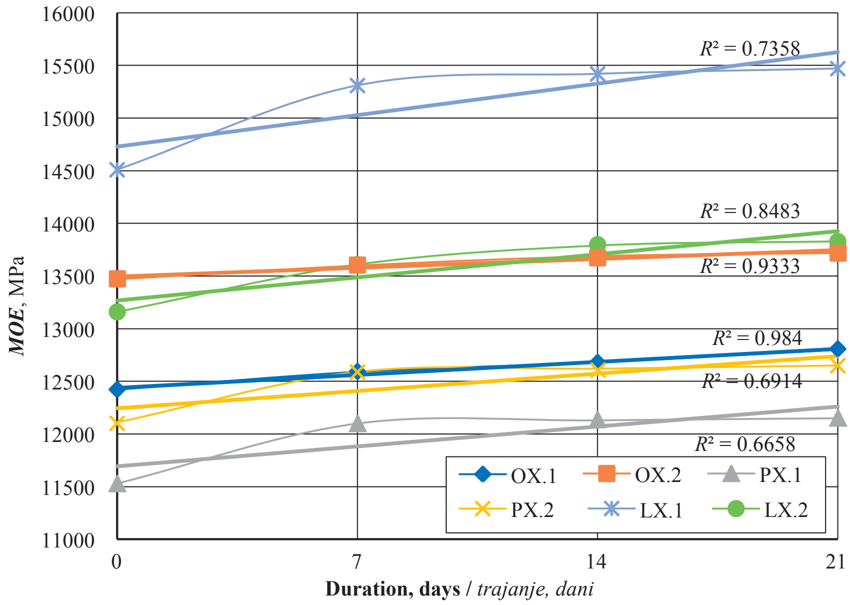

Figure 3 Variations of *MOE* in specimens during a freezing phase
Slika 3. Varijacije *MOE*-a na uzorcima tijekom faze smrzavanja

group '2'. This can be explained by the fact that, just as with the timber, the glue becomes stiffer at lower temperatures and, with its existing orientation, the influence of glue on the entire composite is greater, although its *MOE* is significantly lower (Konnerth *et al*., 2006; Stoeckel *et al*., 2013). Similar results were obtained for other glued timber materials (Ayrilmis *et al*., 2010).

The viscous properties of the specimens also altered during the freezing phase. The variations in the coefficient of damping are shown in Figure 4.

It is clear that the coefficient of damping for all specimens tended to decrease during the freezing phase, i.e. the specimens lost plasticity. The most significant decrease was recorded after the first seven days. The most significant decrease in the coefficient of damping was observed in pine specimens (with an average decrease of 17.4 %), while the least significant decrease was observed in the LVL specimens (at an average of 7.1 %). During further freezing, the coefficient of damping decreased less. For pine specimens, it decreased by an average of 20.0 %, for oak specimens by an average of 16.5 %, and for the LVL specimens by an average of 10.6 %. Unlike the *MOE*, the coefficient of damping in oak and pine specimens was particularly unaffected by the orientation of the glue joint. For the LVL specimens alone, the average coefficient of damping of group '1' specimens decreased by 10.6 %, and by 5.1 % for the specimens in group '2'.

Afterwards, the specimens underwent a drying phase at 40 °C, at 40 % relative air humidity, and with about 1 m/s forced circulation. During the drying process, the mass of the specimens decreased by between

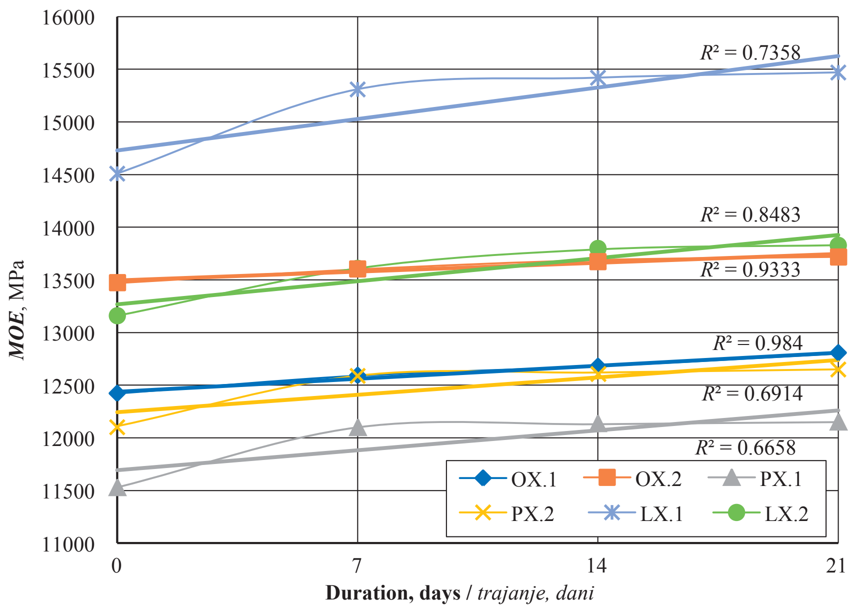

Figure 4 Variations in coefficient of damping for specimens during the freezing phase
Slika 4. Varijacije koeficijenta prigušenja na uzorcima tijekom faze smrzavanja

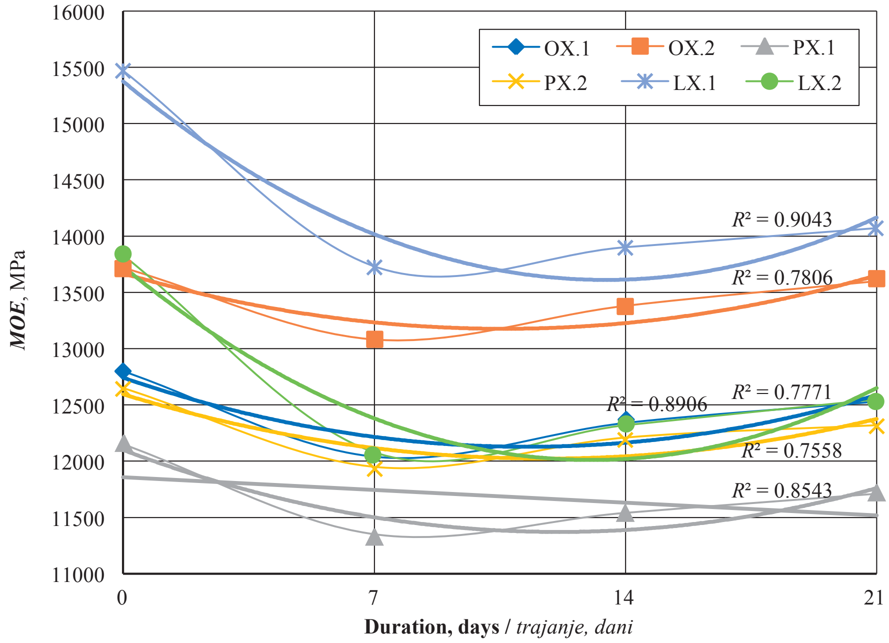

Figure 5 Variations in *MOE* for specimens during the drying phase
Slika 5. Varijacije *MOE*-a na uzorcima tijekom faze sušenja

54-98 g per week. The variations in the *MOE* for the specimens are shown in Figure 5.

It was established that, at the beginning of the drying phase (after the first seven days), the *MOE* for the specimens decreased (by 5.9 % for oak specimens, 6.6 % for pine specimens, and 12.7 % for LVL specimens). This could be explained by the fact that the moisture content decreased by an insignificant level during the first seven days (the specimen mass decreased on average by about 52 g and the average moisture content decreased by about 1.0-1.2 %); however, the timber warmed up and became more flexible. Later, during the drying process, the mass of the specimen decreased, and the *MOE* increased at a similar rate. When compared to the *MOE* of the frozen specimens before drying, after a period of 21 days the average *MOE* for the oak specimens decreased by 2.1 %, for the pine specimens by 3.6 %, while the LVL specimens decreased by 9.3 %. In this case the orientation of the glue joint did not have any significant impact (the difference did not exceed 1 %).

The variation in the coefficient of damping during the drying process is shown in Figure 6.

The results show that, after the first seven days of drying, the coefficient of damping for all specimens increased (by 13 % for the pine and the LVL specimens, and by 9 % for the oak specimens); this was due to the

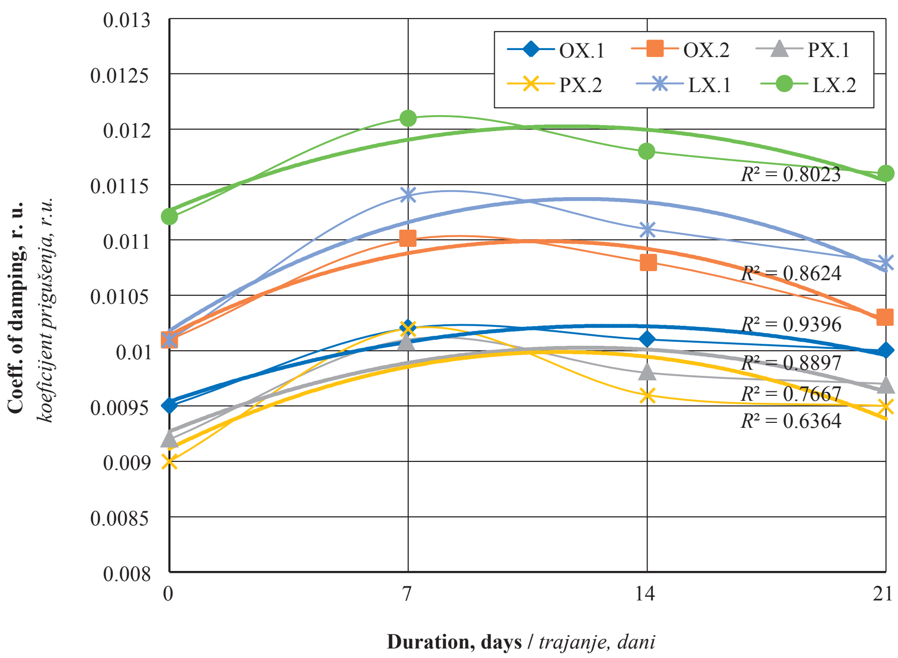

Figure 6 Variation in coefficient of damping for specimens during the drying process
Slika 6. Varijacije koeficijenta prigušenja na uzorcima tijekom faze sušenja

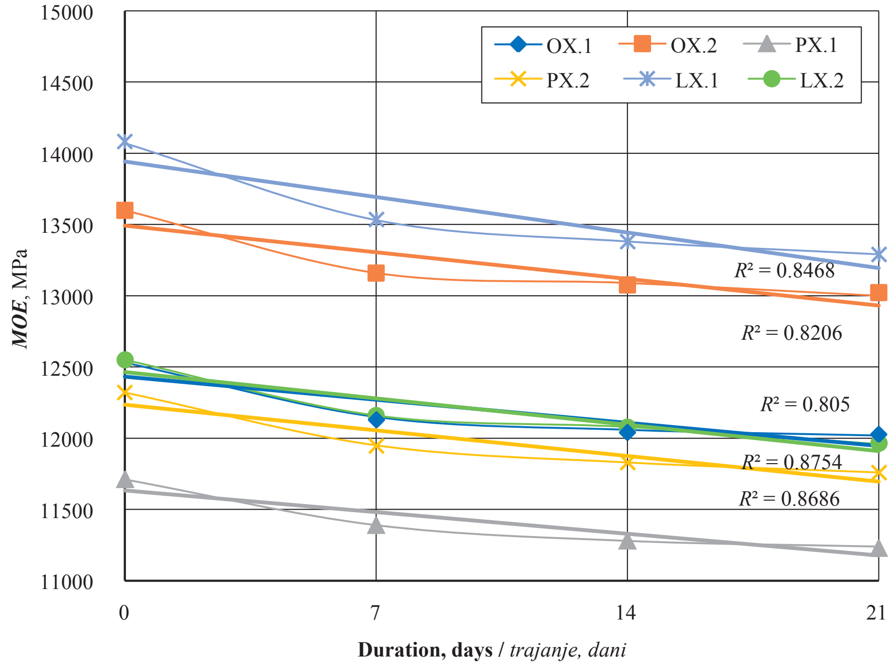

Figure 7 Variation in *MOE* of specimens during the wetting process
Slika 7. Varijacije *MOE*-a na uzorcima tijekom faze vlaženja

fact that the timber warmed up and became more flexible. During further drying, the coefficient of damping decreased by an insignificant amount. When compared to the primary coefficient of damping (after freezing), the coefficient of damping for all specimens, which were dried for 21 days, managed to increase by between 2.0-6.9 %.

The specimens were dampened in a climate chamber at 20 °C and at a relative air humidity of 85 %. The variation in the *MOE* during the wetting process is shown in Figure 7.

It was found that the *MOE* for all specimens decreased by an insignificant amount during the wetting process. The greatest decrease in the *MOE* was observed in the LX.1 specimen group (by an average of 3.8 % during the first seven days and by an average of 5.5 % during a period of 21 days). Variations for other groups of specimens were found to be 3.0 % and between 4.0-4.7 %, respectively. The differences are very small (the mass of the specimens pretty much increased in an identical manner); therefore it can be stated that the humid air had an equal effect on the elastic properties of all of the specimens. The variations in viscous properties (the coefficient of damping) are shown in Figure 8.

It was established that the coefficient of damping for the specimens increased during the wetting process.

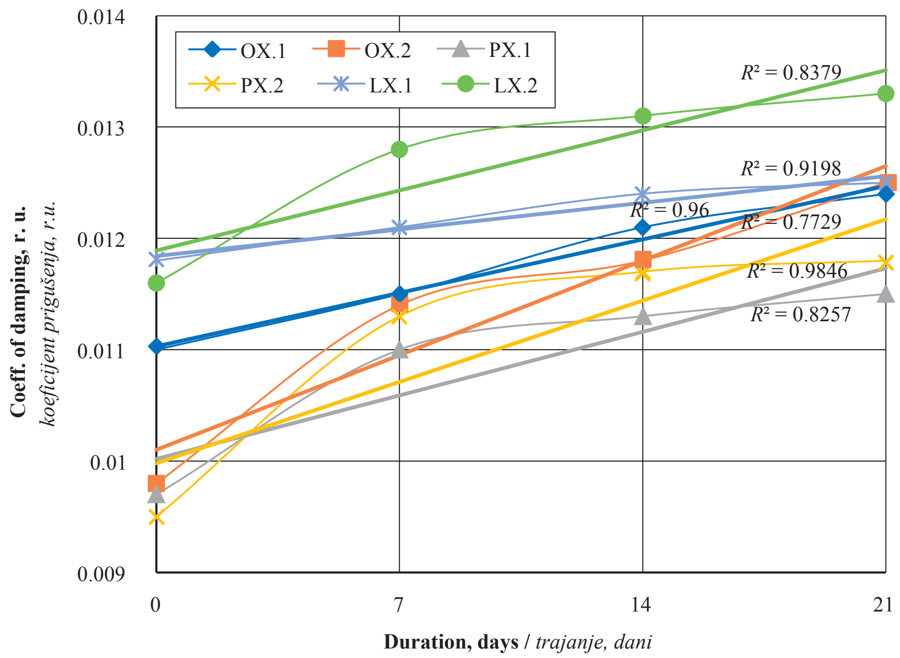

Figure 8 Variations in coefficient of damping for specimens during the wetting process
Slika 8. Varijacije koeficijenta prigušenja na uzorcima tijekom faze vlaženja

The highest growth levels were observed during the first seven days (for all groups of specimens the coefficient of damping increased by between 10-19 %). The lowest growth in coefficient of damping after 21 days was observed for the LVL specimens (14.7 % and 15.7 %, respectively, for individual groups). The average growth of the coefficient of damping in the oak specimens was at 21.4 % and 24.0 %, respectively, whereas the coefficient of damping for the pine specimens was at 18.6 % and 24.2 %. It is likely that the slightly different behaviour of the LVL specimens was prompted by the relatively large number of glue joints, which ensured a more uniform structure in the entire specimen.

The specimens were then immersed in water at a temperature of 20 °C and were then stored for a period of fourteen days; then they were removed from the water and stored at -25 °C for fourteen days; subsequently they were dried at 40 °C for fourteen days with a relative air humidity of 40 % and forced air circulation. This was done in order to intentionally cause defects in the specimens.

Pictures of several specimens after the immersion/freezing/drying process are shown in Figure 9.

It is evident that the drastic environmental impact in most cases caused a serious level of damage to the glulam specimens tested. Clearly-visible cracks emerged when exposed to sources of tension. Visually significant defects were not observed in the LVL specimens. In most cases there were shallow cracks (single-layer thickness) that became visible on the face. Small peelings on the cross section were also observed.

Table 2 shows the values for the mechanical properties of the specimens following the conditioning process (initial) and after the immersion/freezing/drying process (final).

It was established that the extreme humidity and temperature fluctuations had a significant impact on the specimens. The results show that the cracks that appeared resulted in a decrease in the *MOE* of glulam beams by between 13-16 %, while for the LVL specimens this value was a little lower at around 10 %. However, the coefficient of damping for the specimens changed much more significantly. The uniform struc-

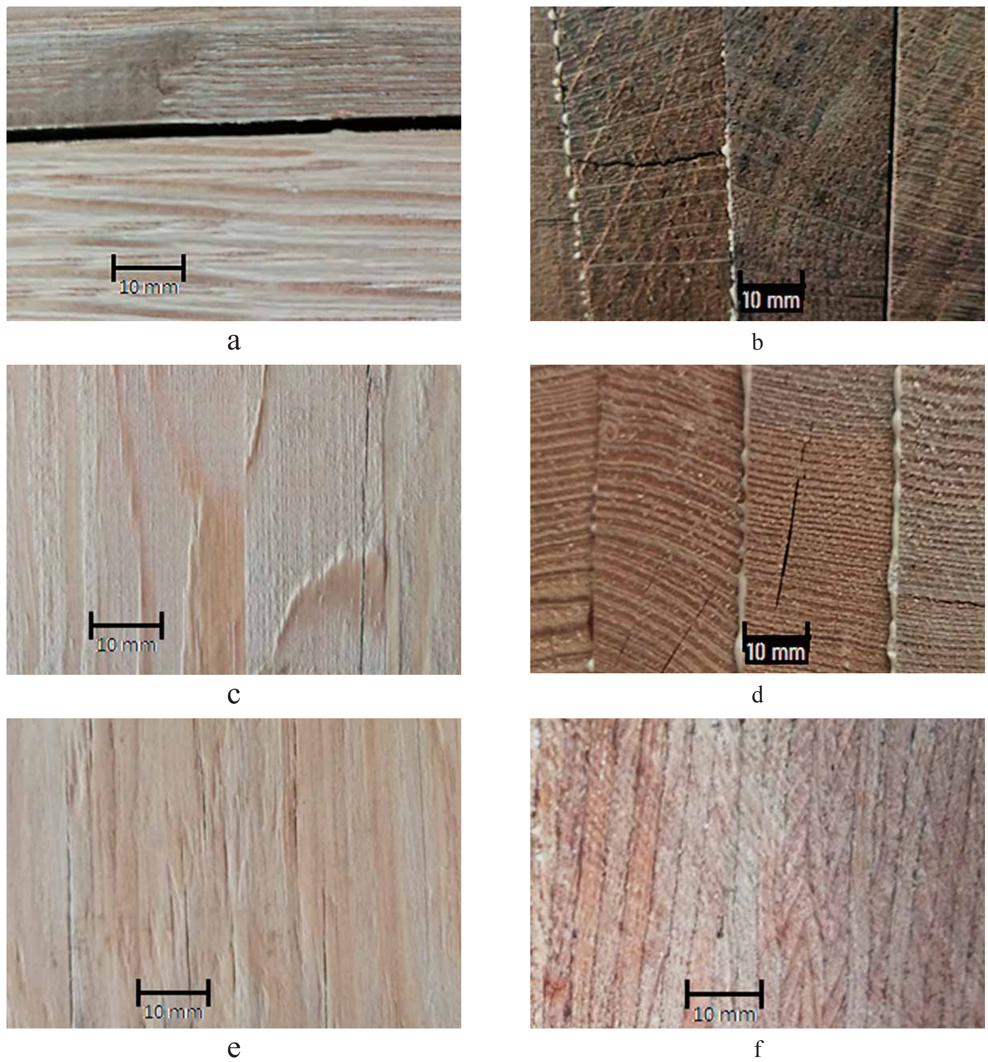

Figure 9 Examples of typical defects in specimens: a) face of oak specimen; b) cross section of oak specimen; c) face of pine specimen; d) cross section of pine specimen; e) face of LVL specimen; and f) cross section of LVL specimen
Slika 9. Primjeri tipičnih grešaka na uzorcima: a) lice uzoraka hrastovine; b) poprečni presjek uzoraka hrastovine; c) lice uzoraka borovine; d) poprečni presjek uzoraka borovine; e) lice LVL uzoraka; f) poprečni presjek LVL uzoraka

Table 2 Changes in mechanical properties after immersion/freezing/drying process
Tablica 2. Promjene mehaničkih svojstava nakon procesa potapanja, smrzavanja i sušenja

Group *Grupe*	***MOE***, MPa		**Difference**, MPa/% *Razlika,* MPa/%		**Coefficient of damping, r.u.** *Koeficijent prigušenja, r.u.*		**Difference, r.u./%** *Razlika, r.u./%*	
	Initial / *Početno*	**Final** / *Završno*			**Initial** /*Početno*	**Final** / *Završno*		
OX.1	12420	10510	1910	15.4	0.0110	0.0168	0.0058	52.7
OX.2	13470	11680	1790	13.3	0.0121	0.0179	0.0058	47.9
PX.1	11530	9980	1550	13.4	0.0115	0.0173	0.0058	50.4
PX.2	12110	10350	1760	14.5	0.0110	0.0167	0.0057	51.8
LX.1	14510	13030	1480	10.2	0.0113	0.0185	0.0072	63.7
LX.2	13160	11790	1370	10.4	0.0118	0.0196	0.0078	66.1

ture of the specimens was destroyed, causing the specimen that underwent vibration treatment to behave like a system involving several bodies rather than as a single body. The coefficient of damping for the natural timber specimens increased by about 50 % and the one for the LVL specimens increased even more.

All of the results were statistically processed. The coefficient of variation for the *MOE* and the coefficient of damping for different groups after each test cycle did not exceed 9.6 % (Pekarskas, 2007).

4 CONCLUSIONS
4. ZAKLJUČAK

It was established that, due to different mechanical properties of timber in different directions (perpendicular and parallel to the positioning directions of the joints), the same glulam beam had different mechanical properties. This difference for individual glulam beams was up to 4.8 %.

During freezing process, the dry glulam beams (at between 11.0-12.5 %) become more elastic. This is shown by the *MOE* which increased by 6.6 % and by the coefficient of damping which decreased by 20.0 %.

After starting the drying process in frozen specimens, during the first seven days their moisture content decreased by an insignificant amount (by 1.2 %). However, the timber warmed up and became more flexible. Therefore, during the period of seven days of drying, the *MOE* decreased by 12.7 %, whereas the coefficient of damping increased by 13.0 %.

As the moisture content of glulam beams decreases, its *MOE* increases and the coefficient of damping decreases (with a moisture content reduction of about 3 % the *MOE* increased by an average of between 2.8-3.2 %, whereas the coefficient of damping decreased by between 2.3-8.5 %).

During the process of wetting, glulam specimens in the air had a moisture content that increased by an average of between 3.0-4.0 %, while their *MOE* decreased by 5.5 %, and the coefficient of damping increased by 24.2 %. This is mainly due to the increase in surface humidity and plasticity.

Coefficient of damping for the LVL specimens increased the least only during the wetting process (on average by 15.7 %). It is likely that the slightly different behaviour of the LVL specimens was prompted by the relatively large number of glue joints, which ensured a more uniform structure in the entire specimen.

Freezing wet glulam specimens and their subsequent drying (which served to cause the defects) showed the lowest levels of deterioration in LVL elastic properties (by an average of 10.4 %); however, the viscous properties increased significantly (the coefficient of damping increased by 66.1 %).

In general it can be stated that the glulam beams and the LVL beams reacted similarly to changing environmental conditions.

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The Relationship between Roughness of Finished Wood Floors and Slip Resistance

Odnos između hrapavosti i klizavosti površinski obrađenih drvenih podova

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ABSTRACT • *The present study investigates the relationship between the roughness of beech wood and oak wood surfaces treated with oil and polyurethane coating and the slip resistance in dry, water-wet and oily conditions. Pendulum tests were conducted for slip resistance assessment, and roughness measurements were performed by stylus instrument using R_a, R_t, R_p, R_z and R_{sm} parameters for surface roughness evaluation. Slip potential in dry conditions was low for all finished wood floors studied. Contamination of the surface with water and oil reduced the slip resistance of finished oak and beech flooring. The strong negative correlation was found between slip resistance on dry finished flooring and roughness parameters R_a, R_z, R_t and R_p, and positive correlation between slip resistance on water-wet finished flooring and roughness parameters R_a, R_z, R_t and R_p. Moreover, the correlations between roughness parameters R_a, R_t, R_p and R_z and slip resistance were very similar, and the roughness parameters correlated more strongly with the slip resistance on dry and water-wet surfaces than with the slip resistance on oil-wet surface. Comparison of the slip potential classifications of finished wood floors based on pendulum data and based on R_z surface roughness parameters showed that in some cases the R_z parameter appeared to overestimate the slip potential of the floors in wet conditions. The results confirm previous research that roughness measurements should only be used as a guide and should not be used as the only indicator of the slip potential of wood flooring materials.*

Keywords: *slip resistance; surface roughness; finished wood floors; surface roughness parameters*

SAŽETAK • *U radu je istraživan odnos između hrapavosti bukovine i hrastovine površinski obrađenih uljem i poliuretanskim lakom i klizavosti suhe površine te površine na koju su se prolili voda i ulje. Klizavost površine određena je klatnom, a hrapavost joj je izmjerena kontaktnim uređajem uz pomoć parametara R_a, R_t, R_p, R_z i R_{sm} za procjenu hrapavosti. Vjerojatnost poskliznuća u suhim uvjetima za sve je ispitivane drvene podove bila niska. Vlaženje površine vodom i uljem smanjilo je otpornost na klizanje površinski obrađenih podova od hrastovine i bukovine. Utvrđena je velika negativna korelacija između otpornosti na klizanje na suhoj površini drvenih podova i parametara hrapavosti R_a, R_z, R_t i R_p te pozitivna korelacija između otpornosti na klizanje na podovima zalivenim vodom i parametara hrapavosti R_a, R_z, R_t i R_p. Nadalje, korelacije između parametara hrapavosti R_a, R_t, R_p i R_z i otpornosti na klizanje bile su vrlo slične. Parametri hrapavosti jače su korelirali s otpornošću na klizanje na suhim površinama i površinama zalivenim vodom nego s otpornošću na klizanje na površinama zalivenim uljem. Usporedba razredbi vjerojatnosti poskliznuća na površinski obrađenim drvenim podovima dobivena klatnom i na temelju parametra hrapavosti površine R_z pokazala je da je u nekim slučajevima parametar R_z dao precijenjenu*

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vjerojatnost poskliznuća na podovima u mokrim uvjetima. Rezultati potvrđuju prethodna istraživanja prema kojima mjerenja hrapavosti trebaju služiti samo kao vodilja i ne smiju se primjenjivati kao jedini pokazatelj klizavosti drvenih podnih materijala.

Ključne riječi: *klizavost; hrapavost površine; površinski obrađeni drvni podovi; parametri hrapavosti površine*

1 INTRODUCTION
1. UVOD

Slip resistance is an important feature of floor safety and can be defined as the ability of a surface to substantially reduce or prevent the risk of someone slipping (CCAA, 2003). Slip resistance is very complex because the likelihood of slipping is a function of many factors such as floor surface, footwear, environmental conditions, physical condition, etc. Falling mainly happens due to insufficient friction between the shoe sole and the floor, and the coefficient of friction (*COF*) is commonly accepted as an indicator of floor surface slipperiness level. The higher the *COF* is, the higher the degree of anti-slippery (slip resistance effect) will be (Chen *et al*., 2015). According to literature, factors affecting the results of friction measurement are floor materials, floor roughness, liquid/solid contaminants on floor, the groove design of shoes and the friction measurement device used (Liu *et al*., 2010; Chen *et al*., 2015). There is no generally accepted method of measuring slipperiness.

The Pendulum Tester is the most widely used for measuring the slip resistance of floorings. The device relies on the measurement of the coefficient of friction between a rubber slider and the flooring to assess the resistance to slip (Mijović *et al*., 2008). This method is used in the standard HRN EN 13036-4:2012 and also in Technical Specification HRS CEN/TS 15676:2010 for determining slip resistance of wood flooring.

It has been shown that the coefficient of friction between the shoe sole and the floor is highly dependent on the roughness of the floor surface (Stevenson *et al*., 1989; Chang *et al*., 2001; Li *et al*., 2004).

Chen *et al.* (2015) reported that shoe materials, floor roughness and liquid viscosity significantly affected slip resistance. Various surface roughness parameters were used in scientific papers to determine the relationship between the roughness of the surface and slip resistance.

Stevenson *et al.* (1989) reported that slip resistance of concrete and steel surfaces measured with dynamic friction testing machine increased with the arithmetical average of roughness (Ra).

Good correlation between dynamic friction and roughness parameter R_{pm} of unglazed quarry tiles surfaces was reported by Chang (1998). Chang (1999) used different slipmeters for investigation relationship among slip resistance of unglazed quarry tile, surface roughness and surface conditions. It has been shown that the effect of surface roughness on friction index depended on the slipmeter used, and that rougher surface generally led to a higher friction index. Among 21 evaluated surface roughness parameters, R_{pk} and R_{pm} parameters had the highest correlation with the measured friction indices for wet surfaces and parameters R_a and R_z for dry surfaces. Kim (2018) conducted dynamic friction tests among three shoes and nine floor specimens under different slippery environments and showed significant effects of floor surface roughness parameters (R_a, R_t, R_{tm}) on slip resistance performance under soapy and oily conditions. Li *et al*. (2004) found very high correlation (r=0.932 to 0.99) between the four roughness parameters (R_a, R_{tm}, R_{pm}, R_q) of five floors and the measured coefficient of friction under wet and water-detergent conditions.

Shaw (2007) reported moderate correlation between the roughness parameters R_p, R_t, R_q, R_a, R_z and R_y and wet *PTV* (Pendulum Test Value, closely related to coefficient of dynamic friction) and strong correlation between a particular combination of parameters (R_p */RS*) and wet pendulum values on a small sample of data from a range of different floor surfaces. This study was extended to over 100 floor samples and it was established that R_p (height of the roughness peak) roughness parameter formed the strongest relationship between any single parameter and wet pendulum values. A strong relationship between wet *PTV* and R_p */RS* was confirmed with a larger sample of data (Shaw *et al*., 2009). Surface roughness measurements are widely used as a secondary indication of slip resistance potential.

According to UK Health and Safety Executive (HSE- GEIS2, 2012) and Health and Safety Laboratory (HSL), R_z (R_{tm}) is a useful parameter for the prediction of the likely slip resistance of a flooring material under water (and other fluid) contamination.

There have been very limited studies of the effects of wood floor roughness on slip resistance. It has been shown that the relationship between surface micro roughness and slip resistance of the pre-engineered wood floors is complicated and, in some cases, there was disagreement between surface roughness and pendulum results (Loo-Morrey, 2007).

The aim of this paper is to investigate the relationship between the roughness of different wood surfaces treated with oil and polyurethane coating and the slip resistance in dry and water-wet and oily conditions.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Radial-textured and tangential-textured samples of oak (*Quercus robur* L.) and beech wood (*Fagus sylvatica* L.) without visible defects were used in this research. Beech and oak are the most common wood species in the production of wooden floors. Before surface finishing, wood samples were conditioned at (23±2) °C and (50±5) % relative humidity (RH) to the constant mass. Wood samples were finished with two-component, solvent-based polyurethane coating (PU) and two-component oil based on isocyanates. Before applying PU coating, wood samples were hand-sanded with paper grit size P80-P120-P180 and wood samples finished with oil were hand-sanded with paper grit size P120. For each type of coating, six samples (three radial-textured and three tangential-textured) were prepared. Coatings were applied with a brush in the amount of 110 g/m^2 for PU coating and 80 g/m^2 for oil per layer. PU coating was applied in three layers (one layer of base coat and two layers of top coat) with a 4 hours drying time between the base and top coat and 24 hours drying time between layers of top coat. The dried base coat was hand-sanded with paper grit size P240. Oil was applied in one coat with wiping excess oil from the wood surface after 15 minutes of application of the oil. Surface finished samples were conditioned for seven days at (23±2) °C and (50±5) % RH before testing of slip resistance and roughness.

2.2 Slip resistance
2.2. Klizavost

The slip resistance measurement was made using pendulum test equipment (Figure 1) and slider 55 on a dry surface, surface contaminated with distilled water and on surface contaminated with linseed oil according to HRS CEN/TS 15676:2010. For each type of wood texture, surface finishing and surface contamination, ten measurements on different places along the grain on the wood surface were made, and average slip resistance was calculated. For measuring slip resistance on wet surface, each measuring place on the sample was moistened evenly with the test fluid and rubber slider was wiped and cleaned after each measurement.

2.3 Surface roughness
2.3. Hrapavost površine

Three samples for each type of wood species, texture and coating were evaluated. Roughness was measured with Surtronic S-126 stylus-type profilometer (Figure 2) manufactured by Taylor-Hobson on ten marked locations on which the slip resistance of the surface was measured. The measuring speed, radius and angle of conical stylus tip were 1 mm/s, 5 mm and 90°, respectively. Roughness measurement was carried out in the direction perpendicular to the wood grain over traverse of 4 mm and roughness profiles were filtered with a cut-off value of 0.8 mm using Gaussian filter. For the evaluation of surface roughness, five parameters were used: R_a, R_t, R_p, R_z and R_{sm}. Definition of used roughness parameters can be seen in Table 1.

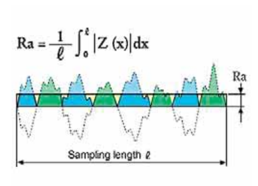
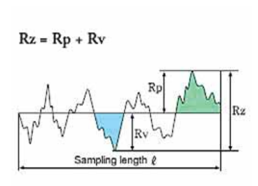
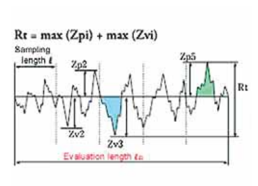
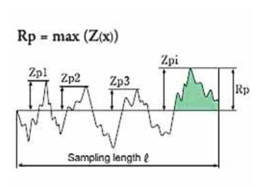
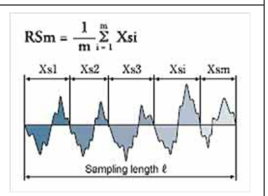
Figure 1 Pendulum test equipment for slip resistance measurement
Slika 1. Uređaj s klatnom za mjerenje klizavosti

Figure 2 Surtronic S-126 stylus-type profilometer
Slika 2. Profilometar Surtronic S-126

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Results of slip resistance of oak and beech wood samples were generally referred to the slip resistance of the coating on the wood surface (Figure 3). It can be seen that the contamination of the surface with water and linseed oil reduced the slip resistance of finished oak and beech wood. The highest slip resistance was measured on dry surfaces, followed by water-wet surfaces and oil-wet surfaces. Lemon and Griffiths (1997) reported that liquids with higher viscosity required higher levels of surface roughness to provide equivalent levels of slip resistance, as the thickness of a squeezed film formed between the flooring and treads increased as liquids viscosity increased. Polyurethane coating eliminated the influence of structural unevenness of the wood surface on the slippage as it created a dry coating film on the surface. This is the reason for very small differences in slip resistance between oak and beech finished with PU coating. Furthermore, the structural unevenness of the wood surface became prominent on the oil-finished specimens because the oil did not form a film on the wood surface. Thus, the slip resistance of the water-wet surface was higher on the oil-finished samples than on the PU-finished samples. However, the slip resistance on a dry surface was higher on PU-finished samples than on oil-finished samples, which can be attributed to the additives for slip resistance in the coating. Furthermore, oil-finished samples showed a greater difference between slip resistance of water-wet and oil-wet surfaces than PU-finished samples. This could be due to raised wood fibers due to wetting of the surface with water. This is also the reason why the slip resistance of oil-finished beech wood samples contaminated with water was greater than the slip resistance of oil-finished oak wood sam-

Table 1 Description of roughness parameters used in this research according to ISO 4287: 1997
Tablica 1. Definicije parametara hrapavosti primijenjenih u istraživanju prema ISO 4287: 1997

Roughness parameter *Parametar hrapavosti*		**Description** *Definicija*	
R_a	Arithmetical mean deviation of the roughness profile *aritmetičko srednje odstupanje profila hrapavosti*	Arithmetic mean of the absolute ordinate values Z(x) within a sampling length *aritmetička sredina apsolutne vrijednosti ordinate Z(x) unutar referentne duljine*	
R_z	Maximum height of the roughness profile *najveća visina profila hrapavosti*	Sum of height of the largest profile peak height Zp and the largest profile valley depth Zv within sampling length *zbroj visina najvišeg vrha profila Zp i najveće dubine profila Zv unutar referentne duljine*	
R_t	Total height of the roughness profile *ukupna visina profila hrapavosti*	Sum of height of the largest profile peak height Zp and the largest profile valley depth Zv within an evaluation length *zbroj najvišeg vrha profila Zp i najveće dubine profila Zv unutar duljine vrednovanja*	
R_p	Maximum profile peak height *najveća visina vrha profila*	Largest profile peak height Zp within a sampling length *najveća visina vrha profila Zp unutar referentne duljine*	
R_{Sm}	Mean width of profile elements of the roughness profile *srednja širina elemenata profila hrapavosti*	Mean value of the profile element widths Xs within a sampling length *srednja vrijednost širine elemenata profila Xs unutar referentne duljine*	

ples contaminated with water. Beech wood has a higher swelling coefficient than oak, so the fibers on beech wood are more raised than on oak wood. Differences in slip resistance due to the texture of wood were relatively small, and a greater difference in slip resistance between radial-textured and tangential-textured samples could only be seen on oil-wet surface of oak wood samples. It can be assumed that oil-wet surface of tan-

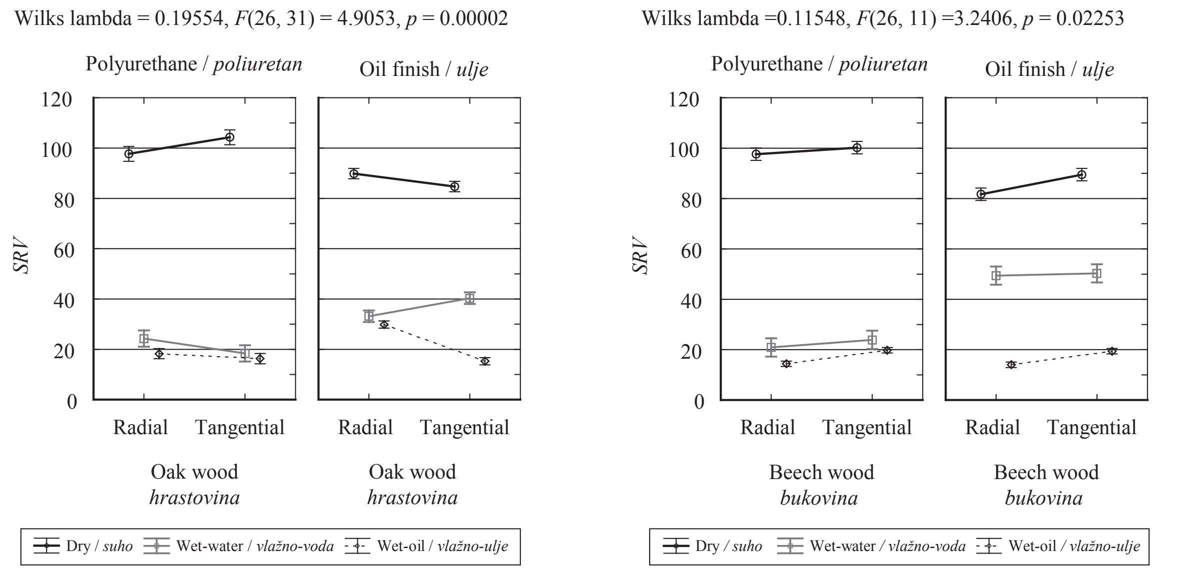


Figure 3 Slip resistance value (*SRV*) of oak and beech wood samples finished with polyurethane coatings and oil
Slika 3. Vrijednosti klizavosti (*SRV*) uzoraka bukovine i hrastovine površinski obrađenih poliuretanskim lakom i uljem

Table 2 Roughness parameters of surface finished oak and beech wood samples
Tablica 2. Parametri hrapavosti površinski obrađenih uzoraka hrastovine i bukovine

Sample / *Uzorak*	R_a, mm	R_z, mm	R_p, mm	R_t, mm	R_{sm}, mm
Oak-PU-radial / *hrastovina - PU - blistača*	0.4[a] (0,17)[b]	2.4 (0.73)	1.6 (0.42)	4.5 (2.05)	395.8 (244.31)
Oak-PU-tangential / *hrastovina - PU - bočnica*	0.3 (0.11)	2.0 (0.77)	1.2 (0.33)	3.7 (2.49)	267.9 (81.25)
Oak-PU-radial / *hrastovina - ulje - blistača*	4.7 (1.08)	26.2 (7.36)	11.3 (2.39)	48.9 (15.02)	177.3 (25.88)
Oak-PU-tangential / *hrastovina - ulje - bočnica*	3.4 (1.22)	19.7 (6.96)	8.5 (2.47)	28.3 (9.44)	159.1 (20.96)
Beech-PU-radial / *bukovina - PU - blistača*	0.4 (0.09)	2.1 (0.37)	1.2 (0.23)	2.9 (0.81)	270,4 (89.01)
Beech-PU-tangential / *bukovina - PU - bočnica*	0.3 (0.07)	2.1 (0.37)	1.2 (0.24)	3.4 (0.98)	235.1 (61.95)
Beech-PU-radial / *bukovina - ulje - blistača*	2.2 (0.38)	16.2 (2.53)	5.9 (1.10)	22.5 (3.9)	104.6 (16.31)
Beech-PU-tangential / *bukovina – ulje - bočnica*	3.9 (1.47)	23.7 (6.26)	9.6 (2.22)	32.7 (8.4)	124.7 (15.97)

[a] The mean value is the result of 30 measurements. / *Srednja vrijednost od 30 mjerenja.*
[b] Values in parentheses are standard deviations. / *U zagradama su standarne devijacije.*

gential-textured oak wood samples had a lower slip resistance compared to oil-wet surface of radial-textured wood samples due to a higher share of latewood, which has smaller pores compared to earlywood.

Table 2 shows the means and standard deviations of roughness measurements of the eight finished wood floor surfaces. For the R_a roughness parameter, there are no variations of means among different wood species finished with PU coating. The average R_a value of the oil finished radial oak wood surface is greater than the average R_a value of the oil finished beech wood surface, which can be explained by the differences in the anatomical structure of these two types of wood.

For R_z and R_t the differences between the oil finished surfaces and those finished with polyurethane are much greater. Since oil is a penetrating finish that does not form a film on the surface, the substrate itself greatly affects the results of roughness measurements. The results of measuring the roughness of radial and tangential surfaces differ much more for oil finished samples than for polyurethane finished samples. The average R_p values of the radial and tangential wood surfaces do not differ much for the surfaces finished with polyurethane coating, while for the oiled surfaces there is a difference in the values of R_p between the radial and tangential surfaces. It can be seen from Table 1 that the average R_{sm} values are much higher for polyurethane finished wood surfaces than for oil finished surfaces. Roughness parameter R_{sm} is the measure of the spacing between the peaks of the surface profile and the R_{sm} values are influenced by the thickness of the film, that is, the application of the polyurethane coating.

Spearman rank correlation coefficients between slip resistance and roughness parameters of surface finished beech and oak wood samples are presented in Tables 3 and 4. It can be seen that there is a significant negative correlation between slip resistance of a dry surface and the type of coating. This was expected because the PU coating forms a film on the wood surface, while the wood absorbs oil and thus the structure of the oil-finished wood surface also affects the slip resistance. Furthermore, a strongly negative correlation between slip resistance of dry surfaces of oak and beech wood and roughness parameters R_a, R_t, R_p and R_z was observed. However, the correlation of slip resistance of a dry surface with R_{sm} parameter was significant and negative and was higher on beech than on oak wood. This can be attributed to the higher standard deviation

Table 3 Spearman rank correlation coefficients between slip resistance and surface roughness of surface finished beech wood
Tablica 3. Spearmanov koeficijent korelacije između klizavosti i hrapavosti površinski obrađene bukovine

Variable *Varijabla*	**Texture** *Tekstura*	**Type of coating** *Vrsta premaza*	**SVR Dry** *SVR suho*	**SVR Wet-water** *SVR mokro - voda*	**SVR Wet-oil** *SVR mokro - ulje*	R_a	R_z	R_t	R_p	R_{Sm}
Texture / *tekstura*	1.000	0.000	0.298	0.126	0.864*	0.197	0.205	0.265	0.230	0.080
Type of coating *vrsta premaza*	0.000	1.000	-0.841*	0.868*	-0.020	0.874*	0.874*	0.868*	0.885*	-0.754*
SVR Dry *SVR suho*	0.298	-0.841*	1.000	-0.670*	0.316*	-0.639*	-0.646*	-0.638*	-0.606*	0.610*
SVR Wet-water *SVR mokro - voda*	0.126	0.868*	-0.670*	1.000	0.069	0.795*	0.789*	0.783*	0.760*	-0.585*
SVR Wet-oil *SVR mokro - ulje*	0.864*	-0.020	0.316*	0.069	1.000	0.134	0.126	0.202	0.178	0.016
R_a	0.197	0.874*	-0.639*	0.795*	0.134	1.000	0.980*	0.962*	0.943*	-0.509*
R_t	0.265	0.868*	-0.638*	0.782*	0.202	0.962*	0.976*	1.000	0.934*	-0.541*
R_p	0.230	0.885*	-0.606*	0.760*	0.178	0.943*	0.954*	0.934*	1.000	-0.606*
R_z	0.205	0.874*	-0.646*	0.789*	0.126	0.980*	1.000	0.976*	0.954*	-0.512*
R_{Sm}	0.080	-0.754*	0.601*	-0.585*	0.016	-0.509*	-0.512*	-0.541*	-0.606*	1.000

*Correlation is significant at p<0.05000. / *Korelacija je značajna pri p<0.05000.*

Table 4 Spearman rank correlation coefficients between slip resistance and surface roughness of surface finished oak wood
Tablica 4. Spearmanov koeficijent korelacije između klizavosti i hrapavosti površinski obrađene hrastovine

Variable *Varijabla*	**Texture** *Tekstura*	**Type of coating** *Vrsta premaza*	**SVR Dry** *SVR suho*	**SVR Wet-water** *SVR mokro - voda*	**SVR Wet-oil** *SVR mokro - ulje*	R_a	R_z	R_t	R_p	R_{Sm}
Texture / *tekstura*	1.000	0.000	-0.167	0.197	-0.732*	-0.092	-0.195	-0.069	-0.091	-0.128
Type of coating *vrsta premaza*	0.000	1.000	-0.757*	0.745*	0.288*	0.818*	0.817*	0.819*	0.818*	-0.432*
SVR Dry *SVR suho*	-0.167	-0.757*	1.000	-0.733*	-0.034	-0.603*	-0.513*	-0.616?	-0.579*	0.319*
SVR Wet-water *SVR mokro - voda*	0.197	0.745*	-0.733*	1.000	-0.027	0.567*	0.484*	0.578*	0.553*	-0.229
SVR Wet-oil *SVR mokro - ulje*	-0.732*	0.288*	-0.034	-0.027	1.000	0.365*	0.431*	0.334*	0.336*	0.076
R_a	-0.092	0.818*	-0.603*	0.567*	0.365*	1.000	0.945*	0.981*	0.988*	-0.162
R_t	-0.195	0.817*	-0.513*	0.484*	0.431*	0.945*	1.000	0.935*	0.954*	-0.240
R_p	-0.069	0.819*	-0.616*	0.578*	0.334*	0.981*	0.935*	1.000	0.981*	-0.184
R_z	-0.091	0.818*	-0.579*	0.553*	0.336*	0.988*	0.954*	0.981*	1.000	-0.198
R_{Sm}	-0.128	-0.432*	0.319*	-0.229	0.076	-0.162	-0.240	-0.184	-0.198	1.000

*Correlation is significant at $p<0.05000$. / *Korelacija je značajna pri* $p<0.05000$.

of roughness parameters R_{sm} on oak than on beech wood (Table 2).

Slip resistance of water-wet surface had a positive correlation with roughness parameters R_a, R_t, R_p and R_z on beech and oak wood, and this correlation was higher on beech than on oak wood. Furthermore, a significant negative correlation of slip resistance on water-wet surface and roughness parameter R_{sm} on beech wood was found, whereas on oak wood this correlation was not significant. It can also be seen that the correlation of slip resistance and roughness parameters R_a, R_t, R_p and R_z was higher on water-wet beech wood surface than on a dry surface. For slip resistance on oil-wet surface, no correlation was found with the investigated roughness parameters on beech wood, while on oak wood there was a small correlation between slip resistance on oil-wet surface and roughness parameters R_a, R_t, R_p and R_z. However, slip resistance on oil-wet surface was in a strong correlation with wood texture on beech and oak wood. The obtained correlation between the parameter R_a and the slip resistance on water-wet and oil-wet surfaces is less than the correlation obtained by Lie *et al*. (2004) on the ceramic floors.

According to the results shown in Table 3, it can be seen that the correlations between roughness parameters R_a, R_t, R_p and R_z and slip resistance are very similar and it can be said that no roughness parameter deviate. Furthermore, it can be seen that the roughness parameters correlated more strongly with the slip resistance on dry and water-wet surfaces than with the slip resistance on oil-wet surface.

The technical specification (HRN CEN/TS 1567) prescribes a pendulum test for determining slip resistance of wood flooring but does not provide slip resistance ratings (or does not provide interpretation of slip resistance data, or classification). The results of slip resistance measurements and R_z roughness measurements in this study were interpreted according to the UKSRG Guidelines (HSE-GEIS2, 2012). The interpretation of pendulum results is shown in Table 5 (HSE-GEIS2, 2012). According to UK Slip Resistance Group, Rz roughness parameter gives a good indication of floor slipperiness in water contaminated conditions. However, the roughness measurement should be considered as a complementary measurement to be used in conjunction with pendulum test values. Slip potential classification, based on R_z microroughness values, is shown in Table 6 (HSE-GEIS2, 2012).

Pendulum results on dry and wet wood surfaces and slip potential in dry and wet conditions are given in

Table 5 Slip potential classification, based on pendulum test value (PTV)[a] (HSE-GEIS2, 2012)
Tablica 5. Razradba vjerojatnosti poskliznuća na temelju ispitivanja klatnom (PTV)[a] (HSE-GEIS2, 2012.)

Pendulum test value *Vrijednosti klizavosti dobivene klatno*m	**Potential for slip** *Vjerojatnost poskliznuća*
24 and below	High / *velika*
25 to 35	Moderate / *umjerena*
36 and above	Low / *mala*

[a]Also known as slip resistance value (*SRV*) / *također poznata kao vrijednost otpora klizanju (SRV)*

Table 6 Slip potential classification, based on R_z microroughness values (applicable for water-wet pedestrian areas) (HSE-GEIS2, 2012)
Tablica 6. Razradba vjerojatnosti poskliznuća na temelju R_z vrijednosti mikrohrapavosti (odnosi se na vodom zalivene površine za hodanje) (HSE-GEIS2, 2012)

R_z (R_{tm}) surface roughness R_z (R_{tm}) *hrapavost površine*	**Potential for slip** *Vjerojatnost poskliznuća*
Below 10	High / *velika*
Between 10 and 20	Moderate / *umjerena*
Above 20	Low / *mala*

Table 7 Slip potential classification, based on pendulum test values (*PTV*)[a] and R_z microroughness values (applicable for water-wet pedestrian areas)
Tablica 7. Vjerojatnost poskliznuća prema testu klatnom (*PTV*)[a] i R_z vrijednosti mikrohrapavosti (odnosi se na vodom zalivene površine za hodanje)

Sample *Uzorak*	**Dry (*SRV*)** *Suho (SRV)*	**Slip potential** *Vjerojatnost poskliznuća*	**Water (*SRV*)** *Voda (SRV)*	**Slip potential** *Vjerojatnost poskliznuća*	**Oil** (*SRV*) *Ulje (SRV)*	**Slip potential** *Vjerojatnost poskliznuća*	**Roughness R_z, mm** *Hrapavost R_z, mm*	**Slip potential in wet-water predicted by R_z** *Vjerojatnost poskliznuća u mokrim uvjetima procijenjena na temelju parametra R_z*
Oak-PU-radial *hrastovina - PU - blistača*	97.7 (4.08)	Low *mala*	24.3 (6.23)	High *velika*	18.3 (2.45)	High *velika*	2.4 (0.73)	High *velika*
Oak-PU-tangential *hrastovina - PU - bočnica*	104.3 (4.29)	Low *mala*	18.4 (3.29)	High *velika*	16.3 (4.10)	High *velika*	2.0 (0.77)	High *velika*
Oak-PU-radial *hrastovina - ulje - blistača*	96.6 (5.5)	Low *mala*	28.1 (2.84)	Moderate *umjerena*	30.0 (3.44)	Moderate *umjerena*	26.2 (7.36)	Low *mala*
Oak-PU-tangential *hrastovina - ulje - bočnica*	85.2 (4.31)	Low *mala*	29.8 (1.94)	Moderate *umjerena*	14.0 (1.79)	High *velika*	19.7 (6.96)	Moderate *umjerena*
Beech-PU-radial *bukovina - PU - blistača*	97.6 (4.05)	Low *mala*	20.9 (6.93)	High *velika*	14.4 (1.20)	High *velika*	2.1 (0.37)	High *velika*
Beech-PU-tangential *bukovina - PU - bočnica*	100.2 (2.56)	Low *mala*	23.9 (6.88)	High *velika*	19.8 (1.78)	High *velika*	2.1 (0.37)	High *velika*
Beech-PU-radial *bukovina - ulje - blistača*	81.7 (4.56)	Low *mala*	49.4 (3.93)	Moderate *umjerena*	14.0 (1.79)	High *velika*	16.2 (2.53)	Moderate *umjerena*
Beech-PU-tangential *bukovina - ulje - bočnica*	89.5 (3.04)	Low *mala*	50.3 (2.05)	Moderate *umjerena*	19.4 (1.56)	High *velika*	23.7 (6.26)	Low *mala*

[a]Also known as slip resistance value (*SRV*) / *također poznata kao vrijednost otpora klizanju (SRV)*

Table 7. Mean average values of the R_z parameter and slip potential in water-wet conditions predicted by R_z parameter (according to UKSRG Guidelines) are also given in Table 7. It can be seen that slip potential in dry conditions was low for all studied finished wood floors. The oil-finished wood floors exhibited moderate slip potential in water-wet conditions, while PU-finished wood floors showed high slip potential in water-wet conditions. Kim (2018) showed that the floor finishes require different levels of surface roughness for different types of environmental conditions to effectively control slip potential. Slip potential in oily conditions was shown to be high for all finished wood surfaces except oiled oak wood radial surfaces, where slip resistance was shown to be moderate. Comparisons of the slip potential classifications of finished wood floors based on pendulum data and based on R_z surface roughness parameters show that in two cases the R_z parameter appears to overestimate the slip potential of the floors in wet conditions. This result, as well as results reported by Lo-Morrey (2007), indicates that the parameter R_z is not recommended as the sole selection criteria for selecting a new floor. The parameter R_z should be considered together with the pendulum measurements in both wet and dry conditions before making a specification decision.

4 CONCLUSIONS
4. ZAKLJUČAK

According to the results obtained in this study, it can be concluded that contamination of the surface with water and linseed oil reduces the slip resistance of finished oak and beech flooring. Furthermore, the viscosity of the contaminant has a greater effect on reducing the slip resistance on flooring finished with penetrating coating materials, while on flooring finished with film-forming coating materials, the viscosity of contaminant has little effect on changing the slip resistance. Based on the results of the roughness measurement, it can be concluded that the oil-finished surface has a greater influence on the roughness than the surface finished with polyurethane varnish. Moreover, the correlations between roughness parameters R_a, R_t, R_p and R_z and slip resistance are very similar and the roughness parameters correlate more strongly with the slip resistance on dry and water-wet surfaces than with the slip resistance on oil-wet surface. According to

HSE-GEIS2 (2012), the slip potential in dry conditions is low for oil and PU-finished wood floors, while the oil-finished wood floors exhibited moderate slip potential in water-wet conditions and PU-finished wood floors showed high slip potential in water-wet conditions. Furthermore, slip potential in oily conditions was shown to be high for all finished wood surfaces except oiled oak wood radial surfaces, where slip resistance was shown to be moderate. The slip potential based on R_z surface roughness parameter indicates that the parameter R_z should be considered together with the pendulum measurements in both wet and dry conditions before making a specification decision.

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Utjecaj parametara rezanja na kvalitetu površine bukovine

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ABSTRACT • *The main objective of this work was to evaluate the effects of flat slicing processes on wood surface characteristics of the European beech (Fagus sylvatica L.). The relation between wettability, roughness and machining methods were studied. Two different wood thickness (3.4 and 4.0 mm) and three levels of compression during slicing (67.5 %, 57.5 % and 47.5 % of desired veneer thickness) were used to prepare surfaces prior to testing. The smaller variation of the thickness of thinner veneers was observed. No significant impact of compression on variation of the thickness was found. The contact angle was lower when roughness measured parallel to the grain was higher. The influence of selected compression on roughness of European beech veneers measured perpendicular to the grain was confirmed. This indicated that the influence of the set of machining processes, such as pressure bar setting during slicing, is significant for wooden veneers surface properties.*

Keywords: *contact angles; wood wettability; European beech; slicing; pressure bar set*

SAŽETAK • *Glavni cilj rada bio je procijeniti učinke plošnog rezanja furnira na svojstva površine bukovine (Fagus sylvatica L.). Proučavan je odnos između kvašenja i hrapavosti bukovine i metoda rezanja furnira. Za pripremu površine za ispitivanja upotrijebljene su dvije različite debljine furnira (3,4 i 4,0 mm) i tri razine kompresije tijekom rezanja furnira (67,5, 57,5 i 47,5 % željene debljine furnira). Uočena su manja odstupanja debljine tanjih furnira. Nije utvrđen značajan utjecaj kompresije na varijacije debljine furnira. Kontaktni kut bio je manji kada je hrapavost paralelno s vlakancima drva bila veća. Potvrđen je utjecaj odabranog pritiska na hrapavost bukova furnira okomito na vlakanca drva. To je pokazalo da postavke procesa obrade, primjerice odabir pritiska tijekom rezanja, znatno utječu na svojstva površine furnira.*

Ključne riječi: *kontaktni kut; kvašenje drva; bukovina; rezanje; postavke pritiska*

1 INTRODUCTION
1. UVOD

According to the European Federation of the Parquet Industry, Poland is the leader in the production of flooring materials in Europe, reaching almost 17 % of the European production, which gives approx. 29.5 million m^2 of flooring produced each year. Most of manufactured floor materials are layered floorboards (EPLF/GFA, 2020). The significance of proper management of raw materials leads to savings and reducing of production costs and forced modification of current-

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ly used machining methods and development of new solutions, such as replacing flat-sawing by more efficient (chipless) technology like slicing. A well-planned production process can provide more proficient production by reducing the amount of waste. It is already known that slicing (or peeling) conditions clearly affect the process energy and forces as well as the quality of wood surface (Aguilera and Zamora, 2009; Aguilera and Muñoz, 2011; Thoma *et al.*, 2015). Thus, the effects of different surfacing methods are of great interest in order to improve the preparation of materials. In every industrial production process, the occurrence of faults in processing is unavoidable. However, in the context of technological requirements, if the quality deviations are within certain limit values, then the detail is considered to have been properly processed. However, it occurs that the dimensions of the detail are within the limit values, and the problem lies in the quality of the machined surface. This is partly due to the fact that mechanical treatments change the chemical and morphological characteristics of wood surfaces (Liptákova and Kúdela, 1994), with the types of machining along with the characteristics of the raw material, or a combination of both these parameters, determining the surface quality and influencing the cost (Kilic *et al.*, 2006; Mitchell and Lemaster, 2002).

In addition to the physical, mechanical, as well as the anatomical properties of wood, the surface quality of finished products is influenced by numerous factors such as: the direction of slicing, geometry of the blade and its sharpness, thickness of the cut part, any sharpening faults, as well as the technological parameters (speed of slicing, speed of movement, pressure bar settings, etc.) (Richter *et al.*, 1995; Hernández and Cool, 2008; Haouzali *et al.*, 2019). Surface properties are usually monitored in order to assess the quality of machining processes (Hernández and Cool, 2008). The surface roughness affects the wetting characteristics of materials, and the increase of surface roughness is associated with an increase of surface wettability. Surface roughness of veneer plays an important role in plywood manufacturing. Because of its effect on gluing and bonding characteristics, veneer surface roughness is an important factor in the production of glued timber products such as LVL (Dündar *et al.*, 2008). Moreover, desired surface roughness is strongly and directly linked to or influenced by the future use condition, making it crucial in flooring production, especially in case of glue laminated floorboards. An effective control of surface roughness is important in production processes related to the adhesive bonding of wood elements and the final processing of finished products (Lemaster *et al.*, 1982; Keturakis, 2007; Arnold, 2010; Thoma *et al.*, 2015). Relatively little research has been made concerning the effects of machining on the wetting characteristics of wood surfaces. Wood of deciduous porous structure has been tested more often (Gindl *et al.*, 2001; Qin *et al.,* 2014; Ugulino and Hernandez, 2015).

Beech, next to birch and oak, is the most abundant deciduous species in Europe (Boratyńska and Boratyński 1990). The total area of beech dominated forest in Europe is estimated to cover ca 14–15 Mha (excluding the Caucasian mountains) with the largest areas in France, central and southern Germany, and the southeast European mountains (Carpathians, Dinaric and Balkan mountains) (Hahn and Fanta, 2001; Standovár and Kenderes, 2003). In Poland only, the stock of thick beech wood is about 90 million m^3. It is estimated that the market share of beech wood will systematically increase due to the observed expansion of this species (Tarasiuk, 1999; Dobrowolska, 2011). European beech is an expansive, fast-growing tree species gradually expanding its area of occurrence, whose wood can be an alternative to the dominant European oak in flooring.

The main objective of this work was to evaluate the effects of slicing processes on wood surface characteristics of the European beech (*Fagus sylvatica* L.). The relations between wettability, roughness and slicing parameters were studied. Two different wood thicknesses and three levels of compression were used during slicing to prepare surfaces prior to testing of selected characteristics.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Typical European beech (*Fagus sylvatica* L.) was selected as a test species, because of its wide application in the European wood industry for the production of floors, both from solid wood and glue laminated wood. Sawn wood of diameters of 20.5 cm × 12.0 cm × 100.0 cm (tangential × radial × longitude) was used. Material derived from Polish forest managed by the State Forests National Forest Holding. Beams were graded into two groups for flat slicing thickness of about 3.4 and 4.0 mm.

The beech wood beams were hydrothermally treated before slicing. The treatment process included: 5 h of heating up to the temperature of 60 °C, 42 h of thermo-hydro treatment at a temperature of 90 °C and 1 h of cooling down to a temperature of 60 °C. The flat slicing process was carried out on a FEZER Lumber Slicer FM 30 adapted for this purpose. The wood was sliced flat with variable compression of 67.5 %, 57.5 % and 47.5 % of desired veneer thickness. Slicing speed was set at 100 m/min. Drying was carried out in a Vanicek 25 dryer. After drying, moisture content of wood was approx. 8.0 %.

The thickness variation of the obtained European beech veneers was determined using an optical microscope (SMZ 1500, Nikon) with image analysing software. The same microscope was used to prepare images of analysed veneer surfaces.

The contact angles of expanding droplets, i.e. advancing angles, were determined using a contact angle measuring device and using the Owens–Wendt methods (Owens and Wendt, 1969) with Petrič and Oven recommendations (Petrič and Oven, 2015) on a Goniometer Haas Phoenix 300 contact angle analyser connected to imaging software. The image analysis system calculated the contour of the drop from an image cap-

Table 1 Levels of tested factors in relation to European beech veneer wettability and roughness
Tablica 1. Vrijednosti ispitivanih čimbenika s obzirom na kvašenje i hrapavost bukovine

Veneer thickness, mm *Debljina furnira,* mm	**Veneer side** *Strana furnira*	**Compression, % of the thickness** *Kompresija, postotak debljine*	**Measurement direction** *Smjer mjerenja*
3.4 4.0	tight / *zatvorena* loose / *otvorena*	67.5 57.5 47.5	perpendicular to the grain (⊥) *okomito na vlakanca drva* (⊥) parallel to the grain (II) *paralelno s vlakancima drva* (II)

tured using a video camera. The contact angle was calculated as the average of both sides of the droplets, to compensate for any horizontality variations. The initial contact angles recorded immediately after droplet deposition were used to estimate the wood surface energies using Berthelot's combining rule (Kwok and Neumann, 2000). The measurements were repeated 30 times. Distilled water was used for testing.

Roughness of the veneers was evaluated in accordance with the requirements of ISO 4287 (1997). As a part of the conducted research, the arithmetic mean deviation of the assessed profile (R_a) was measured. The surface roughness was tested using the Surftest SJ-210 Series 178-Portable Surface Roughness Tester (Mitutoyo Corporation). The parameter R_a was measured 30 times each in parallel and perpendicular to the grain direction for each tested variant. The analysis of wood roughness as well as wood surface wettability were done on the tight ("right") and loose ("left") side of the European beech veneers.

A statistical analysis of the test results was carried out using Statistica v. 10 software (StatSoft Inc.). The data were analysed and provided as the mean ± standard deviation. To determine the relations between the tested wood properties, simple regressions were used. Analysis of variance (ANOVA) was also made at the 0.05 level of significance. The test factors and their variability levels are given in Table 1.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Variation in thickness
3.1. Varijacije debljine

The obtained veneers were characterised by a relatively small variation in the thickness (Figure 1). The coefficient of variation (defined as the ratio of the standard deviation to the mean) was 1.8 % (mean value) for 3.4 mm thick veneers and 2.3 % (mean value) for 4.0 mm thick veneers. These values were in 5 % industrial range recommendation (Feihl, 1986) and so the slicing quality was good. A slight variation of the thickness of thinner veneers was most probably caused by lower tensions in material as slicing thin veneer generates lower cutting forces (Haouzali *et al.*, 2019). Previous experiments (Rahayu, 2016) indicated that it is more difficult to maintain thickness regularity for thinner veneers. On the other hand, a study conducted on *Fagus sylvatica* L. wood (Daoui, 2011) confirmed our conclusion. Probably, an observation of the inverse relation resulted from the use of relatively high material compression during cutting. It allowed to reduce tensions and made dimensions more stable. The regression analysis made for each veneer thicknesses did not confirm the significance of compression values.

3.2 Wettability and roughness of European beach veneers
3.2. Kvašenje i hrapavost bukova furnira

The results of measurements of contact angles as well as the results of measurements of roughness parallel and perpendicular to the grain are shown in Table 2. For the wood surfaces in case of each veneer thickness obtained with different compression, contact angle was in the range of 79.7° to 99.8° for tight side and 85.8° to 93.7° for loose side. There was no significant difference in contact angle measurements on those sides.

The different machining process did not affect surface wettability, as determined by contact measurements. The ANOVA did not confirm significant dependence between veneer thickness, veneer side or use of different compression values (Table 3). It was ob-

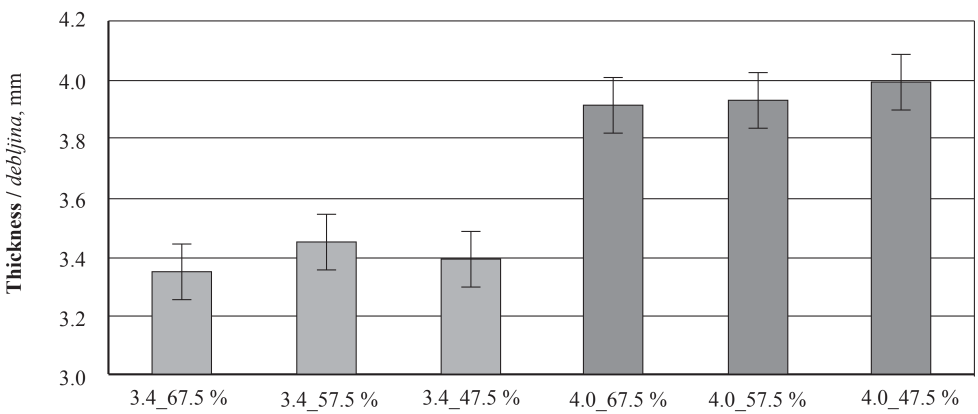


Figure 1 Variation in European beech veneer with a nominal thickness of 3.4 mm and 4.0 mm
Slika 1. Varijacije bukova furnira nominalne debljine 3,4 i 4 mm

Table 2 Contact angles, roughness parallel to the grain and perpendicular to the grain of tested European beech veneers (in parentheses standard deviations are given)
Tablica 2. Kontaktni kutovi, hrapavost paralelno s vlakancima drva i hrapavost okomito na vlakanca drva ispitivanih bukovih furnira (u zagradama su standardne devijacije)

Side *Strana*	**Thickness, mm** *Debljina,*mm	**Compression, % of thickness** *Kompresija, postotak debljine*	**Roughness ⊥, μm** *Hrapavost* ⊥, μm	**Roughness ‖, μm** *Hrapavost* ‖, μm	**Wettability, °** *Kvašenje,* °
Tight *zatvorena*	3.4	67.5	7.85 (1.37)	4.68 (1.45)	99.8 (2.6)
		57.5	8.98 (1.12)	4.81 (2.81)	95.5 (5.7)
		47.5	9.60 (2.05)	4.95 (2.41)	82.4 (3.8)
	4.0	67.5	8.19 (1.96)	4.84 (2.24)	88.8 (8.5)
		57.5	8.82 (1.15)	4.73 (1.04)	87.8 (5.4)
		47.5	9.16 (1.67)	5.10 (1.23)	79.9 (6.1)
Loose *otvorena*	3.4	67.5	13.29 (3.01)	6.45 (0.90)	87.7 (5.8)
		57.5	12.47 (2.65)	7.78 (1.77)	93.7 (4.0)
		47.5	11.58 (2.62)	7.47 (2.06)	90.8 (1.1)
	4.0	67.5	13.45 (2.33)	7.00 (1.16)	85.8 (9.0)
		57.5	11.19 (1.44)	7.59 (2.94)	87.2 (5.6)
		47.5	11.66 (1.79)	5.76 (1.51)	89.3 (4.3)

Table 3 Results of ANOVA for wettability, roughness parallel to the grain and perpendicular to the grain
Tablica 3. Rezultati ANOVA analize vrijednosti kvašenja, hrapavosti paralelno s vlakancima drva i hrapavosti okomito na vlakanca drva

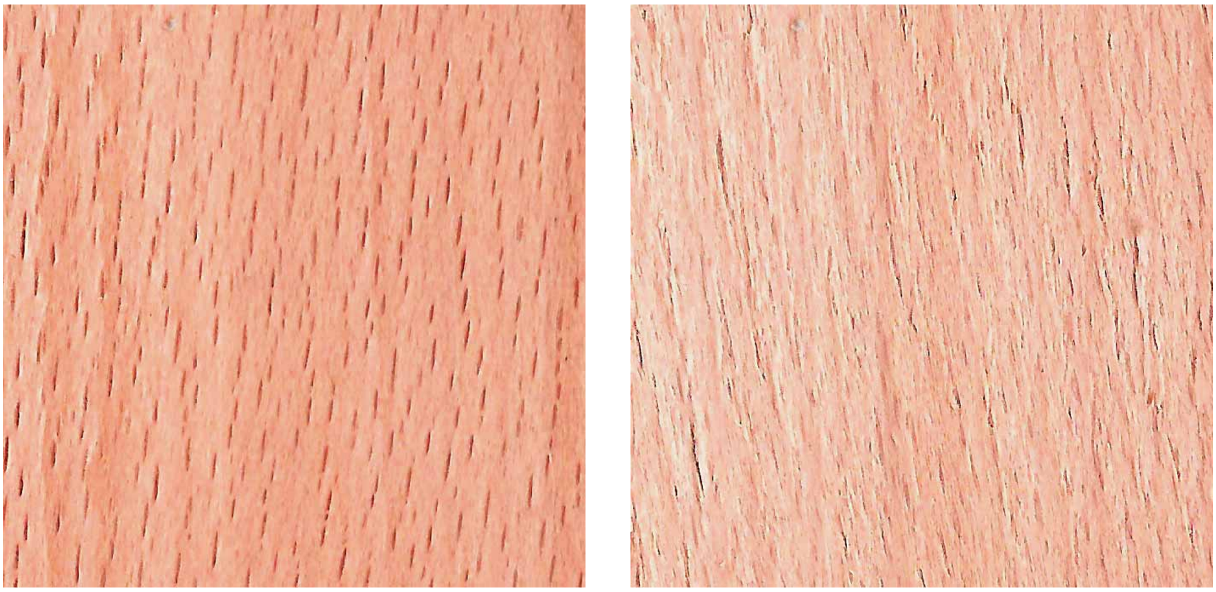
Feature *Svojstvo*	**Factor** *Čimbenik*	**Sum of squares** *Zbroj kvadrata*	**Degrees of freedom** *Stupnjevi slobode*	**Mean sum of squares** *Srednji zbroj kvadrata*	**Fisher's F-test** *Fisherov F-test*	**Significance level** *Razina značajnosti*
		SS	*DF*	*MS*	*F*	*p*
Wettability *kvašenje*	Side / *strana*	0.000	1	0.0000	0.000	0.989304 NS
	Thickness / *debljina*	80.701	1	80.701	3.245	0.114673 NS
	Compression / *kompresija*	72.771	2	36.392	1.463	0.294580 NS
Roughness ⊥ *hrapavost* ⊥	Side / *strana*	36.867	1	36.867	41.563	0.000351*
	Thickness / *debljina*	0.144	1	0.144	0.163	0.698875 NS
	Compression / *kompresija*	0.219	2	0.109	0.123	0.885925 NS
Roughness ‖ *hrapavost* ‖	Side / *strana*	13.944	1	13.944	39.478	0.000411*
	Thickness / *debljina*	0.102	1	0.102	0.290	0.606905 NS
	Compression / *kompresija*	0.545	2	0.273	0.772	0.497982 NS

NS – not significant, * – significant at the 0.05 level / *NS – nije značajno, * – značajno na razini 0,05*

Table 4 Results of simple regression analysis for wettability, roughness parallel to the grain and perpendicular to the grain depending on compression
Tablica 4. Rezultati jednostavne regresijske analize za kvašenje, hrapavost paralelno s vlakancima drva i hrapavost okomito na vlakanca drva u ovisnosti o kompresiji

Side *Strana*	**Feature** *Svojstvo*	**Coefficient of correlation** *Koeficijent korelacije*	**Sum of squares** *Zbroj kvadrata*	**Mean sum of squares** *Srednji zbroj kvadrata*	**Degrees of freedom** *Stupnjevi slobode*	**Fisher's F-test** *Fisherov F-test*	**Significance level** *Razina značajnosti*
		R	*SS*	*MS*	*DF*	*F*	*p*
Tight *zatvorena*	Wettability *kvašenje*	0.776	173.054	173.054	4	6.075	0.069340 NS
	Roughness ⊥ *hrapavost* ⊥	0.945	1.856	1.856	4	33.630	0.004397*
	Roughness ‖ *hrapavost* ‖	0.781	0.072	0.072	4	6.255	0.066696 NS
Loose *otvorena*	Wettability *kvašenje*	0.517	10.857	10.857	4	1.461	0.293387 NS
	Roughness ⊥ *hrapavost* ⊥	0.826	3.062	3.062	4	8.542	0.043125*
	Roughness ‖ *hrapavost* ‖	0.061	0.011	0.011	4	0.015	0.908011 NS

NS – not significant, * – significant at the 0.05 level / *NS – nije značajno, * – značajno na razini 0,05*



a b

Figure 2 Macrographs of tight side (a) and loose side (b) of tested veneers - magnification 4x
Slika 2. Izgled zatvorene (a) i otvorene (b) strane ispitivanih furnira – povećanje 4 puta

served that the higher compression during slicing, the higher is the contact angle with water. Simple regression analysis confirmed the influence of selected compression values on roughness of European beech veneers in both parallel and perpendicular to the grain directions (Table 4). Wood roughness was higher when the compression was lower. This indicates that the influence of the set of machining parameters, such as slicing, is visible in the surface quality. The same conclusion was made by de Moura and Hernández (2007), who tested sugar maple wood surfaces machined with the fixed-oblique knife pressure-bar cutting system.

The wood surface roughness is an important characteristic in terms of surface quality and properties, particularly in the case of finishing treatments (Buyuksari *et al.,* 2011). Veneer with a rough surface can also cause excessive resin use and may result in resin bleeding through the face veneer (Dündar *et al.*, 2008). The roughness of tested veneers varied significantly depending on the measurement direction (parallel and perpendicular to the grain) and veneer side. The roughness values measured perpendicular to the grain were twice as high as those measured parallel to the grain. ANOVA confirmed significance of veneer side on roughness values (Table 3). The loose side was characterised by a greater roughness because more irregularities and cracks appeared on that side due to tensile stresses. Such stresses are an effect of veneer bending during the peeling process. According to previous studies (Candan *et al.*, 2010; Bekhta *et al.*, 2012), the improvement of surface quality of veneers is very important for bonding quality in bonded wood panels. Reducing the roughness, mainly on the loose side, reduces stress points between the wood surface and the adhesive, increasing the shear strength of the glue line (Rahayu, 2016).

Wood is not a homogeneous material, and its properties vary in different directions as a result of its anatomical structure (Li *et al.*, 2018). The measurement perpendicular to the grain contains irregularities that are mainly caused by the size of the structural wood elements. In the case of deciduous wood species, these ele-

a b

Figure 3 Micrographs of tight side (a) and loose side (b) of tested veneers – magnification 20x
Slika 3. Mikrografije zatvorene (a) i otvorene (b) strane ispitivanih furnira – povećanje 20 puta

ments are primarily fibres and vessels. The observed differences were due to the difference in texture in perpendicular and longitudinal direction of European beech wood. Moreover, wood quality depends on surface morphology (Jankowska *et al.*, 2019). In case of tight side of veneers, only a few cell wall fibrillations roughed the surface. Microscopic images revealed that on loose side the wood fibres and other cellular elements were torn out, mechanically destroyed and even crushed. In addition, loos side of veneers exhibited several cracks and some delamination (Figure 2 and 3).

Simple regression analysis was carried out to verify the existence of a relation between surface roughness measured perpendicular and parallel to the grain and wood wettability. According to results, the correlation between these properties was poor in case of roughness measured parallel to the grain (coefficient of correlation $R_{\wedge}$=0.719 was not significant) and in case of roughness measured parallel to the grain $R_{çç}$=0.851 was significant. On the other hand, based on our results, it can be concluded that the contact angle is lower when roughness (value of R_a parameter) is higher and that, consequently, wood wettability is also higher. The same inference was made by Arnold (2010), who tested differently machined solid wood surfaces regarding surface properties and coating performance.

4 CONCLUSIONS
4. ZAKLJUČAK

Based on the results of the research conducted, it can be concluded that compression is significant for the surfaces of wood such as European beech slicing. Using pressure bar set (relatively high material compression) during wood slicing allowed to reduce internal stresses providing dimensions to be more stable. The smaller variation of the thickness was observed in thinner veneers. The contact angle was lower when roughness was higher, thus wood wettability was higher. The influence of selected compression factors on roughness of European beech veneers perpendicular to the grain was confirmed. This indicates that the influence of the machining parameters of processes such as slicing is significant for the surface properties of wooden veneers. This type of innovation has the potential to be used, among others, in the furniture industry and the production of wooden layered floors.

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Influence of Allowances on Taking Log Deliveries

Utjecaj veličine nadmjere na isporuku trupaca

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ABSTRACT • *This paper deals with differences between the declared and actually supplied volume of round wood, which can be seen in the sawmill log yards in taking log deliveries. These differences usually mean the losses for the suppliers. Authors focus on the length accuracy of supplied logs. They start with a comprehensive manual checking of log deliveries (2639 logs) and with calibration of electronic measuring equipment (238 logs) made by an accredited laboratory. Authors analyse the origins of the differences, they quantify the volume "voluntarily" given by the suppliers in the form of oversized allowances and the volume of the losses caused by classifying the logs to a lower length group if the necessary allowance lengths are not observed (the volume is counted using e.g. 1 m shorter nominal length). The term "extra allowance" is introduced for allowances longer than wanted, and the dependences among the length of extra allowances, log diameter, volume of extra allowances and number of logs with too short allowance are defined. Losses caused by both of these defects (over- or under-sized logs) are counted and compared. If the log length value is exactly the required one or close to it (it means nominal length and required allowance), the measuring equipment can still measure a lower value because of the required precision of 1 %. Losses are also caused by reclassifying the logs to a lower group. Suppliers cut the logs longer (make "extra allowances") to ensure that the volume calculation is based on the right nominal length and not shorter. The research shows big differences between particular suppliers and their losses caused by extra allowances or reclassification of logs. The authors searched the optimum allowance in order to minimise the losses of the supplier. The results of the analysis give the following recommendations: for suppliers who do not use harvesters for felling and logging, it would be preferable to supply round timber in tree lengths due to the volume lost by reclassification. Today, however, this is not possible in most cases because large customers buy only logs because of technological reasons. Another aspect is the price, which is usually higher for raw material in logs. In the production of logs, it is preferable to increase the required 2 % allowance by 4-5 cm, if it is possible to produce the logs relatively accurately. If accuracy cannot be maintained, it is preferable to increase the allowance to about 7 cm (e.g. mountainous terrain, poor quality and curved timber, lack of experienced staff).*

Keywords: *log; round wood volume; delivery; allowance; loss*

SAŽETAK • *Tema rada su razlike između prijavljene i stvarno isporučene količine trupaca koje se događaju na stovarištima tijekom isporuke trupaca. Te razlike obično znače gubitke za dobavljače. Autori iznose svoja promišljanja o točnosti dužine isporučenih trupaca. Polazišta analize su rezultati ručnog mjerenja dimenzija velikog broja isporučenih trupaca (2639 komada) i rezultati dobiveni mjerenjima pri kalibraciji elektroničke mjerne opreme (rezultati mjerenja 238 trupaca) koju je obavio akreditirani laboratorij. Autori analiziraju izvor razlika, kvantificiraju volumen koji dobavljači „dobrovoljno" daju kao prevelike nadmjere te volumen gubitaka uzrokovanih razvrstavanjem trupaca u skupine manje dužine u slučajevima nedovoljno velikih nadmjera dužine trupaca (npr. volumen se izračunava uz pomoć metar kraće nominalne dužine). Uveden je pojam „ekstranadmjere" za nadmjere veće od potrebnih, definirane su relacije između veličine ekstranadmjere, promjera trupaca, volumena ekstranadmjere i broja trupaca s premalom nadmjerom dužine. Izračunani su i uspoređeni gubitci uzrokovani navedenim*

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greškama u dimenzijama isporučenih trupaca (trupci prevelike ili premale dužine). Ako je dužina trupaca jednaka zahtijevanoj ili je blizu njezine vrijednosti (zahtijevana je dužina zbroj nominalne dužine i potrebne nadmjere), mjernom se opremom zbog tražene preciznosti od 1 % ipak može izmjeriti manja dužina. Gubitci nastaju i zbog svrstavanja trupaca u skupinu manje dužine. Dobavljači režu trupce na veću dužinu (daju ekstranadmjere) kako bi osigurali da se volumen isporučenih trupaca računa sa stvarnom nominalnom dužinom, a ne s kraćom. Istraživanje je pokazalo da postoji velika razlika između pojedinih dobavljača i njihovih gubitaka koji su posljedica ekstranadmjera ili skraćivanja trupaca zbog nedovoljne nadmjere na duljinu trupaca. Autori su tražili optimalnu veličinu nadmjere dužine trupaca kako bi se umanjili gubitci dobavljača. Na temelju rezultata analize dane su ove preporuke: za dobavljače koji se ne koriste harvesterima za sječu, poželjna je isporuka oblovine u dužini stabla zbog gubitka volumena uzrokovanih reklasifikacijom. Međutim, danas to najčešće nije moguće jer veliki kupci kupuju trupce samo zbog tehnoloških razloga. Drugi je aspekt cijena, koja je obično veća za trupce kao sirovinu. Pri izradi trupaca poželjno je povećati nadmjeru na dužinu od 2 %, što je otprilike 4-5 cm, ako je trupce moguće relativno precizno izraditi. Ako se ne može postići točnost izrade trupaca, nadmjeru je poželjno povećati na 7 cm (npr. zbog planinskog terena, nekvalitetne i zakrivljene oblovine, nedostatka iskusnog osoblja).

Ključne riječi: *trupac; volumen oblog drva; dostava; nadmjera; gubitak*

1 INTRODUCTION
1. UVOD

The round wood volume is one of the most important parameters in the timber trade. Due to irregular body of the tree, the volume is determined approximately. Determined volume depends on the method of the measuring of the log parameters and also on the calculation method of the final volume. The differences between the actual and estimated volume present losses mainly for suppliers of round wood – forest companies.

Measuring can be electronic (2D or 3D) or manual. Differences in round wood measurements using electronic 2D and 3D systems and standard manual method were studied by several authors (Janák, 2007; Sauter *et al*., 2010). The calculation methods are mainly based on log diameter (top or mid) and the length of the whole log. The estimations also use shorter sections, which more or less take into account the form of the log (convergence and curvature). There are many works about this topic (Fonseca, 2005).

Filtration of the scanned data and its methods also affect seriously the calculated log volume (Hunková and Janák, 2014). If scanning is performed over the bark, estimation and subtraction of the bark thickness is the next factor seriously affecting the final log volume (Hunková and Janák, 2006; Duka *et al*., 2020). Many researchers and works were done in the field of log measuring and volume calculation, but to the best of our knowledge, none focused on the losses caused by precision of the length measuring of round wood.

Electronic measuring of the dimensions of round timber is quite common and it is used in the majority of sawmills. With the development of the electronic measurement of round timber, taking measurements of its dimensions was made more precise. This, however, eliminates the “human approach” or acceptable tolerance when taking deliveries of the round timber, which traditional manual inspections allowed. While working in a calibration laboratory and within the framework of collaboration with round timber suppliers, data from measurements taken of the length of spruce round timber in the Czech Republic were collected. The data were subsequently analysed. The analysis was mainly focused on the degree of allowances with respect to the length of logs and round timber.

The allowances were excessive compared to the nominal length required to produce sawn timber of a particular length in the required quality. If the allowance is not observed, the logs are placed into a lower length grade upon taking electronic log deliveries. Then, the volume paid for by the customer to the supplier corresponds to a shorter nominal length. In the Czech Republic, length grades of 0.25 m or 0.5 m are standard for coniferous raw material. Large customers usually grade length 1 m increments. In such cases, the suppliers may suffer relatively large losses. Therefore, suppliers are forced to increase the allowance to ensure that the logs are included in the expected length grade, even with minor inaccuracies in measuring or cutting.

In the Czech Republic and its neighbouring countries, no allowance is added to the volume of round timber. It, therefore, always causes a loss for the supplier. This is due to the requirement to supply round timber at such a length that enables to produce timber of a given nominal length. The rule is based on the past when sawing residues were considered waste. Today, however, almost everything can be used or sold. Large allowances are therefore an advantage for sawmills. However, too high allowance may cause difficulties in the grading of round timber by use of sorting lines of large plants, unless they are equipped with a shortening device. Depending on the size of boxes, they also require the supplier to maintain a maximum allowance length.

Today, a 2 % allowance is commonly required in the Czech Republic. This is set out in the *Recommended Rules for Measuring and Sorting of Wood* (Wojnar *et al.*, 2008). These are non-binding rules, but they are the result of negotiations between suppliers and customers, and most tend to adhere to them.

Length allowance is also determined by the Czechoslovak state standard ČSN 48 0050 *Rough wood. Basic and common regulation of 1992.* Here, the length allowance is specified at 1 %, but not more than 0.10 m. The standard remains valid, but is not often applied in practice.

Since none of these regulations is binding, allowances may also be specified in sales contracts in another way (e.g. at least 5 cm of allowance for 4 m logs) or other values may be required (e.g. 3 % for a long log).

Length is measured to the nearest centimetre. During production at the supplier's, length is usually measured by a tape measure or harvester, and occasionally by a sorting line (the number of forest handling and distribution warehouses is very small today). At the customer's, the length can again be measured by tape measure. Today, most round timber, however, is scaled using sorting lines equipped with electronic measuring equipment.

The accuracy of taking measurements by electronic measuring equipment is required to be at least 1 cm according to EN 1309-2:2006 *Round and sawn timber - Method of measurement of dimensions - Part 2: Round timber - Requirements for measurement and volume calculation rule*. The maximum permissible deviation in length measurement is 1% according to the Recommended Rules for Measuring and Sorting Wood. In some countries, it is supplemented by a maximum deviation of 5 cm. Similarly, this is usually specified in the agreements between suppliers and customers.

The accuracy of electronic measurements is influenced by other factors besides the actual accuracy of the equipment. These include the movement of the round timber on the conveyor during measurement, inclined fronts, curvature of the logs, torn fibres or icing on the surface. Most of these factors result in the measurements being longer than the actual length.

The accuracy of taking log measurements in a forest is affected in a similar manner. Here the main factors include: the measurement method used (tape measure, harvester), working conditions (e.g. forest felling) and the human factor.

The differences between manual and electronic measurements were investigated in the Czech Republic between 2000 and 2007. Janák *et al*. (2005) made the following findings:

Deviations in taking 2D measurements: length is slightly but evenly underestimated, i.e. electronic measurement results show lower values. The average deviation was -0.7 cm, with a minimum of -6 cm and a maximum of +8 cm. On the other hand, the average with the 2D electronic system is slightly higher, but also uniform. Due to the fact that volume is calculated from nominal length, and the shifting of logs to the lower length grade due to length deviation rarely occurs, the influence of lower electronically measured length values on volume is minimal. The influence of higher electronically measured average values prevails, therefore volume values are slightly overestimated.

Deviations in taking 3D measurements: Length is slightly but evenly overestimated, i.e. electronic measurement results show higher values (+0.6 cm on average, with a minimum of -6 cm and a maximum of +17 cm). On the other hand, the average given by the electronic system is slightly lower, but also uniform. Due to the lower influence of electronically measured values of length on volume, the influence of lower electronically measured diameter values prevails. The values of volume are therefore slightly undervalued (Janák *et al*., 2005).

In the bachelor thesis by Přibyl (2005), the accuracy of sawed logs in electronic taking deliveries was studied. Accuracy was assessed for selected logs (100 pcs) that have passed the measuring frame five times in different pivot positions. None of the logs in these five measurements showed conformity with all monitored dimensions (mid- and top diameter, measured and recorded length). The differences were 1-3 cm for length measurement, while the error in thickness determination was mostly 1 cm. It should be noted that the values were already rounded in accordance with current practice, i.e. values after the decimal point were not considered. In such case, an actual difference of 2 mm may result in a 1 cm error (e,g, 22.9 and 23.1 cm correspond to 22 and 23 cm after cut off). The thesis further summarised some of the factors that influence takeover and suggested several ways to limit the effect of these factors.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The analysis was focused on losses due to increasing the length allowance for suppliers (i.e. a profit of raw material for customers). The objective was to find out what increase in allowance was acceptable for suppliers, while reducing the possibility of shifting logs between shorter pieces (and the associated loss of raw material delivered), but not causing the same or higher loss of raw material. Therefore, a theoretical volume and a percentage of losses were calculated. This was compared with practical data.

2.1 A description and marking of analysed parts of logs
2.1. Opis i obilježavanje analiziranih dijelova trupaca

A description and marking of the analysed parts of logs is shown in Figure 1.

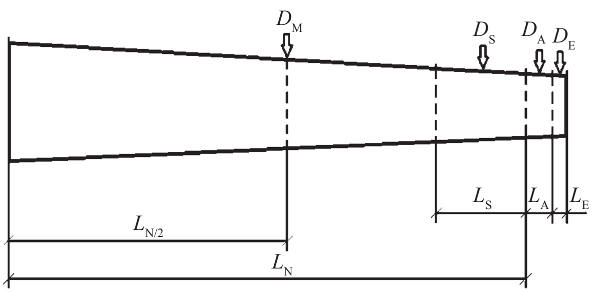

Figure 1 A description and marking of the analysed parts of logs (L_N – nominal length, L_A – length allowance, L_E – extra length allowance, L_S – length of log cut step, D_M – mid log diameter (in the middle of the nominal length), D_A – mid-diameter of the required allowance (2%), D_E – mid-diameter of the extra allowance, D_S – mid-diameter of the cut step)

Slika 1. Opis i označivanje analiziranih dijelova trupaca (L_N – nominalna dužina, L_A – nadmjera na dužinu, L_E – ekstranadmjera na dužinu, L_S – dužina koraka rezanja trupca, D_M – srednji promjer trupca na sredini nominalne duljine, D_A – srednji promjer potrebne nadmjere, 2 %, D_E – srednji promjer ekstranadmjere, D_S – srednji promjer unutar koraka rezanja)

2.2 Data from practice
2.2. Podatci iz prakse

The input data came from two sources:
- check measurements of deliveries taken in 2013 and 2015,
- measurements carried out during calibration of the measuring equipment in sawmills.

2.2.1 Check measurement of deliveries in 2013 and 2015
2.2.1. Kontrolna mjerenja isporuka u 2013. i 2015. godini

As part of the check measurements, data from delivery notes, sawmills and check manual measurements were compared. The manual measurements were performed in accordance with the Recommended Rules for Measuring and Sorting Wood in the Czech Republic 2008. Lengths were measured using a tape measure as the shortest distance between the ends with an accuracy of 1 cm.

1,380 logs were inspected in 2013, which represents 462.29 m^3 of wood. 7 deliveries with a total of 1,084 logs and 8 deliveries with 296 logs were analysed. In 2015, 1,259 logs (384.99 m^3) were measured.

The number of logs with an allowance of less than or equal to the required (2 %) was determined from the check measurements. For logs with larger allowances, the volume of excess allowance was calculated. For logs having a smaller allowance and being rightfully assigned to a lower length category, the volume corresponding to the loss was calculated. The Huber method was used for calculating the volume (for more details, see Theoretical Analysis of Losses). The findings were expressed as a percentage for each individual delivery.

2.2.2 Calibration measurements
2.2.2. Kalibracijska mjerenja

Measurements taken during calibration are more accurate. For the calibration of each piece of equipment, 25-30 logs with straight faces and without any torn fibres were selected. The length of each log was measured in four positions, and the values determined to the nearest millimetre were then averaged. During the taking of electronic measurements, all logs were measured 3 times. For the purposes of this work, values from the calibration of 10 different pieces of equipment performed in 2018 were used. Data from both 2D and 3D measurements were included. In total, 238 logs at lengths of 3, 4 and 5 m were measured by hand and three times electronically. During these measurements, the thickness of the logs was not measured, so the volume of the checked round timber could not be determined.

Therefore, 714 measurements were available to determine deviations on the measuring devices. For these data, the difference between the manually measured lengths (an average of four measurements) and each length measured by the measuring device was calculated. Differences were expressed in both absolute and percentage terms and a basic statistical analysis was performed.

In addition, 238 values were used to determine the additional sizes. The values were divided into three groups: a log group with an allowance of exactly 2 %, a group with a smaller allowance and a group with an extra allowance. In the last two groups, a statistical analysis of the occurrence and magnitude of these values was carried out both in absolute values and as a percentage.

How many times the log could hypothetically be moved to a shorter length grade was evaluated separately. For this purpose, logs with a manually measured length that exactly met the requirements (i.e. with an allowance of 2 %) and larger were selected from the data. The manually measured lengths were then compared to the electronically measured lengths and, in case of undersizing, moved to a lower length grade. This is only a hypothetical re-assignment, as no takeover data were available for calibrations, but only inspection reports for the calibration.

2.3 A theoretical analysis of losses
2.3. Teorijska analiza gubitaka

In the first phase, the volumes of logs were modelled for mid-log diameter ranging from 10-60 cm by 1 cm and lengths of 3-14 m by 1 m. Volumes were determined for logs of nominal length (precise, with no allowance), as well as for the logs that represented a 2% allowance, and finally for logs with an allowance greater than 2 % by 1-10 cm with a 1 cm diameter interval.

The volumes were calculated using the Huber method (1:1 ratio). In this method, the volume of the log is simplified to the cylinder volume. The input parameters are the nominal length L_N and mid-diameter of round timber D_M. Although this method deviates from the real volume values, it is most commonly used in practice and does not have a major effect on the theoretical analysis in terms of allowances.

For this calculation, the mid-diameter is necessary. This was based on the commonly used spruce wood taper of 1 cm/1 m.

Subsequently, the percentage of volume of voluntary extra allowance for logs of a nominal length was calculated, again for mid-diameter in the range of 10-60 cm and a length of 3-14 m. This was then displayed in the graph. For the lengths of logs most commonly occurring in practice, graphs of the extra allowance volume to the mid-diameter of the logs and the length of extra allowance were created.

The next step involved calculating the volume of the part of log that corresponds to the log cut step (most often, 1 m in the Czech Republic). The calculation was carried out for the thinner part of the log using the Huber method and with an assumed diameter interval of 1 cm/1 m. Again, a recalculation to the percentage of this volume compared to the volume of the whole log and graphs of dependencies were compiled. Again, the above ranges were considered, but the results were only shown for values most common in practice.

From this analysis, the values of losses, occurring in both cases, were then derived and an assessment of the advantage/disadvantage of the preparation of logs with different sizes of extra allowance under the given production conditions was made.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Results from calibration measurements
3.1. Rezultati kalibracijskih mjerenja

3.1.1 Deviations in electronic measuring equipment
3.1.1. Odstupanja elektroničke mjerne opreme

From the data obtained during the calibration, deviations in the electronic measurements versus the manual measurements were first determined. Individual electronic measurements were compared with the average of the four manual measurements of each log. Most of the deviations were positive, as also shown by the results of the statistical analysis, presented by the bar graph in Figure 2. The figure shows the deviations in centimetres (lengths of 3, 4, and 5 m were represented). The deviations can be converted to percentage evaluation. The percentage evaluation shows that even outliers (-0.91 and 0.96) do not exceed the tolerance of ±1%. Most of the deviations, i.e. 87 %, were positive. The average value of all measurements was 1 cm; the percentage taking into account the length was 0.24 %. It can be stated that all tested devices slightly overestimated the length.

It was also analysed in how many cases an inaccurate measurement could cause a log with sufficient allowance to be moved to a lower length grade. This would happen in 22 out of 714 cases if there was no tolerance. This equates to 9 logs, which were in one or two measurements out of three underestimated by 1 to 2 cm. Based on the manual measurements, 5 of them had an allowance of exactly 2 % and 4 were 1 cm longer. In total, this error occurred in 3 % of all measurements, but in 32 % of the measurements of individual logs with an exact allowance or with an allowance only 1 cm larger (23 logs, i.e. 69 measurements).

For performing calibrations, logs without any major defects, straight and with perpendicular cuts, were deliberately selected. Also, the logs were not frozen and conveyor dirties were not common. This eliminated the effects of log defects and helped to assess possible defects in the equipment. However, most of these "unfavourable" factors that occur in normal practice affect taking measurements showing positive values (longer lengths than those actually measured).

It should also be pointed out that data from calibrations carried out at regular intervals on measuring devices by customers who take quality check measurements were used. The measurement results of these devices depended on the software, mechanical layout and overall system settings. Therefore, it cannot be said with any degree of certainty that all facilities in the Czech Republic operate with the specified level of accuracy. If a supplier has doubts about the accuracy of the measurements taken, the customer should be advised to perform an independent calibration of the equipment.

The fact that the measuring devices slightly overestimate the actual length is partly consistent with the findings by Janák *et al.* (2005). According to the results of the measurements taken at that time, the 3D measuring systems tended to overestimate, while 2D systems tended to underestimate the values. This time, all inspected systems overestimated the values. At the same time, the variance of deviations from the mean value were significantly lower, and even the outliers did not deviate from the allowed 1 % error tolerance.

3.1.2 Length allowances
3.1.2. Nadmjera dužine

Length measurements taken during calibration were further analysed from the measured data. The input values consisted of manually measured lengths, i.e. lengths unaffected by the accuracy of the measuring equipment. The average was calculated from 4 measurements with an accuracy of millimetres.

Of all 238 logs, only 4 logs were shorter (i.e. 1.68 %). The difference between the length including the desired addition and the measured value was 1 and 2 cm.

Conversely, an extra allowance was found in 232 logs (97.48 %). Here, the average value of the differ-

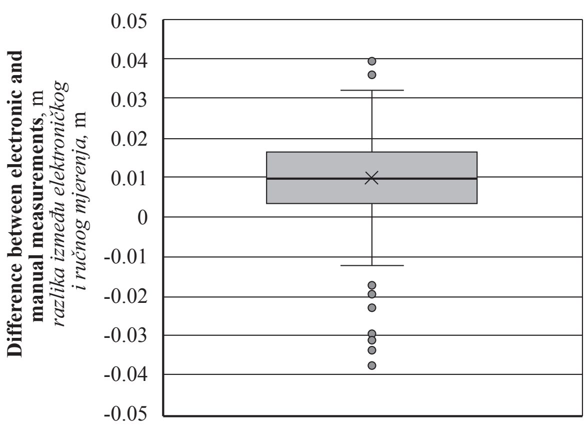

Figure 2 Difference between electronic and manual measurement evaluated from calibration measurements
Slika 2. Razlika između elektroničkoga i ručnog mjerenja procijenjena na temelju kalibracijskih mjerenja

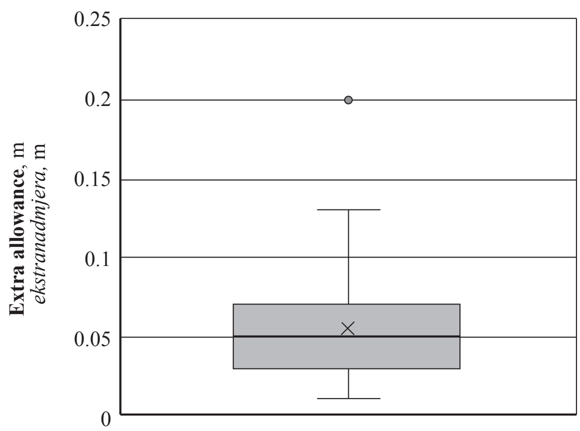

Figure 3 Extra allowances of logs estimated during calibration measurements
Slika 3. Ekstranadmjere dužine trupaca utvrđene tijekom kalibracijskih mjerenja

ence between the desired length and the measured value was 5.5 cm, with the median being 5 cm. The biggest difference was 19 cm (found in a 4 m log). However, this was an exceptional value; the maximum difference was 13 cm (for a 3 m log) – see Figure 3.

The results show that suppliers typically lean towards the safe side and in most cases deliver logs with a length greater than required. No log diameter data was included in the calibration measurements; therefore, no volume loss evaluation could be performed.

3.2 Data from check measurements of deliveries
3.2. Podatci kontrolnih mjerenja isporuka

3.2.1 Check measurements 2013 – round timber
3.2.1. Kontrolna mjerenja u 2013. godini – oblo drvo

The data from check measurements in 2013 were used to assess the size of allowances in standard round timber deliveries and the resulting volume losses. An analysis was performed separately for logs at basic and associated lengths (long round timber). 7 deliveries with a total of 1,084 logs and 8 deliveries with 296 logs were analysed.

The deliveries of long round timber examined in this selection represented a total volume of 252.51 m^3. The average length of extra allowance was 20 cm, as shown in the graph in Figure 4. On average, extra allowances represented a loss of 1.84 %, i.e. about 0.016 m^3 of wood per log. However, the average was slightly adversely affected by outliers; a median of 0.013 m^3 is more suitable for the characteristics of this sample. From the total volume of the entire selection of round timber, the volume of the extra allowances makes up at most 1.5 and 2.3 %, with the average being 1.95 %.

When evaluating the deliveries separately (Figure 5), a slight deviation can be observed in one delivery (indicated by the letter C) in which the average allowance was 26 cm. When recalculating the percentage of the entire round timber volume, this represents 2.45 %.

Of the analysed logs, only 7 were undersized (2.3 % of the logs) – see Table 1. In terms of volume, this amounted to 4.640 m^3, i.e. 0.42 % of the volume of all deliveries together. The average difference between the required allowance and the actual one was 13 cm, but

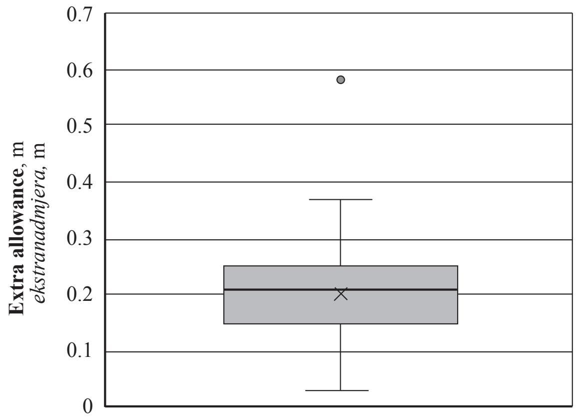

Figure 4 Box chart of extra allowance of round timber
Slika 4. Grafikon ekstranadmjera za oblo drvo

the data set was too small for making a statistical evaluation. The value ranged from 1 to 21 cm.

It was determined that in one case the length was evaluated incorrectly and a log with an exact allowance (10.2 m) was moved to a lower length grade (9 m). The customer thus did not pay for 0.110 m^3 of wood (0.3 %). In the overall evaluation in terms of volume, this represents only 0.04 % of the sum of the volume of all long pieces of round timber.

3.2.2 Check measurements 2013 – logs
3.2.2. Kontrolna mjerenja u 2013. godini – trupci

In the data set containing logs of basic lengths, an analysis of the allowance larger than the required 2 % was also performed separately (Figure 6). The unnecessary excess allowance amounted to 2.543 m^3 of wood, i.e. 1.21 % of the total volume of all deliveries (209.78 m^3). Most often (50 % of the time), logs were delivered 3–7 cm longer (the average being 5.2 with a median of 5 cm). In 95 % of the cases, values ranged from 1 to 13 cm, but in extreme cases, allowances of more than 20 cm were also found. In percentage terms, the extra allowance represented an average of 1.40 % of the volume of the whole log.

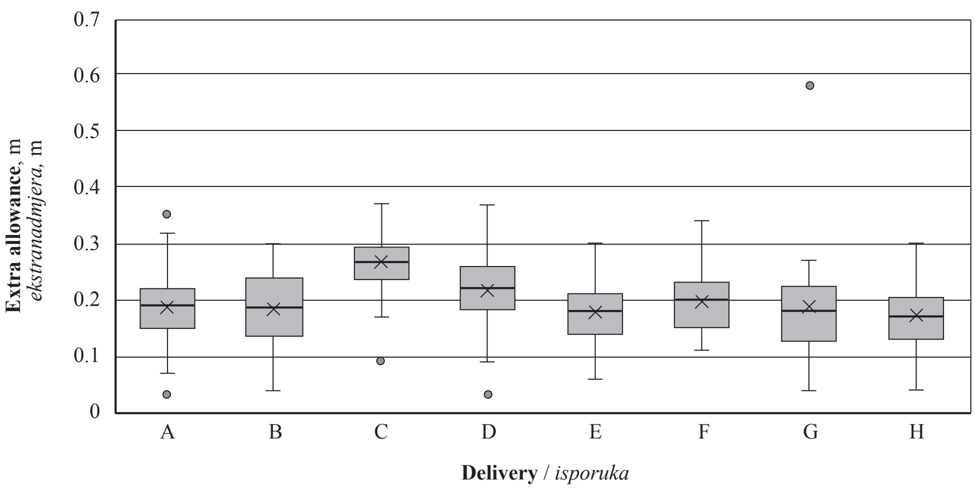

Figure 5 Box chart of extra allowance of round timber evaluating deliveries separately
Slika 5. Grafikon ekstranadmjera za oblo drvo određenih prema isporukama oblog drva

Table 1 Analysis of round timber deliveries
Tablica 1. Analiza isporuke oblog drva

Delivery *Isporuka*	**Delivery volume according to delivery notes, m³** *Količina isporuke prema dostavnicama*, m³	**Number of logs in the delivery** *Broj isporučenih trupaca*	**Number of logs in the delivery with an allowance below 2 %** *Broj isporučenih trupaca s nadmjerom manjom od 2 %*	**Number of logs in the delivery with an allowance below 2% from the entire delivery** *Broj isporučenih trupaca s nadmjerom manjom od 2 % cjelokupne isporuke*	**Volume lost due to classification to a lower length grade, m³** *Gubitak volumena zbog klasifikacije u niži razred dužine*, m³	**Volume lost due to classification to a lower length grade as, %** *Gubitak volumena zbog klasifikacije u niži razred dužine, %*	**Volume of extra allowance (above 2%) in the delivery, m³** *Volumen ekstranadmjere (iznad 2 %) u isporuci*, m³	**Volume of extra allowance (above 2%) in the delivery, %** *Volumen ekstranadmjere (iznad 2 %) u isporuci, %*	**Average length allowance, cm** *Prosječna nadmjera dužine*, cm
A	35.04	38	2	5.26	0.227	0.65	0.602	1.72	17.9
B	37.95	31	3	9.68	0.632	1.67	0.529	1.39	18.1
C	29.70	59	1	1.69	0.073	0.25	0.722	2.43	26.6
D	29.05	36	0	0.00	0.000	0.00	0.643	2.21	21.5
E	25.32	26	0	0.00	0.000	0.00	0.427	1.69	17.7
F	34.60	36	0	0.00	0.000	0.00	0.640	1.85	19.6
G	33.03	27	1	3.70	0.123	0.37	0.557	1.69	18.6
H	27.82	46	0	0.00	0.000	0.00	0.520	1.87	17.0
Total *Ukupno*	252.51	299	7	2.34	1.055	0.42	4.640	1.84	19.6

Similarly to the evaluation of round timber at full lengths, the log deliveries did not show any larger statistical differences. This is evident from the box graph in Figure 7. Slight deviations were found in delivery O, where the median value of allowance was 10 cm larger than required. On average, the log volume in this delivery was larger by 2.1 %.

Of the 1,084 logs analysed, mostly 4 and 5 m in length, 76 logs had an allowance that did not meet the requirement of 2 % (i.e. 7 % of the logs). When these logs were moved to a smaller length grade, there was a loss of 3.096 m³ out of a total of 209.78 m³, i.e. 1.35 %.

The difference between the setpoint and the measured value most often ranged from 1 to 3 cm (see Figure 8). Although not a big error, it always meant a classification to a lower length grade and thus a loss of volume corresponding to a volume of 1 m.

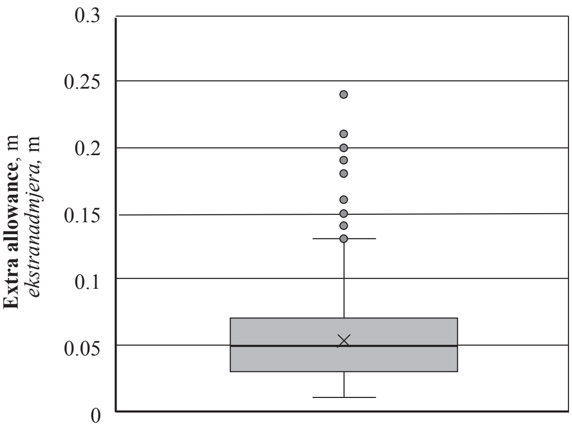

Figure 6 Box chart of extra allowance of logs in 2013
Slika 6. Grafikon ekstranadmjera za trupce u 2013.

The evaluation of individual deliveries revealed certain differences in the accuracy of log production (Table 2). In two deliveries, there were no undersized logs. For the remaining 5, deviations from the requirement varied. The largest number of logs with an insufficient allowance was found in delivery I (36 out of 164 logs). When these logs were moved to a smaller length grade, there was a loss of 1.118 m³, which represents a loss of 4.42 % from the total 25.29 m³ of the delivery.

A special case was delivery O. Here, a large amount of wood (1.77 %) was supplied with an allowance larger than 2 %. At the same time, 3 pieces did not have enough allowance, which represents a loss of 0.88 %. The accuracy of log length was very different. This could be due to poor terrain conditions or the inexperience of the cutting operator.

The best results in terms of accuracy of cuts were found in delivery K. Here, the allowances were the smallest of all the evaluated deliveries and the supplier "donated" only 0.7 % of the wood volume to the customer. In addition, the delivery did not include any undersized logs.

Total volume losses of the deliveries caused due to extra allowances and due to classification to a lower length grade are visible in the graph in Figure 9. It was not possible to establish the relationship between the accuracy of cutting and losses because of the small number of deliveries.

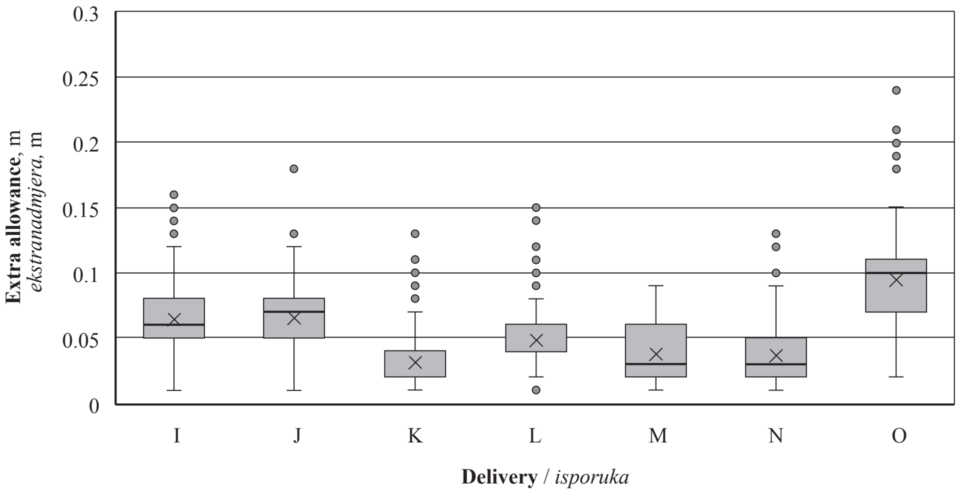

Figure 7 Box chart of extra allowance of logs in 2013 evaluating the deliveries separately
Slika 7. Grafikon ekstranadmjera dužine trupaca prema njihovim isporukama u 2013.

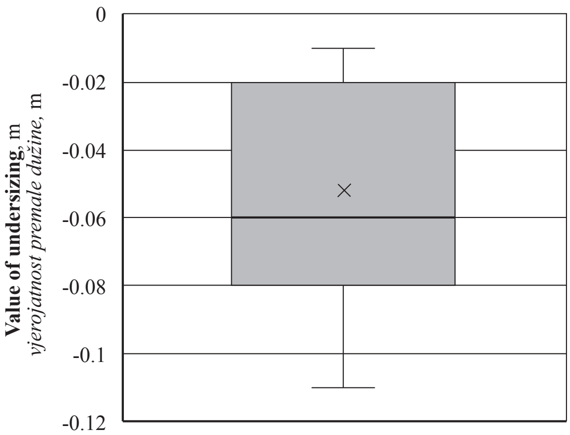

Figure 8 Box chart of the difference between the required allowance and measured value of undersized logs in 2013
Slika 8. Grafikon razlike između potrebnih nadmjera i izmjerene vrijednosti dužine kraćih trupaca u 2013.

3.2.3 Check measurements 2015
3.2.3. Kontrolna mjerenja u 2015. godini

In 2015, a similar check measurement was carried out, but only the deliveries of logs were available. Long round timber was not evaluated. The results are similar to those in 2013, and therefore graphs with detailed results will not be shown. The average extra allowance length was 4.5 cm (a median of 5 cm). Within a delivered volume of 384.99 m^3, this represents 3.782 m^3, i.e. less than 1 %.

The number of undersized logs was 24 out of a total of 1,259. When these logs were moved to a smaller length grade, there was a loss of 0.57 % in volume. Of the 14 deliveries reviewed, only 3 were without a single undersized log. The worst result was found in delivery *i*, in which 7 out of 60 pieces were shorter, and the volume loss due to reclassification was 2.9 %.

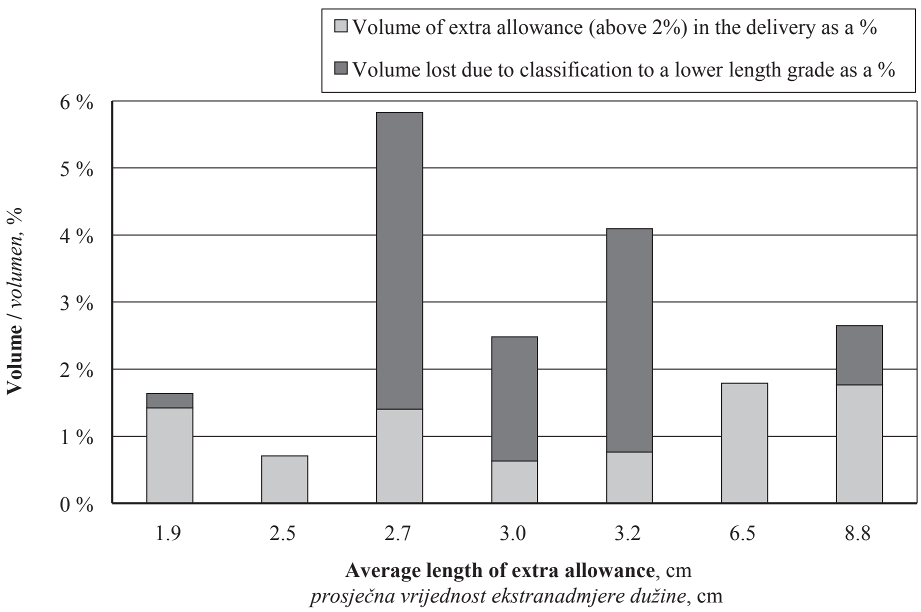

Figure 9 Total losses of wood volume in individual log deliveries
Slika 9. Ukupni gubitci volumena drva u pojedinačnim isporukama trupaca

Table 2 Analysis of log deliveries in 2013
Tablica 2. Analiza isporuke trupaca u 2013.

Delivery *Isporuka*	**Delivery volume according to delivery notes, m³** *Količina isporuke prema dostavnicama*, m³	Number of logs in the delivery *Broj isporučenih trupaca*	**Number of logs in the delivery with an allowance below 2 %** *Broj isporučenih trupaca s nadmjerom manjom od 2 %*	**Number of logs in the delivery with an allowance below 2% from the entire delivery** *Broj isporučenih trupaca s nadmjerom manjom od 2 % cjelokupne isporuke*	**Volume lost due to classification to a lower length grade, m³** *Gubitak volumena zbog klasifikacije u niži razred dužine*, m³	**Volume lost due to classification to a lower length grade as, %** *Volumen izgubljen zbog klasifikacije u niži razred dužine, %*	**Volume of extra allowance (above 2%) in the delivery, m³** *Volumen ekstranadmjere dužine (iznad 2 %) u isporuci*, m³	**Volume of extra allowance (above 2%) in the delivery, %** *Volumen ekstranadmjere dužine (iznad 2 %) u isporuci, %*	**Average length allowance, cm** *Prosječna nadmjera dužine*, cm
I	25.29	164	36	21.95	1.118	4.42	0.355	1.40	2.7
J	29.60	187	0	0.00	0.000	0.00	0.531	1.79	6.5
K	29.53	170	0	0.00	0.000	0.00	0.210	0.71	2.5
L	30.52	222	2	0.90	0.065	0.21	0.434	1.42	1.9
M	29.87	79	8	10.13	0.553	1.85	0.188	0.63	3.0
N	32.12	179	27	15.08	1.070	3.33	0.245	0.76	3.2
O	32.85	83	3	3.61	0.289	0.88	0.581	1.77	8.8
Total *Ukupno*	209.78	1084	76	7.01	3.096	1.35	2.543	1.21	

Here, the explanation could be that the delivery was made for another customer who required an allowance of only 1 % (according to the older ČSN) or 5 cm (as is sometimes the case). When recalculating in accordance with these rules, not a single log was undersized (in Table 3, these hypothetical values are indicated in parentheses). The volume of extra allowance was 1.24 %, with the average allowance being 6.6 cm and the median 6 cm (Figure 10). In the graph, the deliveries are arranged according to the average of extra allowances with the goal to show possible dependence of losses (higher loss due to extra allowance versus lower loss due to moving of the log to a smaller length grade and vice versa).

3.3 A theoretical analysis of losses
3.3. Teorijska analiza gubitaka

As part of the theoretical analysis, the volumes of extra allowances were calculated depending on log mid-diameter (X-axis) and length, and expressed as a percentage of the nominal volume of the entire log. In graph 11, an excess allowance of 5 cm is expressed as a percentage. This allowance corresponds to the average value obtained from the actual data. Each curve represents an increase in the percentage loss of volume with increasing log diameter of the given length. The shorter the log and the larger the log diameter, the greater is the excess in volume.

Similarly, a graph could be made of the proportion of the volume of one length increment in the volume of the entire log that varies depending on the length of the log and its diameter. When moving a log to a lower length grade, diameter has a significantly greater effect on the expected volume loss than length. However, if the loss is recalculated as a percentage of the volume of the log, the length dependence is significant.

The next graph (Figure 12) shows the percentage of extra allowance volume in log volume depending on its mid- diameter (x-axis). Each colour curve corresponds to an extra allowance in centimetres. The graph was compiled for a length of 4 m (most of the suppliers included 4 m logs).

If the suppliers know or can estimate the average length of extra allowances in their deliveries, they may deduce the losses in this graph, e.g. if they usually supply 4 m logs with an average mid-diameter of 25 cm and the extra allowance is 5 cm on average, their loss corresponds to 1.05 %. If they produce logs with an extra allowance of about 7 cm, the extra allowance volume would additionally be 1.47 %.

3.4 General results
3.4. Opći rezultati

In terms of the volume of raw material supplied, it is more advantageous for the supplier to deliver round timber in full lengths, as the losses caused by reclassification to lower length grades do not mean as much loss as for logs.

However, suppliers of long round timber often leave allowances more than 20 cm longer than required. While in 2013 these extra allowances represented 1.21 % in logs, in long round timber, the volume was 1.84% of the volume of wood from the analysed

Table 3 Analysis of log deliveries in 2015
Tablica 3. Analiza isporuke trupaca u 2015.

Delivery *Isporuka*	**Delivery volume according to delivery notes, m^3** *Količina isporuke prema dostavnicama,* m^3	**Number of logs in the delivery** *Broj isporučenih trupaca*	**Number of logs in the delivery with an allowance below 2 %** *Broj isporučenih trupaca s nadmjerom manjom od 2 %*	**Number of logs in the delivery with an allowance below 2% from the entire delivery** *Broj isporučenih trupaca s nadmjerom manjom od 2 % cjelokupne isporuke*	**Volume lost due to classification to a lower length grade, m^3** *Gubitak volumena zbog klasifikacije u niži razred dužine,* m^3	**Volume lost due to classification to a lower length grade as, %** *Volumen izgubljen zbog klasifikacije u niži razred dužine, %*	**Volume of extra allowance (above 2%) in the delivery, m^3** *Volumen ekstranadmjere dužine (iznad 2 %) u isporuci,* m^3	**Volume of extra allowance (above 2%) in the delivery, %** *Volumen ekstranadmjere dužine (iznad 2 %) u isporuci, %*	**Average length allowance, cm** *Prosječna nadmjera dužine,* cm
a	31.18	86	2	2.33	0.114	0.37	0.312	1.00	6.0
b	32.53	106	2	1.89	0.212	0.65	0.102	0.31	1.8
c	30.69	107	1	0.93	0.095	0.31	0.249	0.81	4.9
d	23.64	86	1	1.16	0.068	0.29	0.259	1.10	5.0
e	24.45	111		0.00	0.000	0.00	0.247	1.01	4.5
f	26.37	88	1	1.14	0.075	0.28	0.401	1.52	6.4
g	25.56	66	1	1.52	0.123	0.48	0.324	1.27	5.6
h	27.97	116	4	3.45	0.303	1.08	0.116	0.41	1.7
i	26.37	60	7 (0)	11.67 (0)	0.772 (0)	2.93 (0)	0.082 (0.328)	0.31 (1.24)	2.1 (6.6)
j	26.28	90	1	1.11	0.070	0.27	0.315	1.20	5.4
k	26.08	80	2	2.50	0.221	0.85	0.225	0.86	3.6
l	28.28	105		0.00	0.000	0.00	0.477	1.69	6.8
m	26.34	124	2	1.61	0.146	0.55	0.182	0.69	2.2
n	29.25	34		0.00	0.000	0.00	0.493	1.69	7.1
Total *Ukupno*	384.99	1259	24 (17)	1.91 (1.35)	2.199 (1.427)	0.57 (0.37)	3.782 (4.028)	0.98 (1.05)	4.5 (4.8)

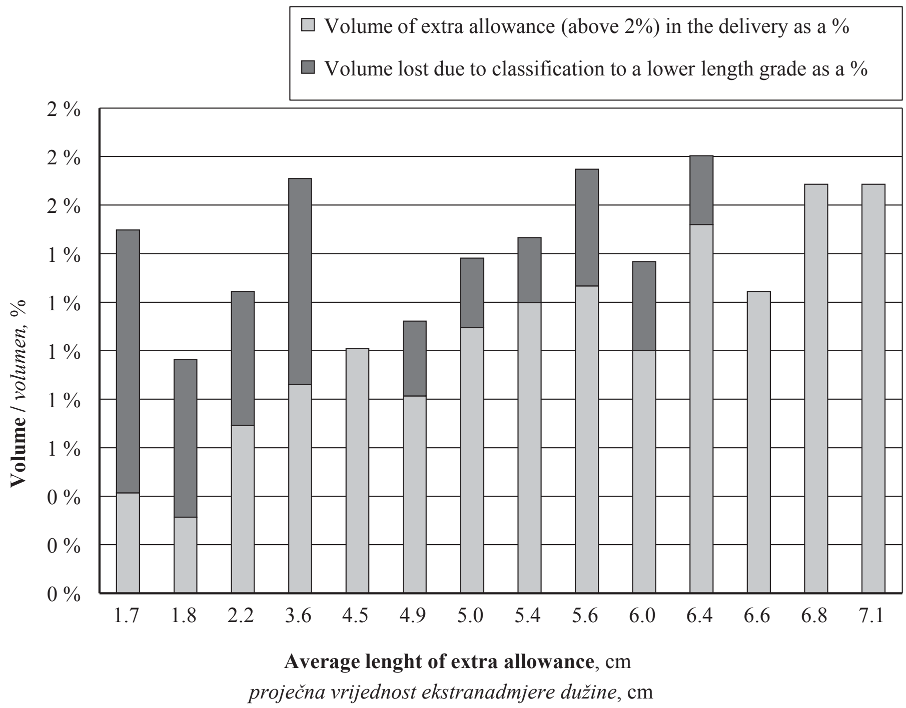

Figure 10 Comparison ("dependence") of the volume loss due to classification of the logs with undersized length to a lower length grade (dark part of the column) and volume, lost due to extra allowances (light part of the column)
Slika 10. Usporedba („ovisnost") gubitka volumena zbog klasifikacije trupaca premale dužine u niži razred dužine (tamni dio stupca) i volumena izgubljenoga zbog ekstranadmjere dužine (svijetli dio stupca)

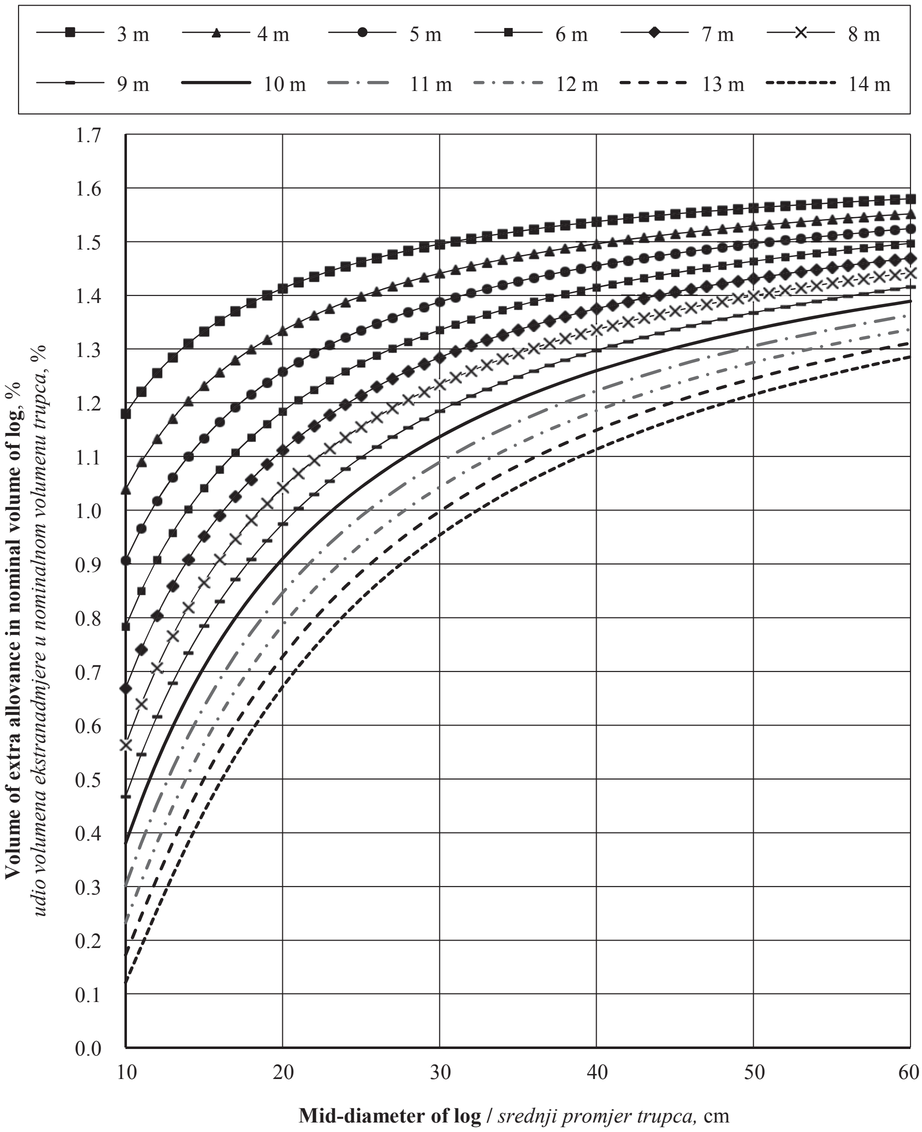

Figure 11 Proportion of volume of extra allowance in mid-diameter (course of curves) and length (single curves) of the log
Slika 11. Udio volumena ekstranadmjere dužine u nominalnom volumenu trupca ovisno o srednjem promjeru (smjer krivulja) i duljini (pojedinačne krivulje) trupca

deliveries. Unfortunately, in the following years, long round timber deliveries were not analysed.

In addition, there was no noticeable difference in the average value of the allowances year-on-year – the average value ranged from 4.5 to 5.5 cm, but the median was the same: 5 cm. When comparing losses caused by undersized logs, there is evident development for the better, i.e. the proportion of undersized logs decreased significantly (from 7 % in 2013 to 1.7 % in 2018).

The results of the experimental measurements show that the most common extra allowance length was 5 cm. In the case of deliveries with a smaller allowance, the incidence of undersized logs was higher. Conversely, for deliveries with an extra allowance close to 7 cm on average, the probability of reclassification was lower, and the difference in lost volume was not very noticeable when the loss in allowance and reclassification was added. In addition, an extra allowance of 5 cm in logs of the most common lengths was outside the permissible measuring device error of 1%. Therefore, if an electronic measurement is underestimated by the maximum permissible deviation (i.e. 5 cm in logs of 5 m in length), the log will not be marked as undersized and moved to a smaller length grade.

Furthermore, the evaluation shows that most deliveries show a loss of at least 1%. The loss is either made up of only the volume of wood that is part of the extra allowance, or a combination of that volume with the volume lost due to reclassification. In the first case, the loss is less costly for the supplier. In the worst case, the supplier loses a small portion for the “fibres” that would be produced at the thinnest part of the round timber. However, this is only possible for very long units, of which more logs will be made with a larger allowance. Otherwise, it means only less of green split billet or firewood (if produced) or fewer cuttings in the forest.

In the latter case, the supplier loses more because the volume deducted upon reclassification is a volume of quality wood, the price of which normally significantly exceeds the price of the above-mentioned wood assortments.

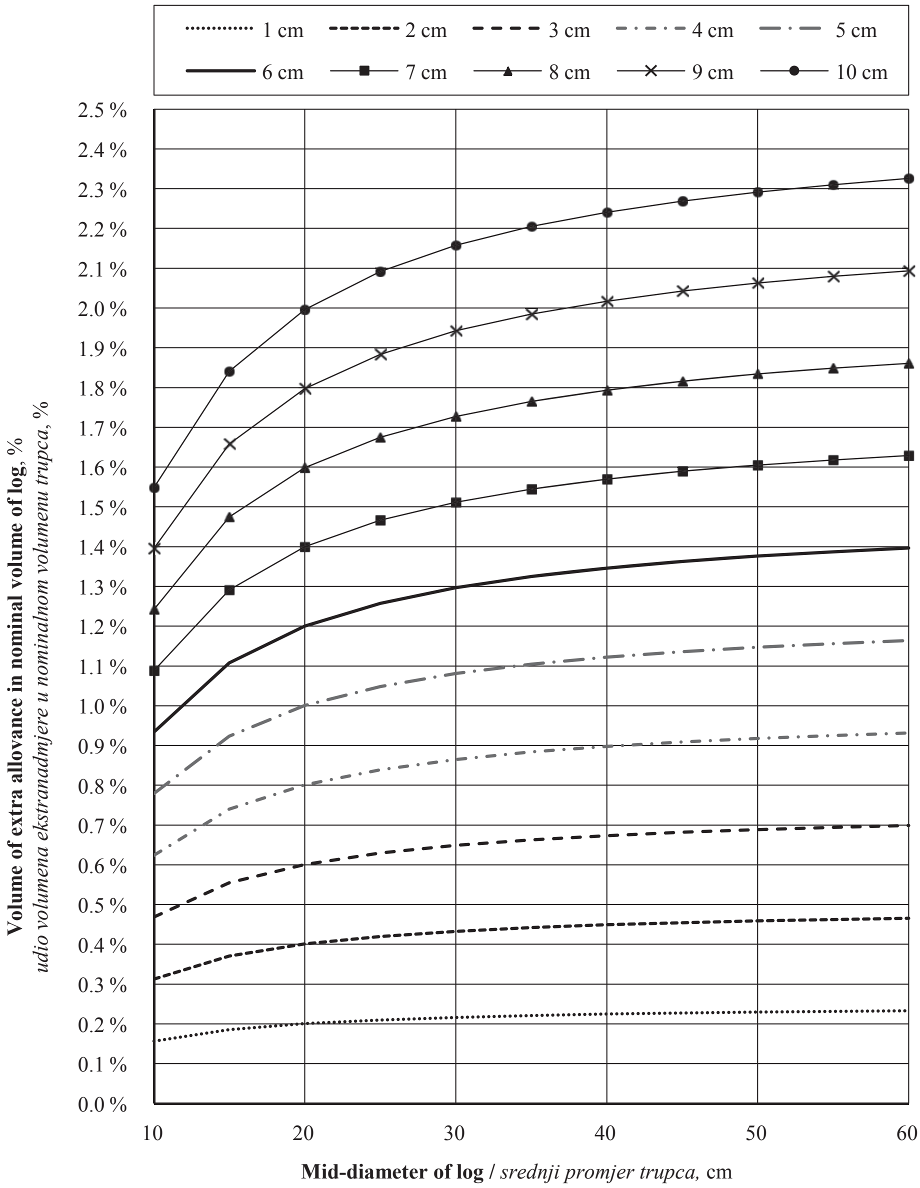

Figure 12 Proportion of extra allowance volume in log mid-diameter (course of curves) and length (single curves) of extra allowance, expressed in percentage of log volume
Slika 12. Udio volumena ekstranadmjere dužine u ukupnom volumenu trupca ovisno o srednjem promjeru trupca (smjer krivulja) i duljini trupca s ekstranadmjerom (pojedinačne krivulje), izraženo postotkom ukupnog volumena trupca

The customer wins in either case. In the case of an unnecessarily large allowance, the customer obtains raw material for the production of split billet (mostly without bark), which can be sold as raw material for other production. In the case of undersized logs, of course, the customer also has material for making split billet. However, in some cases, the cut may be left unabridged, as an addition of 1 % is usually sufficient for the production of lumber of a given length. This is especially true for smaller companies where the operator can focus on individual slots.

The analysis was carried out for 1 m steps, which is nowadays most common in practice for saw logs. At 0.5 m increments, the losses would be halved. However, this also leads to a higher number of produced assortments, splitting of production and higher sorting requirements at the processor. This is only worthwhile for small sawmills.

In any case, it means a loss of quality material, which is then used for split billet or even ends up as fuel for the energy purposes of the processor.

Unfortunately, the measurements taken did not record how the logs were processed. It is therefore not possible to assess whether it was by manual production or a harvester, and whether this affected the accuracy of production. However, it can be expected that the answer is ‘yes’. This factor will be examined in the next stage.

However, classification of a log into a lower length grade may affect the accuracy of the measuring equipment when used for round timber takeover. This could be the case if a log has an allowance of exactly 2

% or only slightly larger. Only one such case emerged from the check measurements. However, not all deliveries had acceptance sheets and therefore it was not possible to detect all these cases.

During calibration measurements, 3 % of all measurements were moved to a lower nominal length. However, these 3 % represent 32 % of the measurements of logs with an exact allowance or an allowance of only 1 cm larger. This shows that it would be appropriate to tolerate deviations of about 1 cm, which corresponds to the observed average measurement accuracy. On the contrary, this is too great a risk for the supplier if the logs are cut precisely.

4 CONCLUSIONS
4. ZAKLJUČAK

The analysis was focused on length allowances with which logs are produced in the Czech Republic. For this purpose, data from check measurements carried out by suppliers in 2013 and 2015 were used, as well as data obtained from calibrations of electronic measuring devices performed by round timber customers. The volume loss represented by an allowance exceeding the required length of 2 % of the length of the log was quantified. Further losses occur when there is an insufficient allowance. The log is moved to a lower length grade, so the loss corresponds to the length of this grade – in the Czech Republic, the most often used increments are 1 m. Both losses were expressed as a percentage of the volume of the log as a whole.

Experience from calibration and an analysis of the measured data show that electronic equipment is regularly maintained and calibrated to the required accuracy. However, this may not be the case for other equipment; in case of any doubts, it would be advisable to have the measuring equipment inspected by an accredited laboratory.

The results of the analysis therefore give the following recommendations: for suppliers who do not use harvesters for felling and logging, it would be preferable to supply round timber in full lengths due to the volume lost to reclassification. Today, however, this is not possible in most cases because large customers buy only logs because of technological reasons. Another aspect is the price, which is usually higher for raw material in logs.

In the production of logs, it is preferable to increase the required 2 % allowance by 4-5 cm if it is possible to produce logs relatively accurately. If accuracy cannot be maintained, it is preferable to increase the allowance to about 7 cm (e.g. mountainous terrain, poor quality and curved timber, lack of experienced staff).

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Climate Signals in Earlywood, Latewood and Tree-Ring Width Chronologies of Sessile Oak (*Quercus petraea* (Matt.) Liebl.) from Majdanpek, North–Eastern Serbia

Klimatski signali u kronologijama ranog drva, kasnog drva i širini goda hrasta kitnjaka (*Quercus petraea* (Matt.) Liebl.) iz Majdanpeka, sjeveroistočna Srbija

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ABSTRACT • *In this article, the dependence of the sessile oak (Quercus petraea (Matt.) Liebl.) radial growth (tree-ring, earlywood, and latewood widths) on climate (the mean monthly temperature and precipitation totals) was studied in the Majdanpek area, north-eastern Serbia. The growth response of the oak trees to the prevailing climate conditions was dendroecologically investigated, by applying the correlation and response function, as well as by pointer years analysis. The site chronology covered 159 years (1855-2013). We found that latewood and total tree-ring width contain the imprinted positive response to the amount of precipitation in summer months (June and July) of the current growing season. The earlywood width showed no direct dependence on climate data, but it was significantly affected by the previous-year latewood width. Moreover, 40 % of the variation in the latewood width is explained by the earlywood variation in the same season. The temperature was not found to have any significant effect on the growth of oak at the study site. The use of pointer years, determined by applying several calculation procedures, has highlighted previous results, indicating that the precipitation in summer months was the deciding climate factor leading to the occurrence of the years with exceptionally wide or narrow tree-rings and latewood. To enhance our understanding of the response of the sessile oak growth at south-oriented sites with a shallow soil profile to precipitation and temperature variations, and expand the current database and knowledge, future studies should be undertaken.*

Keywords: *dendroecology; earlywood; latewood and tree-ring; pointer years; sessile oak; Serbia*

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SAŽETAK • *U radu je proučavana ovisnost radijalnog prirasta (širine goda, širine ranoga i kasnog drva) hrasta kitnjaka (Quercus petraea (Matt.) Liebl.) o klimi (srednjoj mjesečnoj temperaturi i količini oborina) na području Majdanpeka, u sjeveroistočnoj Srbiji. Odziv radijalnog rasta hrastovih stabala na prevladavajuće klimatske uvjete istražen je dendrokronološki, primjenom korelacijske i odzivne funkcije, kao i analizom pokaznih godina. Kronologija staništa obuhvatila je 159 godina (1855. – 2013.). Otkrili smo da kasno drvo i ukupna širina goda sadržavaju utisnut pozitivan odziv na količinu oborina u ljetnim mjesecima (lipnju i srpnju) tekuće sezone rasta. Širina ranog drva nije pokazala izravnu ovisnost s klimatskim uvjetima, ali je na nju značajno utjecala širina kasnog drva iz prethodne godine. Nadalje, 40 % varijacija širine kasnog drva objašnjava se varijacijama ranog drva iz iste sezone. Na istraživanom staništu nije utvrđeno da temperatura ima značajan utjecaj na rast hrasta. Primjena pokaznih godina, koje su određene primjenom nekoliko računskih postupaka, potvrdila je prethodne rezultate upućujući na to da je prevladavajući klimatski čimbenik koji je doveo do pojave izrazito širokih ili uskih godova i kasnoga drva u pojedinim godinama bila količina oborina u ljetnim mjesecima. Da bi se sveobuhvatno razumjela reakcija rasta hrasta kitnjaka na promjene temperature i količinu oborina na južnim ekspozicijama i s plitkim profilom tla, trebalo bi provesti dodatne studije kako bi se proširila baza podataka i spoznaja.*

Ključne riječi: *dendrokronologija; rano drvo; kasno drvo i god; pokazne godine; hrast kitnjak, Srbija*

1 INTRODUCTION
1. UVOD

Although oaks are among the most investigated tree species in Europe in terms of dendrochronology and dendroclimatology, oak dendrochronology is a dynamic and continuously evolving discipline (Haneca *et al.*, 2009). The majority of oak chronologies have been developed in Central and Western Europe (Čufar *et al.*, 2014b). In the Balkan Peninsula, the highest number of oak dendrochronological and dendroclimatological studies have been performed in Slovenia (Čufar and Levanič, 1999; Čufar *et al.,* 2008; 2014a; 2014b; Čater and Levanič, 2015 etc.), Romania (Popa *et al.*, 2013; Ważny *et al.,* 2014; Nechita *et al.,* 2017 etc.) and Bulgaria (Asenova *et al.,* 2001; Mirtchev *et al.,* 2012; Zafirov and Kostov, 2019 etc.). The studies of oak growth-climate relationships, based on the latest dendrochronological procedures, have been rather poorly performed in other countries of this part of SE Europe. In Croatia, Čufar *et al.* (2014a) constructed a pedunculate oak radial growth chronology from Kobiljak and investigated the oak climate-growth relationships for this site near Zagreb. This chronology and an oak chronology from Serbia have been used within a network of 41 local oak tree-ring chronologies to detect common climatic signals in oak tree rings in SE Central Europe (Čufar *et al.,* 2014b). The pedunculate oak sensitivity to climate and hydrological parameters in the floodplain forests in the lowland Croatia was studied by Mikac *et al.* (2018). In Serbia, similar research of the pedunculate oak growth and mortality in oak floodplain forests, depending on the change of water regime and climate, was performed by Stojanović *et al.* (2015). Some facts about the dendroclimatological behaviour of sessile oak in Serbia were presented by Stajić *et al.* (2015). The relationships between the radial increment and stable carbon isotope of *Q. robur* and *Q. cerris* and climatic variables have been most recently examined by Kostić *et al.* (2019), etc.

Despite numerous studies that have been conducted across Europe in the past decades, information about the oak growth-climate response is still lacking in South-Eastern Europe (Stajić *et al.,* 2015). Therefore, given the substantial potential significance of SE Europe for dendrochronological research (Ważny *et al.,* 2014), as well as the insufficient number of such studies in Serbia, the first goal of this research was to construct the sessile oak tree-ring chronology for the study site conditions near Majdanpek (North-Eastern Serbia). After defining the new oak chronologies, further research efforts will be focused on identifying the most important climatic elements that influence the radial growth of this species. To obtain the strongest climatic signal possible, we developed sessile oak chronologies separately for the total ring width (TR), earlywood width (EW), and latewood width (LW).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The research was carried out in a pure mature sessile oak forest (*Quercetum montanum tilietosum tomentosae*) in a regeneration phase, in the locality of Debeli Lug, Majdanpek, in north-eastern Serbia (Figure 1). The sampling (stem discs at breast height) was conducted at around 300 m a.s.l, on shallow soil of slightly steep, south-facing terrain. The climate data were obtained from the "Debeli Lug" meteorological station (290 m a.s.l.). The available climate data covered the period from 1949 to 2013, but the records were quite incomplete. To fulfil the gaps and prepare the data for a dendroclimatological analysis correctly, we applied the Inverse distance interpolation with five nearest nearby meteorological stations (Žagubica, Kučevo, Negotin, Donji Milanovac and Bor), and the data were tested for homogeneity. The average annual temperature (9.8 °C) is close to the average value in Serbia amounting to 10.1°C. The warmest and coldest months are July (20.3 °C) and January (-1.3 °C). The annual sum of precipitation is 734 mm/m^2 and it also reflects the country's average (Popović *et al.,* 2005).

To study oak radial growth-climate relationships, we sampled 19 dominant sessile oak trees with a diameter ranging from 42.6 to 72.3 cm. The measurements of EW, LW, and TR widths were performed in two directions using a Lintab device (38 empirical RAW series). The obtained series were cross-dated visually and

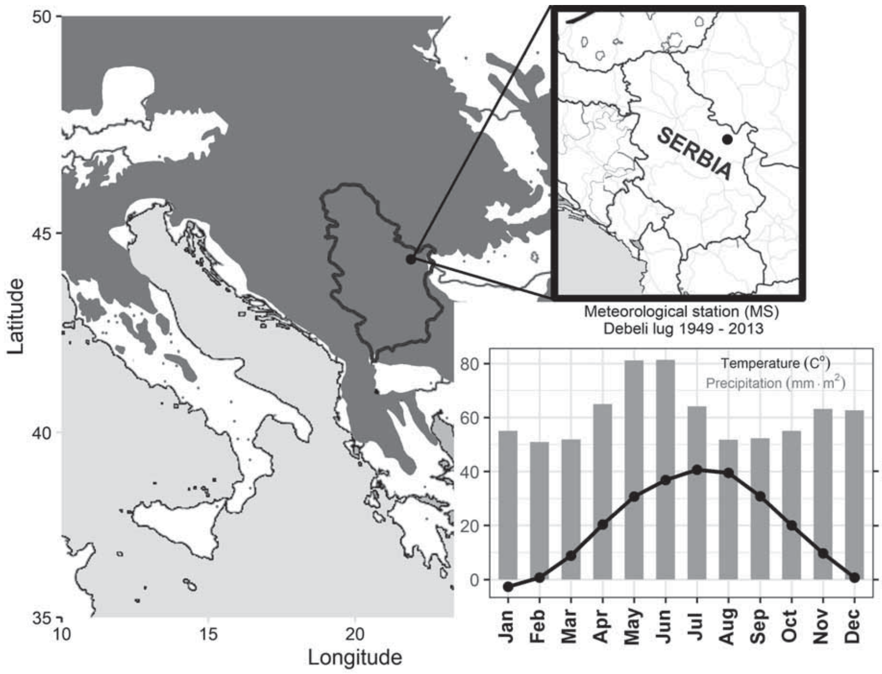

Figure 1 Location of the study stand (black dots) within the sessile oak areal (dark grey) and within the state border of Serbia (upper right corner). The sum of precipitation (grey bars) and mean air temperature (black line with dots) are given in the lower right part

Slika 1. Lokacija istraživane sastojine (crne točkice) unutar područja rasprostranjenosti hrasta kitnjaka (tamnosivo) i unutar državne granice Srbije (gornji desni kut). Ukupna količina oborina (sivi stupci) i srednja temperatura zraka (crna linija s točkama) dani su u donjem desnom dijelu slike.

statistically in the R environment (R Development Core Team, 2008). At the same time, the conventional statistical parameters were calculated. The stand w regularly managed and, therefore, the series were detrended by using a cubic smoothing spline having a 50 % cut-off at 67 % of the series length (Cook and Peters, 1981). The series of standardised indices were obtained after the measured widths were divided by the estimated values. The "prewhitened" series were then established as a residual of the autoregressive modelling, where the order for the individual series was determined by the Akaike Information Criterion. Both types of indices were subsequently averaged by applying a biweight robust estimation of the mean value (Cook *et al.*, 1990). Thus, we developed a standard (STD) and a residual (RES) chronology for each part of the radial increment separately. The presence and the strength of the common signal in the series were evaluated by computing several widely-applied dendrochronological parameters: the mean total, the correlation within and between the trees (r_{tot}, r_{wt}, r_{bt}), Expressed Population Signal (EPS) and Signal-to-Noise Ratio (SNR).

The influence of climatic factors on the width of EW, LW, and TR was studied using (1) the correlation analysis between the developed chronologies and climate and (2) the response function analysis. We used the monthly sum of precipitation and the mean temperature data of the previous August to October of the current year (30 independent variables). Besides, TR, EW, and LW from the current and the previous year were also included in the analysis. The significance of the obtained correlation coefficients was determined following the bootstrapping procedure (Zang and Biondi, 2015). The temporal stability of the radial growth-climate relationships was evaluated using moving windows. Because of the higher number of predictors included in the regression, the coefficients were calculated for 50-year long periods, moved for one year across the common period. Furthermore, pointer years in the longest common period of RES were examined by using three different approaches, i.e., nine calculation variants. For the interval trend (IT), we applied the routines suggested by Schweingruber (1983) and Becker *et al.* (1994), following the instruction of Jetschke *et al.* (2019) for pointer year threshold of 0.95. The calculation of the relative growth change (RGC) was based on four preceding years (Schweingruber *et al.*, 1990). The normalisation in a symmetrically moving window (NW) was implemented by using a window of different sizes as well as different thresholds for the event year occurrence (Cropper, 1979; Neuwirth *et al.*, 2007). For the pointer year identification within RGC and NW methods, we adopted the threshold of 0.75, as recommended by Jetschke *et al.* (2019). All calculations were conducted in R language (R core team, 2008), with the application of dplR (Bunn, 2008), pointRes (Van der Maaten-Theunissen *et al.*, 2015) and treeclim library (Zang and Biondi, 2015).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

To establish a sound basis for a dendroecological study in a new region, it is necessary to understand the characteristics of the sampled trees of the locally avail-

Table 1 (A) Correlation statistics of STI and RES indexed series (1880 – 2013), (B) the main statistical parameters of the STD and RES oak chronology (1855 – 2013). Abbreviations: r_{tot} – total correlation, r_{wt} – within-trees correlation, r_{tb} – between-trees correlation, EPS – Expressed Population Signal, SNR – Signal-to-Noice Ratio, SD – standard deviation, MS – mean sensitivity and AC1 - Autocorrelation order 1.
Tablica 1. (A) Korelacijska statistika STI i RES indeksiranih sekvencija (1880. – 2013.); (B) glavni statistički pokazatelji definiranih STD i RES kronologija hrasta (1855. – 2013.). Kratice: r_{tot} – ukupna korelacija, r_{wt} – korelacija unutar stabala, r_{tb} – korelacija između stabala, EPS – izraženi signal populacije, SNR – omjer signal : šum, SD – standardna devijacija, MS – srednja osjetljivost, AC1 – autokorelacijski red 1.

	Chronology type *Tip kronologije*		r_{tot}	r_{wt}	r_{bt}	**EPS**	**SNR**			**SD**	**MS**	**AC1**
(A)	TR *Širina goda*	STI	0.46	0.73	0.45	0.97	32.1	(B)	STD	0.24	0.23	0.34
		RES	0.47	0.70	0.46	0.97	33.8		RES	0.22	0.26	-0.05
	EW *Širina ranog drva*	STI	0.20	0.36	0.20	0.91	9.8		STD	0.11	0.10	0.44
		RES	0.18	0.31	0.18	0.90	8.5		RES	0.10	0.10	0.23
	LW *Širina kasnog drva*	STI	0.47	0.73	0.46	0.97	33.2		STD	0.32	0.34	0.28
		RES	0.47	0.71	0.47	0.97	34.1		RES	0.30	0.36	- 0.04

able material (Hughes *et al.*, 1978). The longest chronology was composed of 159 tree rings (1855-2013), while the average number of tree rings (N) amounted to 152. The mean width of the TR, EW, and LW raw series amounted to 1.75, 0.60, and 1.15 mm, respectively. Hence, LW amounted to 66 % of the TR width, on average. For raw series, the mean sensitivity coefficient (MS) for LW, TR, and EW was 0.43, 0.30, and 0.24, respectively. Autocorrelation coefficients of the first order (AC1) for raw series varied from 0.58 (LW) to 0.66 (TR). The detrending procedure and the calculation of the standardised indices significantly reduced the AC, while the MS values slightly changed. After the autoregressive modelling of the standardised indices series, the MS values increased, while the AC was removed entirely.

The results of the correlation statistics of the indexed series (standardised – STI and residual – RES) show that the average values of the calculated parameters (r_{tot}, r_{wt}, r_{bt}, EPS and SNR) are almost the same for TR and LW and higher compared to EW (Table 1), indicating that EW contains the lowest common signal. Having averaged the individual series, the STD and RES site chronologies were obtained (Figure 2), and their basic statistical parameters are shown in Table 1B. As the RES chronologies are slightly more sensitive than the STD ones, we decided to use the RES chronologies of TR, EW, and LW for further analysis.

The results of the climate-growth correlations reveal that the EW chronology is significantly positively correlated (r = 0.41, p <0.01) with the LW formed in the previous year (LW_{t-1}) and not directly related to the monthly climate data (Figure 3). The findings that EW is correlated with LW_{t-1} are also confirmed by the results of the response function (Figure 3), indicating that 16 % (p <0.01) of the total variation are related to LW_{t-1}.

The insensitivity of the EW chronologies to the studied monthly climate parameters was also determined by Nechita and Popa (2011) for oak growing in Vaslui region, Romnia. In some cases, when the direct climate-growth relationship could not be confirmed, the dependence of EW on the LW of the preceding year can be noticed (García González, Eckstein 2003; Sohar *et al.*, 2013). Since LW reflects the amount of summer precipitation, this can be seen as a kind of “indirect” climate influence on the EW width in the following year. Contrary to EW and LW, the TR chronologies

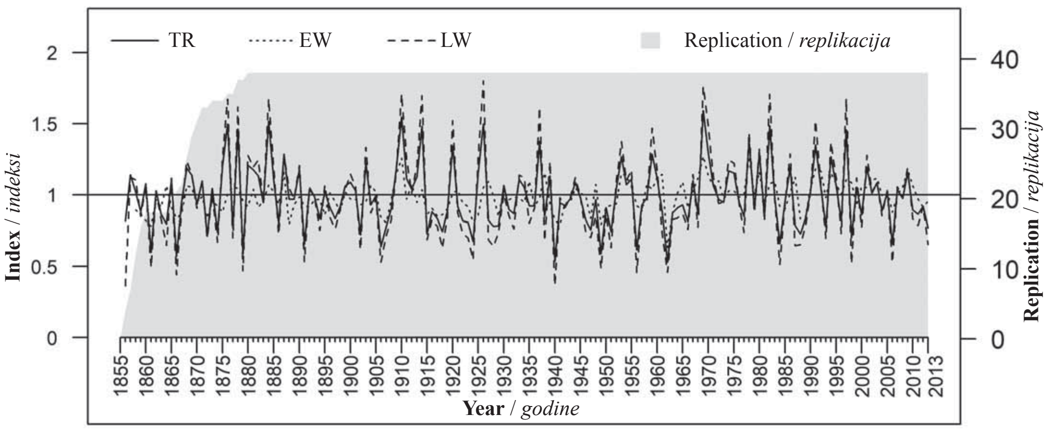

Figure 2 Residual oak chronologies (RES) for TR, EW and LW (1855 – 2013). Abbreviations: TR- tree ring, EW – earlywood and LW – latewood
Slika 2. Rezidualna kronologija hrasta (RES) za TR, EW i LW (1855. – 2013.). Kratice: TR – širina goda, EW – rano drvo i LW – kasno drvo.

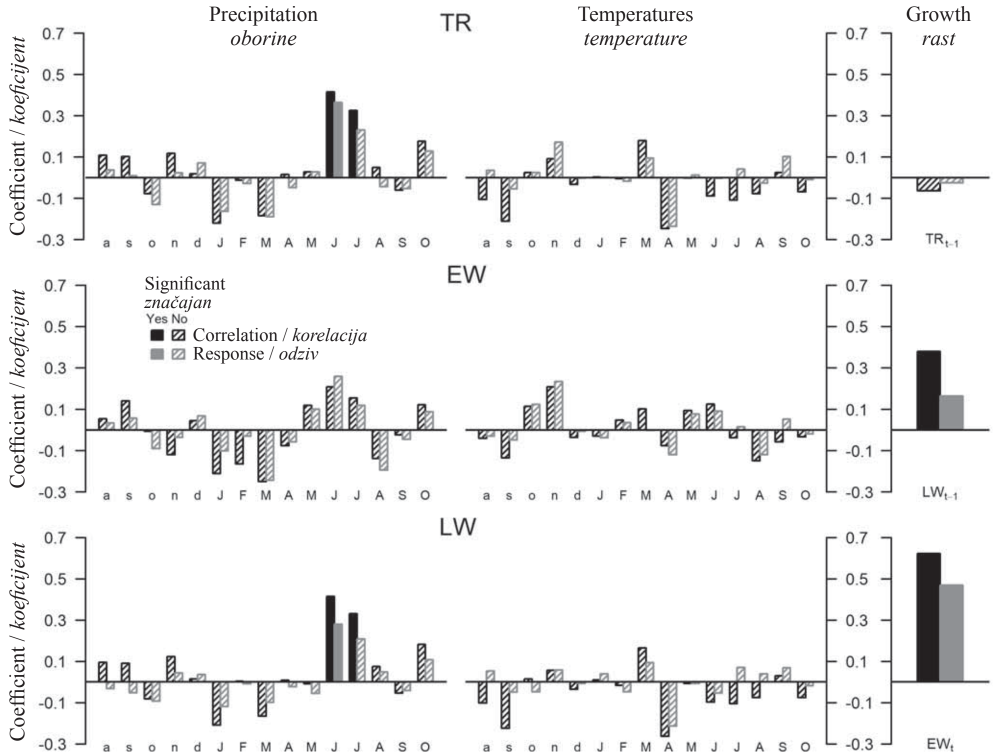

Figure 3 Correlation and response coefficients of TR, LW, and EW, calculated between residual chronologies and monthly temperature and precipitation (1950 – 2013). Lower and upper cases denote month of the previous year and the current year, respectively. Filled bars indicate significant correlation (black) and response (grey) coefficients at the 99 % level

Slika 3. Koeficijenti korelacije i odziva TR, LW i EW izračunani između rezidualne kronologije i mjesečne temperature i količine oborina (1950. – 2013.). Mala i velika slova označuju mjesec prethodne odnosno tekuće godine. Ispunjeni stupci upućuju na značajne koeficijente korelacije (crni) i odziva (sivi) pri razini od 99 %.

were not significantly related to any of the analysed growth independents from the previous growing season (Figure 3). Further, the TR and LW chronologies were positively influenced by the precipitation in the current June (r_{TR} = 0.42, r_{LW} = 0.41) and July (r_{TR}=0.32, r_{LW}= 0.34), indicating that the high precipitation during the summer months of the current year is of the utmost importance for the formation of sessile oak TR and LW in the studied conditions. The LW chronology was also strongly correlated (r = 0.61) to the EW of the current year (EW_t). The results of the conducted response function additionally clarified the obtained findings, suggesting that the widest LW and TR are expected to be produced in the years with abundant June precipitation. Namely, these results showed that TR was positively influenced by the current June precipitation and this variable explained 17 % (p<0.001) of the total variation in the TR chronology.

Climate response and correlation models for LW found June precipitation and EW_t to be statistically significant. These variables (16 % - June precipitation and 40% - EW_t, p <0.001) explained almost 50 % of the total variance in the LW chronology. It must be noted that neither the correlation nor the response analysis found any significant influence of monthly temperatures. Such dependency of the sessile oak radial growth on water availability in early summer is not typical for the growth of sessile oak in the northwestern part of Serbia, on Fruška Gora Mountain (Stajić *et al.*, 2015). These authors found no statistically significant relationships between the sessile oak growth and the current summer monthly precipitation data. The main reason for the observed divergence in the growth reactions of sessile oak is the fact that the soil of the stand on Fruška Gora Mountain is characterized as deep, high-quality, and well-drained soil with a good water-air regime. On this soil, oak trees withstand a lack of precipitation and high temperatures in June and July without much difficulty (Stajić *et al.,* 2015). However, in case of further exposure to high temperatures in August, followed by small amounts of precipitation, it can be expected that typically low growth of oak in August could be even significantly lower, as reported by Stajić *et al.* (2015) for oak in the north-western part of Serbia. On the other hand, oak trees at warmer, south-oriented sites with a shallow soil profile are highly exposed to summer droughts, as is the case in the present study. In such circumstances, during dry summer months, trees suffer from water deficit that acts as a growth-limiting factor.

Besides that, June is characterized by a prolonged photoperiod, which can be an additional reason for increased demand for water supply. Therefore, in case of wet and sunny conditions in June, the maximum wood growth can be expected in many sites in SE Central Europe (Čufar *et al.*, 2014a). However, Čufar *et al.* (2014a) concluded that there were some similarities, but they also found some differences concerning the

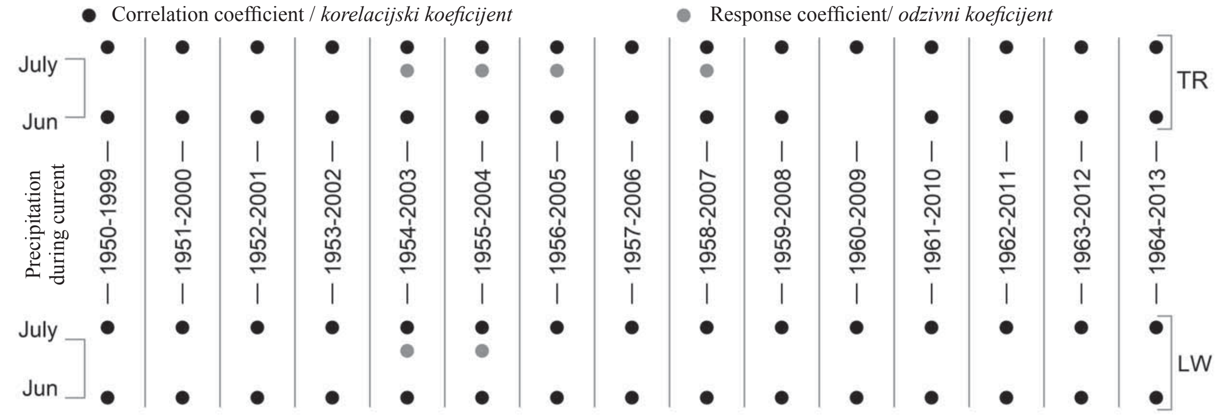

Figure 4 Temporal stability of dendroclimatic relationships, a 50-year moving window of correlation and response function for TR and LW chronology. Only significant coefficients are shown ($p<0.01$)
Slika 4. Vremenska stabilnost dendroklimatskih odnosa, 50-godišnji pomični prozor korelacijske i odzivne funkcije za TR i LW kronologiju; prikazani su samo značajni koeficijenti ($p<0,01$)

effects of climate on the oak tree-ring variability among the studied localities in SE Central Europe. Regarding oak stand in Serbia, which is located near the Sava River in the lowland area of Srem, Čufar *et al.* (2014a) did not find a statistically significant relationship between the oak growth and monthly temperature or precipitation data of the current year. Also, no significant impact of precipitation on the oak growth in Serbia was found for the pedunculate and Turkey oak growing in the lowland area in the northern part of the country (Stojanović *et al.*, 2015).

To evaluate the temporal stability of the dendroclimatic signal observed, we implemented the bootstrap moving response function. The months, which had been previously highlighted as important for the radial growth, were included in this procedure. The results indicated that the detected impact of monthly climate conditions established quite a stable correlation across the common period (Figure 4). The July correlation is significant in each investigated position of the window, while the June correlation showed occasional insignificance. A similar performance was ascertained for the response coefficients in the TR, while the most unstable correlation was revealed for the LW chronology.

The detected link between the sessile oak TR and LW growth and the precipitation in summer months was confirmed by the results of the pointer year analysis (Figure 5). The determination of the pointer years represents a common practice applied in dendroclimatological studies, but the existence of various calculation procedures has caused a sort of selection bias. Therefore, Stajic *et al.* (2017) and Jetschke *et al.* (2019) highlighted the need for standardisation, which would enable reliable comparisons of various results. To address this problem, we have proposed that only those years that are determined by two or more methods used here can be marked as pointer years. Following these recommendations, we determined positive (1997, 1982, 1969, 1926, 1920, 1910, 1903, and 1884) and negative (2006, 1962, 1956, 1940, 1902 and 1891) pointer years common to LW and TR. The positive years of 1994 and 1887 were identified only for TR, while an exceptionally narrow LW portion was formed during 1998, 1984, and 1886. A strict routine in terms of selected thresholds and the use of more than one of the applied methods resulted in the identification of noticeably fewer pointer years (16 for TR and 17 for LW) than in some other oak dendroclimatologial studies. The applied procedures for the pointer year calculation detected the absence of the years with an exceptionally wide or narrow EW portion of a tree ring. The detected pointer years occurred with precipitation anomalies. Both types of pointer years for TR and LW are related to the below and above long-term averages of precipitation in summer months. Three common positive pointer years for TR and LW were 1997, 1982, and 1969, which were characterized by exceptionally abundant precipitation summer months. Compared to the average reference period values (1961-1990), these years in August (1997), July (1982), and June (1969) had 172 %, 209 %, and 257 % more precipitation. Three common positive pointer years for TR and LW that occurred in the years with exceptionally abundant precipitation in July (1982), June (1969), and August (1997) were equal to or higher than the reference period values (1961-1990).

Within the group of negative pointer years, pronouncedly low values of TR and LW were determined by different dry periods of the current year. Namely, these common pointer years (2006, 1962, and 1956) were characterized by the following prevailing low-amounted precipitation drivers: Sep-Oct, May and August, respectively, when the amount of precipitation was 67-91 % below the 30-year average value. Extremely narrow LW widths are related to very pronounced anomalies in the precipitation in June (1998) and August (1984), with 53 % and 19 % of the 30-year average precipitation value, respectively.

The present climate-growth results are mostly in concordance with the common feature of the oak's response in the Balkans and surrounding countries. In Croatia, the pedunculate oak growth was positively

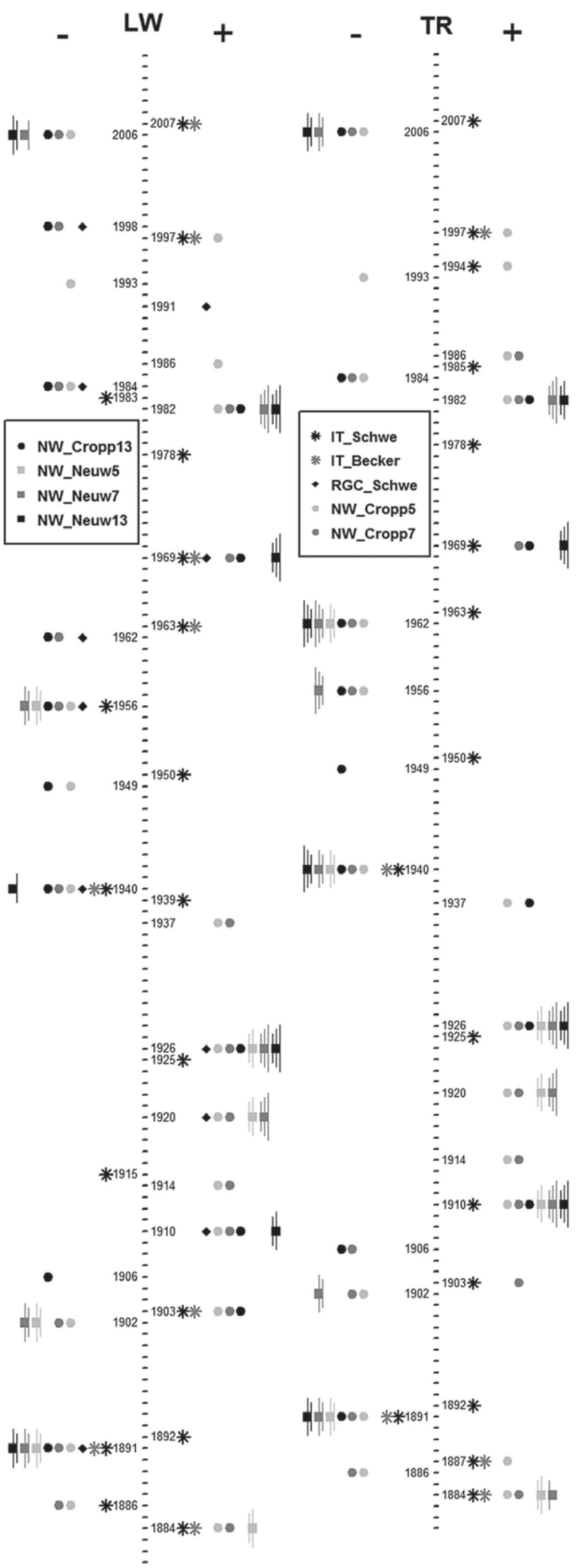

Figure 5 Pointer years for TR and LW determined by applying Interval trend approach, given by Schweingruber (1983) - IT_Schwe and Becker *et al*. (1994) - IT_Becker, relative growth change approach of Schweingruber et al. (1990) - RGC_Schwe and Normalisation in a symmetrically moving window of 5, 7 and 13 years, suggested by Cropper (1979) and Neuwirth et al. (2007) - NW_Cropp5, 7, 13 and NW_Neuw5, 7, 13. The number of vertical lines on Neuw* points indicates the strength of pointer year. One vertical line over squares designates a weak pointer year (C values > 1), two are for strong (C > 1.28), and three are for extremely strong (C > 1.645)
Slika 5. Pokazne godine za širinu goda i širinu kasnog drva određene primjenom pristupa intervala trenda prema Schweingruberu (1983.) – IT_Schwe i Becker *et al*. (1994.) – IT_Becker, pristupa relativne promjene rasta prema Schweingruberu *et al*. (1990.) – RGC_ Schwe i normalizacije u simetričnome pomičnom prozoru širine 5, 7 i 13 godina, predloženima od Croppera (1979.) i Neuwirtha *et al*. (2007.) – NW_Cropp5, 7, 13 i NW_Neuw5, 7, 13. Broj vertikalnih linija na točkama Neuw* svjedoče o snazi pokazne godine. Jedna vertikalna linija iznad kvadrata označava slabu (vrijednosti C>1), dvije jaku (C> 1,28), a tri izrazito jaku pokaznu godinu (C> 1,645).

correlated to June precipitation (Čufar *et al.*, 2014 b). Similar results were found in Romania, in the western part (Popa *et al.*, 2013) and North-West part of the Carpathian Mountains (Nechita *et al.*, 2017), where the sessile oak shows a particular dependency on the precipitation regime in June. In the most comprehensive research of the common climatic signal in the oak chronologies in central Europe and the Balkans, Čufar *et al.* (2014a) determined a positive correlation between the June precipitation and PC1 from 41 studied chronologies. Similarly, Griggs *et al.* (2006) and Kern *et al.* (2012) identified the precipitation in May-June as the most influential period for the oak growth in the Aegean area (Turkey) and western Hungary, respectively. Further, May-August precipitation was the main factor driving the oak growth in the eastern part of the Great Hungarian Plain (Árvai *et al.,* 2018).

4 CONCLUSIONS
4. ZAKLJUČAK

Conversely to many other regions and countries, dendroclimatological studies have not been intensively carried out in Serbia. The results of this study showed that the main factor limiting the process of the TR and LW growth formation in the sessile oak from Majdanpek (Eastern Serbia) was summer precipitation, especially in June. The fact that a higher amount of summer precipitation increases the TR and LW width was confirmed by the multi-approach dendroclimatological procedure. The absence of a significant negative reaction of sessile oak to temperature is not such a common feature of the oak response in many European and Balkan countries. Additionally, the impact of the previous year's climate on the sessile oak growth was not detected. Finally, the main limitation of this research is the spatial representativeness of the sampled stands, since the obtained results represent the first insight into the dendroclimatological behaviour of sessile oak in this part of Serbia. To achieve a better and deeper insight into the reaction of the sessile oak growth at south-oriented sites with a shallow soil profile to precipitation and temperature variations, as well as to expand the existing database and knowledge, future studies should be undertaken.

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Research into Corner L Separable Assemblies in Storage Furniture

Istraživanje rastavljivih kutnih L-sastava namještaja za odlaganje

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ABSTRACT • *This research is based on the testing of the impact of the board (particleboard and medium density fiberboard (MDF)) and hardware type used to connect the sides and the bottom or top of the storage furniture on the joint strength. The hardwares of the following trade mark were used: the confirmat screw, Minifix, Maxifix, Stablofix, RV and Solo 32. Such hardwares make it possible to disassemble the furniture as well as to assemble it (when moving the furniture) without reducing joint strength when reassembling it due to wear and tear on the material (with the exception of the confirmant screw). Research results showed that assemblies with the Maxifix hardware installed in the MDF base exhibited the highest values of bending moment (the average bending moment of 85.88 Nm). On the other hand, assemblies with the Minifix hardware installed in the particleboard exhibited the lowest values of bending moment (over three times lower than the Maxifix) (the average bending moment of 24.50 Nm). Assemblies with the confirmat screw exhibited satisfactory results, although, aesthetic requirements seem to be the main problem here (the average bending moment of 40.38 Nm for the particleboard and of 64.24 Nm for the MDF board).*

Keywords: *corner assembly; separable assemblies; hardware; fitting; storage furniture*

SAŽETAK • *Istraživanje se temelji na ispitivanju utjecaja vrste drvne ploče (iverice i MDF ploče) i tipa okova koji služi za povezivanje stranice i poda ili stropa namještaja za odlaganje na čvrstoću kutnog spoja. Kao spojni okov rabljeni su oni trgovačkog naziva confirmat vijak, minifix, maxifix, stablofix, RV i solo 32. Navedeni okov omogućuje rastavljanje i sastavljanje namještaja (npr. prilikom selidbe namještaja) a da pri ponovnom sastavljanju ne bude narušena čvrstoća spoja zbog habanja materijala (izuzetak je confirmat vijak). Prema rezultatima istraživanja, najveće vrijednosti momenta savijanja zabilježene su u sastava s maxfix okovom ugrađenim u podlogu od MDF ploče (prosječni moment savijanja 85,88 Nm). Najmanje vrijednosti momenta savijanja (preko tri puta manje u usporedbi s maxifixom) izmjerene su za sastav s minifix okovom koji je ugrađen u ploču ivericu (prosječni je moment savijanja 25,40 Nm). Spojevi s confirmat vijkom pokazuju zadovoljavajuće rezultate momenta savijanja, ali su estetski zahtjevi glavni problem tog načina povezivanja elemenata (prosječni moment savijanja za troslojnu ploču ivericu iznosi 40,38 Nm, a prosječni je moment savijanja za MDF ploče 64,24 Nm).*

Ključne riječi: *kutno sastavljanje; rastavljivi sastavi; okov; vezni elementi; namještaj za odlaganje*

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1 INTRODUCTION
1. UVOD

Storage furniture is everywhere around us and there is hardly a living quarter or business premises without it. Such furniture is usually of considerable dimensions so that it is desirable for such furniture to be reassemblable so that it may be easily transported and delivered to its user. It is designed for the storage of objects. It may be classified according to its place of use, dimensions, purpose, constituent material and technology, construction, historic style, etc. Storage furniture is most commonly constructed as cabinets of larger dimensions, so that the desirable construction is the one that makes it possible to assemble and disassemble the cabinet corpus at its end user's location. Therefore, this type of furniture should be connected with fittings. Assembling principles for the cabinet corpus are determined by corner plane L assemblies and the mutual position of the side and the middle side in relation to the bottom and the top. In case of larger cabinets, its back is an important part of its construction. The cabinet back is a plate element closing the corpus from the back side and maintaining the position of the corpus sides at right angles in relation to the bottom and the top. It has a big impact on construction strength and rigidity.

Yerlikayae (2012) tested the corner L joint for strength on specimens made of particleboard. The testing was done on five specimen types connected with five angled plane assembly types: butt joint reinforced with fiber-glass fabric, dowel joint, dowel joint reinforced with fiber-glass fabric, dowel joint with the Minifix hardware, dowel joint and the Minifix hardware reinforced with fiber-glass fabric. The results showed that the glass-fiber composite layer considerably enhances the strength of a joint, and that the increase is significantly higher under compressive load than under tensile load. Both types of test recorded the highest joint strength, i.e. for the dowel joint and for the Minifix hardware reinforced with glass-fiber fabric.

Atar and Ozcifci (2007) analyzed the impact of screws and dowels on the strength of the angled plane assembly. Materials used for the research were: solid beechwood, particleboard, medium density fiberboard (MDF) and wood core plywood. Elements used for assembling corner joints were dowels, screws and PVAc adhesive. The highest value of bending moment of 133.7 Nm was measured on the specimen made of MDF, and the lowest of 111.0 Nm on the specimen made of wood core plywood.

Vassiliou and Barboutis (2009) analyzed the static bending strength of the joint with hardwares of four manufacturers: Hettich, Germany; Häfelle, Germany; Lama, Slovenia and of an unknown manufacturer. As their results showed, static bending strength depends on the manufacturer, hardware type and the type of the material on which the hardware is applied. The results also showed that certain metal hardwares exhibit higher static bending strength values than the plastic ones. Furthermore, the research revealed that the hardware exhibits higher static bending strength values when applied in the MDF (plastic hardware by 32.58 %, metal hardware by 35.72 %) than when applied in the particleboard.

Kurelia and Altinoka (2011) researched into mechanical properties of corner joints (in relation to pressure and tension) made of particleboard, fiberboard and particleboard reinforced with synthetic resins. Three testing types were carried out: testing the corner L joint for compressive strength, testing the corner L joint for tensile strength and testing the corner T joint for tensile strength. The Minifix system was used as the hardware in two versions, with plastic and metal housing. The results showed that the strongest joint was the one in the MDF connected with the metal or plastic Minifix system or in the improved MDF. This also leads to the conclusion that the board and hardware type influence joint strength and that, when making the construction joint, attention should be paid to the choice of the board and hardwares.

Jivkov and Grbac (2011) examined the impact of static and dynamic loading on the bending moment in the angled plane assembly. The specimens were made of 18 mm thick MDF and connected with the dowel, screw, confirmat screw and bolt with the turning pin (two types). The joints with the screw and the confirmat screw exhibited the best results. The joint with the dowel exhibited a 40 % lower bending moment than the assembly with the screw. According to the authors, the assembly with the bolt with the turning pin exhibited the lowest bending moment as expected (80 % lower than the screw).

Ayrilmis and Akbulut (2018) analyzed the screw withdrawal resistance and the interlayer strength in fiberboards. The screw withdrawal resistance increases with the increase in the fiber length in the middle layer and the increase in the resin portion in the middle layer, with the increase in the surface/middle layer ratio and the increase in the board density.

Smardzewski and Ożarska (2005) examined the mathematical model of the rigid composition with the confirmat screw and the numeric model of office furniture assembled with the confirmat screw. It turned out that corner assembly models with the confirmat screw produce firmly fastened assemblies. The deformation of the assembly, as well as of elements to be assembled, represents the rigidity of the construction, which depends on the element geometry after deformation and material properties. The force applied on the screw contributes to its shear loading. When designing and constructing furniture with corner joints, it is important to take into account that material rigidity properties and the flexibility coefficient are characteristic of the angled plane assembly.

Smardzewski and Klos (2011) determined the values of the substitute linear elasticity module in corner joints with dowels subjected to pressure and tension testing. The joint deflection was also tested, and alternative models were made. The research was conducted on the angled plane assemblies with dowels made of solid beech wood with the dimensions of Ø 8 mm × 32 mm. The specimens were made of 16 mm particleboard. The values of numeric calculations obtained from the models truly represent the shape of the tested joints, which are significantly lower than laboratory measurement results. On the other hand, the comparison of the calculation results obtained from models containing nods with substitute linear elasticity modules and the empirical results shows that they are mostly somewhat higher.

Eren and Eckelman (1998) figured out that joint strength and the number of joint components had a correlation. They explained that there are significant differences in strength from board to board. Zhang and Eckelman (1993) analyzed the rational design of multi-dowel corner joints in 19 mm-thick particleboard case construction. Their results indicated that maximum strength was obtained when the distance between the dowels was at least 76 mm.

Žulj *et al*. (2015) researched into the angled plane L assembly made of MDF with the density of 0.826 g/m^3, 18 mm thick and melamine faced. The boards were assembled with dowels, wood biscuits, the Minifix hardware and Tofix hardware. The bending moment was highest in the dowel joint (34.87 Nm), then in the wood biscuit joint (32.34 Nm) and the Minifix hardware (20.35 Nm). The lowest value was recorded in connections with the Tofix hardware (14.85 Nm). Tofix is also the weakest joint, whose average bending moment is 2.4 times lower than the one of the dowel joint.

Župčić *et al*. (2012) researched into the strength of angled plane L assemblies made of particleboard (with the average density of 0.63 g/m^3) connected with the bolt with the turning pin, wood biscuit dowel, screw and confirmat screw. As research results show, the highest bending moment values are those in assemblies with the confirmat and screw, and the lowest in assemblies with the bolt with the turning pin. The glued joint with dowels and biscuits exhibits higher bending moment values in relation to the decomposable joint with the bolt with the turning pin because of the adhesive, which reduces the delamination of the particleboard, increasing thus joint strength.

The type of the selected assembly or connecting element significantly impacts bending moment values and therefore the strength of storage furniture.

The board type, the storage furniture is made of, is not only an important strength factor of such furniture, but also an important factor regarding the price of the future product. Due to larger overall dimensions of such furniture, construction rigidity and decomposable assembly are required. Therefore, the study aimed at researching into the impact of the board type (particleboard and MDF) and the hardware that connects elements on assembly strength.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Making specimen samples
2.1. Izrada uzoraka

The research was conducted at the Faculty of Forestry, University of Zagreb. The tested specimens had the dimensions of 100 mm × 100 mm × 100 mm (angled plane assembly, L assemblies) and the specimens consisted of two elements of different dimensions, one of which had the dimensions of 100 mm × 100 mm × 18 mm and the other of 100 mm × 82 mm × 18 mm, connected into the L assembly. The specimens

Table 1 Marks of specimens used in research
Tablica 1. Oznake uzoraka obuhvaćenih istraživanjem

Specimen mark *Oznaka uzorka*	**Specimen description** / *Opis uzorka*
CO-IT	Specimen made of particleboard and connected with Confirmat screw *uzorak izrađen od iverice povezan confirmat vijkom*
CO-MDF	Specimen made of MDF and connected with Confirmat screw *uzorak izrađen od MDF ploče povezan confirmat vijkom*
MF-IT	Specimen made of particleboard and connected with Minifix hardware *uzorak izrađen od iverice povezan minifix okovom*
MF-MDF	Specimen made of MDF and connected with Minifix hardware *uzorak izrađen od MDF ploče povezan minifix okovom*
MAF-IT	Specimen made of particleboard and connected with Maxifix hardware *uzorak izrađen od iverice povezan maxifix okovom*
MAF-MDF	Specimen made of MDF and connected with Maxifix hardware *uzorak izrađen od MDF ploče povezan maxifix okovom*
STF-IT	Specimen made of particleboard and connected with Stablofix hardware *uzorak izrađen od iverice povezan stablofix okovom*
STF-MDF	Specimen made of MDF and connected with Stablofix hardware *uzorak izrađen od MDF ploče povezan stablofix okovom*
RV-IT	Specimen made of particleboard and connected with RV hardware *uzorak izrađen od iverice povezan RV okovom*
RV-MDF	Specimen made of MDF and connected with RV hardware *uzorak izrađen od MDF ploče povezan RV okovom*
S32-IT	Specimen made of particleboard and connected with Solo 32 hardware *uzorak izrađen od iverice povezan okovom solo 32*
S32-MDF	Specimen made of MDF and connected with Solo 32 hardware *uzorak izrađen od MDF ploče povezan okovom solo 32*

were assembled by a fitting without any adhesive applied. Materials used for the research were an improved 18 mm thick particleboard and an improved 18 mm thick MDF. The boards were of an unknown manufacturer; the internal bond (IB) for the MDF board was 0.309 N/mm^2 and for the particleboard it was 0.358 N/mm^2. Altogether 120 specimens were made, 20 series for six hardware types (Minifx, Stablofix, Maxifix, Solo 32, RV, Confirmat) with ten specimens of the particleboard and ten of the MDF for each of the six hardware types (Table 1). Both boards were melamine faced with the edges left uncoated. The examined hard-

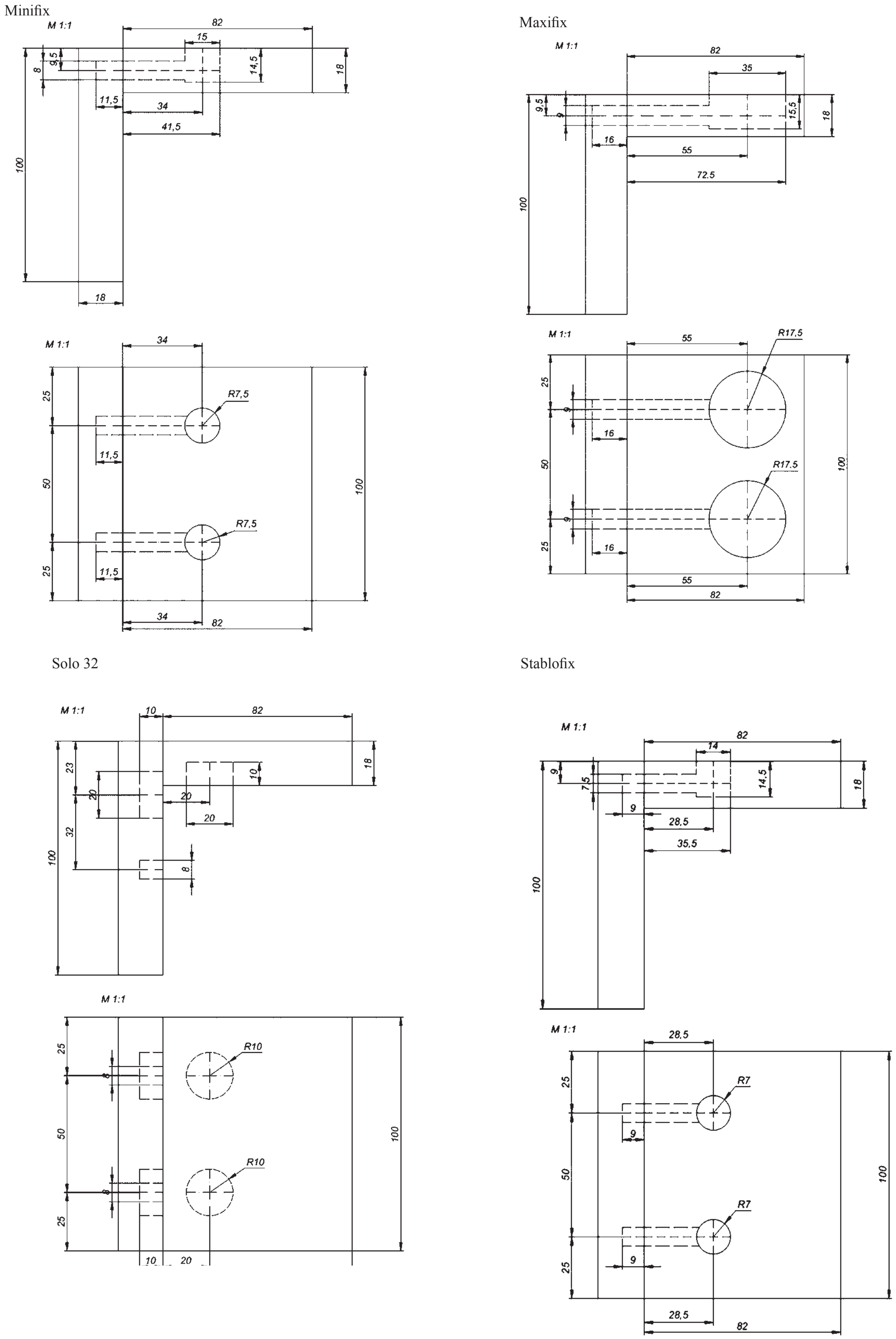

Figure 1 Drawing and layout of L assembly for six hardware types
Slika 1. Nacrt i tlocrt L-sastava za šest tipova okova

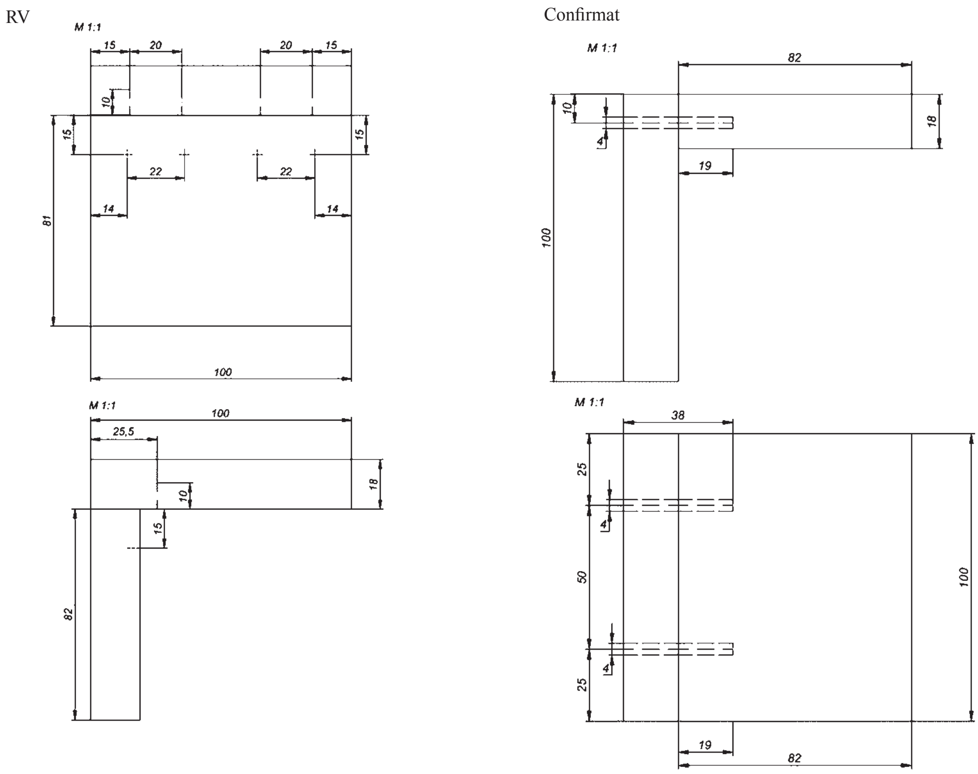

Figure 1 Drawing and layout of L assembly for six hardware types
Slika 1. Nacrt i tlocrt L-sastava za šest tipova okova

ware belonged to the product range of the Häfelle GmbH & Co KG Company, its Zagreb branch. Both board types used for the research originate from a regular sale and were of an unknown manufacturer.

The boards were conditioned at (23 ± 2) °C and (50 ± 5) % relative air humidity for twenty days in the climatic chamber in the Furniture Testing Laboratory, and then the required dimensions were cut. After the cutting, holes were drilled on the elements depending on the hardware applied (Figure 1) and L specimens were assembled in the workshop of the Faculty of Forestry.

The average moisture content was determined by HRN EN 322:2003 and it was 7.50 % for the particleboard and 7.41 % for the MDF board. Density was also determined on the same probes. The average density, determined by HRN EN 323:2008, of the improved particleboard was 0.69 g/cm^3 and 0.86 g/cm^{3}of the improved MDF.

2.2 Testing method
2.2. Metoda ispitivanja

The assembled specimens were conditioned for 25 days (the samples were not assembled under laboratory conditions and were again conditioned) and then tested on the universal testing machine. These assembled specimens were tested on a computer-aided Shimadzu AG-X universal testing machine. The displacement speed during the testing was 5 mm/min. The specimens were tested with the articulation gripping jaws, which enabled their precise positioning (Figure 2). A total of 120 specimens were used for the testing, all of them properly assembled with no visible defects or other damage on the board.

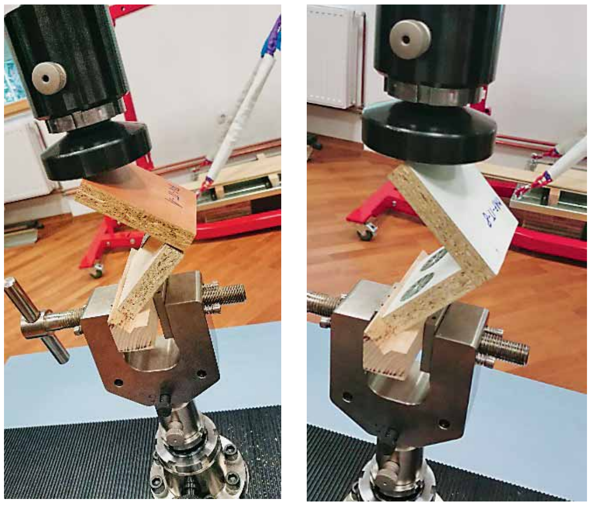

Figure 2 Testing method of bending moment for: a) RV hardware; b) Maxfix hardware
Slika 2. Način ispitivanja momenta savijanja: a) okov RV; b) okov maxifix

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The research results (Table 2, 3, 4 and Figure 3) show that the board and hardware type have an impact on both the bending moment of the assembly and its strength (as the parameters are the same for all specimens and no adhesive was applied when assembling). The choice of board type has a statistically significant impact on the joint strength in all hardware types except for S32 specimens. As a result, joints made of MDF exhibit statistically higher bending moment values in all hardware types (except for S32 specimens) than the joint made of particleboard. Such results were to be expected as the MDF is of a more homogeneous structure as compared to the particleboard and exhibits different mechanical properties.

The hardware type also has a considerable impact on bending moment or joint strength results in specimens made of particleboard and MDF. The highest bending moment value was recorded in MAF-MDF specimens (Maxifix) made of MDF with the average value of 85.88 Nm, while the lowest bending moment value of only 25.40 Nm was recorded in MF-IT specimens (Minifix) made of particleboard. For purposes of the research, 18 mm thick boards were used as they have adequate thickness for all hardware types. The Maxifix hardware is of a robust construction so that it takes a large portion of the loading in the joint. Besides that, this hardware type may be applied on thicker boards so that it can be assumed that, under such conditions, joint strength would be higher. During the testing, the delamination of the board occurred in all MAF specimens. This points to the fact that wood core plywood, veneered wood panel or solid wood panel (solid across its width and length) would reach better joint strength values with this hardware as they are more resistant to delamination. According to the research of Jivkov and Grbac (2011), samples jointed with a confirmation screw have the highest values of bending moment (33.42 Nm), while samples jointed with Minifix and Rafix have the lowest values of bending moment, 9.75 Nm and 6.02 Nm, respectively. The distribution is similar as in this research.

Different hardware types installed in the MDF exhibit a statistically significant difference in the bending moment except for RV and CO specimens and STF and MF specimens. MAF specimens (MDF) have 2.4 higher values as compared to STF specimens, indicating that the choice of the hardware type has a large impact on the assembly strength when assembling storage furniture. IT specimens show a somewhat smaller ratio of 2.1 times (between MAF-IT and MF-IT).

In case of L assemblies, the aesthetic of the assembly matters as well, besides its strength. All hardware types used for this research are on the inner side of the joint except for the confirmat screw. The confirmat screw is therefore the least acceptable aesthetically, as it is visible on the furniture lateral side. Maxifix is a robust and big system that may be hidden beneath cover caps and shows the best results for the boards tested. It may be installed in boards of larger dimensions and, therefore, proves to be the most acceptable. The strength of the same assembly on the various plate materials may deviate significantly. These deviations are even greater with different structural assemblies on the same material (Tkalec and Prekrat 2000).

Besides the strength and aesthetic of the joint, there are other factors that need to be considered such as hardware complexity for installation, its price, market availability, etc. All these factors influence the functionality, safety, reliability and aesthetic of furniture and its technological and financial availability to the customer.

Figure 4 shows load-displacement curve. Force increases in accordance with displacement up to its maximum value and starts decreasing thereafter. The increase in force to the maximum value (for all assemblies) is similar. However, its decrease differs and mostly depends on the hardware type. In MF, MAF and STF specimens, due to force, the following phenomena occur: board delamination in the hardware installation zone, screw head passing through the board in CO specimens, screw withdrawal from the board in RV hardwares, hardware bending in S32 specimens. In case of S32 hardware, the board type has no statistically significant impact on joint strength due to the specific nature of such hardware and hardware bending when tested. Screws that fasten the hardware to the boards and the fitting itself take joint strain (in CO, RV and S32). Therefore, no joint fracture occurs, but rather an easy screw withdrawal from the board and hardware bending.

Table 2 Descriptive statistics of bending moment (Nm) depending on board and hardware type
Tablica 2. Deskriptivna statistika momenta savijanja (Nm) u ovisnosti o vrsti ploče i tipu okova

Specimen *Uzorak*	**Number of specimens, *N*** *Broj uzoraka, N*	**Average** *Srednja vrijednost*	**Standard deviation** *Standardna devijacija*	**Minimum**	**Maximum**	**Q25**	**Median**	**Q75**
CO-IT	10	40.38	3.46	35.21	45.47	36.65	41.24	42.42
CO-MDF	10	64.24	5.21	56.55	72.22	61.15	63.78	66.00
MAF-IT	10	52.91	7.62	34.29	59.95	49.18	54.35	58.78
MAF-MDF	10	85.88	9.22	72.31	99.63	81.32	85.07	92.92
MF-IT	10	25.40	2.56	22.31	28.99	22.48	25.59	27.07
MF-MDF	10	43.04	2.22	40.57	47.81	41.18	42.56	43.88
STF-IT	10	27.29	2.06	23.39	31.18	26.21	27.33	27.51
STF-MDF	10	36.68	3.18	31.61	41.23	34.91	37.53	38.92
RV-IT	10	48.73	3.65	41.31	53.37	47.93	49.16	50.94
RV-MDF	10	63.34	3.34	59.21	69.42	60.20	63.38	65.35
S32-IT	10	50.32	1.23	48.11	51.90	49.51	50.21	51.41
S32-MDF	10	52.16	1.54	48.98	53.76	50.81	52.95	53.21
All specimens *svi uzorci*	120	49.20	16.72	22.31	99.63	38.00	49.24	58.99

Table 3 Statistical testing of variance for all samples together
Tablica 3. Statističko testiranje varijance za sve uzorke

Variable / *Varijabla*	Levene Test of Homogeneity of Variances / *Leveneov test značajnosti varijanci* *Marked effects are significant at p<0.05000 / označeni su efekti značajni pri p<0.05000*							
	SS Effect	*df* Effect	*MS* Effect	*SS* Error	*df* Error	*MS* Error	*F*	*p*
Bending moment, Nm *moment savijanja*, Nm	378.4366	11	34.40332	749.0131	108	6.935306	4.960606	0.000003

Table 4 Post-hoc test for all samples
Tablica 4. Post-hoc test za sve uzorke

Specimen *Uzorak*	**Scheffe Test; Variable: Bending moment, Nm** / *Scheffe tes varijable: moment savijanja,* Nm **Marked differences are significant at *p*<0.05000** / *označeni su efekti značajni pri p<0.05000*											
	(1) M=40.382	(2) M=64.240	(3) M=52.919	(4) M=85.880	(5) M=25.405	(6) M=43.042	(7) M=27.294	(8) M=36.686	(9) M=48.738	(10) M=63.350	(11) M=50.324	(12) M=52.165
CO-IT (1)		0.000000	0.000224	0.000000	0.000002	0.998954	0.000080	0,981340	0,106229	0,000000	0,015308	0.000857
CO-MDF (2)	0.000000		0.001867	0.000000	0.000000	0.000000	0.000000	0.000000	0.000001	1.000000	0.000016	0.000514
MAF-IT (3)	0.000224	0.001867		0.000000	0.000000	0.016755	0.000000	0.000000	0.952237	0.007558	0.999172	1.000000
MAF-MDF (4)	0.000000	0.000000	0.000000		0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
MF-IT (5)	0.000002	0.000000	0.000000	0.000000		0.000000	0.99964	0.001995	0.000000	0.000000	0.000000	0.000000
MF-MDF (6)	0.998954	0.000000	0.016755	0.000000	0.000000		0.000000	0.514195	0.690636	0.000000	0.281478	0,044666
STF-IT (7)	0.000080	0.000000	0.000000	0.000000	0.999964	0.000000		0.031923	0.000000	0.000000	0.000000	0.000000
STF-MDF (8)	0.981340	0.000000	0.000000	0.000000	0.001995	0.514195	0.031923		0.000536	0.000000	0.000027	0.000001
RV-IT (9)	0.106229	0.000001	0.952237	0.000000	0.000000	0.690636	0.000000	0.000536		0.000004	0.999994	0.989972
RV-MDF (10)	0.000000	1.000000	0.007558	0.000000	0.000000	0.000000	0.000000	0.000000	0.000004		0.000090	0.002333
S32-IT (11)	0.015308	0.000016	0.999172	0.000000	0.000000	0.281478	0.000000	0.000027	0.999994	0.000090		0.999972
S32-MDF (12)	0.000857	0.000514	1.000000	0.000000	0.000000	0.044666	0.000000	0.000001	0.989972	0.002333	0.999972	

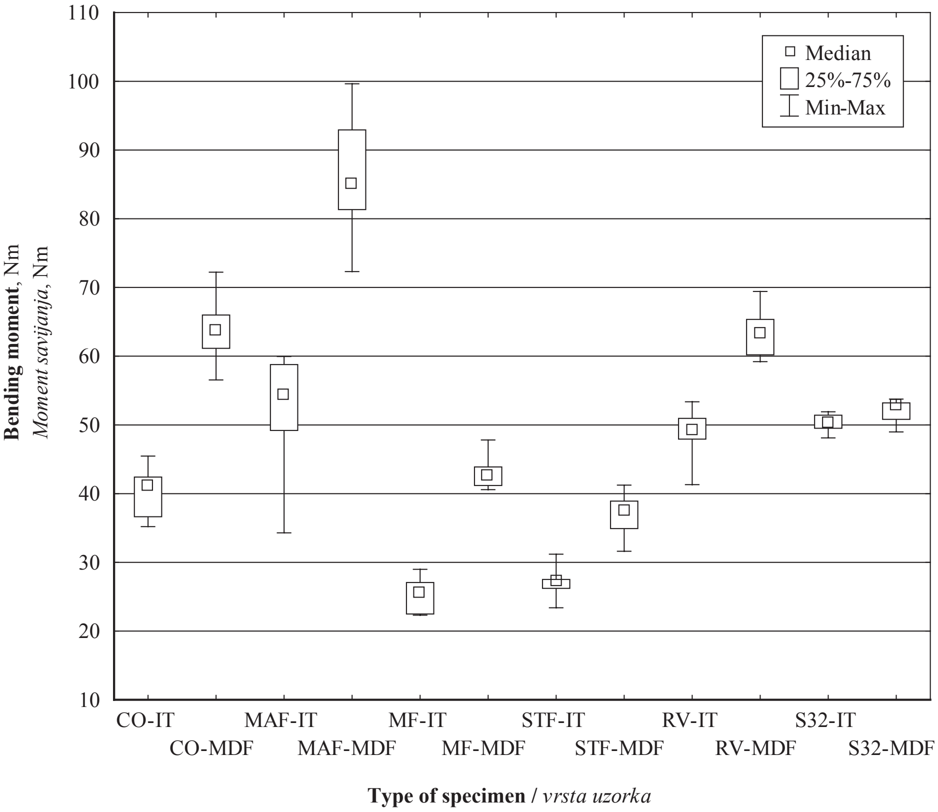

Figure 3 Impact of board and hardware type on bending moment
Slika 3. Utjecaj vrste ploče i tipa okova na moment savijanja

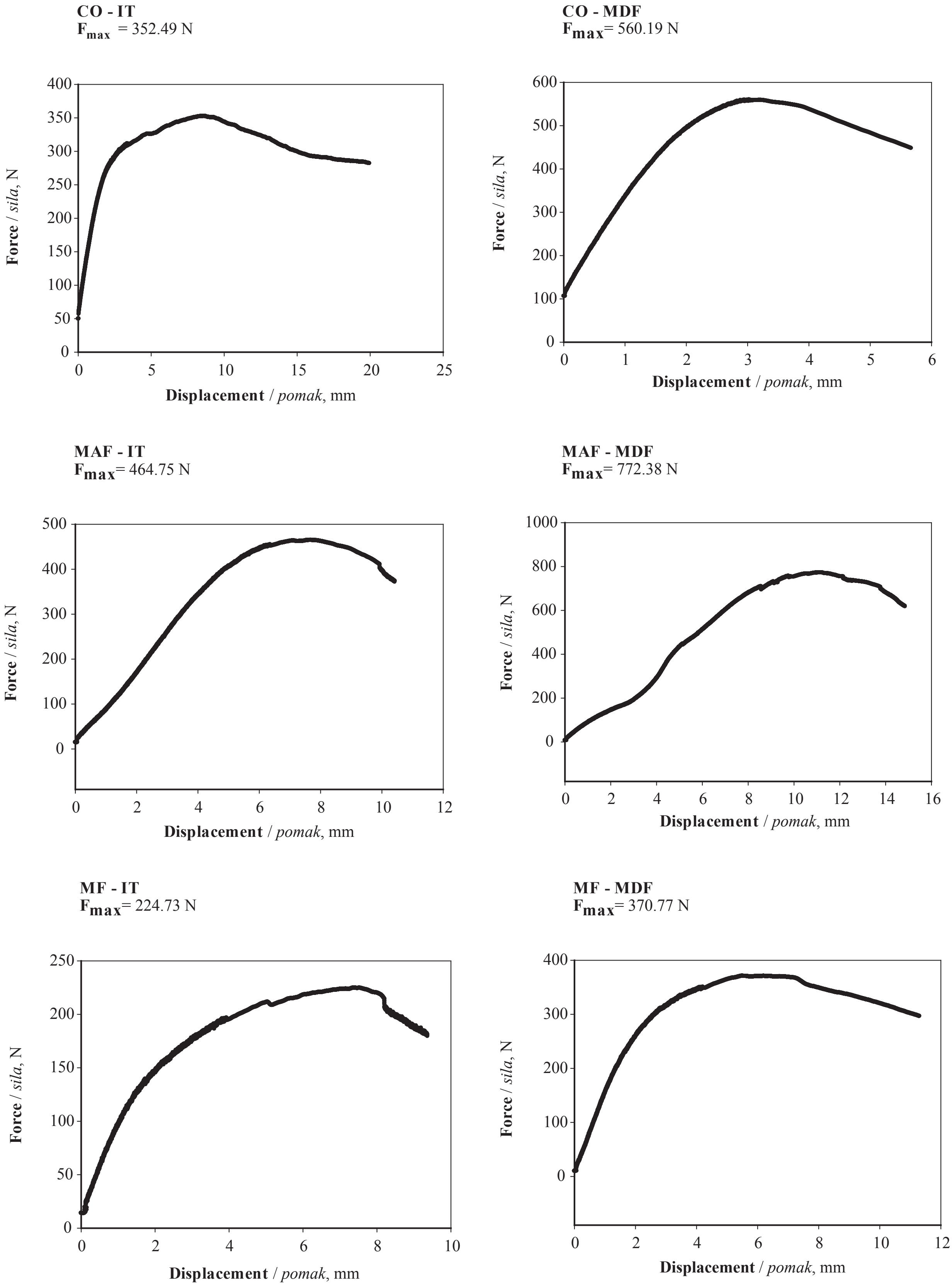

Figure 4 Load-displacement curve (maximum value) for given hardware and board types
Slika 4. Raspodjela sile ovisno o pomaku (najveća vrijednost) za određeni tip okova i ploča (dijagram loma)

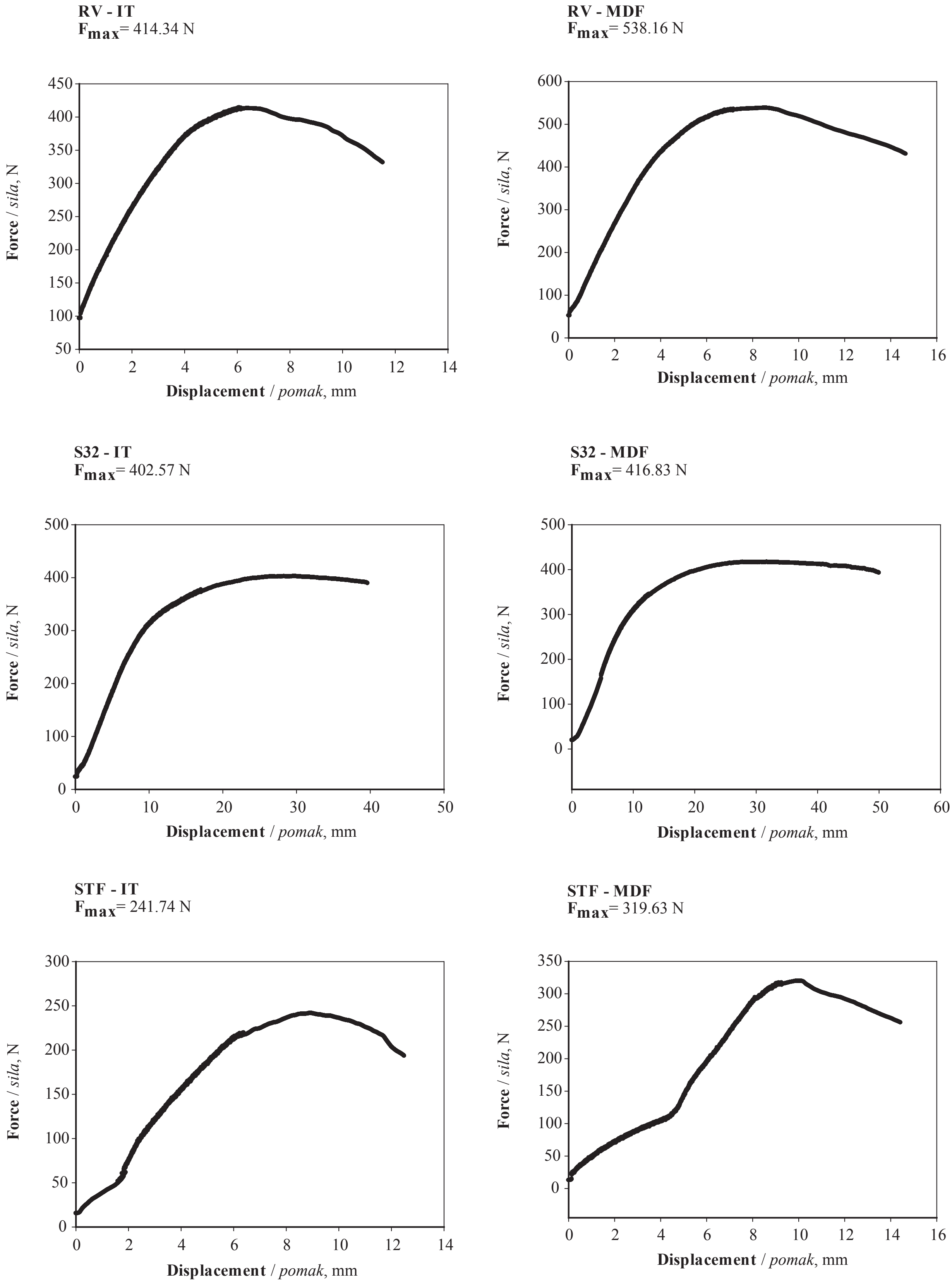

Figure 4 Load-displacement curve (maximum value) for given hardware and board types (continuation)
Slika 4. Raspodjela sile ovisno o pomaku (najveća vrijednost) za određeni tip okova i ploča (dijagram loma) (nastavak)

It may be assumed that edge processing (with a mini ABS tape for example) would increase the strength of the assembly in MAF, MF and STF. The ABS tape would strengthen the board edge increasing the bending moment or the strength of the joint. The visible edge of the particleboard is always coated so that attention should be given to the hardware orientation with regard to the processed edge (the side or the top or the bottom). It can therefore be assumed that an installed hardware in a specific piece of furniture would exhibit even higher values (except for furniture made of lacquered MDF).

4 CONCLUSIONS
4. ZAKLJUČAK

The board type has a statistically significant impact on the strength of assemblies (except for S32 specimens). The hardware installed in the improved MDF has statistically higher bending moment values as compared to the hardware installed in the improved particleboard (except for S32 specimens).

The hardware type has a significant impact on the maximum bending moment or assembly strength. In specimens made of particleboard and MDF, there are statistically significant differences as shown in Table 4. Depending on the hardware type, the average maximum bending moment increases by over two times independent of the board type, which constitutes a significant difference as a furniture strength indicator. Therefore, a proper hardware choice plays an important role in determining the decomposable construction of future storage furniture.

Joint strength in S32 specimens depends on the force required for hardware bending so that the board type has no statistically significant impact.

When testing, the assembly fracture also depends on the hardware type. Board delamination is characteristic for most hardwares except for assemblies with the confirmat screw and the RV hardware fastened by screws.

The Maxifix hardware exhibited the best results of all tested hardware with regard to the bending moment independent of the board type, it is acceptable aesthetically as it is installed from the inner side of the assembly and enables the application on boards with the thickness of over 18 mm.

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In memoriam:

prof. dr. sc. Božidar Petrić

Dana 30. rujna 2020. u krematoriju zagrebačkog Mirogoja od profesora dr. sc. Božidara Petrića oprostila se obitelj, rodbina, prijatelji, suradnici i znanci. Svečani komemoracijski skup održan je10. studenog 2020. na Šumarskom fakultetu Sveučilišta u Zagrebu, na kojemu je profesor Petrić neprekidno radio više od 40 godina,

Božidar Petrić bio je moj profesor i mentor te predstojnik Zavoda u kojemu sam s njim radila ukupno 17 godina, do njegova umirovljenja, tako da ga smatram fakultetskim ocem. Stoga ću se ponajprije osvrnuti na profesionalni dio njegova u cijelosti zaista burnoga i zahtjevnog života.

Božidar Petrić rođen je na Božić 1931. godine. Osnovnu školu i realnu gimnaziju završio je u Zagrebu. Studirao je na Drvnoindustrijskom odsjeku Šumarskog odjela Poljoprivredno-šumarskog fakulteta u Zagrebu, gdje je apsolvirao akademske godine 1953./54., a diplomirao 1956.

Od 1953. radio je kao demonstrator, a od rujna 1956. kao honorarni stručni suradnik u Zavodu za anatomiju i zaštitu drva. Doktorirao je 1967. s disertacijom *Utjecaj starosti i širine goda na promjene strukture i volumne težine bijele borovine* (*Pinus sylvestris* L.). Iste je godine kao stipendist Britanskog savjeta proveo devet mjeseci na poslijedoktorskom usavršavanju u institutu Forest products laboratory u Princes Risboroughu u Velikoj Britaniji. Tijekom 1973. habilitiran je za naslovnog docenta habilitacijskim radom *Varijacije nominalne volumne težine ranog i kasnog drva bijele borovine* (*Pinus sylvestris* L.). Habilitacijskim nastupnim predavanjem *Varijacije submikroskopske građe membrana stanica drva* iste je godine habilitiran u zvanje docenta za znanstveno područje Anatomija drva. Taj je predmet predavao studentima Šumarskoga i Drvnotehnološkog odsjeka sve do odlaska u mirovinu 1997. Vjerojatno je nastavu i ispite samo iz tog predmeta pod njegovim vodstvom prošlo više od 4000 studenata. Skripta kojima su se pritom koristili bila su zorno oslikana uglavnom rukom Božidara Petrića.

Njegova znanstvena specijalizacija bila je struktura i zaštita drva. Istraživao je varijacije strukture drva, njihov utjecaj na svojstva drva i mogućnosti zaštite drva.

U zvanje izvanrednog profesora izabran je 1976., a u zvanje redovitog profesora 1981. godine. Od 1975. predavao je dio nastavnog programa kolegija Poznavanje materijala I na studiju Više škole za proizvodnju namještaja na Šumarskom fakultetu. Na poslijediplomskome znanstvenom studiju Drvnotehnološkog odsjeka Šumarskog fakulteta bio je voditelj znanstvenog područja Znanost o drvu – anatomija drva, u sklopu kojega je održavao nastavu sljedećih pet kolegija: Formiranje i histološka građa drva, Submikroskopska građa drva, Varijacije i greške strukture drva, Identifikacija drva i Metode i instrumenti u istraživanju anatomije drva. Na ostalim znanstvenim područjima poslijediplomske nastave Drvnotehnološkog odsjeka održavao je nastavu kolegija Nauka o drvu. Od 1989. do 1991. predaje i na poslijediplomskom studiju Lesarskog oddelka Biotehniške fakultete, Univerze v Ljubljani, i to kolegij Ksilotomija – sekundarne in traumatske spremembe v lesu. Znanstveno-nastavno vijeće Šumarskog fakulteta povjerilo mu je 1990. nastavu kolegija Zaštita drva i drvnih proizvoda, a od 1992. i organizaciju provođenja nastave kolegija Osnove tehnologije drva i Tehnološke karakteristike drva. U dva odvojena mandata bio je tajnik Zavoda za istraživanja u drvnoj industriji[1]. Obavljao je i dužnost prodekana Drvnotehnološkog odsjeka u dva odvojena mandatna razdoblja[2]. Od 1992. do mirovine bio je glavni i odgovorni urednik časopisa *Drvna industrija*. Tada se časopis suočavao s krizom zbog raspada SFRJ i gašenja Instituta za drvo, pa je za vrijeme njegova uredništva časopis *Drvna industrija* prebrodio i to zahtjevno razdoblje. Bio je predstojnik Zavoda za anatomiju i zaštitu drva te kasnije objedinjenog Zavoda za znanost o drvu, i to neprekidno od 1977. do umirovljenja 1997.

Uz nabrojene aktivnosti, profesor Božidar Petrić bio je aktivan sudionik mnogih stručnih sastanaka, savjetovanja i konferencija u nas i u inozemstvu: *Struktu-*

[1] Akad. god. 1967./68., 1968./69. i 1982./83.
[2] U akad. god.1974./75., 1975./76., 1984./85. i 1985./86.

ra i iskorištavanje drva listača, IAWS, Banska Bystrica, ČSSR, 1975.; *IUFRO Kongres*, Oslo, Norveška, 1976.; *Savjetovanje o znanstveno-istraživačkom radu na području drvne industrije*, Zagreb, 1980.; *Kolokvij o pilanarstvu*, Zalesina, 1983.; *Savjetovanje o optimizaciji finalne tehnologije u drvnoj industriji*, Tuheljske Toplice, 1983.; *Kolokvij o bukvi*, Velika, 1984.; *IUFRO Kongres*, Ljubljana, 1986.; *Struktura i svojstva drva*, Zvolen, Slovačka, 1994. Znanstvena djelatnost profesora Božidara Petrića bila je vezana za istraživanja strukture naših domaćih vrsta drva, a na temelju rezultata tih ispitivanja razradio je i ključeve za identifikaciju ne samo masivnog drva, nego i proizvoda od usitnjenog drva kao što su ploče iverice i vlaknatice. Njegova istraživanja utjecaja strukture na permeabilnost drva četinjača i listača važna su za postupke zaštite drva i poboljšanje određenih svojstava drva pri impregnaciji, stabiliziranju dimenzija i modifikaciji drva. Do umirovljenja je bio član Hrvatskoga šumarskog društva, Međunarodnog udruženja anatoma drva (International Association of Wood Anatomists – IAWA) te Međunarodne istraživačke skupine za zaštitu drva (International Research Group on Wood Preservation – IRG WP). Njegov međunarodno priznati znanstveni rad naveden je i među referencama jednoga od svjetskih udžbenika o drvnoj tehnologiji *Science and Technology of Wood*, kojega je autor George Tsoumis.

Sredinom 20. stoljeća Božidar Petrić neposredno je sudjelovao u osnivanju te u daljnjem stalnom dopunjavanju i održavanju ksiloteke Katedre za anatomiju i zaštitu drva, današnjeg Zavoda za znanost o drvu. Ksiloteka danas sadržava oko 3000 daščica drva iz cijeloga svijeta, najveća je u ovom dijelu Europe te je neprocjenjivo nasljeđe koje nam je profesor ostavio.

Profesor Božidar Petrić sudjelovao je u izradi parcijalne studije međunarodnog projekta izgradnje tvornice namještaja u Conakryju, Gvineja, Afrika. U toj su studiji razrađena svojstva oko 60 vrsta drva kao sirovine ili potencijalnih drvnih sirovina za preradbu i finaliziranje u namještaj. Bio je glavni i odgovorni urednik monografije Šumarski fakultet Sveučilišta u Zagrebu *1985.* Autor je studije *Obrazloženje opravdanosti osnivanja znanstvenog polja drvna tehnologija*, koja je znatno pridonijela javnom priznanju drvnotehnološke znanosti. Božidar Petrić cijeli je radni vijek promovirao svrsishodnu upotrebu drva. Naglašavao je potrebu istraživanja i poznavanja strukture drva, ponajprije domaćih komercijalnih vrsta, ne samo radi njihove prikladne upotrebe, već i radi uspješnije procjene kvalitete drvne mase koju proizvode naše šume. U časopisu *Drvna industrija* nastavio je od 1983. objavljivati rubriku „Strane vrste drva u evropskoj drvnoj industriji", koju je prije njega započeo Franjo Štajduhar. Ta rubrika, u nešto izmijenjenom obliku, postoji i danas.

Tijekom svojega znanstvenog i stručnog rada objavio je više desetaka znanstvenih i stručnih radova te podjednak broj stručnih mišljenja, ekspertiza i sudskih vještačenja vezanih za identifikaciju drva, svojstva drva te biotičku razgradnju i zaštitu drva. Na 4. Drvnotehnološkoj konferenciji u Opatiji 2007. profesoru Božidaru Petriću dodijeljeno je *Priznanje za poseban doprinos hrvatskoj drvnotehnološkoj struci*.

Božidar Petrić, redoviti profesor Anatomije drva i Zaštite drva umro je u miru vlastitog doma 25. rujna 2020. Dragi profesor Petrić među prijateljima je bio poznat kao Piki. Taj je nadimak dobio u mladosti po *Pik baru* što ga je njegov otac imao u Petrinjskoj ulici u Zagrebu, kamo je Piki volio svratiti s društvom. S profesorom Petrićem prvi sam se put susrela 1980., na drugoj godini studija drvne tehnologije, na predavanjima i vježbama predmeta Anatomija drva. Vrlo je brzo uočio moje zanimanje za promatranje strukture drva, tako da sam još za vrijeme studija postala demonstratorica za taj predmet, a kasnije tehnička i stručna suradnica u istraživačkim projektima. Od tada pa do profesorova umirovljenja upoznala sam njegove brojne vrline. Bio je vrlo samozatajan i skroman, višestrano darovit, neumoran nastavnik predavač i uspješan istraživač, a prije svega topao i dobronamjeran čovjek. Njegovo široko tehničko i biološko znanje, spretnost, prvorazredno poimanje prostora te umijeće crtanja, udruženi s nenadmašnim smislom za humor, velikom duhovitošću, strpljenjem, upornošću i neodustajanjem od zacrtanog cilja jamčile su uspješnost zadataka kojih se prihvaćao u svom profesionalnom životu, a njih je bilo izrazito mnogo. Unatoč objektivnim poteškoćama vremena u kojemu je radio te više nego skromnim materijalnim sredstvima za znanstveni i nastavni rad, uspio se, zajedno sa svojim najbližim suradnikom mr. sc. Velimirom Šćukancem zvanim Stric, izboriti za dvoje svojih nasljednika na Fakultetu, te nas osposobiti za daljnja napredovanja, na čemu smo mu neizmjerno i duboko zahvalni. Zvao nas je *decom*, te se upravo tako i odnosio prema nama – obiteljski, s ljubavlju i pažnjom. Uobičajeni svakodnevni raspored aktivnosti u Zavodu bio je sljedeći: doručak, kava s raspravom, posao, kava s raspravom, posao, razlaz. Nakon doručka koji se obično sastojao od jogurta i peciva, po čemu je cijela Katedra za anatomiju i zaštitu drva možda i neslavno nazvana jogurt-klubom, pila se kava i raspravljalo se o raznim aktualnim i stručnim temama. Rasprave su katkad znale biti prilično žive, a profesor ih je nazivao *sabljanjima*. Volio je društvo, naša *sabljanja* i dobru kapljicu. Pritom se ne sjećam da je o ikomu rekao bilo što ružno, te i to pripisujem plemenitosti njegove naravi. Bio je rado viđen gost na svom Zavodu i nakon odlaska u mirovinu, uvijek spreman za društvo, vrckaste dosjetke i šalu. Neizrecivo mi je drago što je tada, u mirovini, s nama *decom* proslavio svoje fakultetske *unuke* i *praunuku*, te što smo ga uspjeli još jedanput vidjeti živahnoga i duhovitog netom prije epidemije koronavirusa i razornog potresa. Osjećam neizrecivu zahvalnost na svemu što smo od njega baštinili i što smo uz njegovu pomoć naučili.

Profesora Božidara Petrića više nema među nama. Ali dok njegov duh i dalje živi u djelima i zauvijek lijepim uspomenama na zajedničke trenutke života, vjerujem da njegova svijetla duša počiva u vječnome miru.

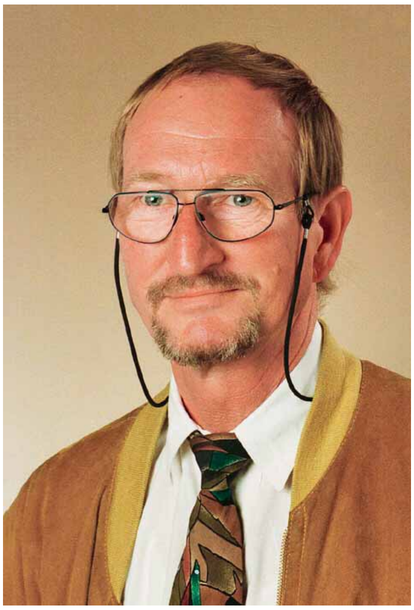
U svoje ime, u ime Zavoda za znanost o drvu te u ime ostalih zavoda Šumarskoga fakulteta obitelji Petrić izražavam iskrenu sućut, sa željom da nas ovaj spomen sve utješi.

prof. dr. sc. Jelena Trajković

In memoriam:

Prof. Dr Jürgen Sell

S tugom i nostalgijom javljamo vam da je u kolovozu 2020. preminuo prof. dr. Jürgen Sell, dugogodišnji voditelj Odsjeka za drvo švicarskoga saveznog instituta EMPA, suradnik našeg časopisa i prijatelj Drvnotehnološkog odsjeka Šumarskog fakulteta.



Jürgen Sell je odmah nakon završetka Studija drvne znanosti na Sveučilištu u Hamburgu 1965. otišao u Švicarsku, gdje je proveo cijeli radni vijek u Odsjeku za drvo Švicarskoga saveznog instituta za ispitivanje materijala i istraživanja (EMPA Dübendorf). Sve do umirovljenja 2002., tijekom 26 godina, prof. Sell bio je i voditelj tog odsjeka. Doktorirao je na sveučilištu ETH (Eidgenössische Technische Hochschule) u Zürichu 1984. Na toj je instituciji 1998. promoviran i u počasnog profesora.

Područje istraživanja prof. Sella bilo je vrlo široko: objedinjavao je osnovna znanja o ustroju, fizici i biologiji drva s istraživanjima njegove primjene, pogotovo u područjima postojanosti, zaštite i površinske obrade građevnog drva. Među studentima kojima je predavao na odsjecima Šumarstvo, Arhitektura i Građevina prestižnog ETH sveučilišta u Zürichu promovirao je drvo kao prvoklasan materijal. Proučavao je anatomsku strukturu drva, pa je iz njegovih mikroskopskih istraživanja proizašao i danas općepoznati „Sellov“ model podustroja stanične stijenke. Kompleksne međusobne odnose kemijskih, fizičkih i strukturnih promjena slobodno izloženog drva studirao je na znanstvenom nivou, ali je spoznaje oblikovao i u praktično znanje koje je prenosio drvnim stručnjacima svih razina – od stolara i inženjera do akademskih kolega. Njegova knjiga *Eigenschaften und Kenngrössen von Holzarten* (*Svojstva i tehničke karakteristike vrsta drva*) postala je osnovni priručnik za svakoga drvnog tehnologa i citira se kao mjerodavni izvor podataka u mnogim EN normama, stručnim knjigama i priručnicima.

Pod vodstvom prof. Sella Odsjek za drvo EMPA instituta oblikovao se u jedan od najprestižnijih istraživačkih centara drvne znanosti u svijetu, ostvarujući živu i vrlo plodonosnu međunarodnu suradnju, naravno, ponajviše na srednjoeuropskom području, ali i sa sjevernoameričkim i australskim kontinentom, na kojima je prof. Sell višekratno proveo dulja razdoblja kao gostujući znanstvenik i profesor. Svojim je autoritetom bitno pridonosio i radu međunarodnih akademskih i strukovnih udruga, od američkih i europskih znanstvenih akademija do odbora za međunarodnu normizaciju. Objavio je 240 izdanja, od čega gotovo 60 % čine izvorni istraživački radovi koji su izlazili u najprestižnijim časopisima naše struke. Bio je recenzent i dugogodišnji urednik u *Holz als Roh- und Werkstoff*, *Wood Science and Technology*, *Wood and Fiber Science* i drugim časopisima, među kojima treba spomenuti i našu *Drvnu industriju*, kojoj je prof. Sell rado pomagao recenzijama i pripremom svojih članaka za objavljivanje.

Suradnja između EMPA instituta i Drvnotehnološkog odsjeka Šumarskog fakulteta započela je u 1990-ima i bila je vrlo opsežna: zajedno smo vodili nekoliko istraživačkih projekata, na kojima su velikim dijelom izrađena i dva naša doktorata, objavili smo petnaestak zajedničkih radova te ostvarili vrlo aktivnu i prijateljsku suradnju u razmjeni znanja, iskustava i zajedničkih javnih nastupa. Prof. Sell nesebično je i rado organizirao gostovanja hrvatskih kolega u Dübendorfu, a našem je Fakultetu donirao vrijednu opremu i knjige. Šumarski je fakultet posjetio 1998. i možemo samo žaliti što je to ostao jedini njegov posjet Zagrebu. Danas bi, nadam se, bio ponosan da vidi koliki je rast ostvarilo sjeme njegova zalaganja za nas u razvoju naših laboratorija, časopisa i drugih tiskovina, ali prije svega naših stručnjaka koji su od njega ili s njim i njegovim švicarskim suradnicima toliko toga naučili.

Prof. Sell bio je srdačna osoba, ozbiljna ali vrlo topla, i to je bio važan činitelj njegova uspjeha u okupljanju suradnika i organiziranju istraživačke suradnje. Bio je znanstvenik „staroga kova“, koji je posjedovao i njegovao enciklopedijsko znanje o drvu i njegovoj primjeni. U svakom je istraživanju naglašavao široku sliku koju znanstvenik mora sagledati, ma kako se fokusirao na njezin uzak detalj: istodobno je razmišljao o anatomskim, fizičkim i kemijskim svojstvima materijala, kao i o tehnologiji izrade i postojanosti cijelih građevina načinjenih od drva. Predstavljao je tip znanstvenika koji neprestano uči, koji podjednako savjesno i iskreno sagledava sve aspekte primjene drva, kako pozitivne, tako i negativne, svjestan njegove ekološke važnosti mnogo prije modernog doba istraživanja životnih ciklusa materijala. U svom je radu Jürgen Sell bio i iznimno hrabar, ne bojeći se nikakva izazova: od mnogočega što sam od njega naučio dopustite mi da prenesem jednu anegdotu koja to ilustrira. Jednom sam upitao Jürgena: „Kako pronađeš, kako odabereš tako zanimljive teme za svoja istraživanja?“ Odgovorio mi je: „To je jednostavno: uzmeš knjigu najvećega svjetskog autoriteta za neko područje i pozorno je pročitaš: kad pronađeš ono što ti se učini najslabijim mjestom u toj knjizi, to uzmeš za temu svog istraživanja.“ Nadam se da će nas tako hrabar, srdačan, topao i konstruktivan duh profesora Sella pratiti i dalje.

prof. dr. sc. Hrvoje Turkulin

In memoriam:

Prof. dr. sc. Stanislav Sever

Nakon duge i teške bolesti 8. kolovoza 2020. u 86. godini života preminuo je profesor dr. sc. Stanislav Sever.

Prof. dr. sc. Stanislav Sever, diplomirani inženjer drvne industrije i diplomirani inženjer strojarstva, rođen je 1935. u Svetom Križu Začretju. Petu mušku gimnaziju u Zagrebu završio je 1954. Diplomirao je 1959. na Poljoprivredno-šumarskom fakultetu Sveučilišta u Zagrebu, Drvnoindustrijski odjel, a 1965. na Strojarskom odjelu Strojarsko-brodograđevnog fakulteta istog sveučilišta. Magistrirao je 1975., a disertaciju *Istraživanje nekih eksploatacijskih parametara traktora kod privlačenja drva* obranio je 1980. na Šumarskom fakultetu Sveučilišta u Zagrebu. Na Šumarskom je fakultetu počeo raditi 1960. kao asistent, a u mirovinu je otišao 2000. kao redoviti sveučilišni profesor. Na Šumarskom je fakultetu obnašao dužnost predstojnika Katedre za strojarstvo te tajnika i predsjednika Savjeta Fakulteta.

Od 1997. do 1998. bio je pomoćnik ministra za poljoprivredu i šumarstvo te ravnatelj Uprave za šumarstvo i lovstvo.

Njegova pedagoška i nastavna djelatnost ponajprije je vezana za rad na Šumarskom fakultetu u Zagrebu te se odnosi na gotovo sve tehničke predmete dodiplomske i poslijediplomske nastave. Usto je sudjelovao u uvođenju i osnivanju novih kolegija, metodičkih jedinica, nastavnih sadržaja i mjernih vježbi.

Predavao je ili sudjelovao u nastavi predmeta Mehanizacija šumarstva s praktikumom, Nacrtna geometrija, Tehničko crtanje, Osnove strojarstva, Transport u drvnoj industriji, Radni strojevi za drvo, Strojevi za transport i dizala, Rukovanje materijalom i dr. Deset je godina (od 1981. do 1990.) bio gostujući profesor na Šumarskom fakultetu u Sarajevu te povremeno nastavnik suradnik na Agronomskom fakultetu u Zagrebu i na Visokoj tehničkoj školi za sigurnost na radu pri Fakultetu strojarstva i brodogradnje. Pritom je, osim članstva u mnogim povjerenstvima diplomskih i magistarskih radova te disertacija, bio i mentor u izradi niza diplomskih radova, magisterija i disertacija.

U znanstvenom radu na području šumarskoga i drvnoindustrijskog strojarstva utjecao je na ustroj, promicanje i prepoznavanje tehničke sastavnice kao dijela šumarskih znanosti.

Najvažnije područje njegova znanstvenoga rada bilo je mehanizirano privlačenje drva, utjecaj šumskih strojeva na tlo te istraživanja transportnih sredstava u drvnoj industriji. Također je važan njegov rad na uvođenju ergonomskih istraživanja pri uporabi šumarske mehanizacije i strojeva u drvnoj industriji, stvaranju sustava tehničke propisnosti, normi i pravilnika za rad na siguran način. Velik je i njegov doprinos u promicanju strukovnog nazivlja.

Većina od preko 550 objavljenih ili izvedenih radova rezultat su mjerenja vezanih za neki proizvodni ili razvojni zadatak u šumarstvu ili drvnoj industriji.

Mnoge njegove objave otkrivale su nove znanstvene spoznaje koje su bile doprinos svjetskom znanju, što je potaknulo daljnja proučavanja tih problema kako u svjetskom šumarstvu, tako i u Hrvatskoj, posebice na Šumarskom fakultetu u Zagrebu.

Sav je taj rad prof. Sever potvrđivao i vođenjem mnogobrojnih projekata, istraživačkih zadataka i eksperimentalnog razvoja ili sudjelovanjem u njima.

Posebno se ističe njegovo zalaganje u prijenosu znanja, što je vidljivo iz pretakanja spoznaja u izradu novih generacija strojeva, u zajednički rad s mnogim strukama i u opredmećenje znanja u novim proizvodima.

Jedan je od pokretača proizvodnje šumskih zglobnih traktora skidera u Hrvatskoj, a njegovo znanje i iskustvo i danas se primjenjuju u konstrukciji novih modela šumskih strojeva za privlačenje drva.

Osim brige o osnutku mnogih mjernih sastavnica nužnih za utvrđivanje karakteristika strojeva i opreme u šumarstvu, brojnim objavama i neposrednim sudjelovanjem u prijenosu znanja u praksu osobito je pridonio raznim oblicima objava o uređivanju časopisa, zbornika, monografija i sličnih tiskovina. Sudjelovao je i u mnogim radijskim i televizijskim emisijama o aktualnim temama i motrištima na inženjerstvo i šumarsku proizvodnju u sklopu cjelokupnih zbivanja u društvu. Osim na materinskom jeziku, svoja je predavanja držao na engleskome, njemačkome i ruskom jeziku, kojima se služio u strukovnom sporazumijevanju.

Posebno treba istaknuti da je profesor Sever od 1990. do 2000. obnašao dužnost zamjenika koordinatora istraživačke grupe IUFRO D3 – 3.06.00 (Pridobivanje drva na nagnutim terenima) te bio član i sudjelovao u radu međunarodnih agencija i međunarodnih strukovnih organizacija: FAO-a (Organizacije UN-a za hranu i poljoprivredu), ILO-a (Međunarodne organizacije rada), ECE-a (Ekonomske komisije UN-a za Europu), ISO-a (Međunarodne organizacije za standarde), The International Society for Terrain-Vehicle Systems itd.

Bio je redoviti član Akademije šumarskih znanosti, Akademije tehničkih znanosti Hrvatske, Hrvatskoga šumarskog društva, Hrvatskoga mjeriteljskog društva, Hrvatskoga strojarskog i brodograđevnog inženjerskog saveza, Udruge za plastiku i gumu, Hrvatskog društva za promicanje zaštite ljudi u radnoj i životnoj okolini, Pokreta prijatelja prirode „Lijepa naša“.

U Državnom zavodu za normizaciju i mjeriteljstvo isticao se u radu Tehničkog odbora za nazivlje i Tehničkog odbora za šumarske strojeve.

Osnivač je te tehnički, a zatim i glavni urednik časopisa *Mehanizacija šumarstva*. Bio je član uredništva časopisa *Drvna industrija*, *Gozdarski vestnik*, *Mjeriteljski vjesnik*, *Rad i sigurnost*, *Metrolog.*

Bio je član Saborskog odbora za dodjelu Državne nagrade tehničke kulture *Faust Vrančić* te predstavnik Vlade RH u Upravnom odboru javnog poduzeća Hrvatske šume od prosinca 1995. do lipnja 1998., član nekoliko radnih grupa za donošenje prijedloga izmjena i dopuna odnosno novih hrvatskih zakona, jednokratni voditelj hrvatskog izaslanstva na 3. ministarskoj konferenciji *Zaštita šuma u Europi* (Lisabon, 1998.) te potpisnik tzv. Lisabonske rezolucije i deklaracije u ime Hrvatske. Bio je i predloženik za nagradu *Nikola Tesla* 1986., a 1998. predsjednik Republike Hrvatske dr. Franjo Tuđman odlikovao ga je *Redom Danice hrvatske* s likom Blaža Lorkovića za osobite zasluge u gospodarstvu.

Studenti i djelatnici Šumarskog fakulteta pamtit će profesora Stanislava Severa kao mirnoga i susretljivog kolegu koji je svoja velika znanja rado i nesebično dijelio sa studentima i suradnicima. Studenti su prepoznavali njegov kulturološki pristup u tehničkim disciplinama, posebice njegovo unošenje mjeriteljske i jezične sastavnice u sadržaje, zakonito iskazivanje spoznajnih rezultata i dr. Podjednako je skrbio o napredovanju nasljednika, znanstvenih novaka, pa i mnogih demonstratora uključenih u nastavni i istraživački proces. Uvijek je nalazio slobodnog vremena za mlade suradnike, prenosio im svoja znanja i iskustva te ih podučavao znanstvenom stilu pisanja i izražavanja.

Uz sav navedeni rad profesora su u slobodnom vremenu zaokupljali glazba (izvođač, voditelj, dirigent, aranžer za mnoge tamburaške sastave i orkestre) i šah (prvak Zagrebačkoga šahovskog kluba 1956.) te hrvatski jezik i povijest.

Dragi profesore, neka ti je vječna slava i hvala.

prof. dr. sc. Marijan Šušnjar

Drvo sucupire (*Diplotropis purpurea* (Rich.) Amshoff)

NAZIVI

Sucupira je trgovački naziv više botaničkih vrsta roda *Diplotropis* i *Bowdichia* iz porodice *Fabaceae*. U rodu *Diplotropis* to su ponajprije vrste *D. martiusii* Benth. i *D. purpurea* (Rich.) Amshoff. *D. purpurea*, poznata i pod istoznačnim imenima *Bowdichia guianensis* (Tul.) Ducke, te *Dibrachion guianense* Tul., *Diplotropis guianensis* Benth., *Diplotropis purpurea* var. *Purpurea* i *Tachigalia purpurea* Rich., a u rodu *Bowdichia* to je *B. nitida* Benth.

Lokalni su trgovački nazivi tog drva sucupira, sucupira preta, cutiuba, macaniba, sapupira (Brazil); arenillo, zapan negro (Kolumbija); tatabu (Gvajana); baaka kiabici, coeur dehors (Francuska Gvajana); chontaquiro, huasai-caspi (Peru); Zwarte kabbes (Surinam); alcornoque, congrio (Venezuela).

PODRUČJE RASPROSTRANJENOSTI

Drvo sucupire potječe s prirodnih staništa Južne Amerike, i to uglavnom iz Brazila, Kolumbije, Venezuele, Gvajane i Perua.

STABLO

Stablo doseže visinu od 14 do 20 m, uz prsni promjer debla od 60 do 120 cm. Deblo je ravno i valjkasto.

DRVO

Makroskopska obilježja

Bjeljika drva je bljedožuta, široka 1 – 2,5 cm, a srž je smeđa do čokoladno smeđa. Drvo se odlikuje ukrasnom teksturom. Tangentne su površine blago izbrazdane porama, a radijalne su zbog dvostruko usukanih vlakanaca neznatno prugaste.

Drvni su traci sitni i katno raspoređeni, što je vidljivo na tangentnim površinama. Aksijalni je parenhim paratrahealno vazicentričan. Žica je ravna ili blago dvostruko usukana. Pore su rastresitog rasporeda, srednje veličine i često su ispunjene svijetlim sadržajem.

Fizička svojstva

Gustoća apsolutno suhog drva, ρ_0	860...880 kg/m^3
Gustoća prosušenog drva, ρ_{12-15}	920...980 kg/m^3
Gustoća sirovog drva, ρ_w	1100...1250 kg/m^3
Radijalno utezanje, β_r	oko 4,9 %
Tangentno utezanje, β_t	oko 7,1 %
Volumno utezanje, β_v	oko 11,8 %

Mehanička svojstva

Čvrstoća na tlak	88...94 MPa
Čvrstoća na savijanje	156...185 MPa
Modul elastičnosti	oko 18 GPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Mehanička obrada katkad je zahtjevna zbog dvostruke usukanosti žice. Oštrice alata jako se troše, pa pri obradi drva treba upotrebljavati alate koji imaju vrh od tvrdog metala. Površine drva pomalo su hrapave. Finalna obrada daje dobre rezultate nakon zatvaranja pora.

Sušenje

Drvo sucupire suši se normalno do sporo, uz slab rizik od deformacija i raspucavanja. Zahtijeva pažljivo sušenje radi izbjegavanja grešaka sušenja. Prije sušenja u sušionici preporučuje se predsušenje.

Trajnost i zaštita

Za razliku od bjeljike, srž drva sucupire otporna je na gljive uzročnice truleži (razred 2), na termite (razred otpornosti D) i bjeljikare (razred D). Slabo je permeabilna, pa se teško impregnira. Prirodna otpornost svrstava drvo sucupire u razred upotrebe 3: u eksterijeru, bez dodira s tlom. Ako je tijekom upotrebe drvo izloženo povremenom vlaženju, nije ga potrebno tretirati zaštitnim sredstvima. Ne preporučuje se upotreba u stalno vlažnim uvjetima.

Uporaba

Drvo sucupire upotrebljava se za izradu furnira, dijelova namještaja, parketa, unutarnjih stuba, za uređenje interijera i eksterijera, za izradu tokarenih proizvoda, unutarnje i vanjske građevne stolarije, za palube u brodogradnji, za dijelove izvan dosega vode i tla u mostogradnji, za nosive dijelove zgrada, a preporučuje se i za izradu prvorazrednih proizvoda.

Sirovina

Drvo je na tržištu rijetko dostupno u obliku trupaca, češće se isporučuje u obliku piljene građe, rezanog furnira i elemenata za izradu parketa.

Napomena

Drvo sucupire nije na popisu ugroženih vrsta u međunarodnoj trgovini CITES. Na popisu ugroženih vrsta međunarodne organizacije IUCN sucupira je svrstana u razred vrsta najmanje zabrinjavajućeg opstanka. Sucupira pripada skupini manje poznatih i manje istraženih tropskih vrsta drva.

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prof. dr. sc. Jelena Trajković
izv. prof. dr. sc. Bogoslav Šefc

Upute autorima

Opće odredbe

Časopis *Drvna industrija* objavljuje znanstvene radove (izvorne znanstvene radove, pregledne radove, prethodna priopćenja), stručne radove, izlaganja sa savjetovanja, stručne obavijesti, bibliografske radove, preglede te ostale priloge s područja biologije, kemije, fizike i tehnologije drva, pulpe i papira te drvnih proizvoda, uključujući i proizvodnu, upravljačku i tržišnu problematiku u drvnoj industriji.

Predaja rukopisa podrazumijeva uvjet da rad nije već predan negdje drugdje radi objavljivanja ili da nije već objavljen (osim sažetka, dijelova objavljenih predavanja ili magistarskih radova odnosno disertacija, što mora biti navedeno u napomeni) te da su objavljivanje odobrili svi suautori (ako rad ima više autora) i ovlaštene osobe ustanove u kojoj je istraživanje provedeno. Cjelokupni sadržaj Drvne industrije dostupan je za skidanje s interneta, tiskanje, daljnju distribuciju, čitanje i ponovno korištenje bez ograničenja sve dok se naznače autor(i) i originalni izvor prema Creative Commons Attribution 4.0 International License (CC BY). Autor(i) zadržavaju izdavačka prava bez ograničenja.

Znanstveni i stručni radovi objavljuju se na hrvatskome, uz sažetak na engleskome, ili se pak rad objavljuje na engleskome, sa sažetkom na hrvatskom jeziku. Naslov, podnaslovi i svi važni rezultati trebaju biti napisani dvojezično. Ostali se članci uglavnom objavljuju na hrvatskome. Uredništvo osigurava inozemnim autorima prijevod na hrvatski. Znanstveni i stručni radovi podliježu temeljitoj recenziji najmanje dvaju recenzenata. Izbor recenzenata i odluku o klasifikaciji i prihvaćanju članka (prema preporukama recenzenata) donosi Urednički odbor.

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drind@sumfak.hr ili techdi@sumfak.hr

Upute

Predani radovi smiju sadržavati najviše 15 jednostrano pisanih A4 listova s dvostrukim proredom (30 redaka na stranici), uključujući i tablice, slike te popis literature, dodatke i ostale priloge. Dulje je članke preporučljivo podijeliti na dva ili više nastavaka. Tekst treba biti u *doc formatu*, u potpunosti napisan fontom *Times New Roman* (tekst, grafikoni i slike), normalnim stilom, bez dodatnog uređenja teksta.

Prva stranica poslanog rada treba sadržavati puni naslov, ime(na) i prezime(na) autora, podatke o zaposlenju autora (ustanova, grad i država) te sažetak s ključnim riječima (duljina sažetka približno 1/2 stranice A4).

Posljednja stranica treba sadržavati titule, zanimanje, zvanje i adresu (svakog) autora, s naznakom osobe s kojom će Uredništvo biti u vezi.

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. Rjeđe 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.

Slike je potrebno rasporediti na odgovarajuća mjesta u tekstu, trebaju biti izrađene u rezoluciji 600 dpi, crno-bijele (objavljivanje slika u koloru moguće je na zahtjev autora i uz posebno plaćanje), formata jpg ili tiff, potpune i jasno razumljive bez pozivanja na tekst priloga.

Svi grafikoni i tablice izrađuju se kao crno-bijeli prilozi (osim na zahtjev, uz plaćanje). Tablice i grafikoni trebaju biti na svojim mjestima u tekstu te originalnog formata u kojemu su izrađeni radi naknadnog ubacivanja hrvatskog prijevoda. Ako ne postoji mogućnost za to, potrebno je poslati originalne dokumente u formatu u kojemu su napravljeni (*excel* ili *statistica* format).

Naslovi slika i crteža ne pišu se velikim tiskanim slovima. Crteži i grafikoni trebaju odgovarati stilu časopisa (fontovima i izgledu). Slova i brojke moraju biti dovoljno veliki da budu lako čitljivi nakon smanjenja širine slike ili tablice. Fotomikrografije moraju imati naznaku uvećanja, poželjno u mikrometrima. Uvećanje može biti dodatno naznačeno na kraju naslova slike, npr. "uvećanje 7500 : l".

Diskusija i zaključak mogu, ako autori žele, biti spojeni u jedan odjeljak. U tom tekstu treba objasniti rezultate s obzirom na problem postavljen u uvodu i u odnosu prema odgovarajućim zapažanjima autora ili drugih istraživača. Valja izbjegavati ponavljanje podataka već iznesenih u odjeljku *Rezultati*. Mogu se razmotriti naznake za daljnja istraživanja ili primjenu. Ako su rezultati i diskusija spojeni u isti odjeljak, zaključke je nužno napisati izdvojeno. Zahvale se navode na kraju rukopisa. Odgovarajuću literaturu treba citirati u tekstu, i to prema harvardskom sustavu (*ime – godina*), npr. (Bađun, 1965). Nadalje, bibliografija mora biti navedena na kraju teksta, i to abecednim redom prezimena autora, s naslovima i potpunim navodima bibliografskih referenci. Popis literature mora biti selektivan, a svaka referenca na kraju mora imati naveden DOI broj, ako ga posjeduje (http://www.doi.org) (provjeriti na http://www.crossref.org).

Primjeri navođenja literature

Članci u časopisima: Prezime autora, inicijal(i) osobnog imena, godina: Naslov. Naziv časopisa, godište (ev. broj): stranice (od – do). Doi broj.

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.

Knjige: Prezime autora, inicijal(i) osobnog imena, godina: Naslov. (ev. izdavač/editor): izdanje (ev. svezak). Mjesto izdanja, izdavač (ev. stranice od – do).

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.)

Müller, D., 1977: Beitrag zür Klassifizierung asiatischer Baumarten. Mitteilung der Bundesforschungsanstalt für Forstund Holzvvirt schaft Hamburg, Nr. 98. Hamburg: M. Wiederbusch.

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).

Autoru se prije konačnog tiska šalje pdf rada. Rad je potrebno pažljivo pročitati, ispraviti te vratiti Uredništvu s listom ispravaka te s formularom za prijenos autorskih prava na izdavača. Ispravci su ograničeni samo na tiskarske pogreške: dodaci ili znatnije promjene u radu naplaćuju se. Autori znanstvenih i stručnih radova besplatno dobivaju po jedan primjerak časopisa. Autoru svakog priloga također se dostavlja besplatan primjerak časopisa.

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Details

Papers submitted shall consist of no more than 15 single-sided DIN A-4 sheets of 30 double-spaced lines, including tables, figures and references, appendices and other supplements. Longer papers should be divided into two or more continuing series. The text should be written in doc format, fully written using Times New Roman font (text, graphs and figures), in normal style without additional text editing.

The first page of the paper submitted should contain full title, name(s) of author(s) with professional affiliation (institution, city and state), abstract with keywords (approx. 1/2 sheet DIN A4).

The last page should provide the full titles, posts and address(es) of each author with indication of the contact person for the Editor's Office.

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Latin names shall be printed in italics and underlined.

Introduction should define the problem and if possible the framework of existing knowledge, to ensure that readers not working in that particular field are able to understand author's intentions.

Materials and methods should be as precise as possible to enable other scientists to repeat the experiment. The main experimental data should be presented bilingually.

The results should involve only material pertinent to the subject. The metric system shall be used. SI units are recommended. Rarely used physical values, symbols and units should be explained at their first appearance in the text. Formulas should be written by using Equation Editor (program for writing formulas in MS Word). Units shall be written in normal (upright) letters, physical symbols and factors in italics. Formulas shall be consecutively numbered with Arabic numerals in parenthesis (e.g. (1)) at the end of the line.

The number of figures shall be limited to those absolutely necessary for clarification of the text. The same information must not be presented in both a table and a figure. Figures and tables should be numbered separately with Arabic numerals, and should be referred to in the text with clear remarks ("Table 1" or "Figure 1"). Titles, headings, legends and all the other text in figures and tables should be written in both Croatian and English.

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Example of references

Journal articles: Author's second name, initial(s) of the first name, year: Title. Journal name, volume (ev. issue): pages (from - to). DOI number.

Example:
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.

Books:
Author's second name, initial(s) of the first name, year: Title. (ev. Publisher/editor): edition, (ev. volume). Place of publishing, publisher (ev. pages from - to).

Examples:
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.

Other publications (brochures, studies, etc.):
Müller, D. 1977: Beitrag zur Klassifizierung asiatischer Baumarten. Mitteilung der Bundesforschungsanslalt für Forst- und Holzwirtschaft Hamburg, Nr. 98. Hamburg: M. Wiederbusch.

Websites:
***1997: "Guide to Punctuation" (online), University of Sussex, www.informatics.sussex.ac.uk/department/docs/punctuation/node00.html. First published 1997 (Accessed Jan. 27, 2010).

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