DRVNA INDUSTRIJA

ZNANSTVENI ČASOPIS ZA PITANJA DRVNE TEHNOLOGIJE • ZAGREB • VOLUMEN 67 • BROJ 2
SCIENTIFIC JOURNAL OF WOOD TECHNOLOGY • ZAGREB • VOLUME 67 • NUMBER 2

Chukrasia tabularis A. Juss.

2/16

UDK 674.031.677.7 CODEN: DRINAT ISSN 0012-6772

UDK 630*8+674 Coden: Drinat ISSN 0012-6772

DRVNA INDUSTRIJA

ZNANSTVENI ČASOPIS ZA PITANJA DRVNE TEHNOLOGIJE
SCIENTIFIC JOURNAL OF WOOD TECHNOLOGY

IZDAVAČ I UREDNIŠTVO
Publisher and Editor's Office
Šumarski fakultet Sveučilišta u Zagrebu
Faculty of Forestry, Zagreb University
10000 Zagreb, Svetošimunska 25
Hrvatska – Croatia
*Tel. (*385 1) 235 25 09*

SUIZDAVAČI
Co-Publishers
Exportdrvo d.d., Zagreb
Hrvatsko šumarsko društvo, Zagreb
Hrvatske šume d.o.o., Zagreb

OSNIVAČ
Founder
Institut za drvnoindustrijska istraživanja, Zagreb

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The journal is published quarterly.

OVAJ BROJ ČASOPISA POTPOMAŽE:

Sadržaj
Contents

NAKLADA (Circulation): *700 komada* · **ČASOPIS JE REFERIRAN U (Indexed in):** *CA search, CAB Abstracts, Compendex, DOAJ, Crossref, EBSCO, Forestry abstracts, Forest products abstracts, Geobase, Paperchem, SCI-Expanded, SCOPUS* · **PRILOGE** *treba slati na adresu Uredništva. Znanstveni i stručni članci se recenziraju. Rukopisi se ne vraćaju.* · **MANUSCRIPTS** *are to be submitted to the editor's office. Scientific and professional papers are reviewed. Manuscripts will not be returned.* · **KONTAKTI s uredništvom (Contacts with the Editor) e-mail:** *editordi@sumfak.hr* · **PRETPLATA (Subscription):** *godišnja pretplata (annual subscription) za sve pretplatnike 55 EUR. Pretplata u Hrvatskoj za sve pretplatnike iznosi 300 kn, a za đake, studente i umirovljenike 100 kn, plativo na žiro račun 2360000 – 1101340148 s naznakom "Drvna industrija"* · **ČASOPIS SUFINANCIRA** *Ministarstvo znanosti, obrazovanja i sporta Republike Hrvatske.* · **TISAK (Printed by)** *– DENONA d.o.o., Getaldićeva 1, Zagreb, tel. 01/2361777, fax. 01/2332753, E-mail: denona@denona.hr; URL: www.denona.hr* · **DESIGN** Aljoša Brajdić · **ČASOPIS JE DOSTUPAN NA INTERNETU:** *http://drvnaindustrija.sumfak.hr* · **NASLOVNICA** *Presjek drva* Chukrasia tabularis *A. Juss., ksiloteka Zavoda za znanost o drvu, Šumarski fakultet Sveučilišta u Zagrebu*

DRVNA INDUSTRIJA · Vol. 67, 2 · str. 111-204 ljeto 2016. · Zagreb
REDAKCIJA DOVRŠENA 2.06.2016.

Pavlo Bekhta, Pavlo Lyutyy, Galyna Ortynska[1]

Effects of Different Kinds of Coating Materials on Properties of Flat Pressed WPC Panels

Utjecaj različitih vrsta materijala za oblaganje na svojstva ravnih prešanih drvno-plastičnih kompozitnih ploča

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 12. 12. 2014.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*832.285; 630*829.3*
doi:10.5552/drind.2016.1444

ABSTRACT • *The effects of different kinds of coating materials on the properties of flat pressed wood plastic composite (WPC) panels were studied in this work. Rotary-cut birch veneer, sliced oak veneer, phenolic impregnated paper, polyethylene (PE) film, and recycled polyethylene (rPE) layer were used as coating materials. One or two-side coating of WPC panels was carried out simultaneously with their flat pressing. No coupling agents were used for production of WPC. It was found that properties of flat pressed WPC panels improved by coating with all investigated coating materials. The highest values of modulus of rupture (MOR) were observed in WPC panels coated with rotary-cut birch veneer and MOR values were higher in along direction than in across direction of veneer fibers. The highest values of water resistance were observed in WPC coated with PE film or rPE layer. Coating of WPC with natural veneer leads to the decreasing of water resistance. Besides, water resistance of WPC coated with one side of natural veneer was higher in comparison with two side coated WPC panels with natural veneer. The two-side coating of WPC with phenolic impregnated paper, PE film or rPE layer leads to the decreasing of water absorption and thickness swelling.*

Key words: *coating materials, flat pressing, recycled polyethylene, veneer, wood plastic composites.*

SAŽETAK • *U radu su predstavljeni rezultati istraživanja utjecaja različitih vrsta materijala za oblaganje na svojstva ravnih prešanih drvno-plastičnih kompozitnih (WPC) ploča. Za oblaganje ploča primijenjeni su ljušteni brezov furnir, rezani hrastov furnir, fenolni impregnirani papir, polietilenska (PE) folija i reciklirani polietilen (RPE). Oblaganje WPC ploča s jedne ili s obje strane obavljeno je istodobno s prešanjem ploča. Za proizvodnju ploča nisu upotrebljavana sredstva za kondenzaciju. Utvrđeno je da su svojstva ravnih prešanih WPC ploča poboljšana oblaganjem bilo kojim navedenim ispitivanim materijalom. Najveće vrijednosti modula loma (MOR) zabilježene su za WPC ploče obložene ljuštenim brezovim furnirom. MOR vrijednosti bile su veće uzduž vlakanaca furnira nego okomito na njihov smjer . Najveća otpornost na vodu zabilježena je u ploča obloženih polietilenskom folijom i recikliranim polietilenskim slojem. Oblaganje WPC ploče prirodnim furnirom utječe na smanjenje otpornosti na vodu. Osim toga, otpornost na vodu WPC ploča obloženih s jedne strane prirodnim furnirom bila je veća nego WPC ploča obloženih prirodnim furnirom s obje strane. Dvostrano oblaganje WPC ploča fenolnim impregniranim papirom, polietilenskom folijom i recikliranim polietilenskim slojem pridonosi smanjenju apsorpcije vode i debljinskog bubrenja.*

Ključne riječi: *materijali za oblaganje, ravno prešanje, reciklirani polietilen, furnir, drvno-plastični kompoziti*

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1 INTRODUCTION
1. UVOD

Wood plastic composites (WPC) are universal materials with high modulus of rupture (MOR) and elasticity (MOE), internal bond strength, water resistance (Klyosov, 2007), biological resistance (Segerholm, 2012; Segerholm, 2007) and non toxicity (Lindfors and Salo, 2012). Therefore, WPC can be used in different sectors of economy and can be produced by different methods: extrusion, injection and compression molding, which depends on the configuration forms of the products and the field of their use (Klyosov, 2007). Extrusion is a predominant technology for manufacturing WPC in the USA and Europe. WPC panels can also be produced by flat-pressing in hot press (Ayrilmis *et al*., 2011; Ayrilmis and Jarusombuti, 2011; Ayrilmis *et al*., 2012; Benthien and Thoemen, 2012; Kargarfard and Jahan-Latibari, 2012). Herewith, the pressing parameters depend on the type of thermoplastic materials and surface configuration. In particular, particleboards, oriented strand boards (OSB), and medium density fiberboards (MDF) are manufactured in this way (Thoemen *et al*., 2010).

Wood flour is usually used as the filler for the production of WPC (Winandy *et al*., 2004). Wood sawdust (Winandy *et al*., 2004), wood fiber (Benthien and Thoemen, 2012) and shavings (Segerholm, 2007) can be used, too. Moreover, except for wood particles, the agricultural residues, in particular wheat (Sardashti, 2009) and rice (Buzarovska *et al*., 2008; Yao, 2008) straw are often used as the filler for production of WPC. Wood flour is mainly used for the manufacture of WPC by extrusion (Winandy *et al*., 2004), while wood particles are used for the manufacture of WPC panels by flat-pressing (Ayrilmis *et al*., 2011; Ayrilmis and Jarusombuti, 2011; Ayrilmis *et al*., 2012; Benthien and Thoemen, 2012; Kargarfard and Jahan-Latibari, 2012).

Nearly 90 % of WPC are produced in the USA by using PE (Klyosov, 2007). In Europe, the use of PE is lower – about 70 %; polypropylene (PP) – 11 % and polyvinyl chloride – 9 % (Eder, 2010). The use of these thermoplastic polymers can be explained by their low melting temperatures (110-160 ºC). The thermal stability of wood becomes worse when higher temperatures (more than 200 ºC) are used (Klyosov, 2007). Further increasing of the temperature (over 200 ºC) causes the decomposition of wood macromolecules and negative changes of wood properties.

Maleic anhydride-grafted can be used as a coupling agent for the increase of bonds between the wood particles and polymeric material. Recycled PE in combination with UF resins were also used (Kargarfard and Jahan-Latibari, 2012). There are also various reactive groups in recycled polyesters. In particular, C=O, -C=C-, $-CH=CH_2$ reactive groups were found in recycled PE and PP (Moldovan *et al*., 2012). These groups can react with cellulose, lignin and other chemical components of wood. Therefore, no coupling agents are required for the production of WPC on the basis of recycled polyester.

However, the enhancing of mechanical properties of flat pressed WPC (in particular its outer layers) can be executed by strengthening their outer layers. For this purpose, the same coating materials, which are usually used for particleboard, can be applied, for example impregnated paper, natural veneers, laminates, paints, varnishes and other coating materials (Istek *et al*., 2010; Norvyda and Minelga, 2006). The possibilities of single-stage pressing of veneered particleboards were also investigated (Borysiuk *et al*., 2011). There were three variants of producing particleboards: variant I – single-layer particleboard; variant II – single layer veneered particleboard produced in two stages, first 14 mm board was pressed, and then finished by veneer; variant III – single layer veneered particleboard, manufactured in single operation. Two different types of thermoplastic reinforcement materials were also used as surface layers for coating of WPC (Schmidt *et al*., 2013). One of them was TWINTEX (reinforcement fabric of commingled thermoplastic and glass filaments), the second one was S-TEX (glass fabric reinforced polypropylene laminate with randomly oriented glass fibers).

However, only a few studies were carried out for surface coating of flat pressed WPC (Schmidt *et al*., 2013). Physical and mechanical properties of WPC can be improved by coating of their surface with different coating materials and this can expand the field of their applications. Therefore, the objective of this study was to investigate the effects of different kinds of coating materials on the properties of flat-pressed WPC panels.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The particles of recycled polyethylene (rPE) and wood with moisture content of 2-3 % were used in this study for making WPC panels. The particles are shown in Figure 1 and their fraction analysis is presented in Table 1.

The ratio of wood particles to rPE was 60:40. Wood particles and rPE (in the natural dry state) were mixed by hand for 10 minutes. The coating was made from one or two surface sides of WPC panel. Two groups of coating materials were used: natural veneer – the rotary-cut birch veneer and sliced oak veneer; and synthetic materials - phenolic impregnated paper, PE film and rPE layer.

Process of one-side coating (Figure 2a). The rotary-cut birch veneer, sliced oak veneer, phenolic impregnated paper, PE film or rPE layer was put into open press-form. Then the mat was formed from the wood-polymer mixture in an open press-form and transferred to the hot press.

Process of two-side coating (Figure 2b). The lower layer of the rotary-cut birch veneer, sliced oak veneer, phenolic impregnated paper, PE film or rPE layer was put into open press-form. Then the mat was formed from the wood-polymer mixture into an open press-form. After that, the outer layer of the rotary-cut birch veneer, sliced oak veneer, phenolic impregnated paper, PE film or rPE layer was put on the prepared composition. Then this sandwich packet was transferred to the hot press.

Table 1 Fraction analysis (by % weight)
Tablica 1. Analiza frakcija (% mase)

Components *Sastavnice*	**Screen hole size, mm** / *Veličina otvora sita, mm*						
	-/5	5/4	4/2	2/1	1/0.63	0.63/0.315	0.315/0
Wood particles / *drvno iverje*	4.75	12.2	15.79	40.28	15.67	9.13	2.18
rPE / *reciklirani polietilen*	9.53	3.04	53.14	32.45	1.83	-	-

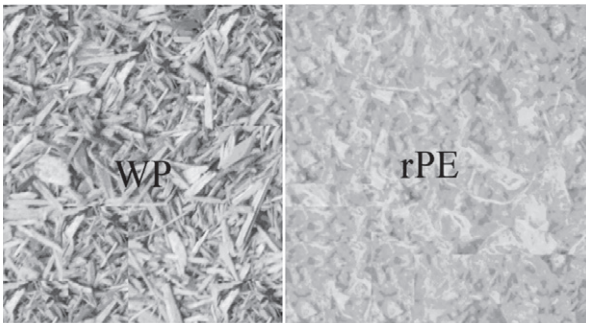

Figure 1 Wood particles (WP) and recycled polyethylene (rPE)
Slika 1. Drvno iverje (WP) i reciklirani polietilen (rPE)

The size of all manufactured WPC test panels was 250 mm in length and 230 mm in width, and 8.0 mm in thickness. All manufactured WPC panels were made in the laboratory press. The hot press was operated in plate position control mode, with the pressure limited to a maximum of 3.5 MPa. The pressing temperature was 180 ºC and pressing time was 8.0 min. At the end of the press cycle, the WPC panels were removed from the press for cooling to the temperature of 30-40 ºC. The density of non-coated WPC panels was 800 kg/m^3. Non-coated WPC panels were manufactured at the same pressing parameters (Lyutyy *et al*., 2014).

Modulus of rupture (MOR) and water resistance (thickness swelling (TS) and water absorption (WA)) of the panels were evaluated according to EN 310 and EN 317, respectively.

The analysis of variance (ANOVA) was conducted to study the effect of different kinds of coating materials (rotary-cut birch veneer, sliced oak veneer, phenolic impregnated paper, PE film and rPE layer) and the type of coating (one or two-side) on the modulus of rupture, thickness swelling and water absorption of coated WPC panels at a 0.05 significance level. Duncan's multiple range tests were conducted for multiple comparisons between the means of the measured properties for different kinds of coating materials and different types of coating.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

ANOVA showed that the kind of coating materials and the type of coating significantly influenced MOR, TS and WA. All investigated coating materials lead to the increase of the MOR of coated WPC panels (Table 2 and 3). The highest values of MOR were observed in WPC panels coated with rotary-cut birch veneer. In particular, the MOR of one-side coated WPC panels with rotary-cut birch veneer increased in 4.9-6.0 times in along veneer fibers and in 1.6-1.7 times in across veneer fibers depending on the coating location (up or down) during the test. Slightly lower values of MOR (in 4.3-5.3 times in along veneer fibers and in 1.5 times in across veneer fibers) were observed in one-side coated WPC panels with sliced oak veneer. The higher values of MOR in one-side coated WPC panels with sliced veneer were obtained in the work (Norvyda and Minelga, 2006). This can be explained by higher initial MOR of non-coated WPC panels and the use of five layers of veneer for coating of WPC panels except for one layer as in our case.

MOR of WPC panels coated with phenolic impregnated paper was increased in 1.7 times and for WPC panels coated with PE film and rPE layer in 2.0-2.2 and about 1.8 times, respectively.

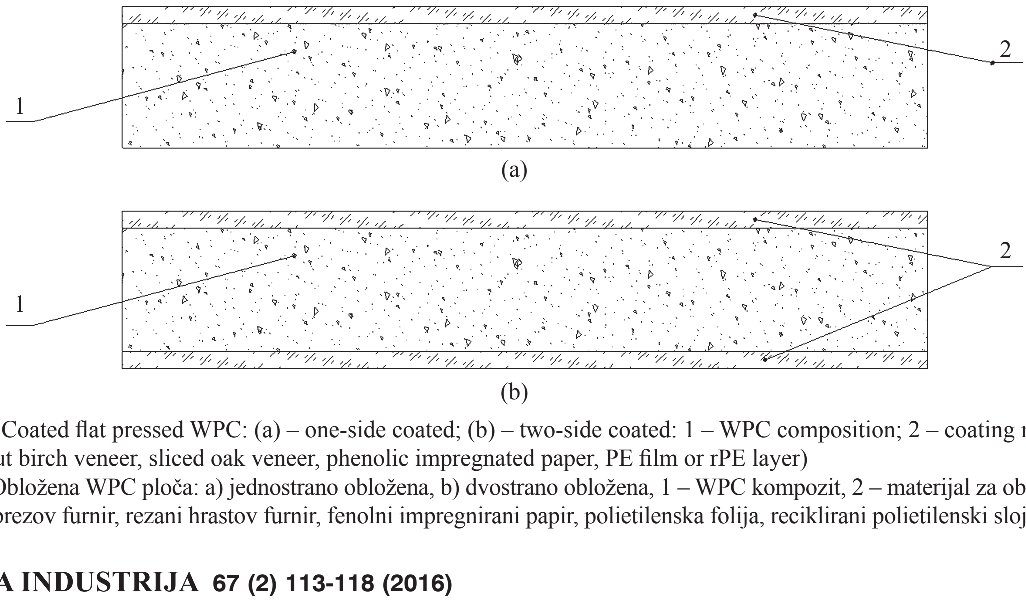

Figure 2 Coated flat pressed WPC: (a) – one-side coated; (b) – two-side coated: 1 – WPC composition; 2 – coating material (rotary-cut birch veneer, sliced oak veneer, phenolic impregnated paper, PE film or rPE layer)
Slika 2. Obložena WPC ploča: a) jednostrano obložena, b) dvostrano obložena, 1 – WPC kompozit, 2 – materijal za oblaganje (ljušteni brezov furnir, rezani hrastov furnir, fenolni impregnirani papir, polietilenska folija, reciklirani polietilenski sloj)

Table 2 Properties of one and two-side coated WPC panels with rotary-cut birch and sliced oak veneers
Tablica 2. Svojstva jednostrano i dvostrano obložene WPC ploče ljuštenim brezovim furnirom i rezanim hrastovim furnirom

Property *Svojstvo*	**Control** *Kontrolni uzorak*	**One-side** / *Jednostrano*				**Two-side** / *Dvostrano*	
		Rotary-cut birch veneer *Ljušteni brezov furnir*		**Sliced oak veneer** *Rezani hrastov furnir*		**Rotary-cut birch veneer** *Ljušteni brezov furnir*	**Sliced oak veneer** *Rezani hrastov furnir*
		Veneer up *furnir je s gornje strane*	Veneer down *furnir je s donje strane*	Veneer up *furnir je s gornje strane*	Veneer down *furnir je s donje strane*		
MOR, MPa	5.6 (0.43) *a*	27.4 (0.62) *c* 9.5 (0.38) *d*	33.6 (0.56) *f* 9.2 (0.51) *cd*	24.2 (0.29) *b* 8.6 (0.16) *b*	29.5 (0.32) *d* 8.7 (0.17) *bc*	48.2 (1.61) *g* 12.7 (0.55) *e*	31.1 (0.88) *e* 9.1 (0.88) *bcd*
WA, %	23.5 (1.30) *a*	35.7 (1.9) *c*		31.1 (1.3) *b*		37.0 (1.75) *cd*	38.6 (3.73) *d*
TS, %	10.1 (0.69) *a*	18.7 (2.2) *c*		15.4 (1.5) *b*		19.2 (2.30) *c*	21.8 (2.60) *d*

Key / *Legenda*: MOR – modulus of rupture / *modul loma* (MPa); WA – water adsorption / *upijanje vode* (%); TS – thickness swelling / *debljinsko bubrenje* (%)
*Values in parenthesis are standard deviations based on twelve samples. / *Vrijednosti u zagradama standardne su devijacije na temelju 12 uzoraka.* **Different letters denote a significant difference. / *Različita slova označuju značajnu razliku.* ***The numerator shows the value of MOR along veneer fibers, and the denominator - across veneer fibers. / *Brojnik pokazuje vrijednost modula loma uzduž vlakanaca furnira, a nazivnik okomito na njih.*

The similar results were found in the work (Borysiuk *et al*., 2011); for example, the coated particleboards showed variable MOR and MOE parameters depending on testing direction (along or across the outer layer veneers). Application of veneers to outer layers strengthened the boards in major axis (MOR and MOE gained around 65 ÷ 72 %) with simultaneous drop in minor axis (by around 23 ÷ 30 %).

The same results were observed in the work (Schmidt *et al*., 2013). The reinforcement of WPC panels with TWINTEX in a single step process leads to 2.4 (4.0) times higher MOE (MOR) in comparison with the unreinforced reference panel. Surface reinforced panels by use of S-TEX show 3.4 (5.6) times higher MOE (MOR). Moreover, the value of MOR of WPC panels coated with TWINTEX was 62.2 MPa and when coated with S-TEX the value of MOR was 89.7 MPa. Such higher values of MOR can be explained by the higher strength of TWINTEX and S-TEX core materials. In particular, the MOR of TWINTEX (in transverse direction) and S-TEX (in longitudinal direction) is 50 and 125 MPa, respectively. S-TEX reinforced material has higher flexural properties than TWINTEX reinforced material because of higher nominal weight and glass content.

MOR of two-side coated WPC panels increased significantly in comparison with one-side coated panels. The values of MOR in two-side coated WPC panels with rotary-cut birch veneer were increased in 8.4 times in along veneer fibers and in 2.3 times in across veneer fibers. Coating of WPC panels with sliced oak veneer also resulted in higher values of MOR; for example, MOR was increased in 5.5 times in along veneer fibers and 1.6 in across veneer fibers. The MOR of WPC panels coated with phenolic impregnated paper and PE film or rPE layer was increased by 79 % and 135 %, respectively.

It should also be noted that WPC panels coated with natural veneers (rotary-cut birch veneer or sliced oak veneer) had higher values of strength properties in

Table 3 Properties of one and two-side coated WPC panels with phenolic impregnated paper, PE film or rPE layer
Tablica 3. Svojstva jednostrano i dvostrano obložene WPC ploče fenolnim impregniranim papirom, polietilenskom folijom i recikliranim polietilenskim slojem

Property *Svojstvo*	**Control** *Kontrolni uzorak*	**One-side** / *Jednostrano*						**Two-side** / *Dvostrano*		
		Phenolic impregnated paper *Fenolni impregnirani papir*		**PE film** *Polietilenska folija*		**rPE layer** *Reciklirani polietilenski sloj*		**Phenolic impregnated paper** *Fenolni impregnirani papir*	**PE film** *Polietilenska folija*	**rPE layer** *Reciklirani polietilenski sloj*
		Paper up *papir je s gornje strane*	Paper down *papir je s donje strane*	Film up *folija je s gornje strane*	Film down *folija je s donje strane*	Layer up *sloj je s gornje strane*	Layer down *sloj je s donje strane*			
MOR, MPa	5.6 (0.43) *a*	9.1 (0.72) *b*	9.5 (0.56) *bc*	11.5 (0.49) *e*	12.3 (0.20) *f*	10.3 (0.53) *d*	10.0 (0.58) *cd*	10.0 (0.64) *cd*	13.4 (0.84) *g*	13.2 (0.61) *g*
WA, %	23.5 (1.30) *e*	25.5 (1.7) *f*		17.5 (1.9) *c*		19.6 (1.35) *d*		23.3 (1.65) *e*	12.9 (1.32) *b*	6.9 (0.97) *a*
TS, %	10.1 (0.69) *c*	14.2 (1.8) *e*		10.0 (1.2) *c*		13.0 (1.7) *d*		8.6 (0.98) *b*	9.2 (0.93) *bc*	5.8 (0.80) *a*

Key / *Legenda*: MOR – modulus of rupture / *modul loma* (MPa); WA – water adsorption / *upijanje vode* (%); TS – thickness swelling / *debljinsko bubrenje* (%)
*Values in parenthesis are standard deviations based on twelve samples. / *Vrijednosti u zagradama standardne su devijacije na temelju 12 uzoraka.* **Different letters denote a significant difference. / *Različita slova označuju značajnu razliku.*

Table 4 Duncan's test results for main effects
Tablica 4. Rezultati Duncanova testa

Main factors *Utjecajni činitelji*	**MOR (along fibers), MPa** *MOR (uzduž vlakanaca), MPa*		**MOR (across fibers), MPa** *MOR (poprečno na vlakanca), MPa*		**WA, %**		**TS, %**	
	Mean	SG	Mean	SG	Mean	SG	Mean	SG
Material / *Materijal*								
control (non-coated) / *kontrolni uzorak (neobloženi)*	5.56	a	5.56	a	23.47	b	10.11	b
rotary-cut birch veneer / *ljušteni brezov furnir*	36.21	f	10.49	d	36.36	d	18.99	d
sliced oak veneer / *rezani hrastov furnir*	28.24	e	8.78	b	34.81	c	17.98	d
phenolic impregnated paper / *fenolni impregnirani papir*	9.65	b	9.65	c	24.36	b	11.66	c
PE film / *polietilenska folija*	12.70	d	12.70	f	15.20	a	9.70	ab
rPE layer / *reciklirani polietilenski sloj*	11.66	c	11.66	e	14.50	a	8.98	a
Type of coating / *vrsta oblaganja*								
control (non-coated) / *kontrolni uzorak (neobloženi)*	5.56	a	5.56	a	23.47	a	10.11	a
one-side coating / *jednostrano oblaganje*	17.68	b	9.85	b	25.85	b	14.20	c
two-side coating / *dvostrano oblaganje*	18.55	c	11.84	c	24.93	b	12.90	b

*SG – statistical group / *statistička skupina*; **Different letters denote a significant difference. / *Različita slova označuju značajnu razliku.*

comparison with the using of synthetic materials (phenolic impregnated paper, PE film or rPE layer). In particular, the MOR values of two-side coated WPC panels were in 4.7 times higher using rotary-cut birch veneer (in along veneer fibers) in comparison with the using of phenolic impregnated paper and in 3.6 times higher in comparison with the using of PE film or rPE layer. Such dependencies could be explained by the properties of coating materials. The strength values of coating materials are quite different. In particular, for birch and oak wood with moisture content of 12 %, the MOR is in the range of 56-117 MPa and 75-125 MPa, respectively, and it should also be taken into account that these values depend on the conditions of tree growth (Green *et al*., 1999). Moreover, the thickness of the coating material should be considered; the rotary-cut birch veneer with the thickness of 1.5 mm, sliced oak veneer with the thickness of 0.5 mm, and PE film with the thickness of 0.1 mm and impregnated phenolic paper with gramature only 80 g/m^2 were used in this study.

The highest water resistance was observed in WPC panels coated with rPE layer. The coating of WPC with natural veneers also resulted in the increasing of TS and WA in comparison with non-coated WPC panels. It was found that coating with rotary-cut birch veneer and sliced oak veneer caused the increasing of TS (WA) on 57 (90) % and 64 (115) %, respectively, in comparison with non-coated WPC panels. It should also be noted that water resistance of one-side coating with natural veneer was higher than two-side coating with natural veneer. The values of water resistance of WPC panels coated with natural veneer were lower in comparison with synthetic materials, which could be explained by higher water absorption of wood veneer. The similar results were observed in the work (Istek *et al*., 2010). The minimum values of WA and TS at 2 and 96 hours were obtained as 56.7 % and 81.4 % in white oak-UF, 11.1 % in common maple-UF, and 14.8 % in white oak-UF (Istek *et al*., 2010) The higher TS and WA values of 21.8 % and 38.6 %, respectively, were reported in another work (Borysiuk *et al*., 2011).

It was found that one-side coating of WPC with phenolic impregnated paper leads to the increasing of TS and WA. In contrast, two-side coating of WPC with phenolic impregnated paper, PE film or rPE layer leads to the decreasing of WA and TS. In particular, the TS (WA) was decreased by 13 (1) % with using phenolic impregnated paper; by 10 (45) % with using PE film and by 46 (68) % with using rPE layer in comparison with non-coated WPC. The polyethylene has high water resistance; its water absorption for 24 hours is 0.10 %. The polyethylene formed water resistance layer (film) on the surface of WPC. This layer does not allow WPC to absorb water and swell. Rotary-cut birch and sliced oak veneers are natural materials in contrast with polyethylene. They can absorb a lot of water, which leads to the increasing of TS and WA of WPC.

The results of Duncan's tests conducted to determine the significance of the relationships between the kind of coating materials, the type of coating and MOR, thickness swelling and water absorption are given in Table 4.

As shown in Table 4, differences in the MOR, TS and WA between all the investigated coating materials and types of coating were statistically significant.

4 CONCLUSIONS
4. ZAKLJUČAK

The values of MOR were increased in WPC panels coated with all investigated coating materials. The highest values of MOR were observed in WPC coated with rotary-cut birch and sliced oak natural veneer. It should be noted that the highest MOR was observed in WPC coated with natural veneer along the grain. WPC panels coated with phenolic impregnated paper, PE film or rPE layer had lower values of MOR in comparison with WPC panels coated with natural veneer. Besides, the MOR was higher in two-side coated WPC panels with all investigated coating materials. The highest water resistance was observed in WPC panels coated with PE film or rPE layer. The coating with natural veneer leads to the decreasing of water resistance of WPC. Moreover, water resistance of one-side coated WPC panels with natural veneer was higher in comparison with two-sided coated WPC panels with natural veneer. The two-side coating of WPC panels with phenolic impregnated paper, PE film or rPE layer leads to the decreasing of WA and TS. As follows, coating materials that are widely used for coating of plywood, particleboards and fiberboards can be successfully used for coating of flat pressed WPC panels. Therefore, the results obtained in this study make it possible to expand the application of WPC panels and also provide important information for future research and use of such flat pressed coated WPC.

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Chemical Composition of Straw as an Alternative Material to Wood Raw Material in Fibre Isolation

Kemijski sastav slame kao alternative drvnoj sirovini za dobivanje vlakanaca

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 17. 12. 2014.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*88; 630*813.1*
doi:10.5552/drind.2016.1446

ABSTRACT • *Wood is still the most widely used raw material for pulp and paper production in the world. However, due to the necessity to supply the paper industry with raw materials used in the extraction of cellulose fibres and the overexploitation of forests, new sources of primary pulp fibres had to be identified. The aim of this research is to highlight the important features of cereal crop residues and their utilization in the paper industry. As the chemical composition of plant materials is one of the most important indicators of how such materials can be used in paper production, the analysis of the chemical composition of straw with the highest grain production was performed. The straw, as a harvesting residue, is a fibre resource available from the annually renewable crops, produced abundantly in numerous regions all over the world. For the purpose of the research, wheat, triticale and barley straw were selected for the analysis. The analysis of carbohydrate, lignin and extraneous material (organic extractives and inorganic minerals) was performed in order to obtain the straw chemical composition. Based on the results of the chemical composition of all analysed straw, it was confirmed that straw, as an agricultural by-product, is rich in cellulosic fibres and, therefore, a valuable raw material for the paper industry. Out of all analysed straw, based on the results of their chemical composition, triticale straw is considered potentially the best source of alternative cellulose fibres.*

Key words: *straw, wheat, barley, triticale, chemical composition*

SAŽETAK • *Drvo je još uvijek najčešća sirovina za proizvodnju celuloze i papira u svijetu. Međutim, s obzirom na količinu sirovine za izdvajanje celuloznih vlakanaca potrebnih papirnoj industriji te na prekomjernu eksploataciju šuma, nužno je pronaći nove izvore primarnih celuloznih vlakanca. Cilj ovog istraživanja bio je istaknuti važnost slame koja je kao poljoprivredni ostatak prikladna sirovina za industriju papira. Kako je kemijski sastav biljnog materijala jedan od najvažnijih razloga njegove upotrebe u proizvodnji papira, određen je kemijski sastav slame žitarica s najvećim doprinosom zrna. Slama, kao ostatak nakon žetve, godišnje je obnovljiv izvor vlakanaca te je u mnogim regijama diljem svijeta dostupna u izobilju. Za ovo je istraživanje izabrana slama pšenice, pšenoraži i ječma. Obavljena je kvantitativna analiza ugljikohidrata, lignina i ekstraktivnih tvari (organski ekstrakti i anorganski minerali) kako bi se odredio kemijski sastav slame žitarica. Na temelju kemijskog sastava svih analiziranih*

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slama potvrđeno je kako je slama kao poljoprivredni nusproizvod bogat izvor celuloznih vlakanaca, a time i vrijedna sirovina za industriju papira. Od svih analiziranih uzoraka slama pšenoraži svojim se kemijskim sastavom nametnula kao najveći potencijalni izvor alternativnih celuloznih vlakanaca.

Ključne riječi: *slama, pšenica, ječam, pšenoraž, kemijski sastav*

1 INTRODUCTION
1. UVOD

Cellulose fibres are a valuable raw material for the paper industry, which has been, in recent years, still one of the fastest growing industries (De Galembert, 2003; Valois *et al*., 2012). The availability of conventional and forest-based raw materials used in fibre isolation became limited due to the increasing demand for pulp and paper products. According to their origin, fibres can be divided into natural cellulose fibres and man-made (synthetic) ones. Since synthetic fibres are completely man made, the length of these fibres is also fully controlled by man (Lainio, 2010). Natural fibres are abundantly present in plants such as wood, grass, reeds, stalks and straw and the length of these fibres is an inherent limitation defined by the natural material they originate from. Wood has been the most widely used raw material for pulp and paper production in the world. As the demand for paper products is increasingly growing, identifying alternative sources of virgin cellulose fibres is of great importance, considering that different types of coniferous and deciduous trees became insufficient raw material for the paper production.

In recent years, non-wood fibres have been considered as a potential source of papermaking raw material. Non-wood fibres, as agricultural residues and annual plants, are low-cost raw materials and, therefore, interesting as sources of alternative fibres to wood cellulose fibres (Sirdach, 2010). The benefit of non-wood plants as fibre sources, with straw being a by–product in the process, is their fast annual growth. Therefore, these non-wood plants, and their straw, represent an annually renewable fibre resource available in abundant quantities in many regions all over the world. Nowadays, countries with a high use of agro residue based fibres are India and China (Jahan *et al*., 2009; Leponiemi, 2008; Chandra, 1998). In European countries such as Italy, Germany, France, Spain, Greece, Hungary and Croatia, agricultural production is relatively high due to the adequate climate (Youngquist *et al*., 1996). These crop species may be an alternative to hardwoods used in paper and paper products (Kamoga *et al*., 2013). The utilization of these residues is of great importance considering that they are burned or ploughed back into the ground.

Namely, straw as a non-wood raw material is defined as part lignin, part carbohydrate and part extraneous material. Just like in wood materials, straw contains carbohydrate and lignin as two major complex and polymeric chemical components. Lower amounts of extraneous materials, mostly in the form of organic extractives and inorganic minerals (ash), are present in straw as well. It is known that all non-wood materials, if compared against wood materials, consist of the same or lower lignin content. On the other hand, they have in general higher nutrient and silicon content (Hunter, 1988). As cereals are annual plants, their chemical composition is considerably more variable than the chemical composition of wood species. Chemical composition varies not only based on the type and cultivar of cereals but also in respect to the geographic location of cereals, climate and soil conditions (Han, 1998). The proportion of cellulose, hemicelluloses, and lignin in agricultural residue is an important criterion when determining both, its suitability as an economically sustainable raw material and the optimum pathway of its conversion for paper industry. Large quantities of cellulose do not necessarily mean that fibres are appropriate for further processing in paper industry; they are, however, the first of many criteria in the selection of raw materials for further processing.

Numerous researches conducted on a global scale are focused on identifying alternative non-wood raw materials as a source of cellulose fibres. Some types of non-wood fibres have been are already used in some paper grade productions, although the paper quality varies based on the source of the fibres. Wheat straw is considered to be one of the most important agricultural residues based on the reported results. Namely, agro-based fibres are mostly used in the packaging and corrugated cardboard (liner and fluting papers) production (Akbari *et al.*, 2012). It would be beneficial to create the accurate inventory of non-wood fibre sources. The currently accessible data are still incomplete information on availability, suitability, sustainability, storage and cost of agricultural residues. Markets will not be fully open to agricultural fibre sources until the aforementioned data has been properly collected, analysed and applied (Rowel *et al.*, 1998). This research focuses on the chemical composition of wheat, barley and triticale straw as one of the most important indicators of the straw usage in paper production.

2 MATERIALS AND METHODS
2. METODE I MATERIJALI

2.1 Straw samples
2.1. Uzorci slame

The straw used in this research was wheat (lat. *Triticum*), barley (lat. *Hordeum vulgare* L.) and triticale (lat. *Triticale* sp.) crop residues obtained from the continental Croatian fields (Table 1). Namely, cereals chosen for this research provided the highest yield, measured as kilograms per hectare of harvested land, and, consequently, the highest quantity of straw as a harvesting by-product. All used straws are crop residues from winter varieties (cereal sown in October 2011 and harvested in July 2012). Wheat and barley are

Table 1 Harvested area, yield per hectare and production of crops in year 2011 in Croatia (Croatian Bureau of Statistics)
Tablica 1. Požnjevena površina, prinos žitarica po hektaru i proizvodnja zrnja u 2011. godini u Hrvatskoj (Hrvatski zavod za statistiku)

Cereal *Žitarica*	**Harvested area, ha** *Požnjevena površina, ha*	**Production, t** *Proizvodnja, t*	**Yield per hectare, t** *Prinos po hektaru, t*
Wheat / *pšenica*	149 797	782 499	5.20
Maize / *kukuruz*	305 130	1733 664	5.70
Barley / *ječam*	48 318	193 961	4.00
Rye / *raž*	871	2 949	3.40
Oat / *zob*	25 344	77 223	3.00
Triticale / *pšenoraž*	9 951	35 149	3.50

ancient agricultural crops, but triticale (hybrid species of wheat and rye) is a relatively new cereal, the use of which has been gradually increasing in agricultural production.

A week after the harvest season, the collected straws were thoroughly washed to remove any extraneous impurities and dried before use. Straw as a residue of wheat, barley and triticale crops was prepared for the analysis of chemical composition in such a way that stalks (nods and internodes) of each straw were cut into small pieces with a razor blade. Pieces of stalk, 1 cm long, were small enough for grounding in an analytical mill IKA A10. The material was then placed in a shaker with sieves in order to pass through a mesh sieve of 0.5 mm. However, the mesh sieve was retained on 0.25 mm. These samples were analysed using plant analysis reference procedures by ICP-MS method for elemental analysis and TAPPI standards for organic and inorganic compounds.

2.2 Chemical characterization
2.2. Kemijska svojstva

Chemical composition of wheat, barley and triticale straw was determined by applying standard isolation methods for major plant chemical components (Fig. 1). Organic (cellulose, α-cellulose, lignin, solvent extractives, moisture) and inorganic compounds were determined according to TAPPI standards.

2.2.1 Determination of ash (w_{ash})
2.2.1. Određivanje količine pepela (w_{ash})

A sample was ignited in a muffle furnace at 525 °C and burnt for 3 hours (TAPPI T211 om-12). For the purpose of ash calculation, a separate sample was analysed for the percentage of moisture by Sartorius moisture analyser. Ash content was calculated as follows:

$$w_{ash} = (\frac{m_1 - m_2}{m_u}) \cdot 100 \quad (1)$$

Where:
m_1 – weight of moisture-free sample before ignition, g
m_2 – weight of sample after ignition, g
m_u – oven-dry weight of sample, g.

2.2.2 Solvent extractives (w_{SE})
2.2.2. Topljive ekstraktivne tvari (w_{SE})

A weight chopped sample was extracted with a mixture of benzene–ethanol (C_6H_6 – C_2H_50H) solvent in a ratio of 1:1 for 8 hours in Soxhlet apparatus. The material, extracted in a round bottom flask, was dried

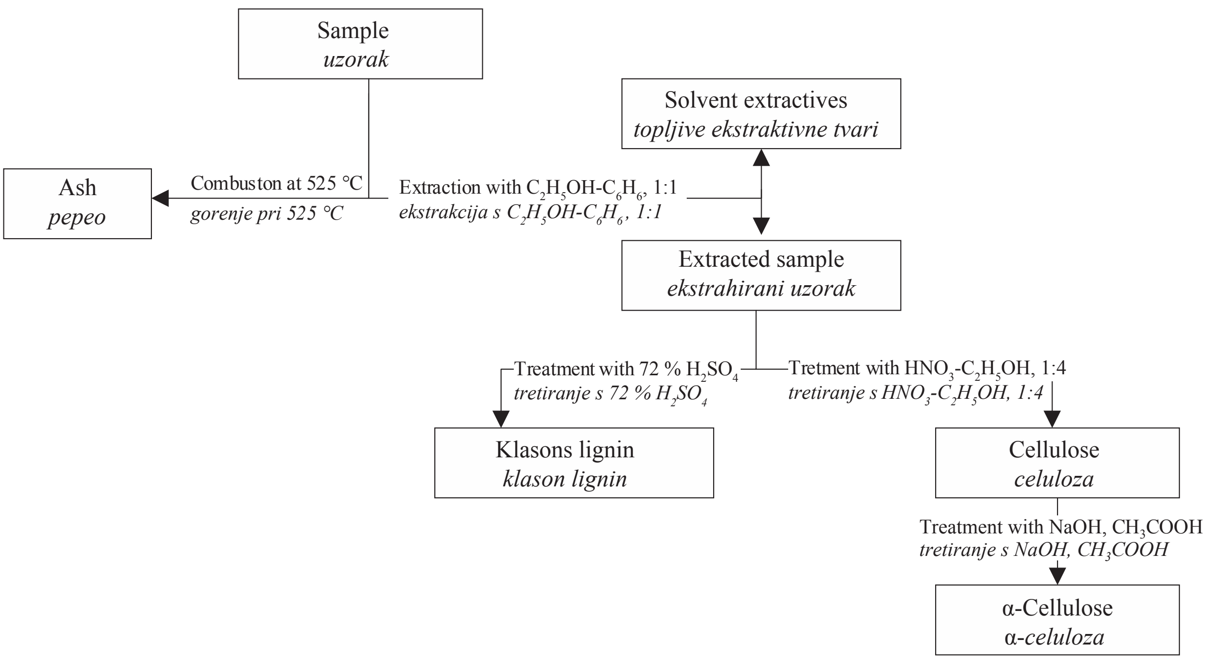

Figure 1 Schematic view of isolation methods for straw chemical characterization
Slika 1. Shematski prikaz izolacijskih metoda za određivanje kemijskog sastava slame

in an oven at the temperature of 80°C to constant weight (TAPPI T204 cm-07). The extracted content was calculated as follows:

$$w_{SE} = (\frac{m_2 - m_1}{m_u}) \cdot 100 \quad (2)$$

Where:
m_1 – oven-dry weight of flask, g
m_2 – oven-dry weight of extract in flask, g
m_u – oven-dry weight of sample, g

2.2.3 Klasons lignin (w_{lignin})
2.2.3. Klason lignin (w_{lignin})

The extracted sample, prior to being cooked in distilled water for 4 hours, had been pre-treated by 72 % sulphuric acid (H_2SO_4) for 2.5 hours. The solid residue lignin was obtained by filtration and drying in an oven at the temperature of 105 °C to constant weight (TAPPI T222 om-11). The Klason lignin content was calculated as follows:

$$w_{lignin} = (\frac{m_2 - m_1}{m_u}) \cdot 100 \quad (3)$$

Where:
m_1 – oven-dry weight of filter paper, g
m_2 – oven-dry weight of filtrated lignin + weight of filter paper, g
m_u – oven-dry weight of sample, g

2.2.4 Cellulose ($w_{cellulose}$)
2.2.4. Celuloza ($w_{cellulose}$)

Küschner–Hoffer method was used for the determination of cellulose. The extracted sample was cooked in a mixture of nitric acid–ethanol (HNO_3 – C_2H_5OH with a ratio of 1:4) in a hot water bath at the temperature of 100°C. Solid/liquid ratio was 1:25. Cooking was done through four extraction cycles until the sludge became completely bleached. Its filtration and drying in an oven at the temperature of 105°C to constant weight provided Küschner–Hoffer cellulose, which was calculated as follows:

$$w_{cellulose} = (\frac{m_1 - m_2}{m_u}) \cdot 100 \quad (4)$$

Where:
m_1 – oven-dry weight of filter paper funnel, g
m_2 – oven-dry weight of funnel + extracted cellulose, g
m_u – oven-dry weight of sample, g

2.2.5 α-Cellulose ($w_{\alpha\text{-cellulose}}$)
2.2.5. α-celuloza ($w_{\alpha\text{-cellulose}}$)

Cellulose extracted from a sample had been obtained through several consecutive extractions with 17.5 % sodium hydroxide (NaOH) solution at 25 °C and then neutralized with 10 % acetic acid solution (CH_3COOH) (TAPPI T203 cm-09). The α-cellulose, as an insoluble fraction, was isolated by filtration and drying in an oven at the temperature of 105 °C to constant weight. The α-cellulose content was calculated as follows:

$$w_{\alpha-cellulose} = (\frac{m_{\alpha-cellulose} \cdot 10^4}{m_{cellulose} \cdot S}) \quad (5)$$

$$S = 100 - w_{moisture} \quad (6)$$

Where:
$m_{\alpha\text{-cellulose}}$ – weight of α-cellulose, g
$m_{cellulose}$ – weight of cellulose, g
S – weight of moisture-free cellulose sample.

2.3 Inductively coupled plasma - mass spectrometry (ICP-MS)
2.3. Spektrometrijska (ICP-MS) masena analiza

The element analysis was performed by applying ICP-MS method. All samples were converted into solution using wet ashing method for organic matter destruction (Campbell *et al*., 1992; Donohue *et al*., 1992). This method enabled the detection of macro elements (potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P)), microelements (boron (B), iron (Fe), copper (Cu), manganese (Mn), molybdenum (Mo), zinc (Zn)) and metals/metalloids (aluminium (Al), barium (Ba), bismuth (Bi), cadmium (Cd), cobalt (Co), chromium (Cr), mercury (Hg), nickel (Ni), lead (Pb), silicon (Si), vanadium (V)).

3 RESULTS
3. REZULTATI

The chemical composition of straw determined by standard isolation methods is presented in Table 2.

Plant nutrients (macro elements, microelements, metal and metalloids) and ash composition of straw are strongly affected by the type of soil and climate conditions during the growth phase of plant. Table 3 presents the results of ICP-MS analysis of the studied straw.

4 DISCUSSION
4. RASPRAVA

The aim of this research was to validate three types of agricultural residues: wheat, barley and triticale as a potential source of raw material in papermaking. Chemical composition of raw materials is the first indication of the possibility of their use in the process of cellulose fibre isolation. From the paper industry's

Table 2 Chemical composition of analysed straw
Tablica 2. Kemijski sastav analizirane slame

***w*, %**	**Wheat** / *Pšenica*	**Barley** / *Ječam*	**Triticale** / *Pšenoraž*
Moisture / *Sadržaj vode*	6.94 ± 0.97	6.62 ± 0.70	7.73 ± 0.82
Ash 525 ºC / *Pepeo*	9.27 ± 0.33	7.14 ± 0.14	5.27 ± 0.16
Solvent extractives / *Topljive ekstraktivne tvari*	3.00 ± 0.57	2.61 ± 0.28	3.02 ± 0.42
Klason lignin / *Klason lignin*	24.66 ± 1.63	21.71 ± 1.17	12.59 ± 1.77
Küschner–Hoffer cellulose / *Celuloza*	48.28 ± 1.01	45.89 ± 0.72	52.88 ± 0.49
α-cellulose / *α-cellulose*	31.47	37.97	44.22

Table 3 Nutrients in analysed straw
Tablica 3. Elementi sadržani u analiziranoj slami

Nutrient *Element*	**Wheat** *Pšenica*	**Barley** *Ječam*	**Triticale** *Pšenoraž*
	mg/kg		
K	10340.50	5014.50	13975.50
Ca	3300.00	3627.50	2769.00
Mg	1051.00	656.50	897.50
P	595.00	1303.00	479.50
Zn	53.69	181.39	22.78
Fe	47.04	101.68	36.52
Mn	30.74	1.43	72.97
Cu	3.78	90.88	8.14
B	3.55	101.67	0.00
Mo	0.99	0.40	0.05
Al	193.24	160.53	31.80
Bi	117.62	149.41	201.72
Si	71.08	147.98	7.74
Ba	42.01	2.81	53.03
Cr	3.68	12.62	2.66
Pb	1.76	26.63	2.91
Ni	1.57	4.77	2.37
Cd	0.15	0.55	0.11
Co	0.03	0.12	0.03
V	0.00	65.95	0.81
Hg	0.00	0.00	0.00

perspective, it is preferred that the plant material contains cellulose in the highest share possible and that the minimum share of other accompanying non-cellulose components is kept to a minimum.

Chemical characteristics of the straw as a raw material for cellulose fibres are important for producing pulp of high chemical purity and high α-cellulose content. The amounts of cellulose (especially α-cellulose) and lignin content in the selected raw materials are the most important indicators of use of raw materials in paper production. In general, the higher the lignin content, the lower is the cellulose content (Han, 1998). It is known that the content of organic and inorganic components depends not only on plant species, but also on botanical classification, stalk height, farming conditions such as climate, soil and human influence on the growing phase of plants (McKean *et al*., 1997). In case of wood species these chemical composition variations also exist but they are not as high as in annual plants. For instance, beech wood that was sampled in different locations with various soil type and phytocoenoses, the statistically significant differences were found in the solvent extractives and cellulose content, while the difference in ash, lignin and wood polyoses content were negligible [Antonović *et al.* 2007]. Therefore, it could be concluded that non-wood fibrous raw materials have more variations in chemical composition for the same species than wood (Hunter, 1988). The analysis presented in this research showed that present amounts of cellulose, lignin and solvent extractives (Table 2) were similar to those encountered in softwood and hardwood (Rowell *et al*., 2005). Cellulose obtained by Küschner–Hoffer method was relatively high in all-analysed straw: barley (45.89 ± 0.72) %, wheat (48.28 ± 1.01) % and triticale (52.88 ± 0.49) %, which makes these cereals interesting raw materials for pulp and paper industry. Lignin content was significantly low in triticale straw (12.59 ± 1.77) %, while it was much higher in two other straws: barley (21.71 ± 1.17) % and wheat (24.66 ± 1.63) %. As expected, ash content determined at 525 ºC was relatively high in all analysed straws, considering that it is a distinguishing quality for all non-wood raw materials. Wheat straw had the highest ash content (9.27 ± 0.33) %, which could be considered as a serious disadvantage in the pulping and papermaking context. Barley straw has somewhat lower ash content (7.14 ± 0.14) % and the triticale straw had the lowest ash content (5.27 ± 0.16) %. The issue of potentially high ash content in straw could be easily solved by fractionating, that is, singling out the components with less desirable properties, such as leaves and nodes (pre-treatment), which will have a positive effect on the ash content, and eventually the pulp and paper properties (McKean *et al*., 1997). According to complete chemical composition presented in Table 2, it is clearly noticeable that triticale straw contains the highest amount of cellulose (52.88 ± 0.49) % and at the same time the lowest amount of non-cellulose components, especially lignin (12.59 ± 1.77) % and ash (5.27 ± 0.16) %.

As previously noted, low mineral content in the plant material is preferred in fibre production (Saijonkari-Pahkala, 2001). By ICP-MS analysis in all straw samples, K was determined in a notably higher concentration than other macro elements (Table 3). That is in correlation with the results obtained in other researches of wheat (Antongiovanni *et al*., 1991; Rousu *et al*., 2002; McKean *et al*., 1997) and barley (Antongiovanni *et al*., 1991). The highest concentration of K was observed in triticale straw. High concentration of K was characteristic of all cereal straw. Macro elements in all-analysed straws followed the sequence K>Ca>Mg>P.

The amounts of some nutrients in straw have negative impacts on facilities equipment used during the raw material conversion to pulp (Si) and some (Cu, Fe, Co, Mn, Pb and Zn) on the optic and quality of paper as a final product of paper production (Saijonkari-Pahkala, 2001). These metals may be added to the paper from the fibre source (straw), which may contain trace elements from the ground in which it was grown, or by the equipment, water and chemicals used in the paper manufacturing process. Their presence can cause disadvantageous changes in paper as it ages and is exposed to mould, high relative humidity, light, and pollution or/and some conservation treatments (e.g., oxidative and reduction bleaching) (Leponiemi *et al*., 2010; Sridach, 2010; McKean *et al*., 1997). From all nutrients, Si is the most damaging element in the raw material for pulping, because it complicates the recovery of chemicals, wears out the installations of paper factories and can affect the paper quality (Saijonkari-Pahkala, 2001; Gonzalez *et al*., 2008; Sotannde *et al*., 2014). According to gained results of straw chemical composition analysis (Table 3), it could be concluded that barley straw contains the highest concentration of all analysed microelements. These microelements are present in wheat straw in a significantly lower concentration, while their concentration is the lowest in triticale straw. This trend does not pertain only to Mn concentration, as this microelement has been determined to have the highest concentration in triticale straw. The results of Si concentration in triticale straw indicate that this cereal contains significantly less silicon than the other two analysed straw crops (Table 3). The concentrations of all analysed nutrients in wheat, barley and triticale straws (Table 3) are in correlation with those reported by Koppejan (Koppejan *et al*., 2008). It was confirmed that the concentration of Si in barley straw is high. The amount of undesirable minerals in a pulping process can be minimised by choosing a suitable straw as the raw material for pulping based on its chemical composition.

5 CONCLUSION
5. ZAKLJUČAK

Chemical composition of three alternative sources of fibres was determined. According to the obtained results, it was evident that straw as non-wood plant material has nearly the same cellulose content as most wood spices, lower content of lignin and higher amount of ash and solvent extractives. Conducted chemical component analysis showed that wheat, barley and triticale straw contain a high amount of cellulose, which justifies their valorisation as a source of fibres in papermaking industry. All obtained results indicated that triticale straw contains the highest amount of cellulose (and α-cellulose) and has, at the same time, the lowest lignin and ash content. Undesirable minerals in a pulping process are present in a low content in triticale straw. It could be concluded from the chemical point of view, that triticale represents the type of fibre source that can bring competitiveness and vitality to paper industry as an alternative non-wood raw material.

Knowledge of the composition of raw materials and their variations due to agro-climatic conditions of growth is essential in the chemical treatment to extracted cellulose fibres. For obtaining a quality pulp from straw, it is important to use the proper method for fibre isolation in order to avoid the loss of cellulose content during the separation of non cellulose components from the lignocellulose structure of straw. It is important to point out that the chemical composition of raw materials is the first indication of their potential use in cellulose fibre isolation. However, physical, chemical and morphological characteristics of isolated fibres also have a great impact on the pulp production and consequently on paper properties. Therefore, further research will be devoted to fibre isolation and to finding out which isolation process could provide the highest quality fibres based on their physical, chemical and morphological properties.

Acknowledgements – Zahvale

This research was performed within the project „Cereal straw as a source of fibres in the newsprint production" supported by the University of Zagreb.

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Resin Content and Board Density Dependent Mechanical Properties of One-Layer Particleboard Made from Willow (*Salix viminalis*)

Mehanička svojstva jednoslojne ploče iverice od drva vrbe (*Salix viminalis*) u ovisnosti o sadržaju ljepila i gustoći ploče

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 14. 1. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*863.21; 630*812.42; 674.031.623.229*
doi:10.5552/drind.2016.1502

ABSTRACT • *The paper presents the results of studies on the mechanical properties of one-layer particleboards made from willow (Salix viminalis). Since the particleboards were to simulate the core layer of typical furniture three-layer particleboards, they were made from coarse particles of the size from 1 to 4 mm using urea-formaldehyde resin as a binder. The effects of board density and resin content were evaluated. Three levels of resin content: 8, 9 and 10 %, and board density: 0.57, 0.60 and 0.63 g/cm³, were assumed. The effects of both factors, for their assumed ranges of variation, on the mechanical properties of particleboard were statistically significant. The modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB) and screw holding strength (SHS) were determined. The effect of board density on MOE and MOR was greater than that of resin content, whereas the effect of board density on IB and SHS was less than that of resin content.*

Key words: *particleboard, Salix viminalis, mechanical properties, resin content, density*

SAŽETAK • *U radu su prikazani rezultati istraživanja mehaničkih svojstava jednoslojne ploče iverice izrađene od drva vrbe (Salix viminalis). Kako bi se dobile iverice koje simuliraju srednji sloj tipične troslojne ploče za izradu namještaja, iverice su izrađene od drvnih čestica veličine od 1 do 4 mm, uz primjenu urea-formaldehidnog ljepila kao veziva. Procijenjen je utjecaj gustoće ploče i sadržaja ljepila na mehanička svojstva ploča. Istražene su tri razine sadržaja ljepila: 8, 9 i 10 %, te tri gustoće ploče: 0,57, 0,60 i 0,63 g/cm³. Utjecaj sadržaja ljepila i gustoće na mehanička svojstva ploča statistički je značajan. Istraživana su ova mehanička svojstva ploča: modul elastičnosti (MOE), modul loma (MOR), unutrašnja čvrstoća vezanja (IB) i čvrstoća držanja vijaka (SHS). Gustoća ploče imala je veći utjecaj na MOE i MOR nego sadržaj ljepila, dok je utjecaj gustoće ploče na IB i SHS bio manji od utjecaja sadržaja ljepila.*

Ključne riječi: *iverica, Salix viminalis, mehanička svojstva, sadržaj ljepila, gustoća*

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1 INTRODUCTION
1. UVOD

One of the possible alternative raw materials in particleboard manufacturing can be fast growing shrubs of willow (*Salix viminalis*). They are cultivated in Poland for energy purposes, and their suitability for particleboard industry was confirmed by a number of studies (Frąckowiak, 2007; Frąckowiak *et al*., 2008; Warmbier *et al*., 2013, 2014a, 2014b). Sean and Labrecque (2006) found the usefulness of Quebec clones of this willow. Kowaluk and Fuczek (2010), and Kowaluk *et al*. (2008) used non-standard, specially prepared, particles from the willow (*Salix viminalis*). These particles, named fibrous chips, were produced on a Pallmann defibrator using a span of 1.2 mm between the hammer and milling disc. The authors showed the suitability of these particles for particleboard manufacturing.

Mechanical properties of particleboards depend on many factors, with the resin content and density of particleboard being the major ones. It is known that an increase in resin content and board density leads to improved mechanical properties of particleboards (Rackwitz 1963; Maloney 1993). However, the quantitative effects of these factors on the mechanical properties of particleboards made from willow (*Salix viminalis*) are not sufficiently known.

A typical particleboard for furniture purposes is a three-layer board, which consists of a core layer and two face layers. It was assumed that willow particles as a substitute for industrial wood particles would be used for manufacturing only the core layer. Therefore, it was decided to investigate a one-layer particleboard as simulating the core layer of a three-layer particleboard. The objective of this study was to evaluate the effects of resin content and board density on the mechanical properties of particleboards made from willow (*Salix viminalis*).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Three-year-old stems of willow (*Salix viminalis*) with a diameter at the base ranging from 28 to 35 mm came from the Wielkopolska Region of Poland. The mean density of the stems was 0.51 g/cm^3 at a moisture content of 12 %, and bark percentage was about 15 % of stem weight. The stems were chipped in a hammermill, and then screened by an analytical sieve shaker using 4 mm and 1 mm sieves. Particles that passed through the 4 mm sieve and remained on the 1 mm sieve were used as furnishes for experimental particleboards that simulated the core layer of three-layer particleboard. The bulk density of these particles was 0.20 g/cm^3. Prior to pressing, the particles were dried in an air-circulation oven to achieve a moisture content of less than 3 %.

Urea-formaldehyde (UF) resin was used as a binder. It had a density of 1.26 g/cm^3 at 60 % solids, pH value of about 7, a viscosity of 400-600 mPa·s at 20 ºC, and gel time of 40 s at 100 ºC. Three levels of resin content: 8, 9, and 10 %, and board density: 0.57, 0.60, and 0.63 g/cm^3, were assumed. The board manufacturing parameters are listed in Table 1. The particleboards were prepared in the laboratory. The target board thickness was 10 mm. After spraying the adhesive on particles in a drum blender, a particleboard mat was manually formed inside a 40 x 40 cm box. The pressing conditions were the temperature of 180 ºC, maximum pressure of 2.5 MPa and pressing time of 3 min. Nine types of boards of different density and resin content were made. Four experimental boards were produced for each board type. The boards were not sanded.

Table 1 Manufacturing parameters
Tablica 1. Parametri procesa proizvodnje ploča

Parameter / *Obilježje*	**Value** / *Vrijednost*
Board thickness / *debljina ploče*	10 mm
Board dimensions / *dimenzije ploče*	40 cm x 40 cm
Press temperature *temperatura prešanja*	180 ºC
Maximum pressure / *maksimalni tlak*	2.5 MPa
Press closing time *vrijeme zatvaranja preše*	25 s
Pressing time / *vrijeme prešanja*	3 min

Prior to testing, all the boards were stored in controlled conditions (50 % relative humidity and 20 ºC) for two weeks. Test specimens were cut from the boards to determine the following mechanical properties according to appropriate EN standards: modulus of elasticity (MOE) and modulus of rupture (MOR) (EN 310, 1993), internal bond (IB) (EN 319, 1993), and screw-holding strength (SHS) (EN 13446, 2002) by using screws with a diameter of 3.5 mm, length of 45 mm and a hole diameter of 2.5 mm. Twenty specimens were prepared for each test and board type. Test specimens for IB and SHA were prepared from the specimens that were formerly tested for MOE and MOR.

The obtained data were statistically analyzed using the Statistica version 10. The analysis of variance (ANOVA) was conducted to determine the significance of the effects of resin content and board density on mechanical properties of particleboards.

3 RESULTS
3. REZULTATI

The results of the ANOVA test are shown in Table 2. Both variables, resin content and board density, significantly affected the mechanical properties of particleboard. The interaction between the variables was not significant for each property.

The effects of board density and resin content on the mechanical properties of particleboards are shown in Figure 1. MOE and MOR increased with increasing board density and resin content. The increases in MOE and MOR, with increasing board density from 0.57 to 0.63 g/cm^3, were on average 18.5 and 29.2 %, respectively. The increases in MOE and MOR, with increasing resin content from 8 to 10 %, were on average 12.9 and 15.7 %, respectively. Thus, MOR was most af-

Table 2 Two-way ANOVA test on the effects of resin content and board density on particleboard mechanical properties (*p*-values)
Tablica 2. Dvosmjerni ANOVA test o utjecaju sadržaja ljepila i gustoće ploče na mehanička svojstva ploče iverice (*p*-vrijednosti)

Variable *Varijabla*	**MOE**	**MOR**	**IB**	**SHS**
resin content *sadržaj ljepila*	<0.0001*	<0.0001*	<0.0001*	<0.0001*
board density *gustoća ploče*	<0.0001*	<0.0001*	0.0016*	0.0016*
resin content x board density *sadržaj ljepila x gustoća ploče*	0.9335^{ns}	0.9929^{ns}	0.9918^{ns}	0.9846^{ns}

* Denotes significance at 0.01 / *Označava signifikantnost pri p=0,01*.
^{ns} Not significant at 0.05 / *Nije signifikantno pri p=0,05*.

fected by increasing board density and resin content. Furthermore, the effect of board density was greater than that of resin content. It is worth mentioning that a relatively small increase in density of about 10 % caused a much greater increase in MOE and MOR. These results can be explained by the fact that the increase in resin content caused more uniform coating particle surface by adhesive, and moreover that the increase in board density resulted in an increase in particle surface due to increasing wood compression (Rackwitz, 1963; Maloney, 1993). Similar effects of resin content on MOE and/or MOR of one-layer particleboards with UF resin as a binder were found in other studies: Papadopoulos *et al*. (2004) for particleboards made from bamboo (*Bambusa vulgaris*), with increasing resin content from 10 to 12 %; Zheng *et al*. (2006) for particleboards made from saline Athel tree (*Tama-*

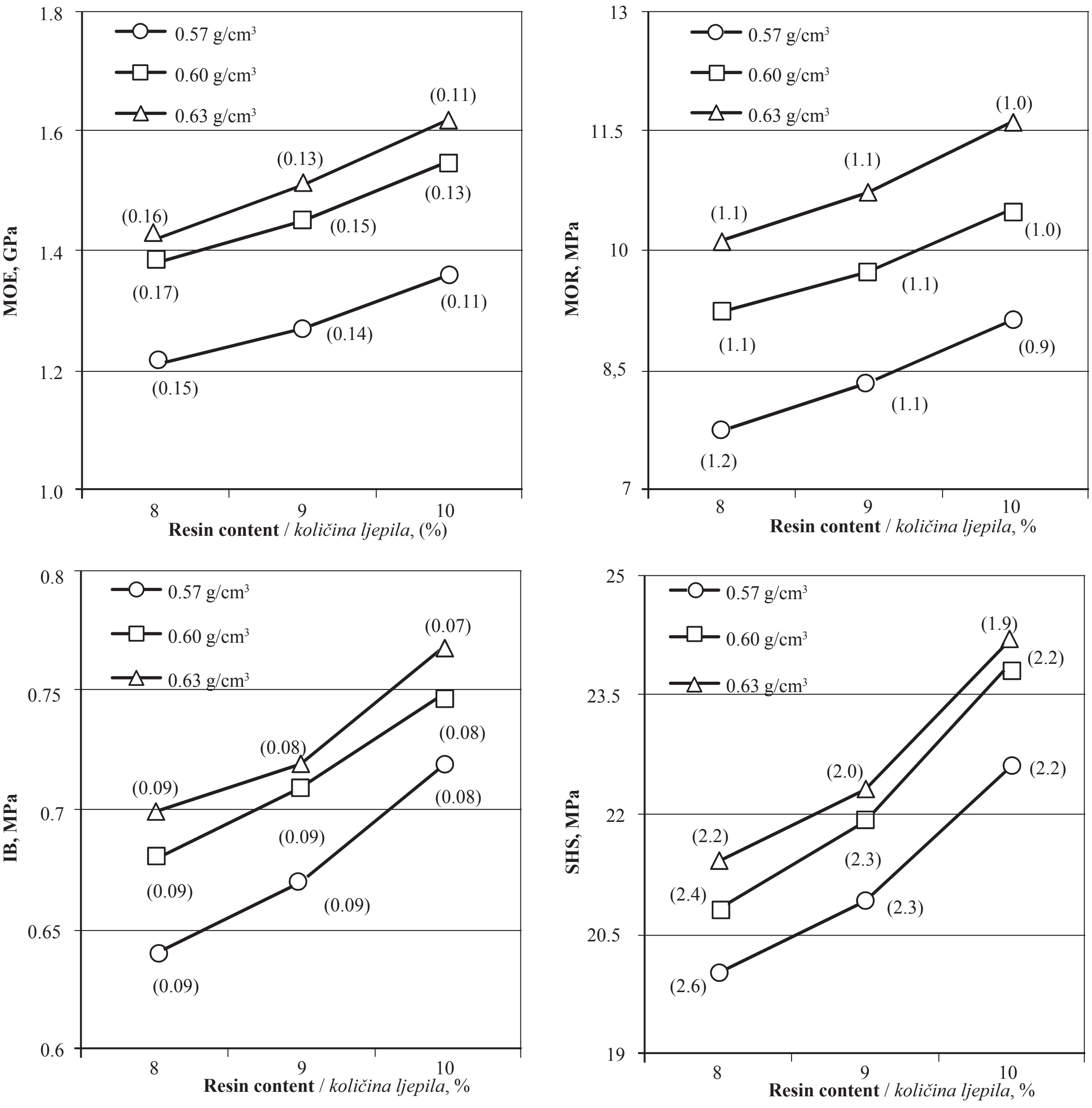

Figure 1 Effect of resin content on modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB) and screw holding strength (SHS) of particleboards with different density (standard deviations in parentheses)
Slika 1. Utjecaj sadržaja ljepila na modul elastičnosti (MOE), modul loma (MOR), unutarnju čvrstoća vezanja (IB) i čvrstoću držanja vijaka (SHS) ploča iverica različite gustoće (u zagradama su navedene standardne devijacije)

rix aphylla), with increasing resin content from 7 to 10 %; Ashori *et al*. (2008) for particleboards made from date palm (*Phoenix dactylifera*), eucalyptus (*Eucalyptus camaldulensis*), mesquite (*Prosopis juliflora*) and saltcedar (*Tamarix stricta*), with increasing resin content from 9 to 11 %; Lin *et al*. (2008) for particleboards made from betel palm (*Areca catechu*), with increasing resin content from 8 to 10 %; Rathke *et al*. (2012) for particleboards made from poplar (*Populus* spp.) and locust (*Robinia pseudoacacia*), with increasing resin content from 7 to 8.4 %. Similar effects of board density on MOE and/or MOR of one-layer particleboards bonded with UF resin were found in other studies: Grigoriou (2000) for particleboards made from a mixture of straw and industrial wood particles, with increasing board density from 0.65 to 0.70 g/cm^3; Grigoriou and Ntalos (2001) for particleboards made from castor stalks (*Ricinus communis*), with increasing board density from 0.66 to 0.72 g/cm^3; Laemlaksakul (2010) for particleboards made from bamboo waste (*Dendrocalamus asper*), with increasing board density from 0.65 to 0.70 g/cm^3; Garcia-Ortuno *et al*. (2011) for particleboards made from giant reed (*Arundo donax*), with increasing board density from 0.69 to 0.74 g/cm^3.

The effects of board density and resin content on IB and SHS of particleboards are shown in Figure 1. IB and SHS increased with increasing board density and resin content. The increases in IB and SHS with increasing board density from 0.57 to 0.63 g/cm^3 were on average 7.9 and 6.9 %, respectively. The increases in IB and SHS with increasing resin content from 8 to 10 % were on average 11.0 and 13.7 %, respectively. Therefore, unlike the cases of MOE and MOR, the effect of board density on IB and SHS was less than that of resin content. The explanation of these increasing properties as a function of increasing board density and resin content is the same as for MOE and MOR. Similar positive effects of resin content or board density on IB and/or SHS were mentioned in previous studies: Grigoriou and Ntalos (2001) for particleboards made from castor stalks (*Ricinus communis*), with increasing board density from 0.66 to 0.72 g/cm^3; Zheng *et al*. (2006) for particleboards made from saline Athel tree (*Tamarix aphylla*), with increasing resin content from 7 to 10 %; Lin *et al*. (2008) for particleboards made from betel palm (*Areca catechu*), with increasing resin content from 8 to 10 %; Rathke *et al*. (2012) for particleboards made from poplar (*Populus* spp.) and locust (*Robinia pseudoacacia*), with increasing resin content from 7 to 8.4 %.

4 CONCLUSIONS
4. ZAKLJUČAK

One-layer experimental particleboards were manufactured from willow (*Salix viminalis*) as a substitute for industrial wood particles. Since the particleboards were to simulate the core layer of typical furniture three-layer particleboards, they were made from coarse particles of the size from 1 to 4 mm. The board density and resin content, for their assumed ranges of variation, affected significantly the mechanical properties of particleboards. The modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB) and screw holding strength (SHS) were determined. The effect of board density on MOE and MOR was greater than that of resin content, whereas the effect of board density on IB and SHS was less than that of resin content.

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Simulating Strength Behaviors of Corner Joints of Wood Constructions by Using Finite Element Method

Simuliranje naprezanja u kutnim spojevima drvenih konstrukcija primjenom metode konačnih elemenata

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 15. 1. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*812.472; 630*824.132*
doi:10.5552/drind.2016.1503

ABSTRACT • *Using finite element method (FEM) has become wide spread in the field of wood mechanics for analyzing difficult problems instead of conventional methods. The objective of this study is to determine the strength properties of wood corner joints using FEM. For this purpose, diagonal compression and diagonal tension experiments were carried out using dowel, mortise and tenon elements. Corner joints (L-type) were prepared with Scotch pine (Pinus sylvestris L.) and Beech (Fagus orientalis Lipsky) woods. Data obtained experimentally were used in FEM computer modeling to determine structural specifications of wood materials. The amount of deformation as a result of compression-tension in the corner joints was determined and then simulated with a computer program using FEM (ANSYS Multiphysics/LS-DYNA). As a result, the amount of deformation obtained from experiments was consistent with the FEM computer modeling with 90 to 97 %. It is suggested that strength properties of joints can be forecast by using FEM computer modeling instead of physical experiments that may cause loss of time, increase of cost and destruction of materials.*

Key words: *Finite Element Method (FEM), ANSYS/LS-DYNA, wood, strain gauge, wooden corner joints, dowel, mortise, tenon*

SAŽETAK • *Za analizu složenih problema u području mehanike drva umjesto konvencionalnih metoda vrlo se često primjenjuje metoda konačnih elemenata (FEM). Cilj istraživanja ovog rada bio je odrediti naprezanja drvenih kutnih spojeva uz pomoć metode konačnih elemenata. Za tu su namjenu provedeni eksperimenti dijagonalnoga tlačnog naprezanja i dijagonalnoga vlačnog naprezanja drvenih spojeva s moždanicima, uz primjenu čepa i rupe. Kutni spojevi (L-tip) pripremljeni su od drva škotskog bora (Pinus sylvestris L.) i bukve (Fagus orientalis Lipsky). Eksperimentalno dobiveni podatci upotrijebljeni su za FEM računalno modeliranje kako bi se utvrdila strukturna obilježja drvnih materijala. Određena je veličina deformacije kutnih spojeva kao posljedica tlačnog naprezanja, a zatim je simulirana primjenom računalnog programa i metode konačnih elemenata (ANSYS Multiphysics/LS-Dyna). Rezultati su pokazali da veličina deformacije dobivena modeliranjem i primjenom metode konačnih elemenata odgovara veličini deformacije dobivene eksperimentalnim mjerenjem, i to u iznosu 90 – 97 %.*

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Istraživanjem je također utvrđeno da se čvrstoća kutnih spojeva može dobro predvidjeti FEM računalnim modeliranjem umjesto provedbom eksperimenata koji zahtijevaju više vremena, povećane troškove i uništavanje većih količina materijala.

Ključne riječi: *metoda konačnih elemenata (FEM), ANSYS/LS-DYNA, drvo, mjerenje naprezanja, drveni kutni spojevi, spoj moždanicima, spoj čep – rupa*

1 INTRODUCTION
1. UVOD

Frame structure represents the most widely used type of furniture constructions. The strength of corner joints in the construction of case-type furniture has a direct effect on the durability of the product. There are a lot of researches related to corner joints in case construction of furniture and frame constructions (Dalvand *et al*., 2014; Nicholls and Crisan, 2002; Cai *et al*., 1995; Eckelman and Suddarth, 1969). Some researches of the strength of furniture joints have mainly focused on mortise and tenon joints and dowel joints (Atar *et al*., 2009).

The rapid development of technology makes the solution to problems encountered in daily life much harder and more complicated. The computer has become an analysis tool that facilitates solutions to these hardships and problems. Therefore, it is possible to produce approximate numeric solutions through simulations. The finite element method (FEM) is a numeric analysis method in which the problem is simulated while considering the physical conditions and features of the materials. Using FEM computer modeling can enable faster, less costly, more optimized product development and examination of detailed product performance that would not be possible to observe experimentally (Yorur, 2012).

Finite Element Method (FEM), applied in various disciplines, is a numerical method used to solve engineering problems that require special analysis. Joints were discussed in the literature, by using different analyzing programs and model approaches of case type furniture (Gustafsson, 1995; Gustafsson, 1996; Gustafsson, 1997; Smardzewski, 1998; Smardzewski, 2002; Nicholls and Crisan, 2002; Guindos and Guaita, 2013; Tankut *et al*, 2014). The literature about finite element method is rich, but there is not sufficient information about wood and wooden materials using FEM computer modeling. The purpose of this research is to answer the question "Can we use a computer aided model instead of physical experiments?"

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Beech (*Fagus orientalis* Lipsky) and Scotch pine (*Pinus sylvestris* Lipsky) wood samples were selected randomly from timber merchants of Bartin in Turkey. For selection of the wood samples, some specifications (non-deficient, proper, knotless, normally grown without zone line, without reaction wood and without decay, insect mushroom damages) were considered according to TS 2470 (TS 2470, 1976).

PVAc D3 adhesive was provided from Polisan, a producer company in Izmit, Turkey. PVAc D3 is an odorless and non-flammable adhesive manufactured according to BS EN204 (BS EN204, 2001) (D3) and DIN 68602 (DIN 68602, 1979) standards. The density of the PVAc D3 adhesive is 1.1 g/m^3. Based on TS 3891 (TS 3891, 1983), approximately 200 g/m^2 of the adhesive were applied to all surfaces of the mortise-tenon and dowel joints.

Dowels produced from beech wood (10 mm in diameter x 57 mm long) were used in samples following the standard TS 4539 (TS 4539, 1985). To ensure the strength of the holes in the wood, a 35-mm-deep hole with a diameter of 10 mm was drilled in element "A" using Computer Numerical Control drill machine, while a 25-mm-deep hole was drilled in element "B". FEM analyses were also carried out by using the same values. Mortise dimensions (width x length x depth 14 x 28 x 32,15 mm) were chosen in samples according to the standard TS 4905 (TS 4905, 1986). Holes of "tenon and mortise joints" were first drilled in element B to form the mortise and then element A was prepared for the tenon. Finally, A and B elements were fit to each other. Glue line was 0.15 mm in thickness for the joint section of all construction parts (dowel and mortise - tenon)

The strain gauges used in the experiments were provided from the manufacturer HBM and had a standard range of 120 Ω ± 0.35 %. The strain gauge version was 20/120LY41. The size of the strain gauges was 32 x 3.2 mm. During the experiment, the deformation values gathered from testbox-1001 were saved and tension values were obtained.

2.2 Preparation of samples
2.2. Priprema uzoraka

As experimental schedule showed in Table 1, a total of 80 experimental samples were used for these studies; two species of wood (Beech and Scotch pine), two joint types (dowel and mortise-tenon), two test methods (diagonal compression and tension), and ten repetitions. A total of 80 samples were conditioned in a room with the temperature of 20 ºC and a relative humidity of 65 % until they reached 12 % equilibrium moisture content. Each L-type corner joint test sample consisted of two elements: "A" with dimensions of 158x42x42 mm and "B" with dimensions 200x42x42 of mm.

During the experiment, a strain gauge was bonded 10 mm far from the joint section of the elements for each sample (the inner edge) and the deformation values were measured by 20/120LY41 strain gauges. The same conditions as in the experiments were applied for computer modeling.

Table 1 Experimental design
Tablica 1. Parametri eksperimenta

Wood species *Vrsta drva*	**Joint types** *Vrsta spoja*	**Tests** *Ispitni postupak*	**Number of samples** *Broj uzoraka*
Beech *bukovina*	Dowel / *spoj moždanicima*	Diagonal compression / *dijagonalno tlačno naprezanje*	40
	Mortise-tenon / *spoj čep - rupa*	Diagonal tension / *dijagonalno vlačno naprezanje*	
Scotch pine *škotska borovina*	Dowel / *spoj moždanicima*	Diagonal compression / *dijagonalno tlačno naprezanje*	40
	Mortise-tenon / *spoj čep - rupa*	Diagonal tension / *dijagonalno vlačno naprezanje*	

2.3 Method
2.3. Metoda

Load application in diagonal compression for FEM computer modeling is shown in Figure 1a. and in diagonal tension in Figure 1b. Loading continued until the strength values at the joint section decreased.

To determine the strength of the L-type dowel and mortise-tenon corner joints, diagonal compression and tension tests were applied with a zwick roell Z50 universal test machine. The loading speed of the machine throughout the tests was adjusted to 5 mm/minute. The loading continued until there was a break or separation at the joint sections of the samples and, at this instant, the load (F_{max}) was determined and recorded. The same amount of the load that caused the experiment break was considered for computer modeling. In computer modeling (ANSYS/LS-DYNA), material selection was made after the method was determined. The chosen element was solid 164. Solid 164 is an 8-pointed solid element that contains features of cracking in tension, crushing in compression, plastic deformation and elasticity. It has 3 directional motions independent in x, y and z directions in the nodes. Punches and anti-friction lining were shell 163. Plastic kinematic was chosen as material properties in ANSYS. The material properties listed in Table 2 were obtained experimentally.

These properties of experiment samples were also chosen for FEM computer modeling. As shown in Figure 2, the L-type corner joint was placed under punch contact point. As in the experiments, B element was placed on the nick in the metal plate. For diagonal compression, the metal plate was fixed in directions of x, y, z in FEM computer modeling but for diagonal tension it was fixed in directions of y and z and released in the direction of x. The punch was fixed only in x and z directions, and in the y direction, only downward movement was allowed, without rotational movement. For a dowel, the number of elements was 45295 and the number of nodes was 9538. For tenon joints, these numbers were 44725 and 9450, respectively. As a result of the punch movements, the internal force distribution and directions of samples in FEM computer modeling are shown in Figure 2.

Table 2 Material properties used in ANSYS/LS-DYNA Program
Tablica 2. Svojstva materijala uvrštena u računalni program ANSYS/LS-DYNA

Mechanical features *Mehanička svojstva*		**Yellow Pine** *Borovina*	**Beech** *Bukovina*
Density / *gustoća*, g/cm^3		0.52	0.67
Elasticity module / *modul elastičnosti*, N/mm^2		10.500	12.500
Poisson rate / *Poissonov koeficijent*, ν		0.30	0.35
Leakage / *puzanje materijala*		32.0	50.0
Stretching / *istezanje*		0.03	0.03
Contact friction *Koeficijent trenja*	Static/*statički*	0.30	0.30
	Dynamic *dinamički*	0.70	0.70

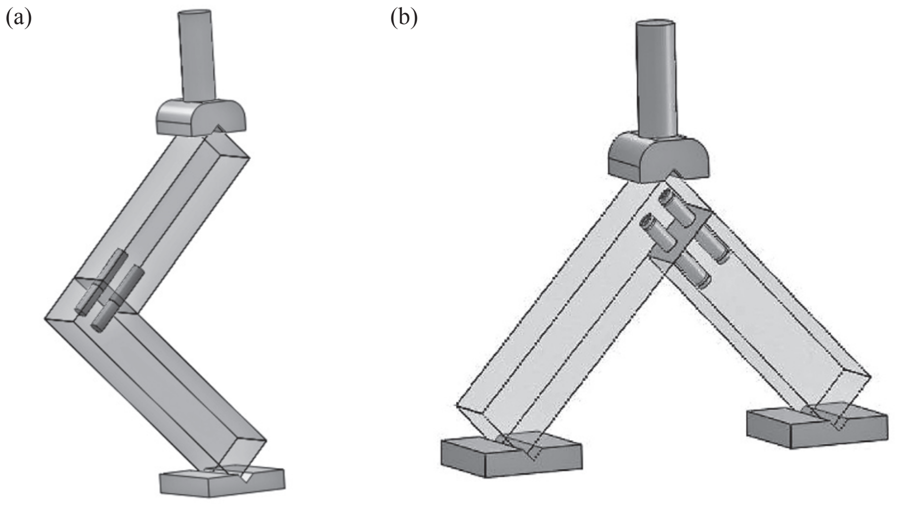

Figure 1 Models for diagonal compression tests (a) and diagonal tensile tests (b).
Slika 1. Modeli za ispitivanje dijagonalne tlačne čvrstoće (a) i dijagonalne vlačne čvrstoće (b)

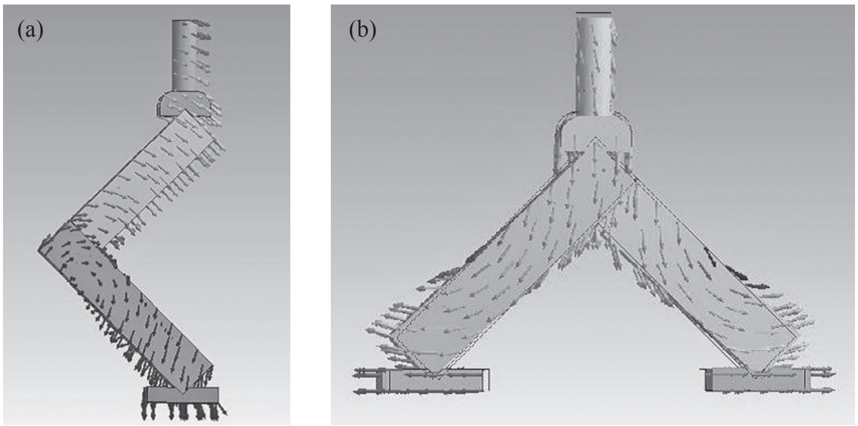

Figure 2 Distribution and direction of force in diagonal compression (a) and diagonal tension (b) samples
Slika 2. Raspodjela i smjer sila pri dijagonalnom tlačnom naprezanju (a) i dijagonalnom vlačnom naprezanju (b)

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The results of diagonal compression and diagonal tension strength tests of L-type corner joints were compared with the strength, strain gauge analysis and stress analysis parameters and the compliance between them is shown in Figure 3, 4 and 5.

As seen in Figure 3, experimental and Ansys results comply with each other. The highest compliance between experimental strength and FEM analysis strength values was obtained in beech dowel joint with 97.76 % and the lowest compliance was obtained in beech tenon with 86.2 %. Imirzi (2008) compared experimental and Ansys results and obtained the compliance of about 60-81 %.

As seen in Figure 4, experimental and Ansys results comply with each other. The highest compliance between experimental strain gauge analysis and FEM computer modeling values was obtained in beech mortise-tenon joint with 96.35 % and the lowest compliance was obtained in Scotch pine dowel with 71.4 %.

In her study, Ertas (2007) used strain gauge technology and stress analysis methods to design industrial products. She suggested that these methods may be useful to recognize certain forms and materials in industrial design.

According to Figure 5, the highest compliance between experimental stress analysis and FEM computer stress analysis values was obtained in beech mortise-tenon joint with the compliance of 93.82 % and the lowest compliance was obtained in Scotch pine dowel with 72.09 %.

The differences between the experimental and FEM analysis results can be explained by sensitivity of the nodes that were chosen to place strain gauge and also by anisotropic characteristics of wooden materials.

3.1 Performance of diagonal compression strength for FEM analysis
3.1 Svojstvo dijagonalne tlačne čvrstoće za FEM analizu

The initial deformation was observed in the upper dowel due to continuous tension and momentum effect and then the tension in the lower dowel reached

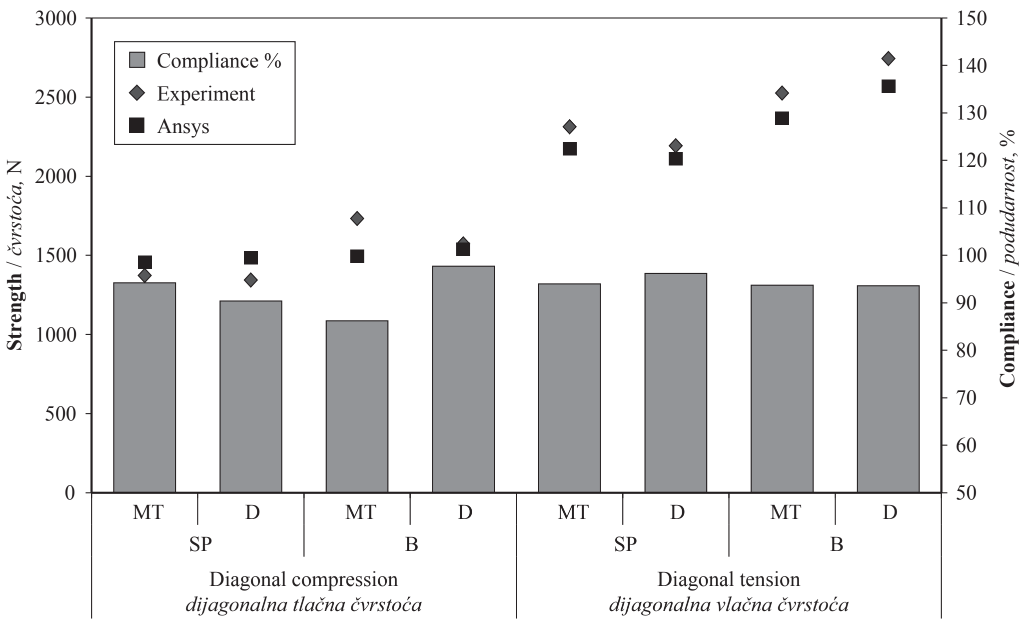

Figure 3 The results of diagonal compression and diagonal tension strength tests of L-type corner joints
Slika 3. Rezultati ispitivanja dijagonalne tlačne čvrstoće i dijagonalne vlačne čvrstoće kutnih spojeva L-tipa

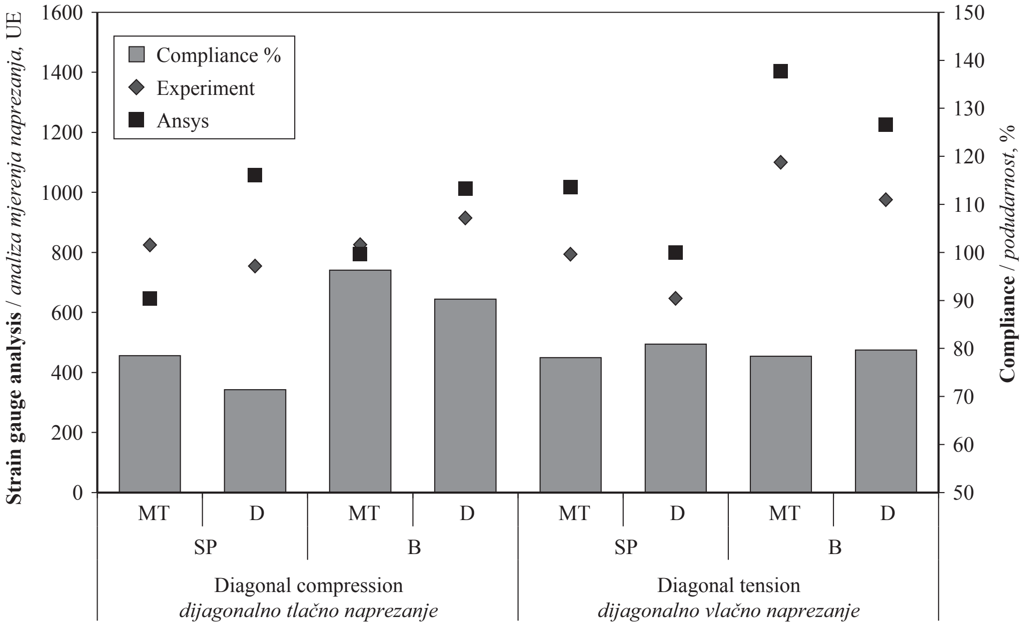

Figure 4 The results of strain gauge analysis of L-type corner joints
Slika 4. Rezultati analize mjerenja naprezanja kutnih spojeva L-tipa

the highest value after the upper dowel break as shown in Figure 6.

When the punch moved 4.604 mm down, 30.807 MPa maximum surface stress, 55.598 Mpa upper dowel stress and also 51.075 MPa lower dowel stress were obtained in L-type corner joints as shown in Figure 6.

In the diagonal compression tests of the L-type mortise-tenon corner joints, initial break occurred in the upper section of the tenon joint. Deformation started and then break was also seen in the edge of element B mortise. The results of FEM computer modeling shown in Figure 7 comply with the results of the experiments.

When the punch moved 9.409 mm down, 7.934 MPa maximum surface stress, 32.456 Mpa maximum tenon diagonal compression strength stress was obtained in L-type corner joints as shown in Figure 7.

3.2 Performance of diagonal tension strength for FEM analysis
3.2 Svojstvo dijagonalne vlačne čvrstoće za FEM analizu

Similar strength values between experiment and FEM analysis were obtained. In the computer model, deformation and tension initially started in lower parts and then breaking occurred.

Figure 8 shows the stress and deformations in the dowel joint beech samples for the diagonal tension tests.

When the punch moved 5.812 mm down, 15.229 MPa maximum surface stress, 52.095 Mpa maximum dowel diagonal tension strength stress was obtained in L-type corner joints as shown in Figure 8.

Figure 9 shows stress and deformations in the mortise-tenon joint of Scotch pine samples for diagonal tension tests

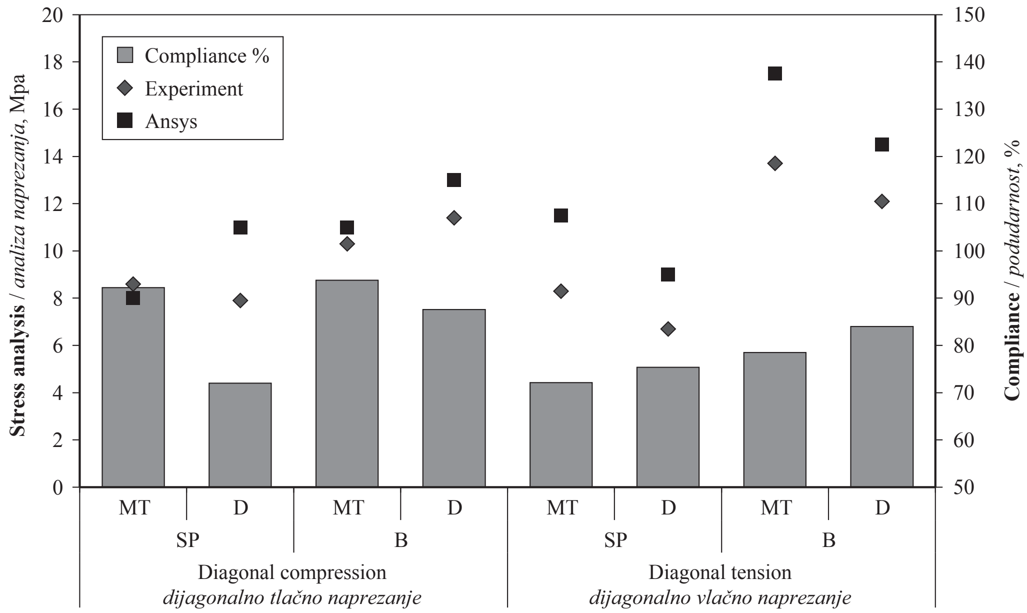

Figure 5 The results of diagonal compression and diagonal tension strength stress analysis of L-type corner joints
Slika 5. Rezultati analize dijagonalne tlačne čvrstoće i dijagonalne vlačne čvrstoće kutnih spojeva L-tipa

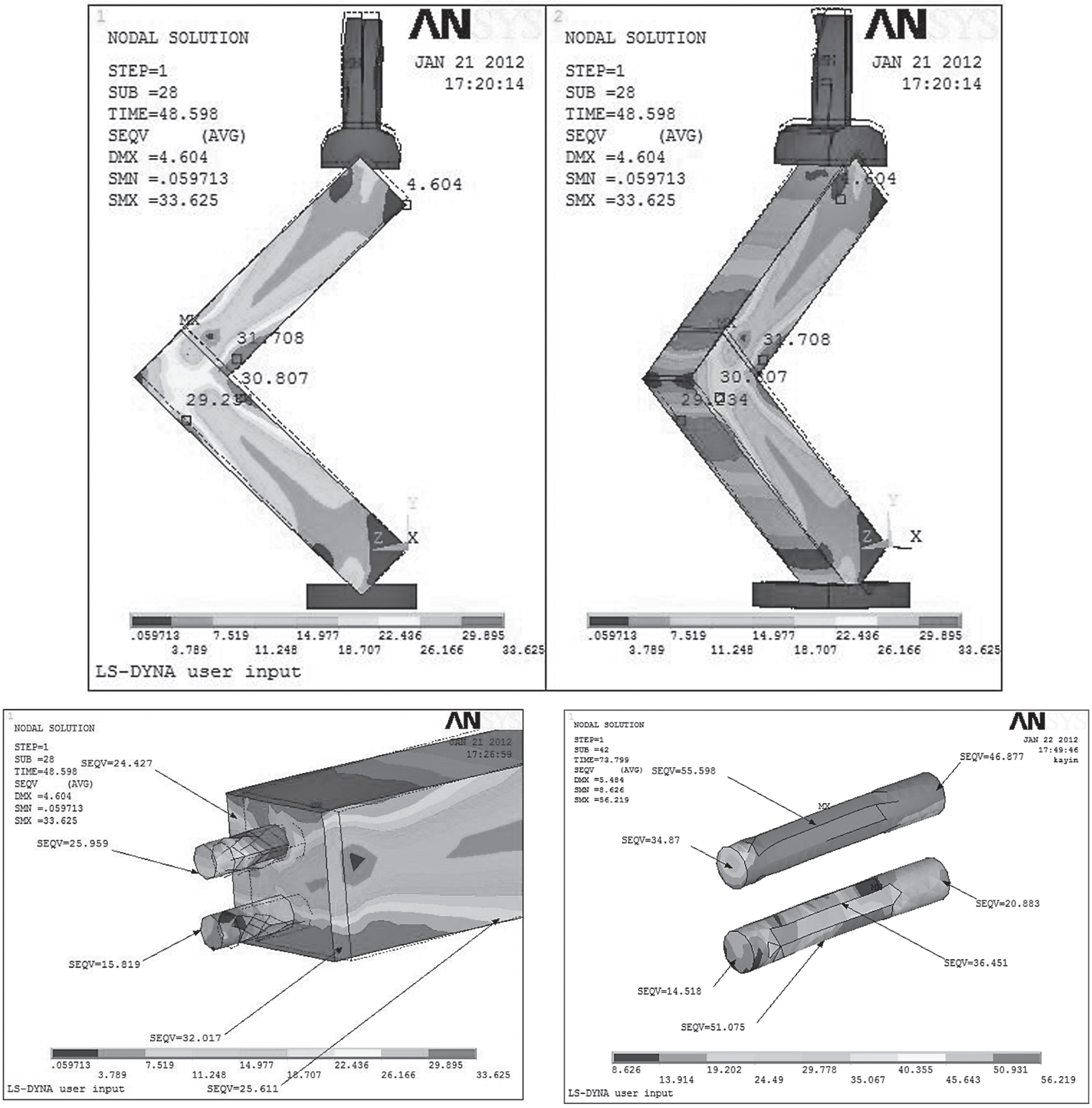

Figure 6 Diagonal compression strength stress and deformations in dowel joint samples of Scotch pine for the diagonal compression tests

Slika 6. Dijagonalna tlačna naprezanja i deformacije uzoraka spojeva s moždanicima izrađenih od drva bora pri ispitivanju dijagonalne tlačne čvrstoće

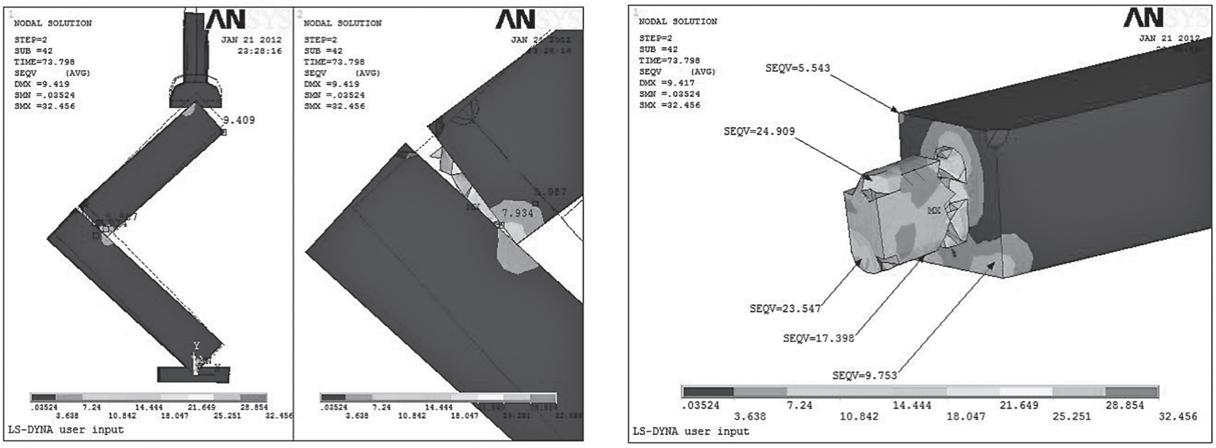

Figure 7 Diagonal compression strength stress and deformations in mortise-tenon joint of Scotch pine samples for diagonal compression tests

Slika 7. Dijagonalno tlačno naprezanje i deformacije u uzorku spoja čep – rupa izrađenome od drva bora pri ispitivanju dijagonalne tlačne čvrstoće

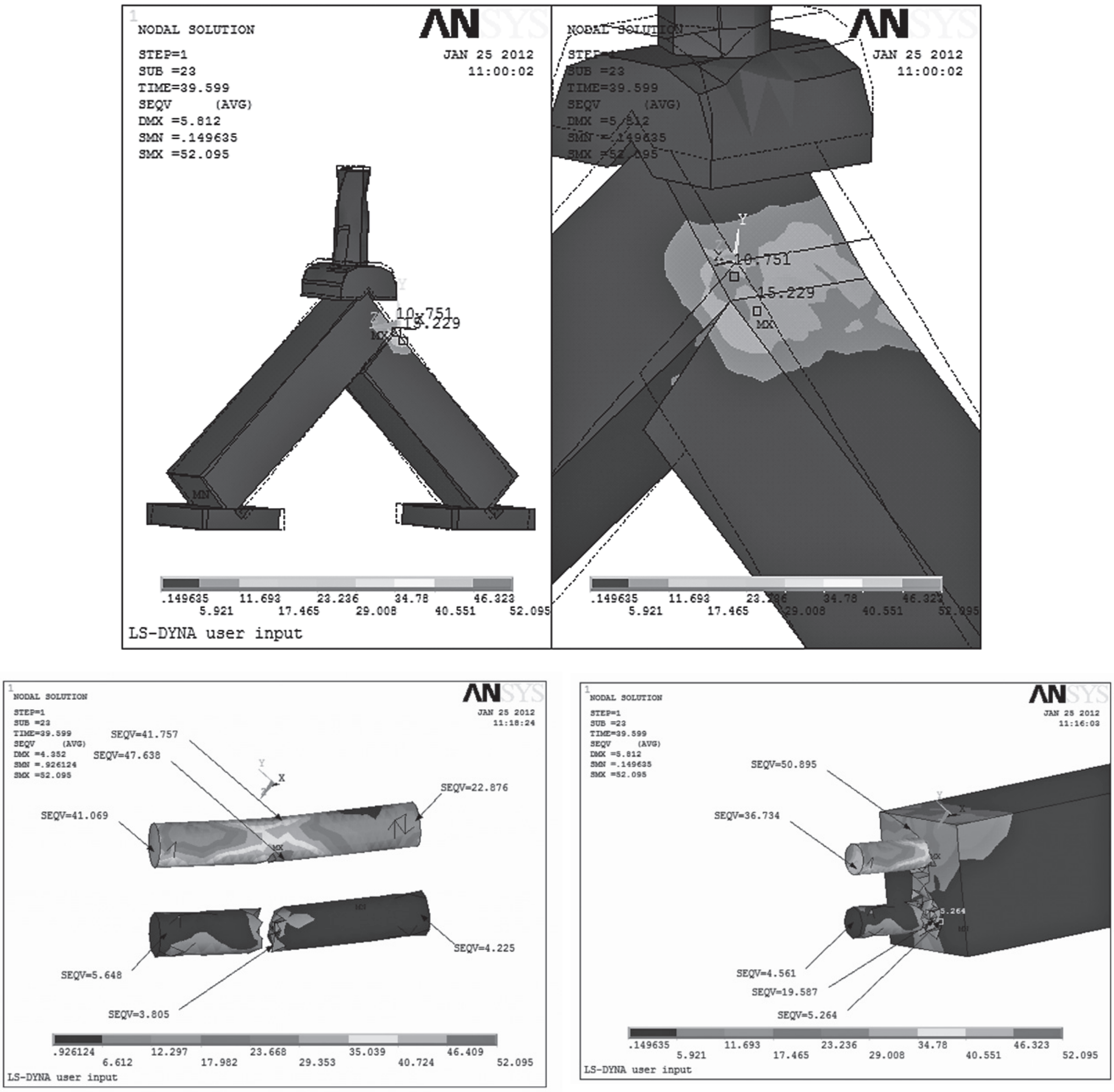

Figure 8 Diagonal tension strength stress and deformations in the dowel joint of beech samples for diagonal tension tests
Slika 8. Dijagonalna vlačna naprezanja i deformacije spoja moždanikom, izrađenoga od drva bukve za ispitivanje dijagonalne vlačne čvrstoće

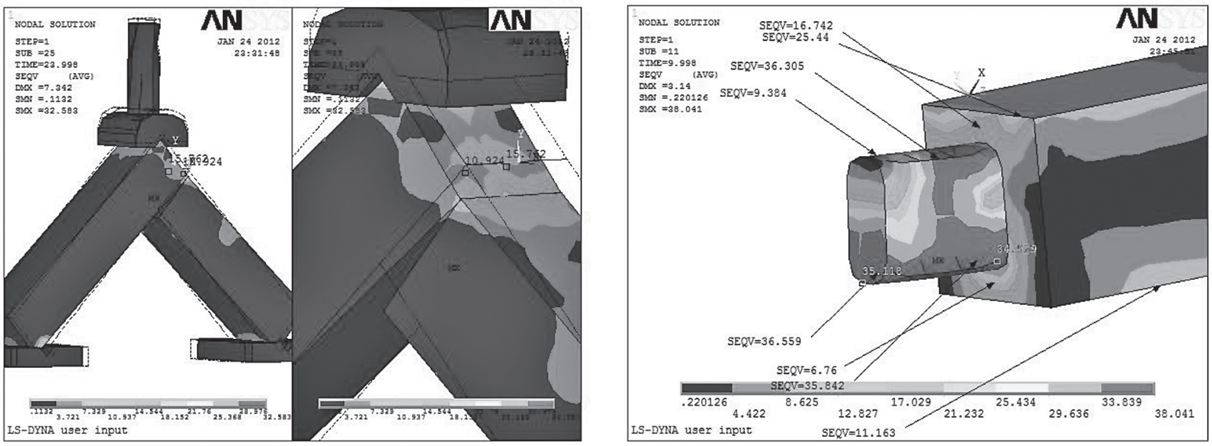

Figure 9 Diagonal tension strength stress and deformations in the mortise-tenon joint of Scotch pine samples for diagonal tension tests
Slika 9. Dijagonalna vlačna naprezanja i deformacije spoja rupa – čep izrađenoga od drva bora za ispitivanje dijagonalne vlačne čvrstoće

In contrast to the diagonal compression test, in the diagonal tension tests of the L-type mortise-tenon corner joints, initial break occurred in the lower section of the tenon joint. Deformation and then break was also seen in the edge of element A mortise. The results of FEM computer modeling shown in Fig. 9 comply with the experiments.

4 CONCLUSION
4. ZAKLJUČAK

In this study, the strength properties of "dowel and tenon corner joints", used in wood industries under various forces, were determined using "experimental methods" and "computer modeling ANSYS/LS-DYNA analysis program", and the results were compared.
1. The results of strength analysis by computer modeling as well as the results of the experimental methods revealed similar values (90-97 %). Experimental data, that cannot be observed with naked eye or measurement techniques, can be obtained more sensitively and in more detailes with ANSYS/LS-DYNA computer modeling
2. "Strain analyses" were carried out to determine the effects of experiment samples on rigidity values in corner joint sections. By using strain gauges on the selected corner joints, strains were measured. In the experiments carried out with this technique, deformations at critical joint sections were measured and converted into stress values. In the light of these data, strength values of different sections can be determined and an idea can be viewed about what possible changes could be made to produce durable material designs.
3. Both experiments and computer modeling with ANSYS/LS-DYNA proved that deformations were mostly observed in the joint sections. These results imply that material designers should choose more appropriate construction models.
4. One of the biggest problems encountered during experiments is that at the end of the experiment materials are destructed, while computer modeling techniques, which can simulate real life conditions, offer non-destructive methods, thus reducing the expenses.

Acknowledgments – Zahvala

This research is a PhD thesis that is supported by the Faculty of Forestry in both Karabuk University and Bartin University.

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Examination of Decision Factors in the Process of Buying Kitchen Furniture Using Conjoint Analysis

Ispitivanje činitelja u procesu donošenja odluke o kupnji kuhinjskog namještaja primjenom združene analize

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 4. 5. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*79; 630*836*
doi:10.5552/drind.2016.1525

ABSTRACT • *The aim of this research was to determine the relative importance of three factors relevant for buying wooden kitchen furniture in Croatia and Slovenia. A survey was made of 172 potential kitchen buyers: 138 in person at two largest furniture stores in Croatia and Slovenia, and 34 online. A conjoint analysis revealed that respondents were more concerned about the manufacturer and design than the price of the kitchen furniture. For all demographic groups, the lower price kitchen furniture was preferable. Only three demographic groups (35-45 years of age, elementary school or less, and unemployed) preferred the classic kitchen furniture design, while all other groups preferred the modern design. For the manufacturer, differences were found among most socio-demographic categories.*

Key words: *kitchen furniture, buying decision process, conjoint analysis*

SAŽETAK • *U ovom je istraživanju ispitivana važnost triju činitelja bitnih za proces kupnje kuhinjskog namještaja. Istraživanje je provedeno u Hrvatskoj i Sloveniji, a u istraživanju su sudjelovala 172 potencijalna kupca kuhinjskog namještaja. Sto trideset i osam ispitanika u istraživanju je sudjelovalo izravno, i to u dvjema najvećim trgovačkim kućama namještaja u Hrvatskoj i Sloveniji, dok su 34 ispitanika u istraživanju sudjelovala putem interneta (online). Conjoint analiza pokazala je da kupci kuhinjskog namještaja više pozornosti pri kupnji pridaju proizvođačima kuhinja i dizajnu nego cijeni kuhinjskog namještaja. Rezultati su pokazali, da je niža cijena činitelj kojemu sve demografske skupine ispitanika daju prednost pri kupnji. Samo tri demografske skupine ispitanika (nezaposlene osobe, osobe niže i srednjoškolske razine obrazovanja te one u dobi od 35 do 45 godina) pokazale su veću sklonost kupnji kuhinjskog namještaja klasičnog dizajna, dok su ostale skupine ispitanika sklonije kupnji kuhinjskog namještaja modernog dizajna. Za činitelj "proizvođač kuhinjskog namještaja" nisu utvrđene razlike među sociodemografskim kategorijama ispitanika.*

Ključne riječi: *kuhinjski namještaj, odluka o kupnji, conjoint analiza*

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1 INTRODUCTION
1. UVOD

It is generally accepted that socioeconomic development greatly depends on investment and, therefore, long-term development can only be achieved through investment, because well targeted investment activity is the primary assumption for all aspects of competitiveness (Ojurović *et al.*, 2013). Furniture companies are facing strong competition in the contemporary global market. They must continually strive to improve or at least maintain their market share. Consumers are nowadays very demanding and they require as much as possible information about the product to be sure about its quality (Oblak and Glavonjić, 2014). Therefore, all producers are forced to continually revise their marketing and production strategies to satisfy the customer and to ease his/her buying decision. To meet these goals, companies must take interest in customer's desires, perceptions and predispositions and use this information to develop more successful products, search for new marketing channels, to determine appropriate prices and create more effective marketing communication.

1.1 The buying process
1.1. Proces kupnje

Marketers must be familiar with the buying decision process to be able to understand customer demands. There is a sequence of stages buyers pass through when they decide which article to buy. A number of factors influence this process; most important among these are motivation, social and environmental demands, and the company's marketing activities. The buying process starts long before the actual purchase takes place and continues for an extended period afterward. Throughout the course of the process, buyers pass through five stages: problem recognition, information search, evaluation of alternatives, purchase decision and post-purchase behavior (Figure 1).

To effectively analyze the buying process, the buyer's activities before and after the purchase must be examined, as well as the customer's reasoning at the time of purchase. Understanding the buying decision process in the furniture market enables furniture companies to influence the customers at each phase of the process. The company can influence the decision or even change it, if it understands how the customer reaches his/her buying decisions, if it is familiar with the factors influencing customer behavior and if it knows how to convince the customer that his/her best choice is exactly the product the company is offering.

1.2 Previous research
1.2. Prethodna istraživanja

Previous research (Spies, 1996; Jelačić *et al.*, 2010; Oblak and Jošt, 2011; Jelačić *et al.*, 2012; Paluš *et al.*, 2012; Kitek Kuzman *et al.*, 2012; Parobek *et al.*, 2014) about the promotion of wood products and research into how to influence the buying decision process when buying furniture shows that it is crucial for furniture companies to understand the buying decision process. The company must establish how the customers will behave at each stage and determine the factors the company can use to influence the customers at each stage.

Any furniture company that is driven by the needs and wants of consumers has to understand consumer behavior. In many cases, consumers might not even be aware of their motivations or behaviors. Understanding consumer behavior is essential for the success of any organization. Furniture companies must understand consumer wishes, inclinations and behavior in order to generate products that will be accepted and purchased. It is, therefore, necessary to know the factors that are most decisively influencing the buying decision-making.

1.3 Conjoint analysis
1.3. *Conjoint* analiza

Furniture manufacturers are constantly developing new products and consider several factors during the product design. They perform various analyses in order to yield better sales results. Classical research methods usually do not provide the desired results, since they are unreliable for establishing customer's needs. The reason for inaccurate outcomes of such analysis lies in the fact that research usually focuses on each decision factor separately and, therefore, overlooks various circumstances of the buying process, most significantly the interdependencies and interactions between influencing factors.

The conjoint analysis is often used in marketing research and is by far the most often employed research method for marketing use with regard to the customer's needs (Anderson and Hansen, 2004; Green *et al.*, 2001; Bryan Evans, 2008; Orme, 2010; Zadnik Stirn, 1998; Gustafsson *et al.*, 2001; Praznik *et al.*, 2014; Grošelj *et al.*, 2014). Green and Srinivasan (1990) report that in the early 1980s conjoint analysis was used for the examination of more than 400 commercial cases. Conjoint analysis enables researchers to explain how people decide between products and services, allowing companies to design new products or services

Figure 1 Five Stage Model of the Buying Decision Process (Kotler *et al.*, 2007)
Slika 1. *Model pet koraka* u procesu donošenja odluke o kupnji proizvoda (Kotler i dr., 2007.)

that fulfill the core needs of the consumers. It is an exceptionally powerful tool for determining which product attributes drive people to buy a specific product and what the consumer actually values in a specific product (Dobney, 2012). Conjoint analysis is superior to other methods for determining consumer preferences, since other methods evaluate consumer preferences for each product attribute individually, while the conjoint analysis takes a more holistic view of the product. In conjoint analysis, each product is defined by a selection of attributes, and then the relative importance of each attribute is determined based on the respondents rating of the product. The consumer gives his/her preference to a specific selection of attributes as an evaluation of the whole product. This approach reflects the consumers' real life situation more closely than examining individual product attributes (Cestre and Darmon, 1997).

1.4 Objectives
1.4. Ciljevi istraživanja

The objectives of this study were to determine buyer preferences regarding three aspects of wooden kitchen furniture: manufacturer type, price level, and design. Potential kitchen buyers were surveyed at two largest kitchen retailers in Croatia and Slovenia, and online. A conjoint analysis of the completed questionnaires is discussed below.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

To assess the research question, "What kind of kitchen furniture would the buyers prefer?" the following phases were used:

1. concept planning (factor and level determination, choosing the model and concept design),
2. survey design
3. data collection,
4. evaluation of the conjoint model, and interpretation of the results

2.1. Concept planning
2.1. Planiranje koncepta

We determined the number of factors and their levels that best represent common attributes that buyers consider when choosing kitchen furniture. We investigated the product manufacturer, price of wood used for the kitchen, and product design (Table 1).

There are many kitchen brands on the market, here covered by the factor 'Manufacturer'. This factor was then divided into three levels: Domestic, Foreign and Carpenter (custom made). In regard to the factor 'Price', only the wooden parts of the kitchen were included in the study. Although kitchen appliances can be included along with the purchase of a kitchen, they were not considered in our research, since appliances were beyond the scope of this study. With these constraints, the average price of € 4,000 was determined for the wooden part of the kitchen. In practice, the price for a kitchen is calculated by length. However, respondents were instructed to disregard space concerns when considering the price. In this manner, the respondents were placed in a situation where they had to decide how much they were willing to spend on new cabinets for the kitchen and not how much space they had in their apartment. It was assumed that a lower price represented higher relative utility to the buyer than a higher price. Therefore, we used a linear relationship: u (lower price) > u (higher price). Since the design, or style, is subject to personal interpretation, we collected images of individual styles and presented them to the respondents in order to assure consistent evaluation. The 'Classic' kitchen differs from the 'Modern' one with regard to the material used and the design aesthetic. In the 'Classic' kitchen, wood and stone are mostly used in natural colors, and rounded elements. They provide a homely, comfortable feeling and a sort of country mood. Their design is timeless. The 'Modern' kitchen is characterized by a minimalistic appearance. Various materials are used, like glass, metal, plastic, laminated timber and straight lines. Typical are large drawers that have replaced cabinets with shelves common in the 'Classic' design. The 'Rustic' kitchen features typical furniture with vintage form and appearance. The main materials are natural – wood being one of the primary materials for construction and interior equipment. The 'Design' factor had a neutral relative utility value. Accordingly, we also used the discrete relationship (1).

2.2 Survey and questionnaire design
2.2. Dizajniranje (izrada) anketnog upitnika

With the selected factors and their levels, 18 different combinations or kitchen profiles can be formed. We used the method of simultaneous evaluation of all factor combinations (full profile, or factorial design). Therefore, our questionnaire contained instructions, descriptions of all 18 kitchen profiles, and questions about the respondent's socio-demographic status including age, education, household income, place of

Table 1 Factors and levels
Tablica 1. Faktori i razine

Factor *Činitelj*	**Manufacturer** / *Proizvođač*	**Price** / *Cijena*	**Design** / *Dizajn*
Level 1 *razina 1.*	Domestic / *domaći*	Less than € 4,000 / *manje od 4000 EUR*	Classic – Standard *klasični – standardni*
Level 2 *razina 2.*	Foreign / *inozemni*	More than € 4,000 / *više od 4000 EUR*	Modern – Trendy / *moderni*
Level 3 *razina 3.*	Carpenter (Custom) / *po narudžbi*	-	Rustic / *rustikalni*

residence, gender and employment status. The survey was to be conducted by distributing the questionnaire in person at two largest furniture manufacturers in Croatia and Slovenia. Additionally, the questionnaire was available online for individuals to complete at home. Thus a convenience sample of potential kitchen buyers was obtained. For our analysis, data were collected by survey using a convenience sample of potential kitchen buyers at two largest furniture stores in Croatia and Slovenia; locations where potential kitchen buyers were likely to be encountered. We also published our contact information and the fact that we were conducting a survey about the factors influencing kitchen purchasing on two online forums, inviting Internet users to participate in the survey. The data were processed using the IBM SPSS Statistics 20 and MS Excel 2003 computer programs.

2.3 Evaluation and conjoint analysis
2.3. Procjena i *conjoint* analiza

In this study, we established a discrete relationship between the levels of each factor, and calculated the relative utility of each factor level as in Hair *et al*. (1998) using the IBM SPSS statistical software program (IBM SPSS, 2011). Further, we used the linear (additive) rule (Hair *et al*., 1998), which assumes that the utility of an entire product is equal to the sum of the utilities of each studied aspect of the product, including a constant. In our study, the aspects are the chosen factors, and the total utility can be expressed as (Eq. 1):

$$\text{Total product utility} = \text{constant} + \text{utility of manufacture} + \text{utility of price} + \text{utility of design} \quad (1)$$

The importance of each factor (I_j) is the difference between the maximum (max_{jk}) and minimum (min_{jk}) utilities for the factor's levels (Eq. 2):

$$I_j = max_{jk} - min_{jk} \quad (2)$$

The relative importance of each factor amongst the others (A_j) is the normalized importance of each factor, divided by the sum of the importance for each factor (Eq. 3). The sum of the relative importance values for all factors is 1, and often expressed as a percentage.

$$A_j = \frac{I_j}{\sum_{j=1}^{p} I_j} \quad (3)$$

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Basic participants' data
3.1. Opći podatci o ispitanicima

There were two ways for the participants to fill out the survey questionnaire:
- in person: participants filled out 138 questionnaires
- on the forum: we received 34 correctly filled out questionnaires.

Therefore, we had a total of 172 participating respondents, 116 female and 56 male. The majority (58 %) were under 30 years of age, which is a representative sample, since young people are likely to buy new kitchens when furnishing their new homes. 52 % of the respondents said they intended to buy a new kitchen in the following year. The high percentage of likely buyers was mostly due to the choice of the place of data collection.

2.2 Conjoint analysis of kitchen properties in the buying decision process by socio-demographic characteristics
2.2. *Conjoint* analiza kupaca kuhinja prema njihovim sociodemografskim karakteristikama u procesu odluke o kupnji

2.2.1 Utility estimates
2.1.1. Procjena usluge

The utility estimates and standard errors for each factor level are presented in Table 2. The assumption of a discrete relationship between levels for the factors 'Manufacturer' and 'Design' means that higher partial utilities correlate to higher preference. However, because of the linear relationship assumed between price levels, an inverse relationship between utility scores for the factor levels 'Price' was found. In this case, the more negative utility estimate correlates to lower preference. The inverse relationship is the result of the linear correlation for the price and the assumption that a lower price represents a higher utility for the buyer than a higher price.

In general, these results reveal that respondents generally prefer domestic or craftsman kitchen furniture to foreign made kitchen furniture. As expected, respondents preferred lower priced kitchen furniture. The modern designs presented were greatly preferred over rustic designs, with classical designs falling between the other types.

Table 2 Factor and level utility estimates
Tablica 2. Činitelji i procjena razine usluge

Factor / Činitelj	**Level** / *Razina*	**Utility Estimate** *Procjena usluge*	**Standard Error** *Standardna pogreška*
Manufacturer *proizvođač*	Domestic / *domaći*	0.562	0.158
	Foreign / *inozemni*	-1.081	0.158
	Carpenter (custom) / *po narudžbi*	0.519	0.158
Price / *cijena*	Less than € 4.000 / *manje od 4000 EUR*	-1.700	0.223
	More than € 4.000 / *više od 4000EUR*	-3.401	0.446
Design / *dizajn*	Modern (trendy) / *moderan*	1.669	0.158
	Classic (standard) / *klasičan*	0.676	0.158
	Rustic / *rustikalan*	-2.345	0.158
(Constant)/ *(konstanta)*		12.050	0.352

2.1.2 Kitchen profile preference
2.1.2. Sklonosti kupaca tipovima kuhinja

Aggregating the partial utilities for each kitchen profile provides a means to compare preference for different kitchen profiles. Joining the partial utilities, as in Equation 1, the total utility of each kitchen profile presented can be computed. For example, the total utility of a kitchen manufactured in Croatia or Slovenia in the modern style for less than € 4,000 is calculated by adding the partial utility of each factor level, plus a constant. For complete kitchen profile results, we used data from Table 2.

Example:

Total utility »kitchen 1« (manufacturer: domestic, price: less than € 4,000, design: modern) = constant + utility of manufacture + utility of price + utility of design = constant + partial utility - manufacturer (domestic) + partial utility - price (less than € 4,000) + partial utility - design (modern) = 12.050 + 0.562 + (-1.700) + 1.669 = 12.581

Analysis of the total utilities for all 18 kitchens revealed that "Kitchen 1" was the most preferred. The least preferred combination had a foreign manufacturer, cost more than € 4,000 and had a rustic design. The constant in the model represents the "average rank" of all ranks. The range of partial utilities (highest to lowest utility) for each factor represents the importance of the factor in regard to the total preference. The factor with a wider partial utilities range plays a stronger role in purchasing decisions than the factor with a narrower range. The factors have the following relative values of importance (according to Eq. 3): Design 44 %, Manufacturer 31 % and Price 25 %. From this, it can be concluded that kitchen design is the most important attribute for the respondents, while price is the least important. The value of Person's R coefficient is 0,983 and the value of Kendall's tau coefficient is 0,935. They provide measures of the correlation between the observed and estimated preferences. They show the size and direction of the correlation and the suitability of the model used.

2.1.3 Socio-demographic preferences
2.1.3 Sociodemografske sklonosti

The socio-demographic characteristics included in the questionnaire reveal several interesting preferences within each category. We considered it neither necessary nor appropriate to combine individual demographic characteristics, since the small sample size could lead to unreliable data. We assumed that the chosen factors (Price, Manufacturer and Design) were statistically significantly related to the chosen socio-demographic attributes. Opinions regarding manufacturer varied between groups. The groups 'Female', 'Above 45 years', 'Gymnasium or vocational school', 'Employed', 'Retired', income 'Below € 1,000' and income 'Above € 2,000' as well as living 'In city' and 'In countryside' would choose a domestic manufacturer. Only the group 'Elementary school or less' would choose a foreign manufacturer. The groups 'Male', 'Under 35 years' and '35 to 45 years', 'College or University', 'Unemployed', 'Pupil or student' and income of '€ 1,000 to € 2,000' preferred the carpenter manufacturer option.

All groups would prefer to pay less than € 4,000 for the wooden parts of the kitchen. This is mostly due to the fact that the respondents had the choice of all possible combinations. It is logical that, for example, everyone would rather buy a kitchen from domestic manufacturer with classic design that costs less than € 4,000 than a kitchen from domestic manufacturer with

Table 3 Total utility for each kitchen profile, in descending order of customer preference (greatest utility on top). All total utility scores also include an additional constant (12,050)

Tablica 3. Ukupna razina usluga za tipove kuhinja prema sklonostima kupaca (silaznim redoslijedom: najviša je razina usluge prva u nizu). Svi rezultati ukupne razine usluge obuhvaćaju i dodatnu konstantu.

Manufacturer *Proizvođač*	**Price** *Cijena*	**Design** *Dizajn*	**Kitchen utility** *Korisnost kuhinje*
Domestic / *domaći*	Less than € 4,000 / *manje of 4000 EUR*	Modern / *moderan*	12.581
Domestic / *domaći*	Less than € 4,000 / *manje of 4000 EUR*	Classic / *klasičan*	11.588
Domestic / *domaći*	Less than € 4,000 / *manje of 4000 EUR*	Rustic / *rustikalan*	8.567
Domestic / *domaći*	More than € 4,000 / *više od 4000 EUR*	Modern / *moderan*	10.880
Domestic / *domaći*	More than € 4,000 / *više od 4000 EUR*	Classic / *klasičan*	9.887
Domestic / *domaći*	More than € 4,000 / *više od 4000 EUR*	Rustic / *rustikalan*	6.886
Foreign / *inozemni*	Less than € 4,000 / *manje of 4000 EUR*	Modern / *moderan*	10.938
Foreign / *inozemni*	Less than € 4,000 / *manje of 4000 EUR*	Classic / *klasičan*	9.945
Foreign / *inozemni*	Less than € 4,000 / *manje of 4000 EUR*	Rustic / *rustikalan*	6.924
Foreign / *inozemni*	More than € 4,000 / *više od .000 EUR*	Modern / *moderan*	9.237
Foreign / *inozemni*	More than € 4,000 / *više od 4000 EUR*	Classic / *klasičan*	8.244
Foreign / *inozemni*	More than € 4,000 / *više od 4000 EUR*	Rustic / *rustikalan*	5.223
Carpenter / *po narudžbi*	Less than € 4,000 / *manje of 4000 EUR*	Modern / *moderan*	12.538
Carpenter / *po narudžbi*	Less than € 4,000 / *manje of 4000 EUR*	Classic / *Klasičan*	11.545
Carpenter / *po narudžbi*	Less than € 4,000 / *manje of 4000 EUR*	Rustic / *Rustikalan*	8.524
Carpenter / *po narudžbi*	More than € 4,000 / *više od 4000 EUR*	Modern / *Moderan*	10.837
Carpenter / *po narudžbi*	More than € 4,000 / *više od 4000 EUR*	Classic / *Klasičan*	9.844
Carpenter / *po narudžbi*	More than € 4,000 / *više od 4000 EUR*	Rustic / *Rustikalan*	6.823

classic design that costs more than € 4,000. In regards to kitchen design, the analysis shows that the buyers in general prefer the modern design option. Only the groups ‘35 to 45 years’, ‘Only elementary school or less’ and ‘Unemployed’ would prefer the classic design. The rustic design is the least preferred of all design options.

We can confirm our assumption that the factors (Manufacturer, Price and Design) and their levels are associates to the socio-demographic characteristics, since we achieved significantly related results. For example, men would prefer to buy a custom made kitchen by a carpenter while women would prefer a kitchen from a domestic manufacturer. Additionally, people with an income below € 1,000 greatly prefer a kitchen priced below € 4,000.

4 CONCLUSION
4. ZAKLJUČAK

Competitiveness in the furniture market is an important reason for performing consumer preference research and analysis. Companies use research to stay current with the latest trends. However, furniture manufacturers most often perform customer satisfaction analyses after the purchase. Very few of them decide to perform a research before designing and producing the furniture. This study used conjoint analysis to analyze customer preferences for three different kitchen furniture factors: manufacturer, design and price. The results demonstrated the suitability of conjoint analysis for analyzing customer purchasing behavior, even though it is somewhat more complicated as it requires defining the factors of interest as well as their levels and performing surveys, compared to the other simpler methods (descriptive statistics, for example). Significantly, though, conjoint analysis allows the researcher to examine multiple aspects of the buying process simultaneously. The customers are placed in a realistic buying situation, since they compare and evaluate a spectrum of kitchen attributes and utilities together, where they rate the importance of each combination. To better reflect the reality of the kitchen purchasing decision process, we should have included more factors and levels, since there are usually many other considerations that influence the purchase of kitchen furniture. Functionality and quality are, for example, very important factors, but they would be hard to define in the way that would allow the respondents to give meaningful answers. We included three factors into our research (price for the wooden parts of the kitchen, design and manufacturer). Using conjoint analysis, we determined that the buyers give most importance to design, followed by manufacturer, and the lowest importance to the price. Based on our experience, the conjoint analysis should be used for investigating the buying process and analyzing the influencing factors.

The small sample size of this study prevents broad generalizations. However, within Croatia and Slovenia, this may be a representative sample because of a relatively small total population of kitchen furniture buyers and since the respondents were considered highly likely to purchase kitchen furniture in the near future. Additionally, as only two options were given for price and these were presented as “more than” and “less than” an estimated average price, it is difficult to place much significance on the importance of price to respondents, as interpretations of this may have varied widely from a small difference in price to a large difference in price (e.g., € 3,999 and €4,001 vs. € 2,500 and € 5,500). However, despite this restraint, demographic groups preferred the lower price option within the factor “price”, even though “price” had the lowest relative importance.

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Wavelet Analysis of X-ray Density Function of Tree Ring Structure

Wavelet analiza funkcije gustoće godova stabla određene X-zrakama

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 30. 6. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*811.4; 630*812.31*
doi:10.5552/drind.2016.1528

ABSTRACT • *The annual ring density of cross-sections of Japanese cedar stems of different ages has been recorded by X-ray density analyser in order to determine the boundary line between juvenile and mature wood. A particular emphasis was put on the tracheid length in the annual rings. The obtained data was analysed by using Wavelet transformation. It can be assumed that the process of formation of woody tissue is a periodic one and that the characteristic periods include several annual rings. This also indicates that the growth of a tree can be separated into distinct processes that can be identified within the juvenile and mature wood zones. It has been shown that the suggested numerical approach enables a rapid and reliable evaluation of the data.*

Key words: *Juvenile/mature wood, Hurst exponent, tracheid length, X-ray densitometry, wavelet transform*

SAŽETAK • *Gustoća godova na poprečnim presjecima debla japanskog cedra različite starosti određena je uz pomoć rendgenskog analizatora gustoće kako bi se utvrdila granična linija između juvenilnoga i zrelog drva. Poseban naglasak stavljen je na duljinu traheida u godovima. Dobiveni su podatci analizirani uz pomoć wavelet transformacije. Može se pretpostaviti da je proces formiranja drvnog tkiva periodičan i da karakteristična razdoblja obuhvaćaju nekoliko godova. To također pokazuje da se rast stabla može podijeliti u različite procese koji se mogu identificirati unutar zone juvenilnoga i zrelog drva. U radu je utvrđeno da predloženi numerički pristup omogućuje brzu i pouzdanu procjenu podataka.*

Ključne riječi: *juvenilno/zrelo drvo, Hurstov eksponent, duljina traheida, rendgenska denzitometrija, wavelet transformacija*

1 INTRODUCTION
1. UVOD

Juvenile wood formation is an important natural process in stem growth and it has been widely studied in the last 50 years (Gartner, 1996; Larson, 1968; Yang *et al*., 1994). Juvenile and mature wood refers to two main zones of the xylem. Juvenile wood becomes especially interesting for forestry because of the short rotation cycle that is typical in plantation forestry. Recently, as a result of change in forestry management, the proportion of juvenile wood in tree stems has increased. This may have a major effect on wood properties and product quality, especially in conifers (Maeglin, 1987). The juvenile wood boundary can be determined by examining a number of different physical or chemical properties (Wang and Stewart, 2013).

Many studies in the area of wood anatomy use only one or two wood attributes to define the demarcation line between juvenile and mature wood. Such meth-

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ods have been widely accepted as the norm for assessing wood juvenility. Unfortunately, these studies did not take into account the complexity of the stem. For example, for a long time, the measurement of annual ring width, specific gravity, tracheid length and microfibril angle have been the most prevalent methods (Fujisaki, 1985; Fukazawa, 1967; Matyas and Peszlen, 1997; Ota, 1971; Yang *et al*., 1986; Zhu *et al*., 2000). Studies in this area also focused on the non-linear, segmented regression method of tracheid length and microfibril angle (Cook and Barbour, 1989; Zhu *et al*., 2005). Based on these methods, the transition is referred to as a zone of gradual changes, rather than an exact demarcation line. These studies have obviously provided a common and simple tool for analysing the growth variation. However, the global nature of the above mentioned processes hides local density-distribution information, and makes the exact determination of distance-related changes impossible. For this reason, the researchers turned to the X-ray density function of the wood and used different mathematical methods to draw information about the wood properties.

The X-ray density profile is the result of the superposition of many different environmental factors, such as rainfall, soil and site conditions, temperature, etc., which cause periodic changes in density along the radius. Franceschini *et al*. (2010, 2013) used the mean ring density profile to study the radial pattern variations and their consistency with changes in temperature and climate. Mutz *et al*. (2004), applied the non-linear mixed-effects model to the average density profile of Scots pine trees in order to statistically model the stem growth. X-ray density profile was also used for determination of the transition from juvenile to mature wood (Koubaa *et al*., 2002; Fujimoto *et al*., 2006).

Our work focuses on the development of different mathematical procedures for the analysis of X-ray density function (XDF) that may enable better understanding of the growth of individual trees along the radius of their bole. In our previous studies (Csoka *et al*. 2005, 2007), we applied Fourier transform to the X-ray density function in order to determine the line that separates the juvenile and mature zones in the tree stem. In the present paper, we will show that the spectral wavelet analysis (Torrence and Compo, 1998; Hurst, 1951) of the X-ray density function can provide information about anatomical variations in the representative sugi trees (*Cryptomeria japonica* D. Don). The wavelet transformation, basically, enables one to draw additional data from the XDF signal. Rozenberg *et al*. (2001) analysed cloning and genetic effects of the Norway spruce by multi-resolution methods of the density profile, and published preliminary results on wood homogeneity using wavelets decomposition. Solomina *et al*. (2010) used wavelet transformation of the early wood ring width and maximum density profiles to study changes induced by climatic fluctuations and solar activity. Here, wavelet analysis was applied to investigate the transition from juvenile to mature wood. The advantage of the wavelet analysis, with respect to previously used Fourier analysis, is that the one-dimensional density set is transformed into a diffuse, two-dimensional distance-frequency image. In the obtained transform, the density frequency of annual rings and their distances from the pith may be studied simultaneously. It should also be noted that the previous studies used only the average or maximum density of annual rings in their calculations. Here, the wavelet transform was applied to the whole set of X-ray density data.

2 METHODS AND MATERIALS
2. MATERIJALI I METODE

In order to sample the independent applicability of the wavelet method with respect to tree life span, the X-ray density profiles of 18 selected Japanese cedar tree stems (from 28-221 year old) were included in our analysis. Here, three stems were selected for detailed analysis (221, 95 and 28 year-old) and the results of the other samples can be found in the supplementary file. The first two stems were taken from natural forest (marked as nf221, nf95) and the third one (the youngest one) was taken from a plantation forest (marked as pf28). The samples were cut at breast height (120 cm) of the stems. The growth ring density curve was obtained by X-ray densitometry (JL Automation 3CS-PC). The density curve from the pith to the bark was recorded to determine the amplitude of the density oscillation.

2.1 Measurement of the tracheid length
2.1. Mjerenje duljine traheida

Small blocks taken from every third annual ring (late wood) were placed in a bottle with a macerating solution (1:1 v:v, 30 % hydrogen peroxide : glacial acetic acid) and left for 48 hours. During this time the blocks began to break down into fragments and the tracheids were liberated. After washing several times, the tracheids were placed on a glass slide and the length (30 different at every third annual ring) was measured manually by using light microscopy (Carl Zeiss, Jena, Germany).

2.2 Wavelet analysis
2.2. *Wavelet* analiza

The present study is an extension of our previous work on Fourier transform analysis of X-ray density profiles of Japanese cedar (Csoka *et al*., 2005; Csoka *et al*., 2007). The wavelet transform is similar to the commonly used Fourier transform but it proved to be a better method in the case of more complex systems. Wavelet transformation uses windows of different sizes and positions to analyse a signal, which enables a fine resolution and control without restriction of the scale of detectable phenomena. The wavelet transform can be used to analyse time series that contain non-stationary amplitude points at many different frequencies (Daubechies, 1990).

The continuous wavelet transform of a discrete sequence x_n (density function of a tree) is defined as the convolution of x_n with a scaled and translated version of the mother wavelet $\psi_0(\eta)$:

$$W_n(s) = FFT^{-1}\left[\sum_{k=0}^{N-1} \hat{X}_k \left(\sqrt{\frac{2\pi s}{\delta t}}\hat{\psi}_0(s\omega_k)e^{i\omega_k n\delta t}\right)\right] \quad (1)$$

where: N is the length of the data series, s is the wavelet scale, dt is the sampling interval (0.015 mm), n is the localized distance index, ω_k is the angular frequency and x_k is the discrete Fourier transform. The normalisation is included in the equation above in such a way that the wavelet function contains unit energy at every scale. In this way defined wavelet transformation enables simultaneous extraction of the distance and frequency information from the signal. The density function of the tree is non-stationary and wavelet analysis was selected to extract the relevant distance-density information from the signal. In this study, the Morlet ($\pi^{1/4}H(\omega)e^{-(s\omega-m)^2/2}$) and Paul ($\frac{2^m}{\sqrt{m(2m-1)}}H(\omega)(s\omega)^m e^{-s\omega}$) mother-wavelet bases were selected for spectral analysis and for the resolution of strong frequency components. The wave number and the Heaviside step function are in the chosen bases. In the wavelet analysis, the factors of Morlet and Paul mother wavelets are very important, because they affect both the peak intensity and the data range. Both bases were used for the wavelet transformation of the XDF signals of our samples. It turned out that the Morlet's basis gave a more distinct picture in the case of the younger samples (pf28 and nf95), while the Paul's basis gave better results in the case of the oldest sample (nf221). When the wavelet analysis was applied to geophysical phenomena, ω_k between 5 and 6 was used in order to attain the sufficient precision in the distance or time domains. For this reason, this condition was also selected. The signal analysis was performed by using AutoSignal software.

2.3 Calculation of the Hurst exponent
2.3. Izračun Hurstova koeficijenta

The statistical operator, the Hurst exponent (H), measures the fractal dimension of a time set and it can be obtained from the following linear regression:

$$\log (R/S)_n = \log c + \log n \quad (2)$$

where the range R is divided by the standard deviation S of the n data elements to produce the normalized range value (R/S) and c is a constant. The parameter H calculated from the slope of the linear function given by Eq. 2 is in the range from 0 to 1. The R/S analysis is non-parametric; there is no assumption about the shape of the underlying distribution. The set of XDFs is similar to log-normal distribution. Series with H values larger than 0.5 are persistent series that contain a memory effect. Each data value is related to a certain number of preceding values. The k (n obs) provides information about the number of cycles, which shows dependence upon the past. These data series reverse signs less frequently than in the case of the white noise.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Different environmental effects can cause severe disruption of growth function (Dobbertin, 2005). Many physical changes can be identified visually, but the most subtle variations can only be noticed by the numerical analysis of the density of annual rings. In the wavelet analysis of the X-ray density profiles of the three sugi trees, the probability amplitudes vary as a function of frequency and distance. The wavelet spectrum of XDF was found fluctuating on inter-distance scales.

The calculated wavelet plots presented in Figure 1 a, b and c show different growth cycle periods of the tree. The thick, black contour indicates the regions where the amplitude of the waves can be found with confidence level of more than 95 % and the growth of annual rings is very uniform.

Morlet mother-wavelet basis set was used in the case pf28 and nf95 samples, while the Paul (c) basis set was used for the nf221 sample. Fourier frequencies are given on the vertical axis in mm^{-1} (that correspond to annual ring widths in mm, given on the right). The distance from the pith to the bark is given on the horizontal axis. The grayscale gradient plot indicates the major contours where the transitions occur. Most peaks are well above the background spectrum (light grey colour). The black contours enclose regions where the amplitudes can be found with a confidence level higher than 95 %. The variation in growth projected on the wavelet scalogram can be related to the annual ring increments. However, wavelet analysis shows that growth cycle periods are distinctly grouped. The whole growth cycle can be separated into well correlated segments within the frequency and distance domains. Note that the correlated segments reflect the growth behaviour of the trees along the distance from the pith to the bark, the process which cannot be clearly observed if only the frequency domain is taken into account. Also, as distance from the pith to the bark increases, the differences between the gradients become uneven. Figures 1 (a),(b), (c) show that in the area of low distances and low frequencies the gradient is low (mostly light gray) and there is no significant correlation between the waves.

Figure 1a shows the wavelet spectrum of the 28 year old sugi tree (pf28). This data set encloses the frequency range from 0.2 to 0.35 mm^{-1}, which corresponds to the annual ring width from 5 to 2.8 mm. The main amplitude contours are located in the mentioned frequency range and they are divided in two groups. The first one includes 14 and the second one 7 annual rings. At the distances between 40 and 60 mm, there is a breaking point, where the most correlated grouping appeared in the lower frequency range due to some environmental anomaly (changes in local climatic conditions). This means that in the range prior to the breaking point, the width of the annual rings is narrower than after (Fig 1a). At distances higher than 80 mm, there is an increase in frequencies (a decrease in the ring widths) suggesting the presence of areas of different anatomy. The distance range, in which the change in the wavelet spectra took place, can be considered as a demarcation line of the transition from juvenile to mature wood in this sample. The wavelet spectrum of the

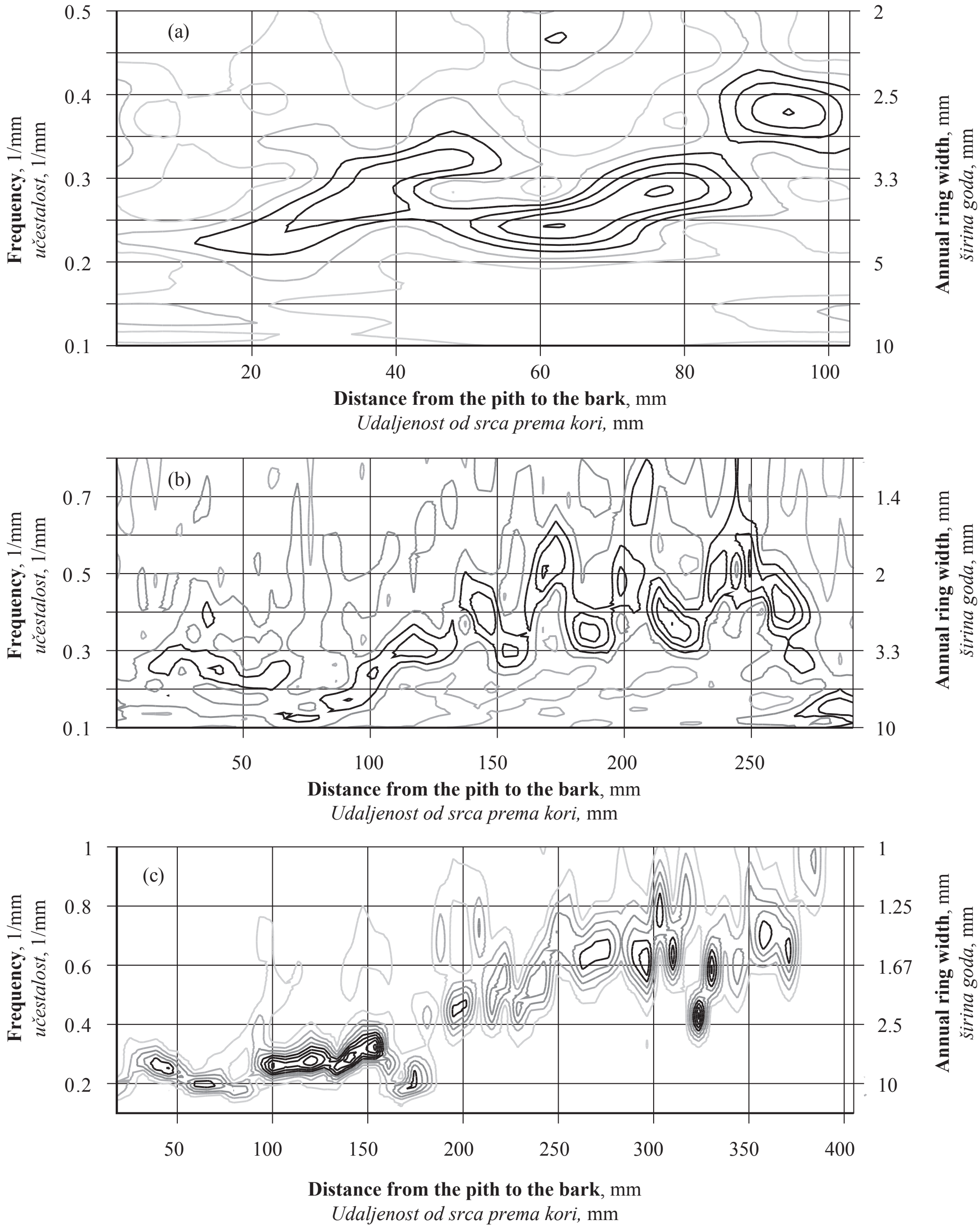

Figure 1 The local wavelet power spectra of X-ray density functions of a) pf28, b) nf95 and c) nf221 samples
Slika 1. Lokalni *wavelet* spektar funkcije gustoće određene X-zrakama za uzorke: a) pf28, b) nf95 i c) nf22

95 year old sugi tree (sample nf95) is shown in Figure 1b. This spectrum includes a wider frequency range (0.15-0.6 mm^{-1}) and it is more distinctive than in the case of the pf28 sample. The wavelet spectrum in the distance range below 75 mm is quite complex¸ suggesting that various environmental factors (probably climatic factors) contributed to the tree ring formation. The transition point from juvenile to adult wood is most likely positioned in the distance region from 30 to 75 mm, where there is a clear drop in the position of black contours that represent high probability amplitude regions. As the distance further increases, the wavelet contours become very disordered. At distances around 130 mm, there are several black contours that mainly contain 7 annual rings.

Figure 1 (c) shows the wavelet spectral feature of the 221 (nf221) year old sugi tree. The first distinct frequency group, up to 90 mm from the pith, contains 23 annual rings. In that group, the width of the annual rings is continuously increasing as a result of the initial growth of the tree. At the distance of 90 mm, the frequency falls to approximately 0.1 mm^{-1} and this value corresponds to the transition point between juvenile and mature wood. The next frequency group (in the distance region from 90 to 170 mm) contains 25 annual rings and the results suggest that in that region the growth became more regular. For this sample, the contours with highest amplitude probability are mostly located in the frequency regions from 0.43 to 1.1 mm^{-1} (from 2.3 to 0.9 mm ring width) and from 0.17 to 0.4 mm^{-1} (from 5.8 to 2.5 mm). The rhythmic structure of short and long-term cycles in the tree-ring chronologies is most likely related to the climatic fluctuations and solar activity (Nowacki and Abrams, 1997). In the study on early wood ring widths,

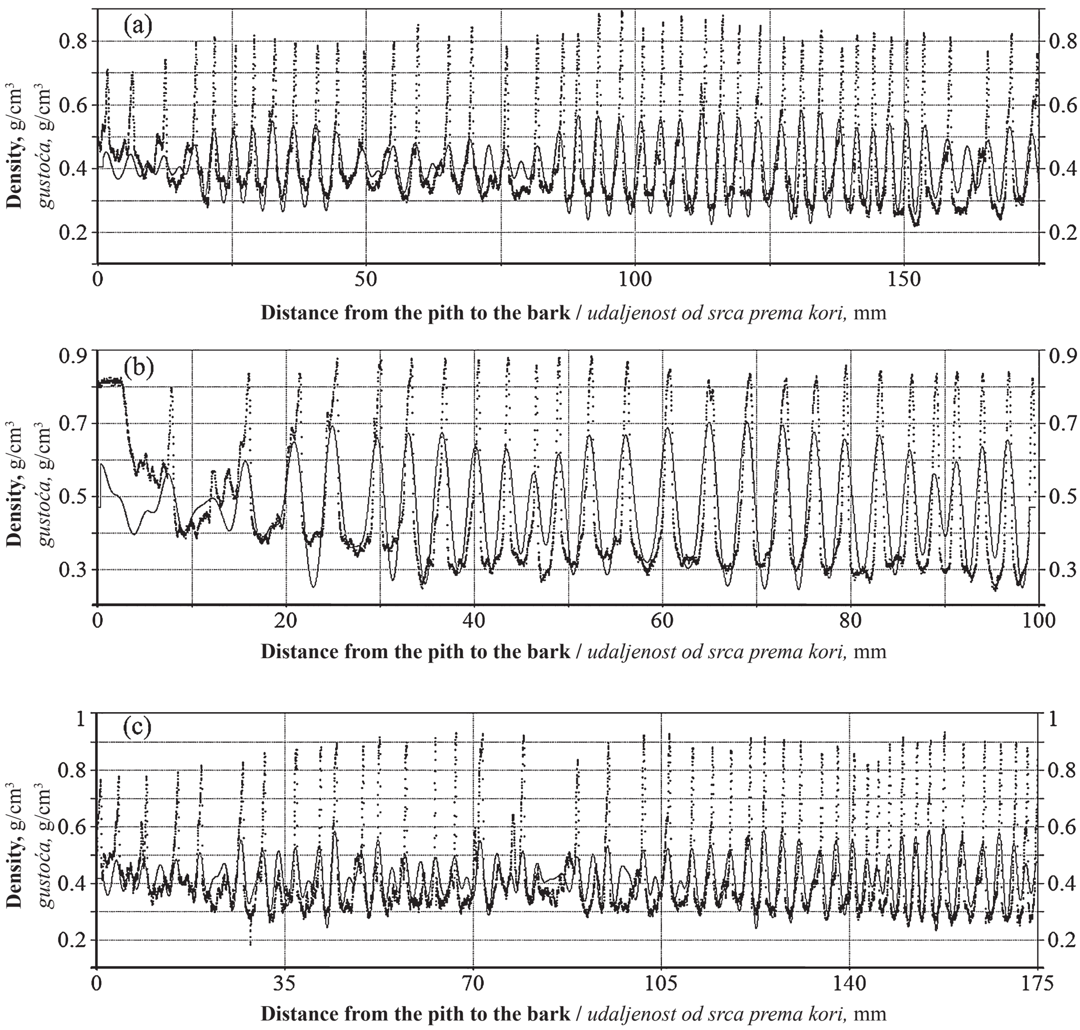

Figure 2 Experimentally obtained (solid line) and reconstructed (dashed line) density spectra of a) pf28, b) nf95 and c) nf221 samples. For clarity, the reconstructed density spectra of nf95 and nf221 samples were shown in the distance range from 0 to 175 mm

Slika 2. Eksperimentalno dobiveni (puna linija) i rekonstruirani (isprekidana linija) spektri gustoće za uzorke: a) pf28, b) nf95 i c) nf221 (radi jasnoće, rekonstruirani spektri gustoće za uzorke nf95 i nf221 prikazani su u rasponu od 0 do 175 mm)

Solomina *et al*. (2010) obtained similar results by using wavelet transformation and the maximum densities of the rings. It is worth emphasizing that in our calculations, we used the whole set of density data and not only the maximum densities of the rings. The transition points determined by using wavelet method correspond well to the results obtained by Fourier transform method (Csoka *et al*., 2005, 2007; Csoka and Djokovic, 2011) and logarithmic regression method of tracheid lengths (TL), which will be presented below. The fact that we were able to determine the distinct transition points contradicts the common opinion that a juvenile gradually turns into a mature wood. The annual ring growth of the trees is a periodic one and influenced by its response to the environmental impacts. These environmental effects induced changes in the boundary between the two main zones from the pith, but the clear separation point still exists. It is important to note that the growth cycles are not significantly affected by tree ageing but there are apparent structural changes during the juvenile formation (Castagneri *et al*., 2013).

During the wavelet transform calculations, we have omitted certain peaks of low probability. In Figure 2 (a), (b), (c), the density function was reconstructed by using inverse wavelet transformation of the data that are included in the initial calculations. As can be seen, there is a good agreement between the experimentally obtained and reconstructed density function. The low probability peaks in the reconstructed spectra of pf28, nf95 and nf221 samples observed in the 80-92 mm, 65-100 mm and 50-90 mm regions, respectively, correlate with the initial growth pattern of the trees. These ranges are the finger print of the events in the juvenile age of the woods. The density fluctuations, before and after these bands, are more uniform. The spectral analysis performed in this work shows that the density function of the investigated species carry the information about juvenile-mature transitions that seemed to be affected by the local environment.

The Hurst plots of three samples presented in Figure 3 suggest that the density functions are substantially homogeneous.

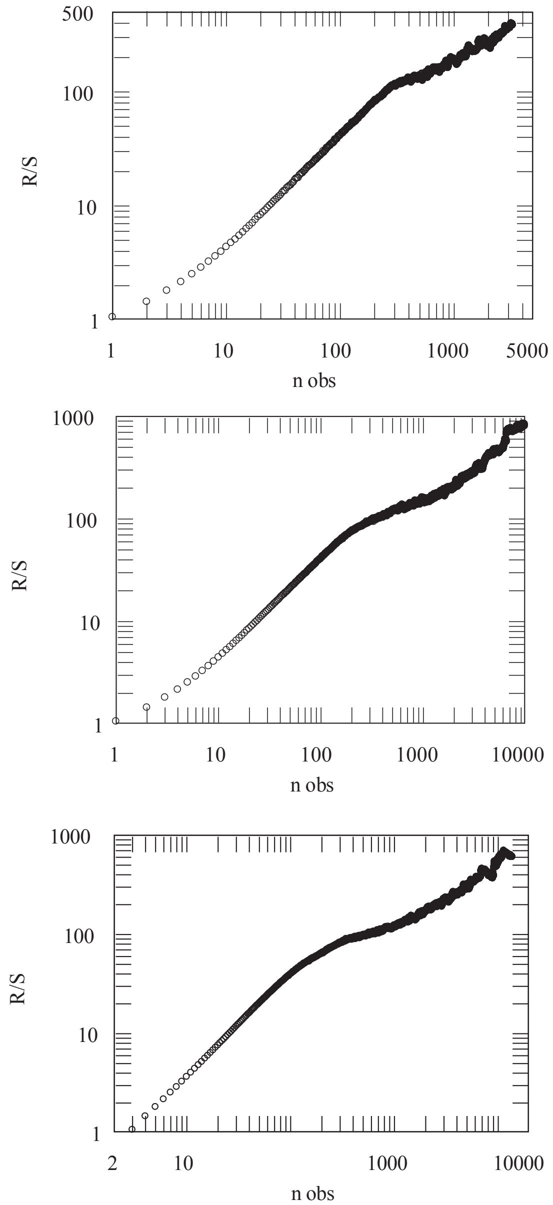

Figure 3 Hurst plots (normalized range value (*R/S*) versus number of observations) of a) pf28, b) nf95 and c) nf221 samples. (Hurst coefficients were estimated by linear regression r^2 = 0.94, 0.93 and 0.99 for the pf28, nf95, nf221 samples, respectively)

Slika 3. Hurstovi grafovi (normalizirani raspon vrijednosti (*R/S*) u odnosu prema broju opažanja) za uzorke: a) pf28, b) nf95 i c) nf221. (Hurstovi koeficijenti procijenjeni su uz pomoć linearne regresije r^2 = 0,94 za uzorak pf28, r^2 = 0,93 za uzorak nf95 i r^2 = 0,99 za uzorak nf221.)

The values of the Hurst exponents are well above 0.5 in the whole life span of the tree. The calculated values are 0.88, 0.93 and 0.76 for the pf28, nf95 and nf221 samples, respectively. The shape of the plots indicates that the periodic growth pattern of the trees is essentially similar during the whole life span. The growth can be predicted to a certain extent knowing the initial growth stages and the data set is obviously distinguishable from Gaussian or white noise. The values of the Hurst exponent that lie between 0.5 and 1 characterise the so-called black noise processes, long-run cyclical patterns that are readily observable in nature (Peters 1994). This implies that the formation of individual annual rings is affected by the environment. However, these effects cannot significantly change the shape of the annual rings. Since the Hurst exponent values are much higher than 0.5, and they were estimated from a long series of data points (>5000), the X-ray density function is substantially different from the noise and can reliably represent the annual growth of trees. Knowing the density function and the Hurst exponent, it is possible to predict the growth of annual rings, which can be further integrated into the local environment model.

Figure 4 shows the results obtained with tracheid length (TL) method. The TL values show typical functional dependence on annual ring number.

The TL values increase exponentially at early stages of the tree growth up to 25 years. After that, the TL exhibits stability or increases gradually over the time. Similar results on TL variability were reported earlier by Franceschini *et al*. (2012). The radial variations in TL were tentatively fitted with the logarithmic curve with a high correlation coefficient. The annual rate increment of TL was calculated from the logarithmic curve by using the point at which the annual increase rate drops below 1 % (Zhu *et al*., 2000). According to Shiokura (Shiokura 1982), the annual ring number at which TL increment rate drops below 1 % is related to the transition point between juvenile and mature wood. The transition point values obtained from the segmented model of tracheid lengths are in good agreement with the values calculated by using wavelet transform, but the two methods are independent (Table 1).

The localised waves in the wavelet spectrum obviously carry information about anatomical changes during the tree growth. For this reason, the wavelet analysis can be considered as an excellent tool for studying wood properties.

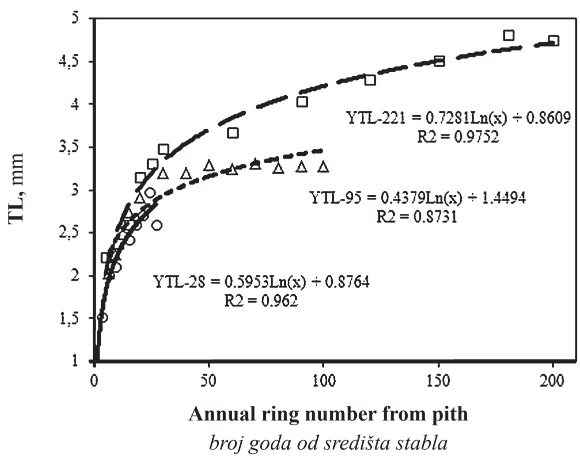

Figure 4 Radial variation of tracheid length (TL) for pf28 (circles), nf95 (triangles nf221 (squares) samples. The lines represent logarithmic curves of TL-s estimated from the experimental data

Slika 4. Radijalna varijacija duljine traheida (TL) za uzorak pf28 (krugovi), uzorak nf95 (trokuti) i uzorak nf221 (kvadrati). Linije predočuju logaritamske krivulje duljine traheida procijenjene iz eksperimentalnih podataka.

Table 1 Transition points between juvenile and mature wood determined by measuring tracheid lengths and by using Wavelet analysis
Tablica 1. Prijelazne točke između juvenilnoga i zrelog drva određene mjerenjem duljine traheida i uz pomoć *wavelet* analize

Sample tree *Uzorak stabla*	**Tree age, years** *Starost stabla*	**TL regression results** *Rezultati regresijske analize duljine traheida*		**Wavelet spectrum** *Wavelet spektar*	
		Annual ring number from pith *Broj godova od srca*	Distance from the pith, mm *Udaljenost od srca, mm*	Annual ring number from pith *Broj godova od srca*	Distance from the pith, mm *Udaljenost od srca, mm*
pf28	28	21-22	82-85	21-22	84.9
nf95	95	14-15	59-65	14-15	64.7
nf221	221	22-23	95-98	21-22	94.2

4 CONCLUSION
4. ZAKLJUČAK

Wavelet analysis can significantly increase the body of information that can be obtained from the investigated signal. It allows simultaneous study of the distance-density domains of the X-ray density function. Even when the signal is quasi non-stationary, as in the case of XDF, the distance domain information can make analysis more precise. In the case of the transition between juvenile and mature wood, wavelet analysis provides the same results as traditional methods in wood science. However, it also enables one to draw additional information about the environmental factors that affect the wood anatomy, which cannot be observed by using former methods. It can be assumed that the process of formation of the wood tissue is a periodic one and that the characteristic periods include several annual rings. This also indicates that the growth of wood can be separated into distinct processes that can be identified within the juvenile and mature wood zones. The presented results strongly support the use of wavelet transformation of XDF in studying the properties of the wood. Nevertheless, further investigations are necessary in order to reveal the potentials and limitations of the wavelet analysis in this particular field.

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Supplementary material – ***Dodatni podatci***

The following supplementary data (S1) is available at *Drvna Industrija* online: additional results on more wood samples can be found in the supplementary file.

Sample tree *Uzorak stabla*	**Tree age, years** *Starost stabla*	**TL regression results** *Rezultati regresijske analize duljine traheida*		**Wavelet spectrum** *Wavelet spektar*	
		Annual ring number from pith *Broj godova od srca*	Distance from the pith, mm *Udaljenost od srca, mm*	Annual ring number from pith *Broj godova od srca*	Distance from the pith, mm *Udaljenost od srca, mm*
C1	28	21-22	96-98	22-23	97.37
pf28	28	21-22	83-86	21-22	84.9
C33	30	21-22	110-113	21-22	111.15
C36	29	20-21	100-105	20-21	104.17
C39	29	18-19	94-99	18-19	98.12
T6	75	21-22	71-74	21-22	71.45
T8	71	24-25	61-64	25-26	65.35
T9	73	22-23	54-56	23-24	59.52
T10	73	16-17	40-43	17-18	46.32
IV1	93	10-11	36-41	10-11	40.17
IV2	94	14-15	40-43	15-16	47.1
nf95	95	14-15	59-64	14-15	63.7
VI1	100	14-15	58-62	14-15	59.72
VI2	94	15-16	44-51	16-17	53.64
VI3	102	17-18	89-96	16-17	88.83
VI4	96	16-17	44-57	17-18	58.94
NRNT T1	216	15-16	54-57	14-15	52.24
nf221	221	22-23	97-101	21-22	94.2

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Utilization of Common Hazelnut (*Corylus avellana* L.) Prunings for Pulp Production

Upotreba biomase nastale orezivanjem stabala običnog lješnjaka (*Corylus avellana* L.) za proizvodnju celuloze

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 2. 7. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*861.01; 674.031.632.1.14*
doi:10.5552/drind.2016.1529

ABSTRACT • *For the purpose of this study, pulp and handseet were produced from common hazelnut (Coryllus avellana L.) wood by using Kraft methods. Chip/solution ratio was chosen as 1/5, cooking temperature was 170°C and time for reaching the maximum temperature was 90 minutes. Screened yield was found best in 20/26 active alkali/sulfidity ratio with 47.59 %. With increased active alkali/sulfidity ratios, screened yield was decreased. The best beating degree has been identified as the 50 SR°. According to cooking parameters, while NaOH/Na2S ratio was 20/26 %, tearing index, breaking length and burst index were reached to the maximum value of 3.83 mN · m²/g, 43.23 N · m/g and 1.87 kPa · m²/g, respectively. These values were used for selecting the optimum cooking parameters.*

Key words: *common hazelnut wood, Kraft pulp production, paper, wood pruning*

SAŽETAK • *Za potrebe istraživanja kraft metodom proizvedena je celuloza od drva običnog lješnjaka (Coryllus avellana L.). Omjer između iverja i otopine bio je 1 : 5, temperatura kuhanja bila je 170 °C, a vrijeme postizanja maksimalne temperature iznosilo je 90 minuta. Najbolji prinos celuloze dobiven je pri omjeru lužine i sulfida 20 : 26 i iznosio je 47,59 %. S povećanjem omjera lužine i sulfida smanjivao se prinos nakon prosijavanja. Pokazalo se da je najbolji stupanj mljevenja 50 SR°. Pri različitim parametrima kuhanja i pri omjeru NaOH/Na$_2$S od 20 : 26 % indeks cijepanja, duljina lomljenja i indeks pucanja postigli su maksimalne vrijednosti od 3,83 mN·m²/g, 43,23 N·m/g i 1,87 kPa·m²/g. Te su vrijednosti upotrijebljene za odabir optimalnih parametara kuhanja.*

Ključne riječi: *drvo običnog lješnjaka, proizvodnja kraft celuloze, papir, drvo od rezidbe*

1 INTRODUCTION
1. UVOD

Hazelnut (*Corylus*) from *Betulaceae* family has natural distribution throughout Balkans, Asia, Iran and northern Turkey, and covers 10 species (Yaltırık and Efe, 2000). Having the highest commercial value in the world, *Corylus avellana* L. (FAOSTAT, 2011) is the widest species in our country (Sarıbaş, 2012). The total hazelnut farming area in Turkey was 6.678.649 ha in the year 2010 (TMO, 2013). *Corylus avellana* L. is the most important among them from the commercial aspect (FAOSTAT, 2011).

The yield of hazelnut is higher in north and east exposures in eastern Black Sea region at altitudes of 250-1000 m, and it has natural distribution at altitudes

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of 0-2500 m (Aydınoğlu, 2012). Although almost 70 % of the world's hazelnut production is provided by Turkey (TMO, 2013), the hazelnut wood could not have industrial use in our country. When cutting old trees with decreased yield, most of them are burnt. Some of their parts are used in traditional handworks such as production of wicker chairs, baskets, and barrel rings (TEMA 2004). However, since the interest in these handcrafts has decreased and not all of pruning residuals are suitable for use in these areas, the hazelnut wood cannot be utilized properly.

In a study, González *et al*. (2011) showed that the prunings from orange trees can be used to obtain soda pulp of acceptable quality with yields from 34.10 to 51.81 %. In another study, Gencer (2015) studied the utilization of kiwi pruning waste for kraft paper production and the effect of the bark on paper properties. According to the results, pulp making should then be decided based on an economic analysis. Pruning waste obtained from the kiwi plant is a sustainable fiber source since the plants are pruned annually. This waste should be utilized in the pulp and paper industry in order to provide income for growers.

In this study, in order to have preliminary information about the usability of hazelnut wood in pulp production, morphological properties and chemical components of the wood have been determined. Based on these properties, it can be concluded whether it is suitable for pulp production. In pulp production, the Kraft method was preferred. Kraft method was selected for its shorter cooking duration, high-resistance of its pulp, and the fact that it is suitable for all wood species (Casey, 1980). When applying the Kraft method, 6 times of cooking were performed in order to determine Na_2S and NaOH ratios,. While producing paper from any pulp, many of the paper characteristics are determined by beating. In other words, paper is produced in a beater. For this reason, in order to determine the characteristics that the paper will gain at different beating degrees, the most appropriate beating level was determined in our study by producing paper from unbeaten pulp and pulps beaten at beating degrees of (18±2), 35 and 50 SR°.

The aim of this study was to investigate the possibility of use of the hazelnut wood residues, not used industrially for any products, in the pulping and paper industry, and also to determine the anatomical and chemical properties of the hazelnut wood.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The common hazelnut (*Corylus avellana* L.) wood used in this study was obtained from north-west exposure at 35-60 m altitude at coordinates of 41°36′ N, 32°19′ E. After being cut into 5 cm parts in longitudinal direction, shredding process was executed manually. The branches and the other parts of the tree were also used in this study. NaOH and Na_2S used in pulp production were obtained from MERCK Darmstadt, Germany. Wood samples were macerated by chloride method (Wise and Jahn, 1952), and the preparations were evaluated from the aspect of their fiber lengths by their measurement.

Elasticity ratio = (*Lumen diameter* x 100) / *Fiber width*.

Runkel ratio = (*Fiber sheath thickness* x 2) / *Lumen diameter*

Felting ratio = *Fiber length* / *Fiber width*

Solidity coefficient = (*Fiber wall thickness* x 100) / *Fiber width*

Holocellulose was determined by Wise's chloride method (Wise and Jahn, 1952), and alpha cellulose (Rowell, 2005), lignin (TAPPI T 222 om-02), ash (ASTM D 1102-84), solubility in alcohol (TAPPI T 204 cm-97) and solubility in cold- and hot-water (TAPPI T 207 cm-99) were also determined. Chip/solution ratio (1/5), time for reaching maximum temperature (90 min.) and duration of cooking at maximum temperature (60 min.) were taken as constant for pulping. In determining the cooking temperature, kraft cooking temperature (170 °C), which was accepted to be ideal by İstek and Özkan (2006), was taken as constant. NaOH (%) - Na_2S (%) ratios were taken as 18-28, 20-26, 22-24, 24-22, 26-20 and 28-18, and six different cooking procedures were executed. Kappa number of pulps was determined according to TAPPI T 236 om-99, while viscosity of pulp was determined according to SCAN-CM 15-62 standards. 13 replicates were produced in accordance with different beating conditions. In all papers dealing with beating at (18±2º SR°), 35±2º SR° and 50±2º SR°, opacity and brightness, tearing index, break index, and burst index values were determined in accordance with TAPPI T 519 om-02, TAPPI T 525 om-02, TAPPI T 414 om-98, TAPPI T 494 om-01 and TAPPI T 403 om-02 standards, respectively. SPSS 16.0 package software was used for assessment of data.

According to Gençer and Şahin (2015), the highest values of breaking length, brightness, burst index, tearing index, opacity and whiteness were taken into account, as well as the values at which the difference between those values was not statistically significant at 5 %, and a scoring table (Tab. 5) was developed in order to determine the optimum conditions. Moreover, the highest values and the value(s) at which the difference between those values was not statistically significant at 5 % were each graded as 1, while all of the remaining values were graded as 0.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

When loading chips into cooking boiler for pulping production, the higher the oven-dry density value of the wood, the higher is the yield obtained from the unit volume of that chip. Therefore, the boiler capacity changes proportionally to the density of wood species. The high density of the hazelnut wood has an important advantage compared to species of wood with low density. Oven-dry density of *Corylus avellana* L. wood was determined to be 0.67 g/cm^3., This value of *Corylus colurna* from the same family, grown in our country, is 0.699 g/cm^3 (Korkut *et al*., 2008), while that of *Corylus colurna* L. grown in the Czech Republic is

Table 1 Comparison of fiber lengths with *Corylus avellana* L. wood
Tablica 1. Usporedba duljine vlakanaca različitih vrsta drva i drva lješnjaka (*Corylus avellana* L.)

Wood species *Vrsta drva*	**Fiber length** *Duljina vlakanaca* mm	**Fiber width** *Širina vlakanaca* µm	**Lumen width** *Širina pore* µm	**Wall thickness** *Debljina stijenke* µm
Corylus avellana L.(1)	1.04	22.2	13.66	4.3
Corylus avellana L.(2)	1.06	23.8	14.08	4.8
Betula verrucosa (3)	1.10	20.0	-	1.9
Eucalyptus globus (3)	1.00	13.0	-	1.6
Fagus silvatica var. *purpurea* (3)	1.03	19.0	-	7.5
Qercus robur (3)	1.10	21.0	-	6.0
Fraxinus excelsior (3)	1.05	16.0	-	3.8

Key/*Legenda*: 1 – authors' finding, 2 – Merev, 1998, 3 – Rydholm, 1965

0.627 g/cm^3 (Zeidler, 2012). The fiber morphology of the raw material plays a decisive role for the characteristics of the paper to be produced. For this reason, Table 1 presents morphological characteristics of some important hardwood trees from literature compared with fiber lengths of *Corylus avellana* L. wood.

According to IAWA (1989), the trees with mean fiber lengths between 900 and 1600 µm are considered as "medium length" fiber group. As can be seen in Tab. 2, it was determined that *Corylus avellana* L. wood is in this group with its 1.04 mm fiber length. Merev (1998) has determined the fiber length, fiber width, lumen width, wall thickness, and trahe length of *Corylus avellana* L. wood to be 1.05 mm, 23.76 µm, 14.08 µm, 4.80 µm, and 599.98 µm, respectively. Merev's determinations show similarities with the values obtained in our study. They are the same as *Taxus brevifolia* and *Quercus stellate*, and have similarities with *Carya cordiformis* and *Ulmus alata* (0.66 g/cm^3) (Miles and Smith, 2009).

Elasticity coefficient, rigidity coefficient, Runkel ratio, and felting ratio of hazelnut wood are 61.53, 19.23, 0.63, and 46.90, respectively, and these values show similarity with those of kiwi (Yaman and Gençer, 2005) calculated to be 61.99, 19.00, 0.61, and 44.03. When the relationship between specific weight and fiber lengths of hazelnut wood was examined, it could be seen that elasticity coefficient was 61.53 and specific weight was 0.67 g/cm^3. The woods with elasticity coefficient of 50-75 and weight of 0.55-0.70 g/cm^3 are classified into this group. The woods in this group provide papers with good resistance characteristics, because they are partly grinded since their lumen gaps are wide although wall thicknesses are a little bit high (Bostancı, 1987). With such characteristics, *Corylus avellana* L. is classified into elastic fiber class, and it has advantages in paper production compared to species having fibers with thick and thin wall. Since thick-walled cells do not collapse, the potential contact area decreases. Consequently, the burst resistance depending on fiber connection also decreases. On the other hand, since the individual fiber strength of thin-walled fibers is low, their tearing resistance is also low (Panshin and de Zeeuw, 1970).

The rigidity coefficient has been found to be 19.23. The physical resistance characteristics of papers made of fibers having high rigidity coefficients are affected negatively and not enough inter-fiber connection can be established (Yaman and Gençer, 2005). High rigidity coefficient means low physical resistance qualifications, especially the low level of burst and breaking resistances. Runkel ratio has been calculated to be 0.63. If the Runkel ratio is less than 1, it is classified into thin-walled fiber class. Except the tearing and folding resistance, all of the characteristics of paper made of these fibers show improvement. Felting ratio has been found to be 46.93. Although the fibrous raw materials having felting ratio less than 70 are considered to be invaluable in terms of paper production, since it has been revealed that the physical characteristics of pulps obtained from the fibers of hardwoods having felting ratio less than 70 are good, it can be stated that this ratio does not indicate a systematical relationship with various physical characteristics of paper but indicates the relationship only with tearing resistance of the paper (Bostancı, 1987). According to these results, hazelnut wood can compete with forest trees having significant place in pulp production (Table 1) from the morphological aspect. *Corylus avellana* L. and *Corylus colurna* L. are two important hazelnut species in Turkey. Some physical and chemical characteristics of these wood species are presented in Tab. 2.

Table 2 Some physical and chemical characteristics of *Corylus avellana* L. and *Corylus colurna* L. woods
Tablica 2. Neka fizikalna i kemijska svojstva drva *Corylus avellana* L. i *Corylus colurna* L.

Characteristics *Obilježje*	***Corylus avellana* L.** (Findings)	***Corylus colurna* L.** (Korkut *et al.,* 2009)
Extractive matter, % / *ekstraktivne tvari, %*	2.83	7.42
Cold-water solubility, % / *topljivost u hladnoj vodi, %*	2.90	6.30
Hot-water solubility, % / *topljivost u toploj vodi, %*	3.70	7.40
Holocellulose, % / *holoceluloza, %*	82.07	68.80
α-cellulose, % / α-celulo*za, %*	41.33	43.50
Lignin, % / *lignin, %*	15.89	23.60
1 NaOH solubility, % / *topljivost u lužini, %*	18.48	25.50
Ash content, % / *sadržaj pepela, %*	0.72	0.30

Table 3 Screened yield, screenings, total yield, Kappa number, and viscosity of pulps obtained from *Corylus avellana* L. wood
Tablica 3. Prinos prosijavanja, prosijavanje, ukupni prinos, Kappa broj i viskozitet celuloze proizvedene od drva *Corylus avellana* L.

$NaOH-Na_2S$ %	Screened yield *Prinos prosijavanja* %	Reject Škart %	Total yield *Ukupni prinos* %	Kappa number *Kappa broj*	Viscosity *Viskozitet* cm^3/g
K1/ 18-28	45.72	0.20	45.92	17.25	778.26
K2/ 20-26	47.60	0.05	47.64	17.35	947.01
K3/ 22-24	45.06	0.13	45.19	15.25	697.17
K4/ 24-22	43.55	0.07	43.62	14.65	685.47
K5/ 26-20	40.67	0.06	40.73	14.55	680.39
K6/ 28-18	38.21	0.06	38.27	14.45	607.48

K - Kraft pulping / *priprema kraft pulpe*

When physical and chemical properties of *Corylus avellana* L. wood, presented in Table 2, are compared with those of *Corylus colurna* L. wood, it can be concluded that solubility values, α-cellulose, and lignin contents are low in *Corylus colurna* L. wood, while holocellulose and ash content values are high in *Corylus avellana* L. wood .

3.1 The effect of active alkali/sulfidity ratio on pulp yield
3.1. Utjecaj omjera lužine i sulfida na prinos celuloze

Some characteristics of Kraft pulp obtained from *Corylus avellana* L. wood, such as screened yield, total yield, Kappa number, and viscosity, are presented in Table 3.

When producing paper from pulp, many characteristics of the paper depend on the beating degree. Beating mainly affects the physical characteristics. With beating, primary fiber wall is shivered, fiber length decreases, elasticity increases, and outer specific area of fiber increases. As the duration of beating increases, the breaking and burst indices increase, tearing index of paper sheets increases rapidly and then these properties decrease. Opacity and brightness of paper sheets decrease. Similar results are generally determined due to beating (Gencer and Sahin, 2015).

When examining Table 4, it can be seen that the same letters in the same columns indicate that the differences are statistically non-significant at confidence level of 95 %. When examining the effect of different active alkali/sulfidity ratios on opacity, it can be seen that the highest opacity in papers produced from non-beaten pulps has been measured to be 99.93 % at active alkali/

Table 4 Some physical, optical, and mechanic characteristics of sample papers obtained from *Corylus avellana* L. wood and Duncan test
Tablica 4. Određena fizikalna, optička i mehanička svojstva uzoraka papira proizvedenih od drva *Corylus avellana* L. i rezultati Duncanova testa

SR°	No	Optical characteristics *Optička svojstva*		Mechanic characteristics *Mehanička svojstva*		
		Opacity *Neprozirnost* %	Brightness *Sjajnost* %	Tearing index *Indeks cijepanja* $mN·m^2/g$	Breaking index *Indeks lomljivosti* N·m/g	Burst index *Indeks pucanja* $kPa·m^2/g$
18±2	K1	99.88 G	25.18 H	2.93 BCD	34.86 C	1.51 D
	K2	99.89 G	25.39 I	3.83 I	43.23 D	1.87 E
	K3	99.92 G	26.05 K	2.64 ABC	34.69 C	1.30 C
	K4	99.93 G	26.99 M	2.60 AB	29.71 B	1.37 C
	K5	99.85 F G	29.38 O	2.41 A	29.57 B	1.11 B
	K6	99.79 F G	32.17 P	2.34 A	24.41 A	0.95 A
35±2	K1	99.21 C	19.50 C	3.86 I	80.66 I	4.62 K
	K2	98.44 B	19.33 C	3.63 GHI	83.29 I	5.01 L
	K3	99.70 EF	21.69 F	3.70 HI	76.91 H	4.04 I
	K4	99.69 EF	20,19 G	3.61 FGHI	70.03 F	3.80 H
	K5	99.69 EF	25.67 J	3.49 FGHI	69.36 F	3.41 G
	K6	99.59 E	28.68 N	3.43 FGH	62.61 E	3.33 FG
50±2	K1	98.51 B	17.75 A	3.39 FGH	86.29 J	4.63 K
	K2	97.87 A	18.26 B	3.34 EFGH	87.86 J	5.19 M
	K3	99.37 D	20.07 D	3.26 DEFG	81.16 I	4.16 J
	K4	99.41 D	21.23 E	3.23 DEF	73.78 G	3.81 H
	K5	99.38 D	23.19 G	2.99 CDE	67.52 F	3.43 G
	K6	99.16 C	26.31 L	2.89 BCD	62.12 E	3.25 F

After one-way analysis of variance (ANOVA), the Duncan test was used to determine the difference between groups. Important differences between groups were marked by the letter A, B, C…, etc. The letter means the difference between the groups. / *Nakon jednosmjerne analize varijance (ANOVA) primijenjen je Duncanov test kako bi se odredile razlike između skupina podataka. Značajne razlike među skupinama prikazane su slovima A, B, C itd. Različita slova označuju značajne razlike među skupinama.*

Table 5 Scoring the optimum pulp production conditions and beating degree
Tablica 5. Bodovanje optimalnih uvjeta proizvodnje celuloze i stupnja mljevenja

Properties / *Svojstvo*	**K1** x/y/z	**K2** x/y/z	**K3** x/y/z	**K4** x/y/z	**K5** x/y/z	**K6** x/y/z
Opacity / *neprozirnost*	1/0/0	0/0/1	1/1/1	1/1/1	1/1/1	0/1/1
Brightness / *sjajnost*	0/0/0	0/0/0	0/0/0	0/0/0	0/0/1	1/1/1
Tear index / *indeks cijepanja*	1/1/0	1/1/1	0/1/0	0/1/0	0/1/0	0/1/0
Breaking index / *indeks lomljivosti*	0/1/0	1/1/1	0/0/0	0/0/0	0/0/0	0/0/1
Burst index / *indeks pucanja*	0/0/0	1/1/1	0/0/0	0/0/0	0/0/0	0/0/0
Pulp yield / *prinos celuloze*	0/0/0	1/1/1	0/0/0	0/0/0	0/0/0	0/0/0
Kappa number / *Kappa broj*	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	1/1/1
Viscosity / *viskozitet*	0/0/0	1/1/1	0/0/0	0/0/0	0/0/0	0/0/0
Total point x/y/z / *ukupan broj bodova x/y/z*	2/2/0	5/5/6	1/2/1	1/1/1	1/2/2	2/4/4

x – 18±2 SR°, y – 35±2 SR°, z – 50±2 SR°

sulfidity ratio of 24/22. It can be seen that opacity of paper sheets decreased in all samples as the beating duration was increased. When examining the effect of different active alkali/sulfidity ratios on brightness in non-beaten pulps, it can be concluded that the highest brightness value was 32.17 % at active alkali/sulfidity ratio of 28/18. This value was decreased in all of the samples as the duration of beating was increased.

When examining the effect of different active alkali/sulfidity ratios on tearing index, it can be seen that the tearing index of paper sheets obtained from different active alkali/sulfidity ratio of 20/26 was 3.83 mN·m^2/g for non-beaten pulp and 3.86 mN·m^2/g for pulp beaten at 35 SR°. As the duration of beating increased, this value also increased in all samples initially, and then it decreased in all of them at 50 SR°. Breaking index value at active alkali/sulfidity level of 20/26 has peaked in non-beaten pulp and pulps beaten at 35 SR° and 50 SR°, and it increased with beating. It was found to be 43.23, 80.66 N·m/g and 87.86 N·m/g, respectively. When evaluating the effects of different active alkali/sulfidity ratios and beating on burst index, it can be seen that, with 20/26 active alkali/sulfidity ratio, the sample papers made of unbeaten pulp and pulp beaten at 35 SR° and 50 SR° had the highest values, and namely 1.87, 5.01 and 5.19 kPa·m^2/g, respectively. Burst and tearing index values obtained from *Corylus avellana* L. wood at similar Kappa number and SR° levels are higher than those obtained from papers made of *Olea europaea* wood (Requejo *et al.,* 2012).

According to Tab. 5, the most ideal beating conditions were determined by giving 1 point to the best value and to the values having statistically non-significant difference from the best value at confidence level of 95 %. When interpreting the columns of Table 4, all 3 freeness or schopper degrees were taken into consideration. However, while scoring in Table 4, by evaluating each beating value at 18±2 SR°, 35 SR° and 50 SR° beating levels, *x*, *y* and *z* columns were created. This was done with the aim of determining the best beating degree.

When evaluating the pulp, high yield and viscosity values and low Kappa number are desired. The aim of the assessment was to determine the highest yield and viscosity and the lowest Kappa number. Since these values are the properties related to pulp, they are the same for every beating degree. Table 5 presents the scoring used to determine the optimum conditions.

According to Tab. 5, the paper made of K2 pulp gained the highest scores at every beating degree, and peaked when beaten up to 50 SR° degrees. According to these results, the cooking conditions of common hazelnut wood can be considered as 20/26 active alkali/sulfidity, cooking temperature of 170 °C, 1/5 chip/solution ratio, 90 min. for reaching the maximum temperature, 60 min. of cooking at the highest temperature, and beating degree of 50 SR°. In our study, pulp has been produced from Common Hazelnut (*Corylus avellana* L.) wood by Kraft method, and the best beating degree has been determined. However, in order to achieve an exact judgment, we believe that other pulp production methods should also be investigated.

4 CONCLUSION
4. ZAKLJUČAK

The fibers of the Hazelnut wood presented in Tab. 1 were determined to be similar to the fibers of the hardwoods commonly used in the wood products industry. Therefore, it can be said that the paper produced from hazelnut wood can be an alternative to commonly used hardwood species. Hazelnut wood has a high α-cellulose ratio and a low lignin ratio, hence it can easily be used in an alternative pulping process.

Acknowledgements - Zahvala

This study has been financially supported by the Scientific Research Center of Bartın University within the scope of the project. We thank the management of Bartın University for their full support throughout the project No: 2013.1.87.

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Physical Properties of Wood in Poplar Clones ’I-214’ and ’S1-8’

Fizikalna svojstva drva klonova topole ’I-214’ i ’S1-8’

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 12. 1. 2016.
Accepted – prihvaćeno: 5. 5. 2016.
UDK: 674.031.623.23; 630.812.23; 630*812.31*
doi:10.5552/drind.2016.1604

ABSTRACT • *Physical properties play an important role in predicting the quality of wood raw material. Variation in wood density and wood shrinkage of two different poplar clones cultivated on plantation "Drnje" near Koprivnica in Croatia was measured. One of poplar clones is* **’***I-214***’**, *whose wood properties have already been studied and often compared. Other poplar clone is ‘S1-8′, whose wood properties have been poorly researched, despite its good survival and growth rate. The results indicate that wood density of clone* **’***I-214***’** *is significantly higher in comparison to clone ‘S1-8′, but the difference, as far as practice is concerned, is negligible. In both clones, wood density increases and shrinkage decreases from pith to bark. Increased growth rate has a negative effect on wood density of researched clones.*

Key words: *Poplar clones, ‘I-214′, ‘S1-8′, wood density variation, wood shrinkage variation*

SAŽETAK • *Fizikalna svojstva drva važan su pokazatelj za predviđanje kvalitete drvne sirovine. U ovom su radu ispitane varijacije gustoće i utezanja drva dvaju klonova topole naraslih na plantaži Drnje u blizini Koprivnice u Hrvatskoj. Jedan od klonova topole je ‘I-214′, čija su svojstva drva već istraživana i često uzimana kao usporedna. Drugi je klon ‘S 1-8′, a svojstva njegova drva nedovoljno su istražena, usprkos njegovu dobrom preživljavanju i priličnoj brzini prirasta. Rezultati pokazuju da je gustoća drva klona ‘I-214′ signifikantno veća u usporedbi s klonom ‘S1-8′, ali je ta razlika za praksu zanemariva. Gustoća drva obaju klonova se povećava, a utezanje drva se od srčike prema kori smanjuje. Brzina prirasta negativno se odražava na gustoću drva istraživanih klonova.*

Ključne riječi: *klonovi topola, ‘I-214′, ‘S1-8′, varijacije gustoće drva, varijacije utezanja drva*

1 INTRODUCTION
1. UVOD

Trends in forestry are towards shorter rotations and more complete utilization of trees. Global poplar resources have been rapidly increasing in the last few decades, due to increasing demand for raw material. Rotations in poplar breeding are, depending on purpose, up to 15 years (DeBell *et al*., 2002). In relation to their rapid growth, poplar plantations can produce large volumes of wood in a short period of time. Considering the fact that future wood supplies may become more scarce, poplar clonal plantations present great domestic breeding potential in Croatia.

Poplar wood provides numerous product options, ranging from lumber to veneer, plywood and composites as wood-based products, as well as pulp and paper as fiber-based products. It is well known that different

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end uses require specific wood characteristics (Zhang *et al*., 1997). The selected clones must meet the needs of processing industry. Ongoing cultivar evaluation criteria are mainly growth rate, coppicing ability, adaptability and disease resistance. However, little attention has been paid to the wood quality of selected poplar clones. This is why additional emphasis needs to be placed on the utilization properties of the material, such as physical properties.

In general, wood density is considered to be the most important factor affecting wood quality (Zobel and van Buijtenen, 1989). Wood density is strongly related to other wood properties, such as mechanical strength (Panshin and de Zeeuw, 1980). Poplar wood is very versatile, with low density similar to that of softwoods, but with high strength values related to their limited density (Isebrands and Richardson, 2014). Wood density also responds well to genetic improvement (Zobel and Jett, 1995), such as in poplar breeding.

Additionally, wood dimensional stability is another significant physical property, mainly for the manufacture of solid wood products. Wood shrinkage is affected by a number of variables, density being one of them. According to Tsoumis (1991), greater shrinkage is generally associated with greater density. Until now, only a few studies on wood shrinkage in poplars have been carried out (Karki, 2001; Pliura *et al*., 2005; Kord *et al*., 2010).

For best utilization of wood, it is also important to know the effect of age on wood properties. Large portion of wood produced in poplar clones is in the juvenile core (Balatinecz *et al*., 2001). The juvenile wood properties generally change from pit outward.

The best known within-tree variability in wood is the change from the pith to the bark. The low density diffuse-porous woods, such as *Populus*, seem to have a somewhat higher density at the pith (Zobel and van Buijtenen, 1989).

Significant clonal variation in wood density of poplars has been reported by many authors (Yanchuk *et al*., 1984; Fang and Yang, 2003; Zhang *et al*., 2003; Kord and Samdaliri, 2011; Huda *et al*., 2014). Properties of poplar wood, showing significant interclonal variation, could indicate the possibility of identifying clones with superior wood properties.

Among registered cultivars in Croatian *Populus* culture, two poplar clones 'I-214' and 'S1-8', have been planted on the experimental site near the Drava river and previously investigated by means of wood anatomical properties (Šefc *et al*., 2009). On that site, clone 'S1-8' showed superior growth increment and better survival compared to clone 'I-214' (Pfeifer, 1994). The Italian clone, 'I-214', is a good example of an exceptional clone adapted to a large variety of sites and growing conditions (Ahuja and Libby, 1993). From the technological point of view, density of the wood produced is low compared to most other cultivated clones (Peszlen 1994). It shows density values of 300 kg/m^3 (Isebrands and Richardson, 2014). On the other hand, the results point to the intensive development of the Serbian clone, 'S1-8', in the juvenile phase of development (FAO 1998). Until now, physical properties of clone 'S1-8' have not been investigated.

The aim of this study is to determine physical properties of poplar clones 'I-214' and 'S1-8' from one site in Croatia, to investigate variations in wood density and shrinkage of the mentioned poplar clones and to investigate the relationship between the two properties.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

For the purpose of this study, three test trees of poplar clone 'I-214' and three of poplar clone 'S1-8' were selected according to the standard HRN ISO 3129:1999. Both poplar clones came from the same habitat. They were cultivated on plantation "Drnje" near Koprivnica in Croatia, located along the natural flow of the Drava River. The site is characterized by a continental climate and the soil is alluvial soil, more gravely and sandy. Both clones were planted in deep planting technique and with the density of 3.5 × 3.5 m.

Relevant parameters were collected and measured on the growth location of all test trees, such as: ground plan projection canopy, trees orientation toward the cardinal points, diameter at breast height, total tree height, height up to the first living branches and stump height (Table 1).

After cutting down, a test trunk, having the length of approximately 80 cm, was sawn from each test tree. Test trunk length started at breast height (1.3 m), downwards to root collar. Afterwards, these 80 cm long trunks were sawn into bark to bark cores of approximately 6 cm in thickness (Figure 1). Cores were then submitted to natural drying on dry and drafted stock. The samples were sawn in the radial direction from heart to bark and

Table 1 Tree characteristics of poplar clones 'I-214' and 'S 1-8'
Tablica 1. Svojstva stabala klonova topole 'I-214' i 'S 1-8'

Clone *Klon*	**Tree mark** *Oznaka stabla*	**Site** *Stanište*	**Total tree height** *Ukupna visina stabla* m	**Trunk height** *Visina trupčića* m	**Height up to first living branch** *Visina do prve žive grane* m	**Diameter at breast height** *Promjer na prsnoj visini* cm
'I-214'	18	Drnje (KP)	32.5	21	11.7	31
'I-214'	20	Drnje (KP)	30	18	10	31
'I-214'	21	Drnje (KP)	35	19	6.4	25
'S 1-8'	28	Drnje (KP)	37.5	17	8	34
'S 1-8'	29	Drnje (KP)	29.7	18	18	33
'S 1-8'	32	Drnje (KP)	33.3	23	6	26

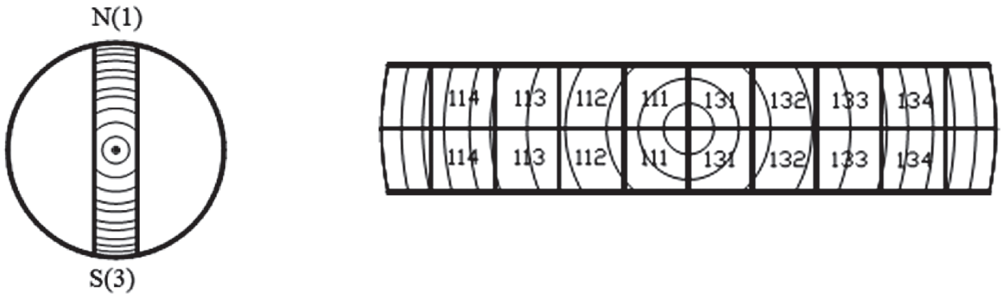

Figure 1 Bark to bark core (North – South) and samples of 20 mm × 20 mm × 25 mm from core
Slika 1. Srednjača (sjever – jug) i uzorci dimenzija 20 × 20 × 25 mm iz srednjače

labelled with markers that indicate from which tree they were sawn, to which side of the world they belong to and the ordinal number from pith to bark. After the cores had dried to a water content of about 12 %, rectangular samples of 20 mm × 20 mm × 25 mm were made from the highest part of the core, which was in the area of the breast height (1.3 m), (Figure 1).

In this study, the following physical properties were determined: density in absolutely dry condition and nominal density according to HRN ISO 3131:1999, radial and tangential shrinkage according to HRN ISO 4869:1999 and volumetric shrinkage according to HRN ISO 4858:1999.

Statistical analysis of the results and their comparison were carried out in specialised statistical programme Statistica 8. Statistical analysis showed the number of measured samples (n), minimum (min), average (aver) and maximum (max) value of certain measured properties as well as their standard deviation (STDEV) and coefficient of variation (CVAR).

3 RESULTS AND DISCUSSION
3. REZULTATI I DISKUSIJA

Physical properties of wood, especially wood density and dimensional stability, are important factors affecting wood quality. Average wood density in absolutely dry condition of clone ′I-214′ is 388 kg/m^3 (Table 2). The value is somewhat higher than findings of other authors for the same clone (Peszlen, 1998; Balatinecz *et al.*, 2014). Average wood density in absolutely dry condition of clone ′S1-8′ is 372 kg/m^3 (Table 2).

Statistical analysis showed the difference in average wood density between the two clones (Table 2). However, the difference in wood density between clones is only about 4 %, and for the purpose of wood processing and forestry practice this could be negligible.

The advantage of ′S1-8′ is its better survival, better diameter growth rate and thicker bark compared to clone ′I-214′ (Šefc *et al.*, 2009). Considering their low wood density, poplars have relatively high shrinkage values. According to some authors, this is mainly due to their chemical composition, e.g. relatively high polysaccharide content (Balatinecz *et al.*, 2014). Average shrinkage values between the two investigated clones are insignificant (Table 3). This is in accordance with Koubaa *et al.* (1998a), who reported that shrinkage values are in the same range for fast-growing hybrid poplars.

There are opposite findings about radial distribution of wood density for poplars. Einspahr *et al.* (1972) report that in *Populus tremuloides* wood, density was high near the pith, lower from three to five rings, and then increased towards the bark. Similar result was reported by Yanchuk *et al.* (1983). Scaramuzzi (1958) found uniform wood density from pith to bark in *Populus euroamericana* clones.

In this research, wood density in absolutely dry condition increased from pith to bark in both investigated clones (Figure 2). This is in accordance with the findings of Boyce and Kaiser (1961), Curró (1960),

Table 2 Statistical values of density in absolutely dry condition, nominal density, maximum radial, tangential and volume shrinkage of poplar clone ′I-214′ and poplar clone ′S 1-8′
Tablica 2. Prikaz statističkih vrijednosti gustoće u apsolutno suhom stanju, nominalne gustoće, maksimalnoga radijalnog, tangencijalnog i volumnog utezanja klona topole ’I-214’ i klona topole ′S 1-8′

Poplar (Clone ′I-214′) *Topola (klon ′I-214′)*						**Poplar (Clone ′S1-8′)** *Topola (klon ′S1-8′)*				
ρ_o g/cm^3	ρ_y g/cm^3	$\beta_{r\,max}$ %	$\beta_{t\,max}$ %	$\beta_{v\,max}$ %		$\beta_{v\,max}$ %	$\beta_{t\,max}$ %	$\beta_{r\,max}$ %	ρ_y g/cm^3	ρ_o g/cm^3
28	28	28	28	28	*N*	29	29	29	29	29
0.360	0.311	3.9	7.5	13.0	*MIN*	11.3	7.2	2.7	0.300	0.346
0.388	0.336	5.1	9.7	15.6	*AVE*	15.1	9.6	4.6	0.323	0.372
0.449	0.392	8.2	12.4	19.0	*MAX*	17.9	12.1	7.7	0.362	0.414
0.022	0.022	1.16	1.12	1.63	*STDEV*	1.70	1.28	0.99	0.017	0.017
5.77	6.38	22.62	11.65	10.47	*CVAR*	11.26	13.32	21.30	5.09	4.52

Key/*Legenda*: ρ_o – density in absolutely dry condition / *gustoća u apsolutno suhom stanju*, ρ_y – nominal density / *nominalna gustoća*, $\beta_{r\,max}$ – total radial shrinkage / *totalno radijalno utezanje*, $\beta_{t\,max}$ – total tangential shrinkage / *totalno tangencijalno utezanje*, $\beta_{v\,max}$ – total volumetric shrinkage / *totalno volumno utezanje*, *N* – number of specimen / *broj uzoraka*, *MIN* – minimum value / *minimalna vrijednost*, *MAX* – maximum value / *maksimalna vrijednost*, *STDEV* – standard deviation/ *standardna devijacija*, *CVAR* – coefficient of variation / *koeficijent varijacije* (%)

Table 3 Pearson's correlation coefficients for the relationship between mean values of researched physical properties of poplar clone 'I-214' and poplar clone 'S1-8'
Tablica 3. Pearsonov koeficijent korelacije između srednjih vrijednosti određivanih fizikalnih svojstava klona topole 'I-214' i klona topole 'S1-8'

Poplar (Clone 'I-214') *Topola (klon 'I-214')* / **Poplar (Clone 'S 1-8')** *Topola (klon 'S 1-8')*	**Density in absolutely dry condition** *Gustoća u apsolutno suhom stanju*	**Nominal density** *Nominalna gustoća*	**Total radial shrinkage** *Totalno radijalno utezanje*	**Total tangential shrinkage** *Totalno tangencijalno utezanje*	**Total volumetric shrinkage** *Totalno volumno utezanje*
Density in absolutely dry condition / *gustoća u apsolutno suhom stanju*	*p*= **0.007**				
Nominal density / *nominalna gustoća*		*p*= **0.017**			
Total radial shrinkage / *totalno radijalno utezanje*			*p*= 0.131		
Total tangential shrinkage / *totalno tangencijalno utezanje*				*p*= 0.949	
Total volumetric shrinkage / *totalno volumno utezanje*					*p*= 0.478

Key / *Legenda*: Correlations are significant at $p < 0.05$ / *Korelacija je signifikantna pri p < 0,05*

Farmer and Wilcox (1968) and DeBell *et al.* (2002). Kord (2010) also reported an increasing trend in wood density, longitudinal, radial, tangential, and volumetric shrinkage, from the pith to bark in *Populus euramericana* trees. This can be explained by the fact that juvenile wood is known to be of lower density than mature wood (Dadswell, 1958; Zobel and Buijtenen, 1989). Similar patterns of wood density variation in the axial direction have also been reported in hybrids involving *P. alba*, *P. grandidentata*, and *P. tremuloides* (Johnson, 1942), in *P. trichocarpa* (Okkonen *et al*., 1972), and in *P. tremuloides* (Yanchuk *et al*., 1984).

There are conflicting findings on the correlation between wood density and ring width in poplars. Kennedy and Smith (1995) reported that there is an increase in wood density with faster growth. Density of wood is not related to ring width according to Göhre (1960). Mutibarić (1967) wrote about a slight negative correlation between ring width and wood density in *Euramerican poplar* hybrids in Yugoslavia.

In this research, negative correlation between wood density in absolutely dry condition and ring width was found in both investigated clones (Figure 3).

Dense wood results from fiber with thick walls and a low microfibril angle, which produces minimal longitudinal shrinkage, and increases radial and tangential shrinkage (Dadswell, 1958). Changes in wood shrinkage with cambium age are likely related to radial inter-tree variation in wood density, which often displays an inverse pattern of changes (Johnson, 1942; Okkonen *et al*., 1972; Yanchuk *et al*., 1984; Kord, 2010).

Pliura et al. (2005) found a positive correlation between wood density and both radial and tangential shrinkage. According to Koubaa and Smith (1959), there is a

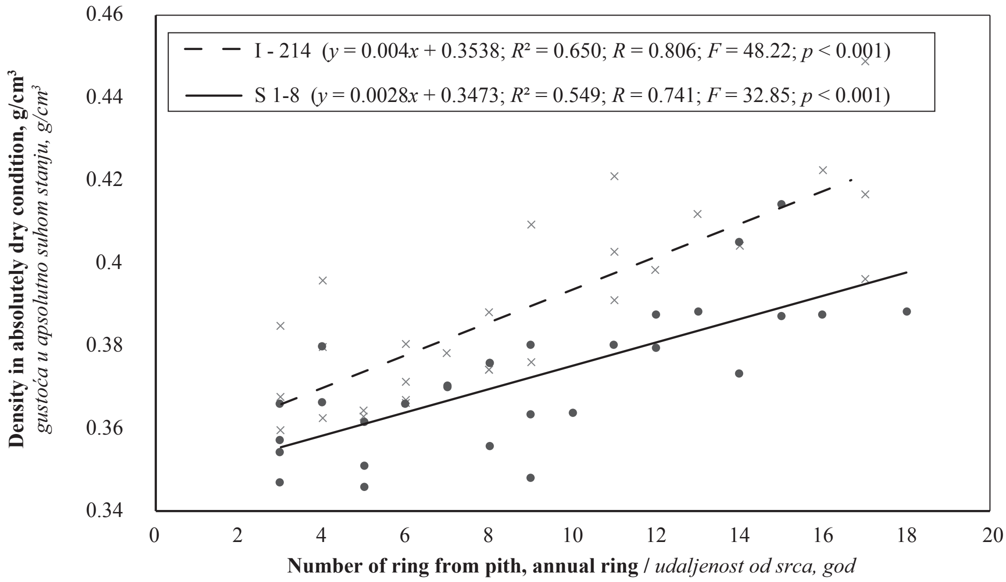

Figure 2 Radial distribution of wood density in absolutely dry condition of clone 'I-214' and 'S1-8'
Slika 2. Radijalna raspodjela gustoće u apsolutno suhom drvu klonova 'I-214' i 'S1-8'

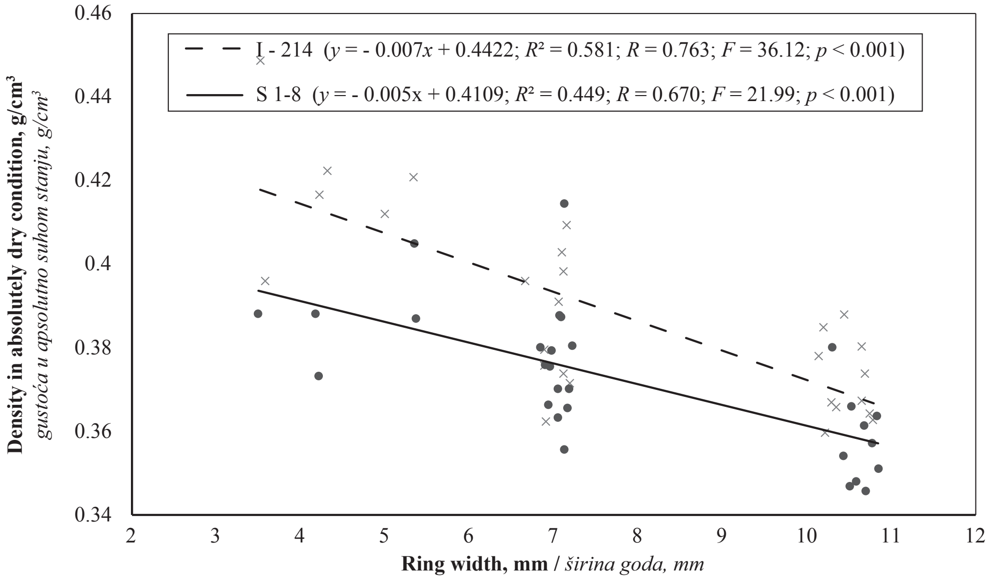

Figure 3 The ratio between wood density in absolutely dry condition and ring width of clone ’I-214’ and ’S1-8’
Slika 3. Odnos gustoće apsolutno suhog drva i širine goda drva klonova ’I-214’ i ’S1-8’

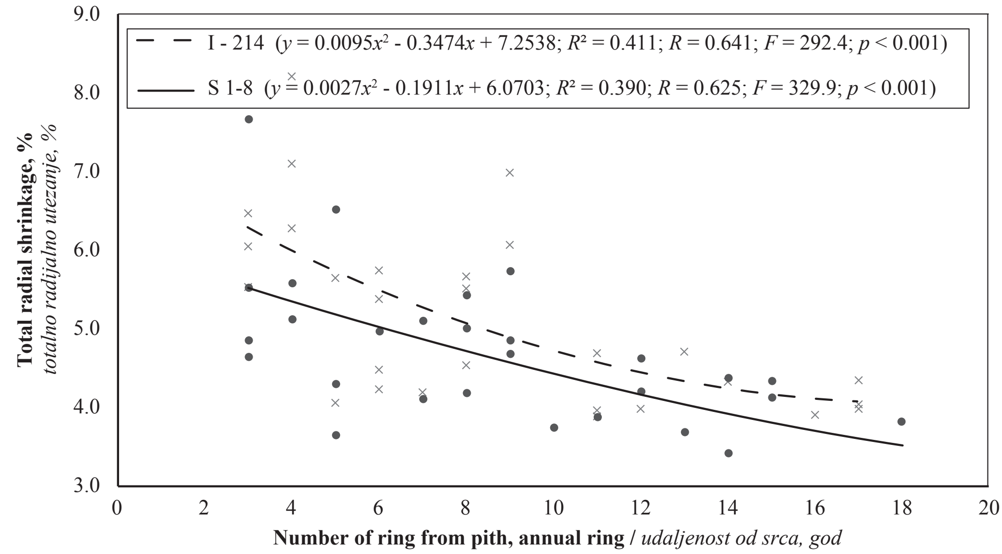

Figure 4 Radial distribution of total radial shrinkage of wood in clone ’I-214’ and ’S1-8’
Slika 4. Radijalna raspodjela totalnoga radijalnog utezanja drva klonova ’I-214’ i ’S1-8’

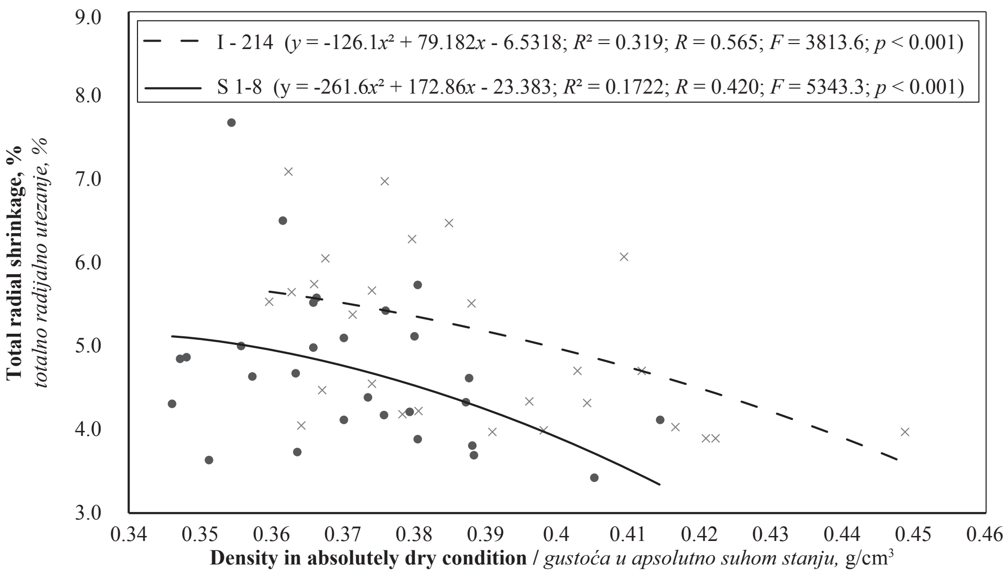

Figure 5 The ratio between total radial shrinkage of wood and wood density in absolutely dry condition of clone ’I-214’ and ‘S1-8’
Slika 5. Odnos totalnoga radijalnog utezanja drva i gustoće u apsolutno suhom drvu klonova ’I-214’ i ’S1-8’

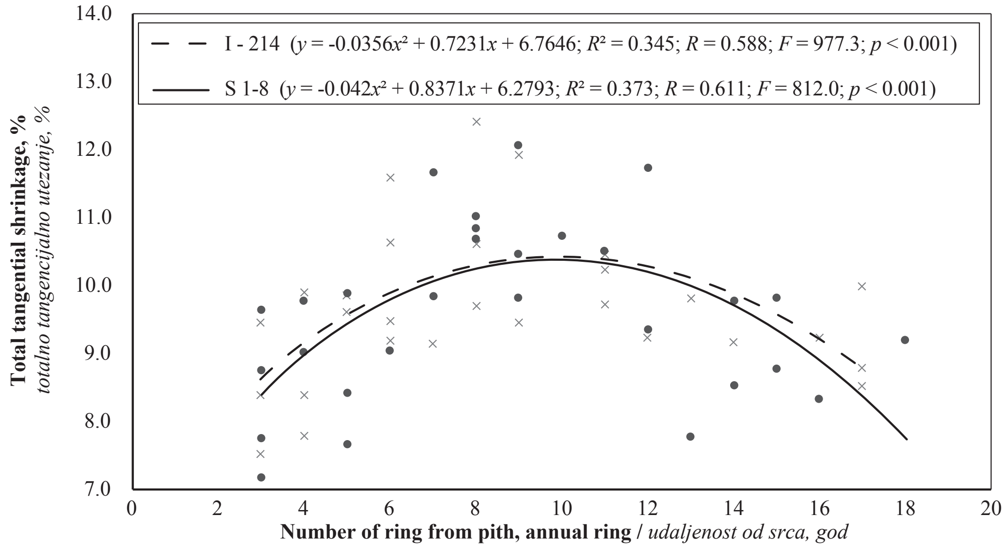

Figure 6 Radial distribution of total tangential shrinkage of wood in clone 'I-214' and 'S1-8'
Slika 6. Radijalna raspodjela totalnoga tangencijalnog utezanja drva klonova 'I-214' i 'S1-8'

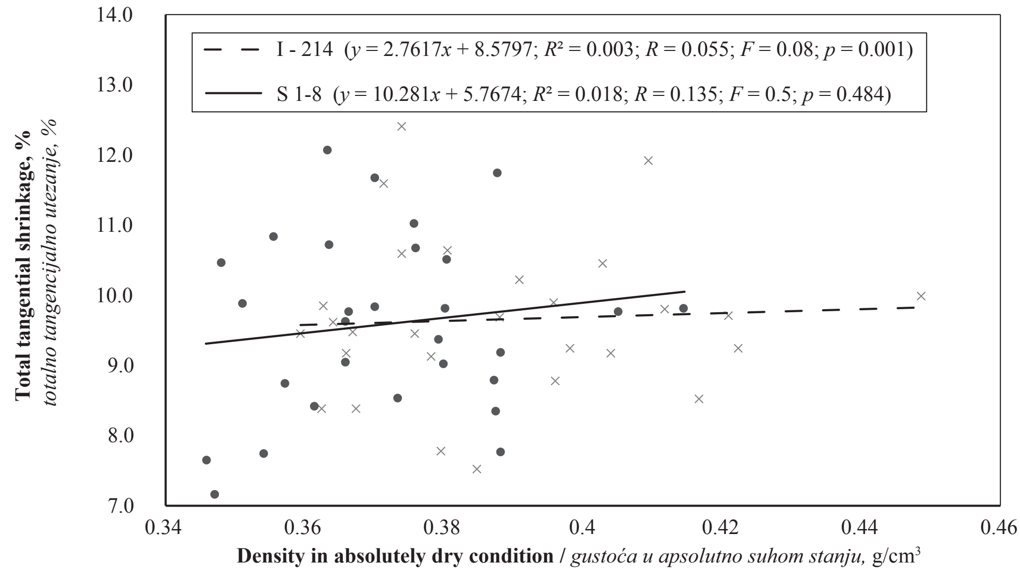

Figure 7 The ratio between total tangential shrinkage of wood and wood density in absolutely dry condition of clone 'I-214' and 'S1-8'
Slika 7. Odnos totalnoga tangencijalnog utezanja drva i gustoće u apsolutno suhom drvu klonova 'I-214' i 'S1-8'

significant positive correlation between basic wood density, and radial, tangential, and volumetric shrinkage in *Populus euramericana* hybrid clones. Kord *et al*. (2010) also reported a positive correlation between wood density, and radial, tangential, and volumetric shrinkage.

This research gave different results, and found a negative correlation between wood density in absolutely dry condition and total radial and volumetric shrinkage in both investigated clones (Figure 5 and 9). Due to a low correlation coefficient between total tangential shrinkage and density in absolutely dry condition (Figure 7) it is not possible to determine their relation. This could be explained by increasing of wood density from pith to bark and decreasing of wood density with growth rate.

There is a larger dissipation of measurements in total radial, tangential and volumetric shrinkage from pith to approximately the tenth annual ring (Figure 4, 6 and 8). From the tenth annual ring to bark, the correlation is negative with higher coefficient ratio. This might be explained by the above mentioned research on juvenile and mature wood of Dadswells (1958) and Zobel and Buijtenen (1989).

4 CONCLUSION
4. ZAKLJUČAK

There is a significant difference in wood density in absolutely dry condition and nominal density between poplar clones 'I-214' and 'S1-8' from Osijek. However, the difference in wood density between clones is only about 4 %, and for the purpose of wood processing and forestry practice this could be negligible. Total radial, tangential, and volumetric shrinkage showed no significant difference.

There was a general trend in the radial direction in both clones, in which wood density in absolutely dry condition increased from the pith to bark. On the contrary, total radial, tangential, and volumetric shrinkage

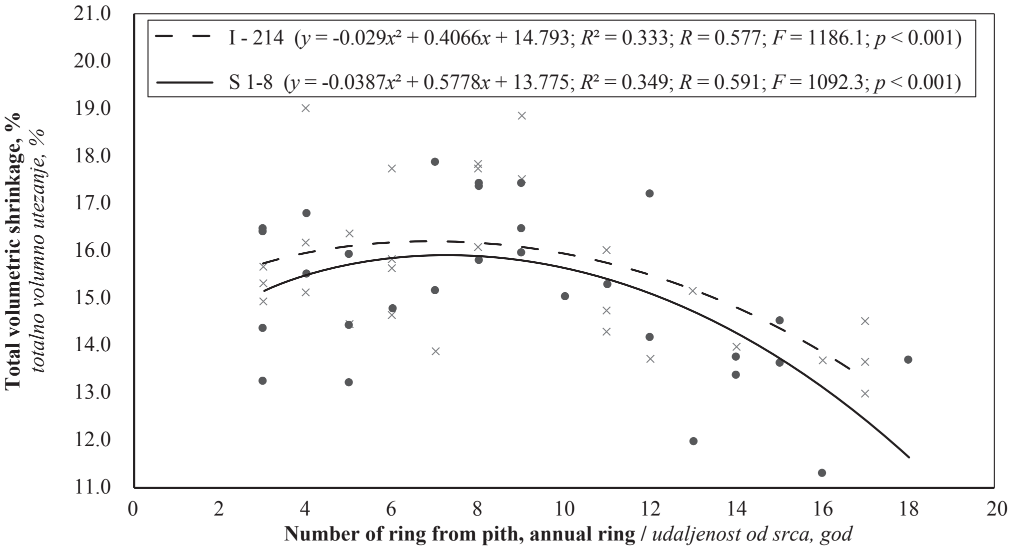

Figure 8 Radial distribution of total volumetric shrinkage of wood in clone 'I-214' and 'S1-8'
Slika 8. Radijalna distribucija totalnoga volumnog utezanja drva klonova 'I-214' i 'S1-8'

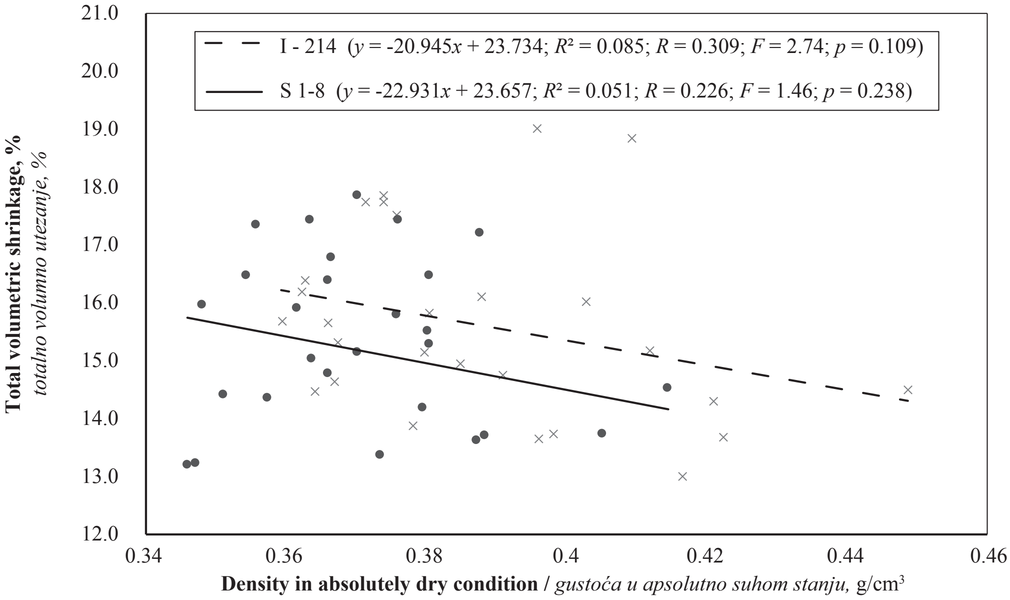

Figure 9 The ratio between total volumetric shrinkage of wood and wood density in absolutely dry condition of clone 'I-214' and 'S1-8'
Slika 9. Odnos totalnoga volumnog utezanja drva i gustoće u apsolutno suhom drvu klonova 'I-214' i 'S1-8'

showed a general decreasing trend in the radial direction from the pith to bark in both clones.

In general, there was a negative correlation between wood density in absolutely dry condition, and total radial, tangential, and volumetric shrinkage; although, tangential shrinkage was weakly correlated with wood density.

Forestry practice tends to provide high annual growth rate of clones and uniformity in wood density of material. The results of this research suggest the opposite. For better prediction of wood quality of these two clones, further investigation on mechanical properties should be carried out.

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Evaluation of Office Chair Comfort

Procjena udobnosti uredskih stolica

Original scientific paper • Izvorni znanstveni rad
Received – prispjelo: 14. 3. 2016.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*836.1*
doi:10.5552/drind.2016.1615

ABSTRACT • *The studies of office chair constructions have identified differences in perception of comfort provided by different types of seats. Four seat constructions and the comfort provided to the users were compared by means of subjective indicators. After a two-day sitting on each of the studied chairs, the subjects scored their perception of comfort and discomfort, using the questionnaire with 17 statements. Unlike most similar studies, subjects evaluated seats on their own work places and in the environment to which they are accustomed. Constructional forms of the seat and materials that contributed more to the sense of comfort by minimizing fatigue and pains developed by sitting were determined. Results have shown that the chair with a net is significantly more comfortable than other chairs. The chair with molded PUR foam is significantly more comfortable than the chair with springs, but statistically it does not differ significantly from the chair with slabstock PUR foam. It has been concluded that the chair with a net got higher scores, which might be attributed to its frame construction and the absence of a hard base under the sitting surface.*

Keywords: *subjective method, sitting, comfort, discomfort, office chair*

SAŽETAK • *Istraživanjem konstrukcija uredskih stolica utvrđene su razlike u osjećaju udobnosti sjedenja na različitim sjedalima. Uspoređene su četiri konstrukcije sjedala i njihove udobnosti za korisnika, i to na temelju subjektivnih pokazatelja. Ispitanici su nakon dvodnevnog sjedenja na stolici ocjenjivali osjećaj udobnosti ili neudobnosti odgovarajući na upitnik sa 17 ponuđenih tvrdnji. Za razliku od većine sličnih istraživanja, ispitanici su ocjenjivali sjedala na svojim radnim mjestima i u okolini na koju su naviknuli. Ispitivanjem su određeni konstrukcijski oblik sjedala i materijali izrade stolica koje pridonose osjećaju veće udobnosti time što minimaliziraju osjećaj zamora i pojavu bolova pri sjedenju. Rezultati su pokazali da je stolica s mrežom znatno udobnija od ostalih. Stolica s hladno lijevanom PUR spužvom mnogo je udobnija od stolica s oprugama, ali se statistički ne razlikuje od stolica s rezanom PUR spužvom u sjedalu. Zaključeno je da je stolica s mrežom najbolje ocijenjena zbog njene okvirne konstrukcije i zato što ispod površine za sjedenje nema tvrde podloge.*

Ključne riječi: *subjektivna metoda, sjedenje, udobnost, neudobnost, uredska stolica*

1 INTRODUCTION
1. UVOD

Office work, as work performed in sitting position, requires sitting during most of the work time, with short walking and standing intervals (Hermenau, 1999; Wilder *et al.*, 1996). According to Kapica and Grbac, the basic principle of a comfortable seat is contained in the system where the sitting bones take the body weight off, while the feet are not loaded and the spine maintains its natural posture. Construction of upholstery, shape and hardness of the sitting surface, degree of the seat and backrest deformity, etc. along with the product's overall construction determine the sitting comfort and level of tiring (Kapica and Grbac, 1998). It is a known fact that most of us rather sit than stand, that sitting does not require as much muscular work as does standing and that it is much easier to work while sitting because it stabilizes postures (Lueder, 2004), the arms and hands can be used freely and it is also easy to oper-

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ate pedals or controls with the feet (Kroemer *et al.*, 2003). However, according to Grandjean (quoted by Hermenau, 1999) sitting, unlike standing, increases the pressure to intervertebral discs up to 35 %. Other analytical studies addressed the pressure in the intervertebral discs as a function of trunk posture and body support (Kroemer *et al.*, 2003). In addition, prolonged sitting can have many disadvantages, with long-term consequences to human health (van Deursen *et al.* 1999).

The debate in the literature concentrates on the difference between comfort and discomfort. De Looze *et al.* (2003) quote that several researches simply defined discomfort as the lack of comfort and vice versa (Hertzberg 1958; Floyd and Roberts 1958). Richards (1980), quoted by the same authors, stresses that comfort is the state of a person involving a sense of subjective well-being, in reaction to an environment or a situation. Other studies dealing with ergonomics, and in contrast with the concept of two discrete states, believe that comfort and discomfort are two opposites on a continuous scale, ranging from extreme discomfort through a neutral state to extreme comfort. The factors of comfort and discomfort can be classified into several sub-groups: impression, relief/energy, well-being, relaxation, and fatigue, restlessness, pain/biomechanics, strain and circulation. Discomfort is usually caused by biomechanical factors and fatigue (Zhang *et al.,* 1996). According to Ljuljka (1976), humans sit while traveling, in the cinema and theatre and particularly throughout their schooling. For this very reason, the chairs, in addition to responding to contemporary trends and design, must provide comfort above all. It is not that easy to accurately define comfort of the furniture to sit on. There was a time when comfort was related to softness. Nowadays, it is accommodation to human body that counts. Quite true, soft furniture accommodates to human body, but that fact carries some additional problems. The basic factor of contemporary comfort is a specific pressure to the body. This pressure is smaller when the contact surface of human body is larger. It should be noted that the characteristics of upholstery are important for comfort and proper distribution of pressure (Ergić, 2002; Grbac and Ivelić, 2005). Thermal conductivity and humidity penetration to the upholstery are very important and significantly affect the comfort feeling (Vlaović *et al.*, 2012). However, they have not been taken into consideration in this paper. The occurrence of CTDs (Cumulative Trauma Disorders) in the office environment has seen a tremendous increase in the recent years. While performing sedentary tasks, the worker should not feel any discomfort due to improper seating, that is, the worker should be in a state of non-awareness of the seat (Branton, 1969; quoted by Fernandez and Poonawala, 1998). Some of the aims of ergonomic sitting are to increase individual effectiveness, reduce tiredness and maintain the "correct" sitting posture. Improper sitting is the main cause of reduced performance during the work. Furniture users must not experience distracting pressure on their body. Furniture must allow the body to reach a desired posture, e.g. during lying on the bed, and if possible to achieve utmost comfort in that position (Grbac, 1984). The same principle can be applied to the seating furniture (Vlaović, 2005).

Along with the need to evaluate the chair suitability, the primary objective of Drury and Coury (1982) study (quoted by Fernandez and Poonawala, 1998) was to discover its strengths and weaknesses or to compare it directly to other chairs. Rating and ranking are the two most common methodologies for evaluating ergonomic office chairs. A questionnaire containing comfort and discomfort scales is valuable for determining if comfort and discomfort ratings exist as a bipolar continuum (Potter *et al.*, 1998). The methodology of direct interview about comfort degree (Richards, 1980; quoted by de Looze *et al.*, 2003) is very direct given that comfort/discomfort is a subjective perception. In the perception of comfort/discomfort, the factors of comfort become secondary as long as the factors of discomfort are present. Biomechanical discomfort factors increase as a function of time of day, and chair design did not seem to matter (Kleberg and Ridd, 1987). This explains why previous researchers have had difficulties in differentiating between chairs in ergonomic evaluations. Many authors have observed that chair users, seemingly unaware, change posture constantly, supposedly to relieve the buildup of body pressure and discomfort. For example, crossing legs and putting one leg on top of the other changes the pressure distribution under the ischial tuberosities (Helander and Zhang, 1997). Potter *et al.* (1998) have shown that it takes several hours to make an accurate evaluation of a chair. Proper ergonomic evaluation and identification of a chair comfort during 8-hour workday requires at least three hours (Fitzgerald *et al.*, 1996). Due to the fact that comfort descriptors related to chair design are not affected by time, whereas comfort descriptors related to well-being and most discomfort descriptors are affected by time, it is difficult to propose a measurement procedure. One option is to only evaluate one chair per day at a standard (predefined) time. It has been proved (Zhang *et al.*, 1996; Helander and Zhang, 1997) that both comfort and discomfort can be quantified independently, and the scales developed for the Chair Evaluation Checklist (CEC) provide consistent results, suitable for practical evaluation of chair comfort and discomfort.

Further to the above, subjective method was used in this paper with the use of modified CEC. The aim of the paper was to find connection between different seat designs of office chairs and their comfort/discomfort by subjective evaluation questionnaire.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Samples and subjects
2.1. Uzorci i ispitanici

The samples of ergonomic office chairs selected for the research were in accordance with the relevant European Norms (EN). The samples provided natural

a) Model A b) Model B c) Model C d) Model D

Figure 1 Chair models used in the study
Slika 1. Modeli stolica obuhvaćeni istraživanjem

and appropriate sitting posture and relative comfort achieved by mechanism, seat and backrest quality and shape, and by adjustable armrests. Study design included four (4) seemingly equal chair models, different in seat construction. All chairs were coded: Model A was the chair with the slabstock PUR foam in the seat (40 kg/m^3, thickness 50 mm), Model B was the chair with the molded PUR foam in the seat (40 kg/m^3, thickness 50 mm), Model C was the chair with the combination of the pocket micro-springs (D_{spring} 45 mm, d_{wire} 1,6 mm, height 40 mm) and molded PUR foam (40 kg/m^3, thickness 15 mm), and Model D was the chair with the seat made of elastic net. The models are shown in Figure 1.

Thirty-six subjects (18 females and 18 male) from 22 to 60 years of age (mean 35.1; SD 9.7), with the height of 156 to 187 cm (mean 173.6; SD 8.6) and weight of 48 to 103 kg (mean 71.9; SD 12.8) participated in the study. Their jobs were mostly performed in sitting position, within the time-span of 3 months to 27 years. The subjects were grouped in nine syndicates of four. Before the experiment, subjects completed the questionnaire about their health problems, with the following results: headache 8 %, shoulder pain 11 %, neck pain 19 %, cervical spine pain 14 %, thoracic spine pain 3 %, lumbar spine pain 11 %, hip pain 0 %, legs pain – varicose veins 3 %, poor circulation 14 %, joint pain 6 %, leg swelling 8 %, knee pain 6 % and epiphany of hemorrhoids 11 %. Nineteen persons (53 %) did not report any health problem.

2.2 Methods
2.2. Metode

The method for this research is based on modified CEC questionnaire (original Chair Evaluation Checklist was developed by Helander and Zhang, 1997), some adjusted questions within CEC, and some additional questions (Vlaović, 2005). The questionnaire consists of 17 statements about comfort and discomfort, which were, contrary to the original CEC, mixed together. Besides, some questions were adapted to this study in order to emphasize the feeling obtained from the seat, not the chair: «The chair is spacious» was replaced by «The seat is spacious» and «The seat feels soft» instead of «The chair feels soft». The statement «I feel uncomfortable» was excluded, and: «I feel pain caused by sitting», «I feel cramped», «I feel numb» and «I feel calm» were added. Later in the statistical analysis, all statements were separated, like in the original CEC, into those of comfort (6 statements) and those of discomfort (8 statements) in order to get inherent conclusions. Three of the above mentioned statements were later excluded from further statistical analysis to avoid potential bias, as they were not part of the original CEC.

9. I feel uneven pressure on thighs and buttocks

Not at all Moderately Extremely

1 2 3 4 5 6 7 8 9

Figure 2 An example of the questionnaire question
Slika 2. Primjer pitanja iz upitnika (s rasponom skale *nimalo – umjereno – jako*)

The statements on comfort scale were the following ones: «The chair looks nice», «I like the chair», «The seat feels soft», «I feel relaxed», «The seat is big enough», «I feel restful», «I feel calm» and «I feel comfortable». The statements on discomfort scale were: «I feel tired», «I feel restless», «I have sore muscles», «I feel pain induced by seating», «I feel stiff», «I feel uneven pressure on thighs and buttocks», «I feel cramped», «I have heavy legs» and «I feel numb».

The answering order was not strict, but the answers had to be provided between 11 a.m. and midday. Each of 17 questions included a statement (e.g. I feel uneven pressure on thighs and buttocks) and the numbered line. To answer, subjects had to mark with «X» the respective place on the line (Figure 2).

Every subject tested four chairs, each over two working days according to the preset scheme: first day, the subjects adjusted the correct position and body position and started using a chair; on second day, after three hours of sitting, they had to complete the questionnaire. Afterwards they changed the chair and repeated a two-day cycle. They were also introduced to the research aim and to different seat cores. As in real office-work situations, posture was not fixed or controlled except necessary chair adjustment – according to the instructions of an expert.

2.2.1 Testing of reliability and validity of comfort and discomfort scales
2.2.1. Ispitivanje pouzdanosti i valjanosti skala udobnosti i neudobnosti

For the purpose of determining the reliability of created comfort and discomfort scales, statistical procedure was carried out to determine the reliability of the measuring instrument. The internal consistency cri-

Table 1 Characteristics of comfort and discomfort scales
Tablica 1. Obilježja skala udobnosti i neudobnosti

	Comfort scale *Skala udobnosti*	**Discomfort scale** *Skala neudobnosti*
Arithmetical mean *Aritmetička sredina*	5.28	2.95
Standard deviation *Standardna devijalcija*	0.56	0.82
Minimum / *Minimum*	4.21	1.84
Maximum / *Maksimum*	5.72	4.17
Standardized Cronbach alpha *Standardizirani Cronbach alfa*	0.86	0.88

terion *Cronbach alpha* was used to analyze reliability. Scale reliability testing was performed on overall results. In that way, for each statement of comfort scale (a total of 6) and each statement of discomfort scale (a total of 8), an average result was obtained for that particular statement. In accordance with the reviewed scale used by Helander and Zhang (1997), when creating scales, the statements "I feel cramped" and "The seat is big enough" were thrown out, and the statement "I feel comfortable" was not included in the comfort scale either, but it was used as a criterion variable during the processing. Based on the values of the consistency coefficient obtained (Cronbach alpha), it can be concluded that in both cases the scales are highly reliable in measurement (Table 1).

Another measurement characteristic is validity. The statement "I feel comfortable" was treated as a criterion variable, and for correlation testing of the comfort scale results, discomfort scale results and the statement "I feel comfortable" a *Pearson r* correlation coefficient was used. According to the correlations obtained, the following can be concluded: (1) there is statistically significant negative correlation of medium strength between the comfort scale and discomfort scale (r = -0.55; p < 0.01), which is in accordance with the hypothetical model of comfort and discomfort suggested by Zhang *et al.* (1996); (2) correlation between the comfort scale and the statement "I feel comfortable" is statistically significant and high (r = 0.76; p < 0.01) and of positive sign, and (3) correlation between the discomfort scale and the statement "I feel comfortable" is statistically significant, of medium strength and of negative sign (r = -0.56; p < 0.01).

The reliability results of the comfort and discomfort scales, as well as validity of measurement, verified via correlation with the statement "I feel comfortable", have confirmed the obtained results and enabled the use of these scales to verify the influence of different construction of office chair seats based on subjective experience of comfort.

3 RESULTS
3. REZULTATI

3.1 Evaluation of comfort and discomfort
3.1. Procjene udobnosti i neudobnosti

Subjective evaluation through the questionnaire was compiled on the level of a statement and divided by total number of subjects (36) in order to get the average result for a specific statement evaluation. Complete results are published in Vlaović *et al.* (2008).

Given the fact that evaluation factor referred to comfort and discomfort, i.e. varied at two levels, whereas the chair factor varied at four levels (Models A, B, C and D), eight MANOVA variables were developed to check the effect of each chair on the evaluation of comfort/discomfort. Figure 3 shows the results of evaluation of each chair discomfort and comfort.

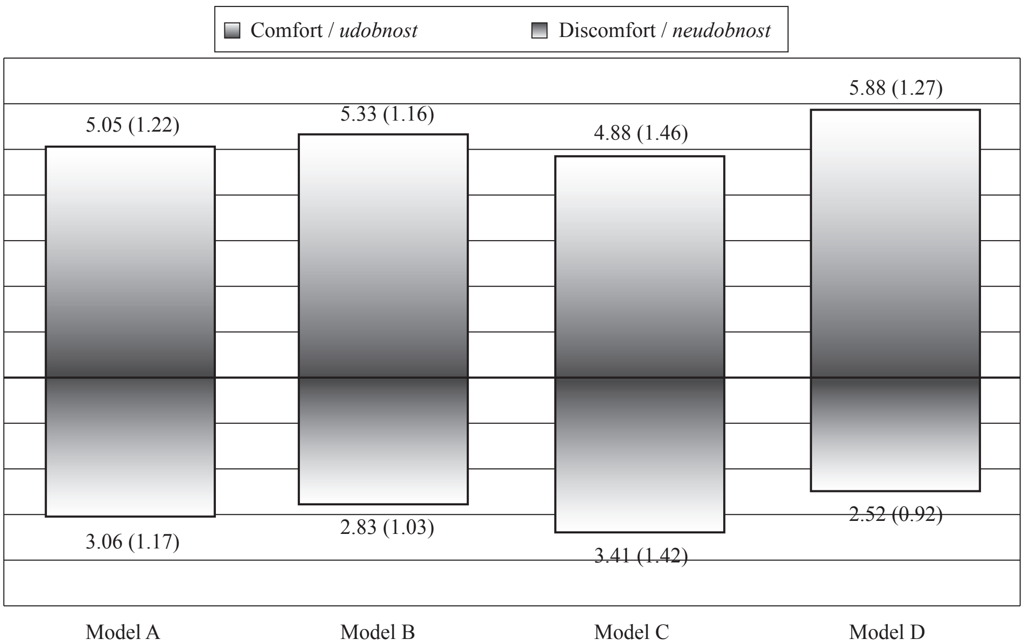

Figure 3 Average scores (and standard deviations) of comfort and discomfort – MANOVA variables
Slika 3. Prosječne ocjene (i standardne devijacije) udobnosti i neudobnosti – MANOVA varijable

Table 2 MANOVA – significance of tested differences
Tablica 2. MANOVA – značajnost testiranih razlika

	F	*p**
Scales / *Skale*	79.202	0.00
Chairs / *Stolice*	2.531	0.12
Scales * Chairs / *Skale * stolice*	5.259	0.03

**p* = significance of differences / *značajnost razlike*

3.2 The differences in evaluation due to seat construction and material
3.2. Razlike u procjenama s obzirom na konstrukciju i materijal sjedala

The data were processed by statistical software SPSS 10.0.7. Significance of differences in subjective evaluation of comfort and discomfort was checked by multivariate analysis of variance (MANOVA) with repetitive measuring of two factors – evaluation and chair (Table 2).

In evaluating all studied chairs, the scores for comfort on the respective scale were significantly higher than those for discomfort on the respective scale. This means that the subjects scored all chairs as more comfortable than uncomfortable.

Evaluation interaction on scales and on chairs was statistically significant. In order to determine on which scale evaluations are significantly different, a post-hoc analysis with t-test for dependent samples was carried out. *T*-test results are given in Table 3.

According to the below table, in testing differences in comfort evaluation between Model D and Model C, the first one has shown to be significantly more comfortable ($t = 3.58$; $p = 0.00$); in testing differences in discomfort evaluation between Model D and Model C, the second one has shown to be significantly more uncomfortable ($t = -3.66$; $p = 0.00$); in testing differences in comfort evaluation between Model D and Model B, the first one has shown to be significantly more comfortable ($t = 2.61$; $p = 0.01$); while in testing differences in discomfort evaluation between Model D and Model B, there has been no significant difference, etc.

Table 3 *T*-test of significant evaluation differences of chairs on comfort and discomfort scales
Tablica 3. Testiranje značajnosti razlika u procjenama stolica na skalama udobnosti i neudobnosti *t*-testom

	Comfort scale *Skala udobnosti*		**Discomfort scale** *Skala neudobnosti*	
	t	*p*	*t*	*p*
Model D vs. Model C	3.58	0.00*	-3.66	0.00*
Model D vs. Model B	2.61	0.01*	-1.58	0.12
Model D vs. Model A	3.14	0.00*	-2.24	0.03*
Model C vs. Model B	-2.11	0.04*	2.62	0.01*
Model C vs. Model A	-1.00	0.32	1.48	0.15
Model B vs. Model A	1.52	0.14	-1.09	0.28

*The differences are statistically significant at 5 %. / *Razlike su statistički značajne na razini 5 %.*

4 DISCUSSION AND CONCLUSION
4. RASPRAVA I ZAKLJUČAK

The reliability results of the comfort and discomfort scales and validity of measurements via internal consistency *Cronbach alpha* and *Pearson r* correlation coefficient with the statement "I feel comfortable", have confirmed the results obtained so far. Those facts enabled the use of comfort and discomfort scales for the verification of different constructions of office chairs based on personal experience of comfort.

T-test for dependent samples has shown that the Model D is significantly more comfortable than other chairs. Model B is significantly more comfortable than the Model C, but statistically it does not differ significantly from the Model A. The rank of studied seat constructions/chairs by comfort is as follows: a seat with a net (D – the most comfortable seat), a seat with molded PUR foam/seat with PUR foam (B/A) and a seat with springs (C – the least comfortable seat).

Also, statistically significant differences have been obtained by evaluation on a discomfort scale. Significant differences appear in evaluation of the chairs with a net, with springs and with PUR foam. The difference in evaluated discomfort of Model D and Model B is not statistically significant. Significant is the difference between the evaluated discomfort of Model C and Model B, where the former one is scored significantly higher on the discomfort scale. The rank of studied seat constructions/chairs by discomfort is as follows: a seat with springs (C – the most uncomfortable seat), a seat with PUR foam (A) and a seat with molded PUR foam/a seat with a net (B/D – the least uncomfortable seat).

It should be noted that the subjects showed more preference for the statements about aesthetic characteristics of the chairs that were closely related to the comfort scale, rather than to discomfort scale, which can be verified in Vlaović (2005). It has been concluded that the chair with a net got higher scores, which might be attributed to its frame construction and the absence of a hard base under the sitting surface. This fact, along with good elasticity of the net, enables uniform and desirable pressure distribution. On the other hand, the chair with the most common seat design (slabstock foam) proved to be the next favorite. The reason for that can be found in the thickness of the seat foam (50 mm). The same explanation can be applied to a molded seat. Although all chairs (except the one with the net) had an even seat thickness, in the seat with springs, the layer of the PU foam was only 15 mm. As a result of the user's body load, the seat reached bottom-out (lack of support under full weight load) very quickly, and therefore users felt discomfort.

Unquestionably, support must be given to further similar interdisciplinary research on materials and constructions, which are inherently different from the top scored netted model in this study and which provide significantly less differences in perception of comfort than do the available ones. That joint consideration of the furniture mostly used during daytime must be designed so as to provide comfort and prevent various disorders of the spine, joints, blood circulation, allergies, etc.

Acknowledgements – Zahvala

This research was supported by University of Zagreb, Faculty of Forestry, Department for Furniture and Wood Products. The authors are grateful to Anaks d.o.o. Zagreb and Tapo d.o.o. Zagreb for technical support.

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Prilog istraživanju određenih troškova proizvodnje investiranjem u računalno vođenu tehnologiju izrade drvnih elemenata s predblanjanjem piljenica

Contribution to Research on Certain Production Costs by Investing into Computer Aided Technology of Production of Wooden Elements with Pre-Planing of Sawn Wood

Preliminary paper • Prethodno priopćenje
Received – prispjelo: 14. 12. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*79; 630*832.11; 630*832.155*
doi:10.5552/drind.2016.1543

SAŽETAK • *U ovom su radu analizirani troškovi proizvodnje elemenata od drva tvrdih listača računalno vođenom tehnologijom uzdužno-poprečnog načina piljenja s predblanjanjem piljenica. Tim se postupkom prosušene piljenice prije raspiljivanja blanjaju kako bi se kalibrirala njihova debljina i da bi greške drva na njihovoj površini postale vidljivije. Predblanjanje pridonosi njihovoj uspješnijoj daljnjoj obradi. Troškovi tehnologije izrade drvnih elemenata predblanjanjem uspoređeni su s troškovima njihove izrade uobičajenom klasičnom tehnologijom poprečno-uzdužnog načina izrade drvnih elemenata te računalo vođenom tehnologijom uzdužno-poprečnog načina piljenja bez predblanjanja.*
Rezultati istraživanja pokazuju da se računalno vođenom tehnologijom s predblanjanjem piljenica postiže najbolja produktivnost i troši najmanje električne energije po jedinici proizvoda, najbolje se kontrolira broj izrađenih komada te postiže najbolje iskorištenje piljenica jer se njihova kvaliteta određuje uz pomoć skenera za drvo. Iz navedenoga se može zaključiti da računalno vođena tehnologija s predblanjanjem daje bolje rezultate od druga dva načina izrade drvnih elemenata. Početna investicija za tu tehnologiju znatno je veća od ulaganja u druge dvije istraživane tehnologije. Ovo bi istraživanje trebalo pomoći investitorima pri donošenju odluke za koju se tehnologiju izrade elemenata odlučiti.

Ključne riječi: *drvni elementi, blanjanje, klasična doradna pilana, doradna pilana vođena računalom, trošak proizvodnje*

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ABSTRACT • *This article presents the analysis of the production costs of hardwood elements produced by computer aided technology of rip-cross sawing with pre-planing of sawn boards. In this procedure, sawn wood is planed prior to sawing to calibrate the thickness of sawn elements and to make wood defects more visible on the surface. Pre-planing contributes to more successful further processing of the sawn elements. The costs of production technology of pre-planed sawn elements were compared with the costs of the classic cross-rip production technology of sawn elements and with the costs of computer aided rip-cross production technology without pre-planing.*
Research results show that computer aided production technology with pre-planing of sawn elements gives the best productivity, the lowest consumption of electricity per product unit, the best control of the number of produced elements, and the best utilization of sawn wood since the quality is defined by using wood scanners. Further to the above, it can be concluded that better results are achieved by computer aided technology with pre-planing than by two other researched technologies. The disadvantage of this technology is the starting investment, since the price of this technology is significantly higher than that of other two researched technologies.
This research should help investors in decision making process when choosing between different technologies of wood element production.

Key words: *wood elements, planing, classic secondary sawmill, computer aided secondary sawmill, production costs*

1. UVOD
1 INTRODUCTION

Izradom drvnih elemenata od lošije piljene građe bitno se povećava vrijednost takvih manje kvalitetnih pilanskih proizvoda. Taj se proces najčešće izvodi u sekundarnim odnosno doradnim pilanama.

Pojam sekundarnog raspiljivanja zapravo obuhvaća raspiljivanje tih piljenica i izradu različitoga piljenog materijala manjih dimenzija, posebno „piljenih elemenata“ te, eventualno, daljnje raspiljivanje („repariranje“) krupnih pilanskih ostataka (Brežnjak, 1997.).

Mehanička obrada u proizvodnji namještaja najčešće počinje u odjelu grube strojne obrade procesom smišljenoga poprečnog ili uzdužnog raspiljivanja (formatiziranja) piljenica ili sortiranih grubih namjenskih elemenata. Nasuprot tome, u pilanskoj proizvodnji raskrajanjem piljenica obično završava mehanička obrada, a cilj joj je izrada pilanskih proizvoda i u doradnoj fazi – grubih, poludovršenih ili gotovih namjenskih elemenata.

Tijekom raskrajanja piljenica one se određenim redoslijedom, okrajčivanjem i prikrajčivanjem, dimenzioniraju na potrebnu širinu i duljinu. Ako je potrebno, obradci se mogu raspiliti i paranjem na potrebnu debljinu. Pri tome se nastoji postići što racionalnije iskorištenje sirovine u kvantitativnome i kvalitativnom odnosno optimalnome vrijednosnom smislu.

Tehnološki proces pilanske obrade može se organizirati kao jednofazni ili dvofazni. U jednofaznoj obradi cjelokupna se mehanička obrada (primarno raspiljivanje trupaca i sekundarno krojenje piljenica) obavlja u jednome neprekidnom i povezanom tehnološkom tijeku, dok su pri dvofaznoj obradi primarna i sekundarna faza vremenski i prostorno odvojene. To znači da se nakon primarnog raspiljivanja trupaca i odvajanja (ili neodvajanja) kvalitetne, obično neokrajčene komercijalne građe ostala dobivena piljena građa djelomično ili potpuno suši, a potom se, u drugoj fazi, kroji u okrajčenu građu i drvne elemente.

1.1. Krojenje piljenica
1.1 Sawing boards to elements

Načini industrijskog raspiljivanja piljenica obično se dijele na:

- poprečno-uzdužni način,
- (poprečno)-uzdužno-poprečni način.

U oba načina, ovisno o pristupu raspiljivanju, debljina piljenica u konačnici može činiti širinu ili debljinu izrađenih drvnih proizvoda

Šoškić i Popadić (2003.) navode da se u sekundarnoj obradi četinjača po pravilu može primijeniti uzdužno-poprečni način piljenja, dok se pri obradi listača može također upotrijebiti (poprečno)-uzdužno-poprečni, ali i poprečno-uzdužni način piljenja. Odabir načina obrade ovisi o duljini i kvaliteti gotovih obradaka, ali i o kvaliteti ulazne sirovine.

Poprečno-uzdužni način piljenja
Cross-rip sawing to elements

Piljenica se najprije prikrati tako da se čelo piljenice izravna približno pod pravim kutom s obzirom na uzdužnu os i otpili onaj dio čela piljenice na kojemu se nalazi veći broj malih grešaka (npr. čelne pukotine). Ako je piljenica zakrivljena ili na sebi ima još neke druge greške (npr. kvrge), obično se još poprečno prepili na jednome ili više mjesta, uz eventualno odstranjivanje neprihvatljivih grešaka. Kriteriji za određivanje mjesta piljenja jesu:

- položaj na kojemu se nalazi vršna točka zakrivljenosti piljenice ili neka druga greška
- duljine elemenata zahtijevanih u radnom nalogu.

Nakon toga se iskrojeni dijelovi piljenice uzdužno raspiljuju u elemente, pri čemu treba paziti na raspored preostalih grešaka, ako ih ima, i o zadanim širinama elemenata.

(Poprečno)-uzdužno-poprečni način piljenja
(Cross)-rip-cross sawing to elements

Taj način obrade piljenica ponajprije obilježava uzdužno raspiljivanje piljenica u „letve“ kao prva operacija obrade, uz vođenje brige o rasporedu grešaka i zadanim širinama elemenata. Piljenice po pravilu ne smiju imati greške zakrivljenosti. Obično se zakrivljenost prethodno izbjegne poprečnim krojenjem već u primarnoj pilani, no pritom treba nastojati da piljenice ostanu što dulje ili da su barem višekratnici duljine budućih elemenata. Nakon toga se od letava poprečnim prepiljivanjem izrađuju drvni elementi zadanih duljina. Kriteriji za određivanje mjesta piljenja postavljaju se na temelju:

- položaja na kojemu se nalaze greške drva koje nisu dopuštene
- širine i duljine elemenata određenih radnim nalogom.

1.2. Blanjanje piljenica ili letava
1.2 Planing of sawn boards or laths

Dvostrano ili četverostrano blanjanje nije nužna tehnološka operacija, pa se zato primjenjuje kao fakultativno tehnološko rješenje i uvodi u tehnološki sustav samo uz posebnu narudžbu. Dva su razloga uključivanja te operacije u tehnološki sustav.

Prvi bitni razlog je u to da se u daljnjoj obradi piljenica i letava na oblanjanim plohama jasnije uočavaju sve greške, koje se kasnije ručno označavaju, odnosno strojno skeniraju i prenose u računalo radi njihova lakšeg i bržeg prepoznavanja. Znači, radi efikasnijeg označivanja ili skeniranja piljenice odnosno letve, po pravilu treba očistiti i otvoriti njezinu površinu, odnosno oblanjati barem jednu površinu. Ipak pretpostavlja se da će biti potrebno i oblanjati i drugu površinu piljenice, osobito ako je debljina piljenica 50 mm i više, u kojih greška sa suprotne strane može probijati plohu koso od gornje površine. Takav način uočavanja grešaka, osobito njihovih krajnjih granica, sigurno može biti bitno jasniji na blanjanim površinama drva. Posebnu važnost blanjanje površina ima pri postojanju grešaka uz koje su granice normalnoga i drugačijeg drva mnogo nejasnije, osobito između središnjega i perifernog dijela drva, pri različitim diskoloracijama, na drvu zahvaćenom truležnim promjenama ili sl. Tako obrađena površina dobra je osnova za daljnje automatsko skeniranja grešaka na površini.

Drugi bitni razlog za uvođenje te tehnološke faze jest kalibriranje drva, što podrazumijeva obostrano blanjanje piljenice ili četverostrano blanjanje letve, jer se time svi elementi obrađuju na jednaku i točnu debljinu odnosno debljinu i širinu, što olakšava daljnji rad na svim ostalim strojevima i transportnim uređajima za obradu koja slijedi, što znači i produljenje trajnosti svih ostalih strojeva i alata. Blanjanjem se uklanjaju i sve ostale nečistoće s površine piljenica te se smanjuje mogućnost zastoja elemenata u zahvatu stroja zbog netočne debljine i širine. Osim toga, ta tehnološka faza može poslužiti kao kontrola točnosti obrade i dimenzija piljenica i letava, što će osigurati mnogo veću razinu kvalitete elemenata.

1.3. Tehnologije obrade
1.3 Production technologies

Pilanski su elementi proizvodi izrađeni podužnim i poprečnim piljenjem piljenica u doradnim pilanama. Svojstva piljenice od koje će se izrađivati elementi, osim kvalitete, određuju i način izrade elemenata.

Izradom elemenata od lošije građe bitno se povećava vrijednost manje kvalitetnih pilanskih proizvoda te su na bazi toga razvijene određene tehnologije obrade. U praksi se primjenjuju različiti načini proizvodnje elemenata.

Klasičan način proizvodnje elemenata počinje poprečnim raspiljivanjem piljenica radi uklanjanja grešaka, i to određivanjem duljine budućih sortimenata. Nakon toga se dijelovi piljenica na kružnim i tračnim pilama uzdužno kroje na određene širine elemenata. Sortiranjem se slažu u pakete istovrsnih dimenzija. U toj tehnologiji često se pojavljuje problem izvršenja specifikacije jer su međufaze u proizvodnji izvan kontrole zato što se nikad točno ne zna koliki je broj komada u proizvodnji i koliko će ih izaći kao gotovi element. Drugi osnovni problem u toj tehnologiji jest velika količina kratkih i uskih elemenata koji imaju i znatno nižu cijenu na tržištu.

S naglim razvojem računalne tehnike prevladalo je i drugačije razmišljanje o izradi elemenata. Veliku prednost u kontroli izvršenja specifikacije čini računalo. Ono određuje optimalno točne dimenzije elemenata, obavlja točnu kontrolu broja komada izrađenih elemenata, omogućuje odabir kvalitete elemenata te je proces kontinuiran i kontroliran. Kako se danas traže sve dulji i sve širi elementi, tehnologija je ponajprije usmjerena na uzdužno raspiljivanje, a zatim i na poprečno. Nakon toga slijedi sortiranje i slaganje elemenata u pakete.

Određivanje načina izrade elemenata već je dugo jedno od najvažnijih pitanja obrade piljenica. Nakon odabira poprečno-uzdužnoga ili uzdužno poprečnog načina izrade elemenata cijeli se daljnji proces može automatizirati jer su današnji strojevi opremljeni računalima koji tu automatizaciju provode u vrlo kratkom roku i s velikom točnošću. Stoga je preporučljivo pronaći mogućnost za automatsko određivanje načina izrade elemenata.

Automatsko određivanje načina izrade elemenata posebno je poželjno pri obradi tvrdog drva listača (hrasta i bukve). Primjena drugih vrsta drva (jeftinija sirovina) uglavnom je rasprostranjenija te se osim elemenata visoke kvalitete proizvode i manje kvalitetni elementi, kao i oni u kojih se zahtijevaju samo dobra mehanička svojstva. Namjena elemenata određuje njihovu kvalitetu u smislu dopustivih grešaka. U proizvodnji elemenata od tvrdih vrsta drva kvalitativno iskorištenje ovisi o dimenzijama elemenata. Cilj te proizvodnje jest dobivanje elemenata što većih dimenzija, uz zadovoljenje određenih kvalitativnih zahtjeva kao što su potpuna čistoća elemenata, pravilnost žice, jednoličnost strukture i teksture, bez kvrga i pukotina.

Automatsko određivanje načina izrade elemenata moguće je samo uz upotrebu računala. Takav bi sustav morao imati skener (čitač grešaka na piljenici) koji bi sliku piljenice, sa svim njezinim greškama, automatski slao u računalo na analizu, gdje bi se računalno odredilo koji je način raspiljivanja bolji: uzdužno-poprečni ili poprečno-uzdužni. Naravno, nakon određivanja načina piljenja za daljnju bi obradu piljenica bile potrebne i dvije neovisne linije na koje bi se, sukladno rezultatu simulacije, upućivale piljenice.

S obzirom na sve lošiju sirovinsku bazu kako u primarnim, tako i u doradnim pilanama, pitanje kvalitete pilanskih proizvoda ima važno mjesto među pokazateljima uspješnosti drvne industrije (Babunović, 1992., 1999.).

Rezultati istraživanja Butkovića (1998.) pokazali su da sekundarna pilana koja je računalno upravljana daje najbolje rezultate, troši najmanje električne energije, ima najmanje troškove proizvodnje po prostornome metru elemenata, osigurava potpunu kontrolu broja komada i nadzire kvalitetu elemenata. No takva pilana ima i jedan nedostatak – početno je ulaganje znatno veće nego za klasične doradne pilane.

Osnovni cilj ovog istraživanja jest unapređenje i modernizacija proizvodnje u neimenovanoj tvrtki, i to usporedbom proizvodnih troškova (cijene rada, utroška električne energije i cijene opreme).

Za potrebe istraživanja provedena je usporedba triju vrsta tehnologije izrade drvnih elemenata, uz pretpostavljeni godišnji kapacitet u jednoj smjeni. To su:

a) *classic technology cross-rip saw* – klasična tehnologija izrade drvnih elemenata poprečno-podužnim načinom piljenja (raspiljivanje 4000 m^3 piljenica te 2000 m^3 izrađenih elemenata)
b) *computer aided technology rip-cross saw* – računalom vođena tehnologija izrade drvnih elemenata podužno-poprečnim načinom piljenja bez predblanjanja piljenica (raspiljivanje 4500 m^3 piljenica te 2250 m^3 izrađenih elemenata)
c) *computer aided technology rip-cross saw and pre-planing* – računalom vođena tehnologija izrade drvnih elemenata podužno-poprečnim načinom piljenja s predblanjanjem piljenica (raspiljivanje 10 000 m^3 piljenica te 5500 m^3 izrađenih elemenata).

2. MATERIJALI I METODE
2 MATERIALS AND METHODS

U istraživanju je primijenjena metoda istraživanja prema Butkoviću (1998.). Uspoređeni su parametri koji mogu biti važni pri donošenju odluke, a to su:
- broj djelatnika
- cijena rada
- produktivnost
- instalirana snaga
- utrošak električne energije
- cijena opreme.

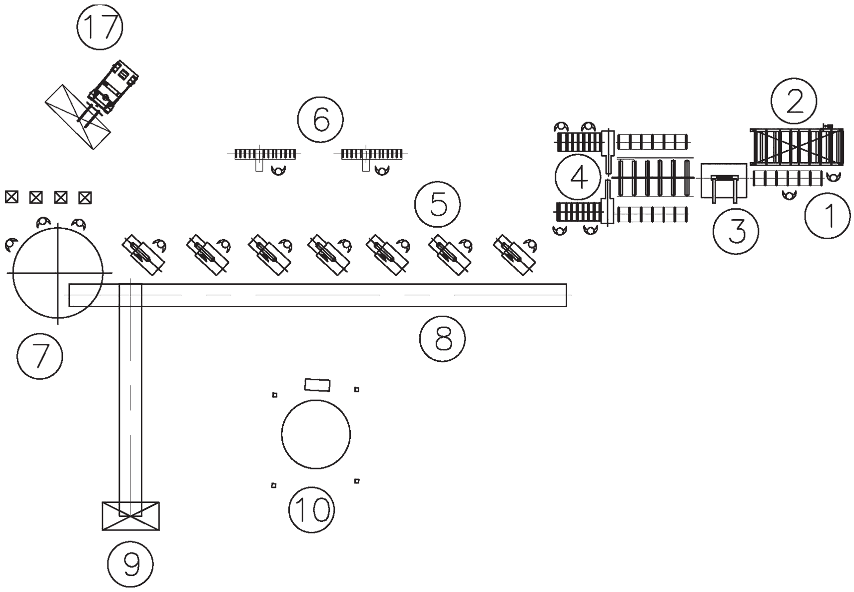
2.1. Opis tehnologije
2.1 Description of technology

2.1.1. Klasična tehnologija izrade drvnih elemenata poprečno-podužnim načinom piljenja
2.1.1 Classical cross-rip sawing production technology of wood elements

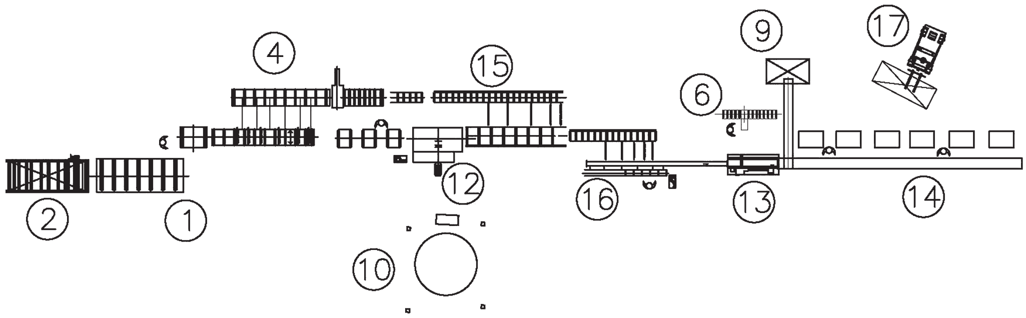
Tom se tehnologijom piljenice ulaznim transporterom (1) dopremaju do kružne pile za uzdužno raspiljivanje (3) na kojoj se piljenice uzdužno raspiljuju tako da se dobiju bazni rubovi za prislon na vodilice i za pravokutno prepiljivanje na sljedećoj poziciji. Nakon obrade na toj kružnoj pili piljenice se transportiraju (2) do kružne pile za poprečno piljenje (4), na kojoj se raspiljuju na potrebne duljine. Nakon toga se dijelovi piljenica otpremaju do tračnih pila (5), gdje se raspiljuju (paraju) na potrebne širine. Izrađeni se elementi odlažu na transportnu traku i otpremaju do sortirnice s okretnim stolom. Nakon toga elementi se izuzimaju sa stola te se sortiraju i slažu na palete. Eventualna dodatna dorada i reparacija elemenata s greškama izvodi se na kružnim pilama (6). U toj se tehnologiji često pojavljuje problem izvršenja specifikacije jer su međufaze u proizvodnji izvan kontrole pa se nikad točno ne zna koliki je broj komada u proizvodnji te koliko će ih izaći kao gotov element. Problem je i velika količina kratkih i uskih elemenata koji imaju nižu cijenu na tržištu (sl. 1.).

2.1.2. Računalom vođena tehnologija izrade drvnih elemenata podužno-poprečnim načinom piljenja bez predblanjanja piljenica
2.1.2 Computer aided rip-cross sawing production technology of wood elements without pre-planing

S razvojem elektroničke i računalne tehnike u industriju se uvodi računalo i u fazu kontrole izvršenja specifikacije. Računalo kontrolira broj izrađenih elemenata. Piljenice se ulaznim transporterom (1) dopremaju na uzdužno raspiljivanje na višelisnoj kružnoj pili (12), a nakon toga se letve poprečno kroje računalom upravljanom kružnom pilom (13) na određene optimizirane duljine, s tim da se na računalom upravlja-



Slika 1. Klasična tehnologija izrade drvnih elemenata poprečno-podužnim načinom piljenja
Figure 1 Classic technology of wood elements production by cross-rip sawing



Slika 2. Računalom vođena tehnologija izrade drvnih elemenata podužno-poprečnim načinom piljenja bez predblanjanja piljenica
Figure 2 Computer aided technology of wood elements production by using rip-cross sawing without pre-planing

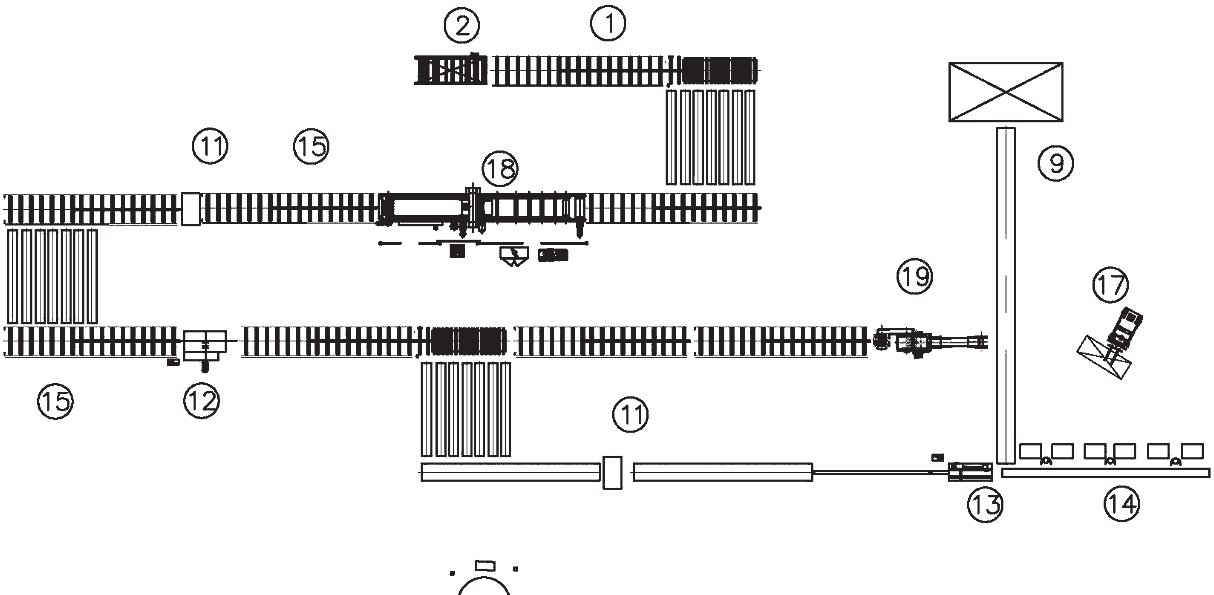
noj poprečnoj kružnoj pili odstranjuju dijelovi drva s greškama koje su prije toga označene kredom. Nakon toga slijedi sortiranje i slaganje elemenata (14) u pakete istovrsnih dimenzija i kvalitete (sl. 2.).

2.1.3. Računalom vođena tehnologija izrade drvnih elemenata uzdužno-poprečnim načinom piljenja s predblanjanjem piljenica
2.1.3 Computer aided rip-cross sawing production technology of pre-planed wood elements

Načelo izrade elemenata slično je načinu opisanom u prethodnoj tehnologiji. Piljenice se ulaznim transporterom (1) dopremaju na blanjalicu (18) na kojoj se dvostrano blanjaju. Nakon toga se skeniraju (11), pri čemu se uz pomoć skenera prema kvaliteti piljenica odredi optimalno krojenje po širini, a zatim se piljenice uzdužno raspiljuju na višelisnoj kružnoj pili (12). Dobivene se letve zatim ponovno skeniraju (11) te na računalo upravljanoj kružnoj pili poprečno kroje na određene optimizirane duljine (13). Na poprečnoj kružnoj pili odstranjuju se dijelovi drva s greškama koje su prije toga određene uz pomoć skenera. Nakon toga slijedi slaganje elemenata (14) u pakete istovrsnih dimenzija i kvalitete (sl. 3.).

Specifikacija strojeva i opreme na slikama 1. – 3.:

- pozicija 1. ulazni transporter za građu / *entry transporter*
- pozicija 2. hidraulični podizni stol za građu / *hydraulic lift table for sawn wood*
- pozicija 3. jednolisna kružna pila za uzdužno piljenje / *single circular saw for rip sawing*
- pozicija 4. kružna pila za poprečno piljenje / *circular saw for cross sawing*
- pozicija 5. tračna pila za izradu elemenata / *band saw for making elements*
- pozicija 6. kružna pila za doradu ili repariranje elemenata / *circular saw for making elements*
- pozicija 7. rotacijski sortirni stol / *rotating sort table*
- pozicija 8. trakasti transporter (dvostruki) za elemente i drvni ostatak / *double transporter for elements and wood residue*
- pozicija 9. trakasti transporter za krupni drvni ostatak s deponijem / *transporter for large wood residue with depo*
- pozicija 10. silos za piljevinu / *saw dust silo*
- pozicija 11. skener za drvo / *wood scanner*



Slika 3. Računalom vođena tehnologija izrade drvnih elemenata podužno-poprečnim načinom piljenja s predblanjanjem piljenica
Figure 3 Computer aided technology of wood elements production using rip-cross sawing with pre-planing

- pozicija 12. automatska kružna pila za uzdužno piljenje / *automatic circular saw for rip sawing*
- pozicija 13. računalom upravljana kružna pila za poprečno piljenje / *automatic circular saw for cross sawing*
- pozicija 14. automatska sortirinica za elemente / *automatic sorting of elements*
- pozicija 15. sustav transporta / *transportation system*
- pozicija 16. stol za označivanje grešaka / *defects marking table*
- pozicija 17. viličar / *forklift truck*
- pozicija 18. blanjalica za piljenice / *planing machine for saw wood*
- pozicija 19. drobilica za drvni ostatak / *wood residue chipper.*

2.2. Broj djelatnika
2.2 Number of workers

Kao što je vidljivo u tablici 1., pretpostavljeni broj radnika pri klasičnoj tehnologiji izrade drvnih elemenata poprečno-podužnim načinom piljenja bio bi 19, uz računalo vođenu tehnologiju izrade drvnih elemenata podužno-poprečnim načinom piljenja bez predblanjanja piljenica taj bi broj bio sedam, a pri računalom vođenoj tehnologiji izrade drvnih elemenata podužno-poprečnim načinom piljenja s predblanjanjem piljenica bilo bi potrebno zaposliti pet djelatnika.

2.3. Cijena rada djelatnika
2.3 Working hour price

Pretpostavljena bruto vrijednost sata rada (c_p) djelatnika u prosjeku iznosi oko 5 EUR/h.

2.4. Produktivnost
2.4 Productivity

Produktivnost je izračunana na temelju utrošenih sati rada djelatnika u odnosu prema proizvedenoj količini elemenata u svakoj tehnologiji posebno prema izrazima (1) do (3).

$$T_{h/god.} = T_s \cdot d \cdot n_d \qquad (1)$$

$T_{h/god}$ – ukupni broj utrošenih sati djelatnika u godini, h/god. / *total number of annual working hours spent by workers, hours in a year*

T_s – broj radnih sati u smjeni, h / *total number of working hours per shift, hours*

d – broj radnih dana u godini / *total number of working days in a year*

n_d – broj djelatnika / *number of workers*

$$T_{h/m3} = \frac{T_{h/god.}}{V_{el./god}} \qquad (2)$$

$T_{h/m3}$ – utrošak radnih sati za jedinicu proizvoda, h/m^3 elemenata / *working hours spent by unit of product, h/m^{3}elements*

$T_{h/god.}$ – ukupni broj utrošenih sati djelatnika u godini, h/god. / *total number of annual working hours spent, hours in a year*

Tablica 1. Broj djelatnika i instalirana snaga u ovisnosti o izabranoj tehnologiji
Table 1 Number of employees and installed capacity depending on chosen technology

Pozicija *Position*	**Klasična tehnologija poprečno-podužnog piljenja** *Classical technology cross-rip sawing*		**Računalom vođena tehnologija podužno-poprečnog piljenja** *Computer aided technology rip-cross sawing*		**Računalom vođena tehnologija podužno-poprečnog piljenja s predblanjanjem** *Computer aided technology rip-cross sawing and pre-planing*	
	Broj djelatnika *number of workers*	Instalirana snaga *installed power* kW	Broj djelatnika *number of workers*	Instalirana snaga *installed power* kW	Broj djelatnika *number of workers*	Instalirana snaga *installed power* kW
1.		2		2		2
2.		6		6		6
3.	2	20				
4.	4	14	1	11		
5.	7	49				
6.	2	4	1	3		
7.	3	5				
8.		6				
9.		3				3
10.		20		10		10
11.						11
12.			1	40		40
13.				12		12
14.			2	10	4	10
15.				9		9
16.			1			
17.	1		1		1	
18.						50
19.						9
∑	19	129	7	103	5	162
Cijena opreme *equipment costs*	64 000 EUR		220 000 EUR		1 500 000 EUR	

$V_{el./god.}$ – godišnja proizvodnja elemenata, m³ el./god. / *annual production of elements*, *m³elements per year*.

$$N_{el.} = T_{h/m3} \cdot C_p \quad (3)$$

$N_{el.}$ – vrijednost rada, EUR/m³ elemenata / *work value, EUR/m³ elements*
T_{h/m^3} – utrošak radnih sati za jedinicu proizvoda, h/m³ / *working hours spent for unit of product*, *h/m³*
C_p – bruto vrijednost sata rada, EUR/h / *brutto working hour value, EUR/h.*

2.5. Instalirana snaga elektromotora
2.5 Installed electric power

Za svaki elektromotor dan je koeficijent njegova opterećenja pri radu, kao i koeficijent iskorištenja vremena rada. Koeficijent opterećenja pri radu motora i koeficijent iskorištenja vremena rada procijenjeni su na osnovi iskustva i uputa ponuđača opreme. Umnoškom instalirane snage elektromotora i koeficijenta opterećenja dobije se maksimalna potrebna snaga motora pri opterećenju za vrijeme rada prema izrazu (4):

$$P_{maks.} = P_{inst.} \cdot k_{em} \quad (4)$$

$P_{maks.}$ – maksimalna potrebna snaga elektromotora pri opterećenju za vrijeme rada / *maximum needed power of electric motor while working*, kW
$P_{inst.}$ – instalirana snaga elektromotora / *installed power of electric motor*, kW
k_{em} – koeficijent opterećenja elektromotora pri radu / *coefficient of electric motor burden while working.*

2.6. Utrošak električne energije
2.6 Electric energy consumption

Utrošak električne energije izračunan je kao umnožak broja sati rada stroja i maksimalno korištene snage pojedinog elektromotora prema izrazu (5). Broj sati rada stroja i koeficijent iskorištenja vremena rada stroja procijenjeni su na osnovi dosadašnjeg iskustva u radu s takvim tehnologijama.

$$E = P_{maks.} \cdot t_s \quad (5)$$

E – utrošak električne energije / *consumption of electric energy*, kWh
$P_{maks.}$ – maksimalna potrebna snaga elektromotora pri opterećenju za vrijeme rada / *maximum power of electric motor needed while working*, kW
t_s – broj sati rada stroja / *number of machine working hours.*

Količina sati rada izračuna se umnoškom koeficijenata iskorištenja vremena rada stroja k_s i ukupnog broja radnih sati u godini prema izrazu (6):

$$T_g = T \cdot k_s \quad (6)$$

T_g – količina sati rada u jednoj smjeni, h/god. / *amount of workin hours in one shift, hours in a year*
T – ukupan broj radnih sati u godini / *total number of working hours per year*
k_s – koeficijent iskorištenja vremena rada stroja / *coefficient of machine work time utilization*

Godišnji ukupni utrošak električne energije odnosno utrošak po jedinici proizvoda te cijena električne energije po jedinici proizvoda izračunani su prema izrazima (7) do (9).

$$\sum E = E_1 + E_2 + ... + E_n \quad (7)$$

$$E_{kWh/m3el.} = \frac{\sum E}{V_{el./god.}} \quad (8)$$

$$EC_{Eur/m3} = E_{kWh/m3el.} \cdot c_e \quad (9)$$

$\sum E$ – ukupni utrošak električne energije u godini, kWh/god. / *total consumption of electric energy per year*, *kWh per year.*
$E_1 \ldots E_n$ – godišnji utrošak električne energije pojedinog elektromotora (stroja) / *annual consumption of electric energy per each electric motor*, kW
$E_{kWh/m3el.}$ – godišnji utrošak električne energije po jedinici proizvoda, kWh/m³ elemenata / *annual electric enegry consumption per unit of product, kWh/m³ elements*
$V_{el./god}$. – godišnja proizvodnja elemenata, m³ elemenata/god. / *annual production of elements*, *m³elements/year*
$EC_{Eur/m3}$ – cijena elektroenergije po jedinici proizvoda, EUR/m³ elemenata / *price of electric energy per unit of product, Eur/m³ elemenata*
c_e – jedinična cijena elektroenergije, EUR/kWh / *price of electric energy per unit of energy*, *Eur/kWh.*

2.7. Cijena opreme i amortizacija
2.7 Equipment costs and amortisation

Ukupna cijena opreme prikazana je u tablici 1. Iz nje je izračunana amortizacija, koja se predviđa za vrijeme od pet godina. Uzet je isti vijek trajanja opreme kako bi se moglo izračunati koliko veličina investicije utječe na konačnu kalkulaciju po jedinici proizvoda. U dogovoru s ponuđačima opreme, određen je optimalni vijek trajanja opreme od pet godina, što je ujedno i vrijeme otplate kredita. Vrijednost opreme procijenjena je na osnovi dviju ponuda različitih proizvođača opreme. Amortizacija po jedinici proizvoda izračunana je prema izrazu (10):

$$A = \frac{\frac{N_o}{G}}{V_{el.god.}} \quad (10)$$

A – amortizacija po jedinici proizvoda, EUR/m³ elemenata / *amortisation per unit of product*, *EUR/m³ elements*
N_o – ukupna vrijednost opreme, EUR / *total equipment value, EUR*
G – broj godina amortizacije / *number of amortisation years*
$V_{el./god.}$ – godišnja proizvodnja elemenata, m³ elemenata/god. / *annual production of elements*, *m³elements per year.*

3. REZULTATI ISTRAŽIVANJA
3 RESULTS OF THE RESEARCH

3.1. Produktivnost i vrijednost rada istraživanih tehnologija
3.1 Productivity and work value of researched technologies

Podatci o produktivnosti i vrijednosti rada navedeni su u tablici 2.

Tablica 2. Produktivnost i vrijednost rada istraživanih tehnologija
Table 2 Productivity and work value of researched technologies

Produktivnost i vrijednost rada *Productivity and work value*	**Klasična tehnologija poprečno-podužnog piljenja** *Classical technology cross-rip saw*	**Računalom vođena tehnologija podužno-poprečnog piljenja** *Computer aided technology rip-cross saw*	**Računalom vođena tehnologija podužno-poprečnog piljenja s predblanjanjem** *Computer aided technology rip-cross saw and pre-planing*
broj utrošenih sati djelatnika u godini h/god. / *Number of spent hours by workers in a year, h/year*	35 625	13 125	9375
utrošak radnih sati za jedinicu proizvoda, h/m³ elemenata *Working hours spent per unit of product, h/m³elements*	17,8	5,83	1,70
vrijednost rada, EUR/ m³ elemenata *Work value, EUR/m³ elements*	89,00	29,15	8,50

3.2. Utrošak električne energije
3.2 Consumption of electric energy

Podatci o utrošku električne energije dani su u tablicama 3. i 4.

3.3. Vrijednost opreme i amortizacija
3.3 Equipment price and amortisation

Cijena opreme i amortizacija prikazani su u tablici 5. za svaku tehnologiju posebno.

3.4. Ukupni trošak proizvodnje pojedinih tehnologija
3.4 Total production costs of each technology

Pri obračunu direktnih troškova nisu uzeti u obzir troškovi režijskoga i administrativnog osoblja ni ulazna cijena sirovine, dok su troškovi održavanja opreme i oštrenje alata uvršteni u obračun. Rezultati su navedeni u tablici 6.

4. DISKUSIJA I ZAKLJUČAK
4 DISCUSSION AND CONCLUSION

Razmišljanje o namjenskoj pilanskoj obradi listača s proizvodnjom elemenata nametnulo se onog trenutka kad su pilane počele ostvarivati sve slabije rezultate, kad je uočen znatan porast proizvodnih troškova i kad je postala očita činjenica da je produktivnost rada naših pilana neusporedivo niža od europ-

Tablica 3. Utrošak električne energije prema pozicijama strojeva i opreme
Table 3 Electric energy consumption per position of machine and equipment

Poz.	**Klasična tehnologija poprečno-podužnog piljenja** *Classical technology cross-rip sawing*					**Računalom vođena tehnologija podužno-poprečnog piljenja** *Computer aided technology rip-cross saw*					**Računalom vođena tehnologija podužno-poprečnog piljenja s predblanjanjem** *Computer aided technology rip-cross saw and pre-planing*				
	k_{em}	$P_{maks.}$ kW	k_s	T_g h	E kWh/god.	k_e	$P_{maks.}$ kW	k_s	T_g h	E kWh/god.	k_e	$P_{maks.}$ kW	k_s	T_g h	E kWh/god.
1.	0,4	0,8	0,4	750	600	0,4	0,8	0,4	750	600	0,4	0,8	0,4	750	600
2.	0,6	3,6	0,5	937,5	3375	0,6	3,6	0,5	937,5	3375	0,6	3,6	0,5	937,5	3375
3.	0,5	10,0	0,7	1312,5	13 125	-	-	-	-	-	-	-	-	-	-
4.	0,5	7,0	0,8	1500	10 500	0,6	6,6	0,4	750	4950	-	-	-	-	-
5.	0,6	29,4	0,8	1500	44 100	-	-	-	-	-	-	-	-	-	-
6.	0,4	1,6	0,7	1312,5	2100	0.6	1,8	0,8	1500	2700	-	-	-	-	-
7.	0,7	3,5	0,8	1500	5250	-	-	-	-	-	-	-	-	-	-
8.	0,7	4,2	0,8	1500	6300	-	-	-	-	-	-	-	-	-	-
9.	0,7	2,1	0,8	1500	3150	-	-	-	-	-	0,7	2,1	0,8	1500	3150
10.	0,8	16,0	0,8	1500	24 000	0,8	8,0	0,8	1500	12 000	0,8	8,0	0,7	1312,5	10 500
11.	-	-				-	-	-	-	-	0,7	7,7	0,7	1312,5	10 106
12.	-	-				0,8	32,0	0,8	1500	48 000	0,8	32,0	0,8	1500	48 000
13.	-	-				0,7	8,4	0,8	1500	12 600	0,7	8,4	0,8	1500	12 600
14.	-	-				0,6	6,0	0,8	1500	9000	0,6	6,0	0,8	1500	9000
15.	-	-				0,7	6,3	0,8	1500	9450	0,7	6,3	0,8	1500	9450
16.	-	-				-	-	-	-	-			-		-
17.	-	-				-	-	-	-	-			-		-
18.	-	-				-	-	-	-	-	0,7	35,0	0,8	1500	52 500
19.	-	-				-	-	-	-	-	0,7	6,3	0,8	1500	9450
∑	-	78,2	-	13 312,5	112 500	-	73,5	-	11 437,5	102 675	-	116,2	-	14 812,5	168 731

Legenda / *Key*: k_{em} – koeficijent opterećenja elektromotora pri radu / *coefficient of electric motor overload while working*; P_{maks} – opterećenje elektromotora pri radu / *electric motor burden while working*, kW; k_s – koeficijent iskorištenja vremena rada stroja / *coefficient of machine utilization of working time*; T_g – broj sati rada u godini / *number of hours per year*; E – utrošak električne energije u godini / *electric energy consumption per year*, kWh /god.

Tablica 4. Utrošak električne energije po jedinici proizvoda
Table 4 Electric energy consumption per unit of product

Utrošak električne energije *Electric energy consumption*	**Klasična tehnologija poprečno-podužnog piljenja** *Classical technology cross-rip saw*	**Računalom vođena tehnologija podužno-poprečnog piljenja** *Computer aided technology rip-cross saw*	**Računalom vođena tehnologija podužno-poprečnog piljenja s predblanjanjem** *Computer aided technology rip-cross saw and pre-planing*
utrošak električne energije kWh/god. *Electric energy consumption, kWh per year.*	112 500	102 675	16 831
utrošak električne energije po jedinici proizvoda, kWh/m^3 elemenata *Electric energy consumption per unit of product, kWh/m^{3}elements*	56,25	45,63	30,68
cijena elektroenergije po jedinici proizvoda, EUR/m^3 elemenata *Price of electric energy per unit of product, EUR/ m^{3}elements*	3,94	3,19	2,15

Tablica 5. Amortizacija i cijena opreme
Table 5 Equipment price and amortisation

Amortizacija i cijena opreme *Amortisation and equipment prices*	**Klasična tehnologija poprečno-podužnog piljenja** *Classical technology cross-rip saw*	**Računalom vođena tehnologija podužno-poprečnog piljenja** *Computer aided technology rip-cross saw*	**Računalom vođena tehnologija podužno-poprečnog piljenja s predblanjanjem** *Computer aided technology rip-cross saw and pre-planing*
vrijednost opreme, EUR *Equipment value*, EUR	64 000	220 000	1 500 000
godišnja amortizacija, EUR/god. *Annual amortisation, EUR per year*	12 800	44 000	300 000
amortizacija po jedinici proizvoda, EUR/m^3 elemenata *Amortisation per unit of product, EUR/m^3 elements*	6,40	19,56	54,55

Tablica 6. Ukupni trošak po jedinici proizvoda
Table 6 Summary cost per product unit

Trošak po fazama, EUR/m^3 elemenata *Costs by phases, EUR/m^3 of elements*	**Klasična tehnologija poprečno-podužnog piljenja** *Classical technology cross-rip saw*	**Računalom vođena tehnologija podužno-poprečnog piljenja** *Computer aided technology rip-cross saw*	**Računalom vođena tehnologija podužno-poprečnog piljenja s predblanjanjem** *Computer aided technology rip-cross saw and pre-planing*
trošak (vrijednost) rada *Costs (value) of work*	89,00	29,15	8,50
trošak opreme *Equipment costs*	6,40	19,56	54,55
trošak električne energije *Costs of electric energy*	3,94	3,19	2,15
ukupni trošak / *Total costs*	99,34	51,90	65,20

skog prosjeka. Pilansku obradu u Hrvatskoj obilježava jedan svojevrsni ekonomski paradoks, prema kojemu neki proizvod vrijedi manje što se više rada uloži u njegovu proizvodnju.

Primjerice, u proizvodnju popruga i ukupnu manipulaciju treba uložiti najviše rada, a popruga je najmanje vrijedan proizvod. I obrnuto, proizvodnja komercijalnih samica zahtijeva najmanji angažman, a samice su jedan od najvrednijih pilanskih proizvoda. Padom kvalitete pilanske sirovine pojavila se potreba za sve intenzivnijom i detaljnijom obradom, što je značilo i više uloženog rada, povećanje troškova i smanjenje produktivnosti, a globalna je vrijednost pilanske proizvodnje unatoč tome stalno padala zbog sve većeg udjela sortimenata manje vrijednosti na štetu vrednije robe. Moguće rješenje trebalo je obuhvatiti osnovne komponente, i to uz povećanje produktivnosti rada i smanjenje proizvodnih troškova te povećanje ukupne vrijednosti proizvodnje.

Povećanje produktivnosti rada treba se postići uvođenjem potrebne mehanizacije i automatizacije u proizvodni proces te zamjenom teškoga fizičkog rada gdje god je moguće. Time se izravno smanjuju troškovi proizvodnje. Istodobno treba povećati ukupnu vrijednost proizvoda i osloboditi se suvišnih proizvodnih troškova.

Iz prikazanog istraživanja i dobivenih rezultata o troškovima proizvodnje elemenata različitih tehnologija može se zaključiti sljedeće.

Klasična tehnologija izrade drvnih elemenata poprečno-podužnim načinom ima najveće troškove rada i električne energije, ali ima najmanje troškove opreme. Ta linija ujedno ima ukupno najveće troškove po jedinici proizvedenih elemenata i najlošiju kontrolu broja izrađenih elemenata.

Računalom vođena tehnologija izrade drvnih elemenata podužno-poprečnim načinom piljenja bez predblanjanja piljenica daje ukupno najmanje troškove proizvodnje, trošak rada i električne energije manji je nego na klasičnoj liniji, a veći je od doradne pilane vođene računalom s predblanjanjem piljenica. Na toj je liniji kontrola broja izrađenih komada mnogo bolja negoli u klasičnoj doradnoj pilani.

Računalom vođena tehnologija izrade drvnih elemenata podužno-poprečnim načinom piljenja s predblanjanjem piljenica rezultira najboljom produktivnošću i troši najmanje električne energije po jedinici proizvoda te ima najbolju kontrolu izrađenog broja komada i najbolju iskorištenje piljenica jer se kvaliteta određuje uz pomoć skenera za drvo. Nedostatak te tehnologije jest visoka početna investicija koja je gotovo sedam puta veća nego za prethodnu tehnologiju. Dobiveni su zaključci potvrdili citirane spoznaje do kojih je u svom istraživanju došao Butković (1998.).

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Semantics of Symbolic Decoration on Macedonian Traditional Movable Furniture from 19th Century

Semantika simboličkih ukrasa na makedonskome tradicionalnom pokretnom namještaju iz 19. stoljeća

Professional paper • Stručni rad
Received – prispjelo: 21. 1. 2015.
Accepted – prihvaćeno: 5. 5. 2016.
*UDK: 630*836.1*
doi:10.5552/drind.2016.1505

ABSTRACT • *The analysis of symbolic decoration on movable furniture is a process defined by expressing the inner world of thoughts and ideas through the outside, living world. The furniture and other household equipments were made with high functionality. Functionality of the furniture was the most important, more precisely its aestetics was a result of functionality. The world of the symbolic decoration was personal, intimate or beloged to the family, and although it was conceived and handmade by self-taught carpenter/the host, analyses reveal deep cosmological links of images with the past and tradition. Therefore, the aim of this paper is to analyze the process of creating the decoration and semantics of the Macedonian traditional movable furniture from the 19th century. Researches and analyses were made in the Republic of Macedonia, more specifically in several villages around the mountain of Skopska Crna Gora and in the village Dzepciste from the Tetovo region, and the region of the citty of Veles. Based on measurements of the objects, photos, drawings, foto-documentation, the paper exposed their actual appearance. Based on these drawings, analyses of symbols and forms were made, as well as a deeper analysis of the religious context within which they were made. The analyzes showed that the symbolic decoration of movable furniture in the Macedonian traditional house from the 19th century has its roots in the past as the archetypal signs follow the furniture through the ages. The purpose of this paper was to analyze cosmological pictures of the furniture, to describe them clearly and in the future perhaps be able to apply them in a new modern context.*

Key words: *semantic, symbolic decoration, antique context, Christian context, identification, formalization, cosmological character of decoration, expression, traditional furniture***.**

SAŽETAK • *Analiza simboličkih ukrasa na pokretnom namještaju proces je definiran izražavanjem unutarnjeg svijeta misli i ideja prema vanjskome, živom svijetu. Namještaj i ostali proizvodi i uređaji za kućanstvo proizvedeni su tako da budu što funkcionalniji. Funkcionalnost namještaja je najvažnija, a njegova je estetika rezultat funkcionalnosti. Svijet simboličkih ukrasa najčešće je bio osobna, intimna ili obiteljska odrednica, a rezultat je*

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maštovitosti i rada samoukih stolara. Analize otkrivaju duboke kozmološke veze sa slikama iz prošlosti i tradicijom te njihovo ponavljanje u povijesti. Stoga je cilj ovog rada bio analizirati proces stvaranja ukrasa i semantiku makedonskoga tradicionalnog pokretnog namještaja iz 19. stoljeća. Istraživanja i analize obavljeni su u Republici Makedoniji, u nekoliko sela oko planine Skopska Crna Gora, zatim u selu Dzepciste, u regiji oko grada Tetova te u području grada Velesa. Na temelju mjerenja objekata, fotografija, crteža i fotodokumentacije, u radu je izložen njihov pravi i stvarni izgled. Na temelju tih crteža obavljene su analize simbola i oblika te dublje analize religijskog konteksta pod utjecajem kojega su ti ukrasi nastali. Analize su pokazale da simbolički ukrasi pokretnog namještaja u makedonskoj tradicijskoj kući iz 19. stoljeća ima korijene u prošlosti, unutar koje se na temelju arhetipskih znakova može pratiti razvoj namještaja kroz stoljeća. Cilj rada bio je jasno opisati analizu kozmološke slike namještaja i tu sliku nekad u budućnosti možda prenijeti u novi, moderni kontekst.

Ključne riječi: *semantika, simbolički ukrasi, antikni kontekst, kršćanski kontekst, identifikacija, formalizacija, kozmološko obilježje ukrasa, izražavanje, tradicionalni namještaj*

1 INTRODUCTION
1. UVOD

1.1 Historical aspect
1.1. Povijesni aspekt

Symbolic decoration on movable furniture is a process defined by expressing the inner world of thoughts and ideas through the outside, living world. For the local craftsman, the only way to recognize what part of the world different crafts come from was through identification. Identification was achieved through interference between the complexes of experiences linked to a certain existential sphere, and some elements or occurrences from the person's immediate surroundings, all of this deriving from the person's archaic consciousness (Nikoljski, 2013).

This paper differentiates the antique and the Christian contexts, these two being the basic expression topics of people living in this area for the analyzed period of time. It can be obviously concluded that both the antique and the Christian contexts have left significant imprints on cosmological images and performances of both movable and built in furniture in Macedonia, during the 19th century (Causidis, 2008).

The process of decoration has always begun with the three dimensional geometric projections of the cosmic space and shape, because these are the basic images that people have unconsciously reinterpreted again and again in the form of decoration on the furniture surface.

Researching decorative semantics and the self-taught craftsman's need to express himself through drawing on, engraving and carving the furniture, it is exstremely easy to notice people's need to decorate their surroundings. Various examples have shown that the methods for designing hand-made furniture are often used for the same type of expression (Nikoljski, 2009).

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Methods of historical research
2.1. Metode povijesnog istraživanja

2.1.1 Religion's impact on decoration
2.1.1. Religijski utjecaj na dekoracije

The horizontal projections of the cosmos on everyday appliances and furniture in antiquity (the second half of the first millennium B.C. until the first half of the first millennium A.D.), were projected in two different ways:

- more often as an artistic embellishment of the objects, delivered through geometric and figural motifs.
- less often as basic geometric concepts of the objects or compositions.

With the establishment of the Eastern Roman Empire, especially with the recognition and spreading of the new religion, the Balkan and the Mediterranean regions started to adopt a new aspect of understanding of the universe, which science now classifies as being "typical for the spirit of the Orient." Starting in the 3rd century A.D. and continuing throughout the following centuries, this tendency, in its ultimate instance, has been manifested in the Christian cosmological scheme.

In the concept of Christianity, it had been more important to understand the cosmos through its opposing hierarchal systems, such as: "above heavens" - "below heavens", "light" - "darkness", "pure" - "heathen", "this time" - "that time", and moreover between the categories "sacred" - "profane" or more accurately "sacred - most sacred"(Causidis, 2008).

Still, as opposed to the antique cosmological models, the Christian model, being in denial of its spherical shape, portrayed the cosmos in a quadrilateral form.

2.1.2 The impact of the Christian quadrilateral cosmic model
2.1.2. Utjecaj kršćanskoga četverokutnog kozmičkog modela

The geographical core of the cosmic space models in the Christian world originates from the regions of Asia. The ancient Chinese portrayal of space is the most accurate one compared to our idealized model. It portrays the Earth as a flat board, or a pyramid. It is fixed and surrounded by sea. Above it, there is a round, dynamic sky. For example, two of these authentic models are manifested in Mandalas and in stoups (Causidis, 2008).

Of course, the portrayal of this idealized model on both the geometrical and figural levels has been brought up as an artistic ornamentation of decorations and decorated surfaces of the movable furniture. The local craftsman's need to express himself through channeling the inner world of thoughts and ideas to the outside has occurred through two processes, which, although seemingly subsequent to one another, are actually synchronized, mutually intertwined and inseparable. These processes are identification and formalization.

2.2 Methods of research with identification of semantic concepts
2.2. Metode istraživanja s identifikacijom semantičkih koncepata

The act of relating to or identifying things is the basic concept of understanding the world around us. Identification is achieved through interference between the complexes of experiences linked to a certain sphere of the macro-cosmological existence, and some elements or occurrences from the person's immediate surroundings. In this process, the surrounding occurrences have the following characteristics, or in other words, they need to be:

- initiators of the given occurrence in the macro-cosmos (this piques interest),
- a key for permeation into its essence (which leads to reasoning),
- an element that completes the perception of the occurrence (this process leads to recognition),
- an element that would export the perception of the occurrence outside of the subconscious (which initiates presentation), and
- a factor for presenting personal perceptions onto other units of the given cultural complex, which initiates communication (Causidis, 2008).

Thus, the concept of identification is the basic concept of presentation and understanding space.

With the development of rational human consciousness, the degree of correlation between what is identified (for example some occurrences in the macro-cosmos) and its identifier (the symbols) decreases, which causes the process of intertwining to transition from the cognitive sphere into the sphere of styles and forms (recognized in the symbolic and artistic context).

2.3 Formalization
2.3. Formalizacija

The perception of the shape of the macro-cosmos, or the formalization, begins with its identification, and it is usually linked to a certain symbol, a.k.a. an identifier. In the archaic consciousness of our people, this process did not just start with the perception of ideas, but also with the perception of forms.

To analyze the aspect of forms and shapes of the macro-cosmos means to analyze the levels of its shape, which are based on the primary impressions of space that the archaic consciousness has created.

The observations presented in this thesis, which refer to furniture decoration in a restored Macedonian house of the 19th century, are in close correlation with the aspects of space. On one hand they result from these aspects, but on the other hand they define them to a large degree, and thus they shed light on human relations with this most abstract level of existence of the universe.

3. RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Cosmological character of decoration
3.1. Kozmološko obilježje dekoracije

The cosmos is presented on various objects from the material culture, such as everyday objects, furniture, fabrics, bed sheets and jewelry, in two ways:

- embedded in the basic geometric composition of furniture,
- as an artistic decoration of furniture using geometric and figural motifs.

As opposed to architecture, the cosmological nature of the pictures represented in this cultural sphere (on movable furniture and household furnishing) is much harder to prove. This is mainly because of the fact that the sphere they belong to is not as accessible as the architectural one. Quite the contrary – they are much more intimate and personal, and because of that, they are much less affected by canons of the official ideology. The transposition of the spiritual in the artistic elements on furniture had been accomplished using a smaller degree of control coming from the codified spiritual and religious systems. Thus, it had been largely influenced by spontaneity and collective work of people. In these frameworks, the creators' freedom to invent played a big role, whether it came from amateur authors and craftsmen, self-taught villagers and carpenters, or even professional craftsmen of certain crafts and artists (Nikoljski, 2009).

Because of their nature, the cosmological images that decorate furniture and everyday objects are presented without the accompanying verbal context, so that the discovery and interpretation of their cosmological dimension is nowadays conducted painstakingly, using complex scientific methodology. Due to their complex nature, and because of the small degree of previous exploration and lack of literature and material data, decoration on furniture from this period was analyzed very carefully, gradually and precisely.

3.2 Concentric organization of cosmic zones
3.2. Koncentrična organizacija kozmičkih zona

The former cosmological character of ornamental compositions present on movable furniture is indicated by the use of motifs and their layout, despite their non-preserved narrative context. Illustration-example is shown in Fig. 1 and Fig. 2. With movable furniture from the 19th century Macedonian house, the concept of concentric organization of the cosmic zones was usually followed in the following order:

- The Earth is represented by the ornamented zones that cultivate the rectangular composition and appears in the form of an external and internal border - a continuation of lozenge-shaped forms.
- The link between the lozenge shape and the Earth is rooted in its Christian cosmological model, whose geometric shape is square. In this model, a given area on the Earth, seen when standing on it, resembles a rhombus (a square seen in perspective). It is the lozenge shape that is often seen in carvings on movable furniture, especially on dressers and chests.

- The continuation of round motifs laid out between the rhombs often symbolizes the Earth's center or core, but could also be interpreted as the latent presence of vegetation, or the vegetative force in the Earth's womb.
- The aboveground level is represented by four schematically arranged plants, or with the help of triangles symbolizing houses. However, this is not the only interpretation of triangles, as they nurture different layers, starting with a female system, fertility, a home or a house.
- The sky is represented through the middle area as well as the central rosette, which has a clear morphological relationship with the sun. Originally it could have represented the whole sky as a circle. In addition to this representation of the sky, two three-legged swastikas joined by crescent-shaped motifs (crescent moons) represent the solar and lunar cycles (Gavazzi, 1996).

All of these shapes can be found in carved decoration on movable furniture, while the rosettes are usually a centerpiece and are located in the middle of the front side of the chest or dresser.

3.3 Geometry in movable furniture design
3.3. Geometrija u dizajnu pokretnog namještaja

The transition from two-dimensional to three-dimensional geometric displays of space had been very logical for contemporary culture representatives, as well as for contemporary furniture design. This is a result of the fact that they are the most accurate, immediate and objective projections. Analyzing the historical aspect of furniture decoration in the revived Macedonian house from the 19th century, these clean and abstract geometric manifestations usually represent the long-gone stadiums of the mythological symbolic design of space (Fig. 1. and Fig. 2).

Their appearance can be defined as a process of gradual reduction of all that is geometric, or more precisely, getting rid of the material cosmic models in which the geometric aspect is always implicitly embroidered.

3.4 Most common geometric forms
3.4. Najčešći geometrijski oblici

In the area of geometric decoration, the following forms and shapes are usually encountered on the furniture in Macedonian houses:

A quadrilateral

A quadrilateral with an inscribed circle or a quadrilateral with a described circle. The quadrilateral symbolizes the Earth, and the round rosettes symbolize the sky. Therefore, both feminine and masculine principle can be seen (Fig.1).

A trapezoid

As a quadrilateral, the trapezoid falls in the category of geometrical representatives of the lower levels of space. According to one analogy, this means that the trapezoid has probably emerged as a product of a transformation of the triangle. Another one claims that when the rectangular shape of the Earth is seen in perspective, it looks like a trapezoid. (Fig.1).

The trapezoid symbolizes the mother-earth or woman-earth relationship.

A circle

The circular segments in the shape of cut-outs - or parts of the circle - could have represented the sides of the world, or maybe even the phases of the solar cycle. (Fig.1).

The rosette-like cut-outs in the circles represent the phases in which the sun rotates around the Earth.

The concentric circular zones found in the decoration of some furniture represent a two-dimensional projection of the three-dimensional model of the cosmos, mimicking a sphere made of several sub-spheres moving concentrically one into another. However, this spherical representation of the cosmos is not accepted among our people, because it is considered to be pagan. Instead, it has been opposed by the widespread "quadratic-circular" Christian model, nurtured by the craftsmen in the area.

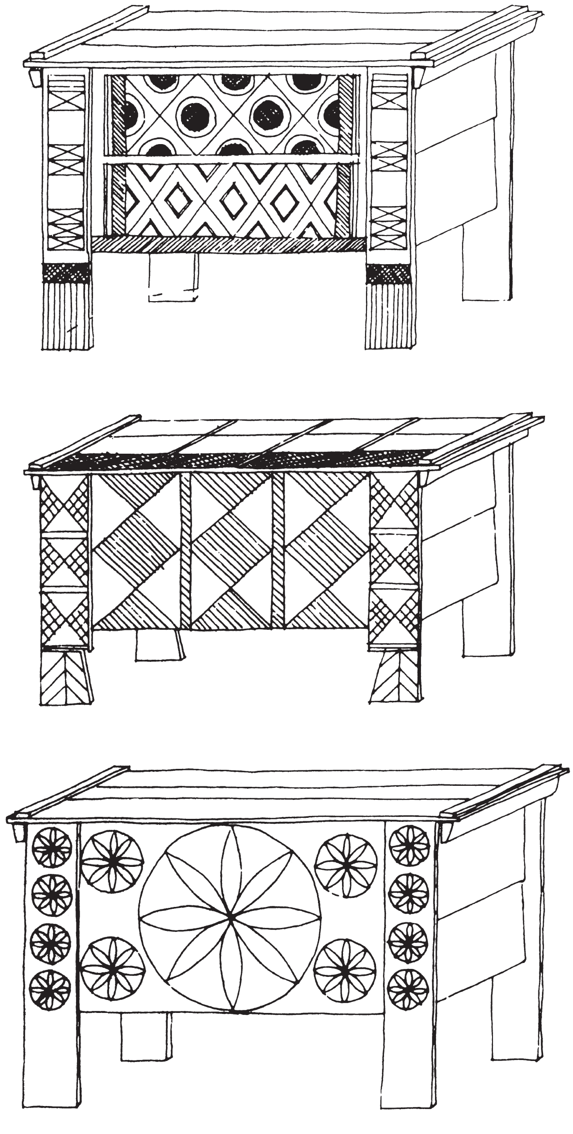

Figure 1 Carved decoration with geometrical inspiration on movable furniture, Villages of Skopska Crna Gora[1]
Slika 1. Geometrijski inspirirani ukrasi urezani na pokretnom namještaju (sela u području planine Skopska Crna Gora)

A triangle, a rhomb

In the Slavic cultural complex, these iconographic elements - despite their archaic meanings which have always been linked to the female body, or women's clothing - could also have induced a second, cosmological meaning, linked to the Earth as a cosmic element, while the rhombic and triangular ideograms have accented the Earth's fertility, alluding to the female organs, or the plots and fields that the Earth is separated into. (Fig.1).

3.5 Interaction between anthropomorphic and geometrical decoration
3.5. Interakcija između antropometrijskih i geometrijskih ukrasa

On a geometrical level, metamorphosis is manifested as a process of interaction between the female figure and the basic geometric representations of the lower cosmic zones (rhombs, squares, rectangles, triangles, trapezoids and circles) or the more complex geometric ideograms deriving from them (Fig. 1, Fig. 2). The intensity of the anthropomorphic and geometric impression on a mythological image is in perfect balance, so that it can be categorized equally as a geometric product of the anthropomorphic images and the opposite, an anthropomorphic product of geometric images. The interaction between the anthropomorphic and geometric is also motivated by the animistic perception of the world, which is inherent in the archaic consciousness. The concept of an animistic perception of the world, as a global trans-historic and trans-cultural phenomenon, appears independently at the same time in the archaic cultures from different centuries and parts of the world.

3.6 Stylization of vegetative and zoomorphic forms
3.6. Stilizacija biljnim i zoomorfnim oblicima

Throughout the history of decoration, phytomorphological images often appear. They often symbolize the relation of the woman in childbirth with the Earth (mother-Earth). In this equalization, the plants, especially the weeds, symbolize the woman's hair. Among Slavic peoples, there is a popular belief that "the one who pulls weeds, pulls the hair of his or her mother." This symbolical identification is the base for the green hair that fairies and pixies are known for, and maybe even the fact that in Roman culture, women thanked Venus for their hair. In South Slavic tradition, these mythologems resonate the name Biljana (a personal name coming from the word "bilje" or herbs), often represented in traditional songs (Causidis, 2008).

The phytomorphization can include all of the female figure, turning her into a plant, so that her torso adopts the role of a trunk, her extremities adopt the form of bent branches, leafs or tendrils, while the neck and head take on the role of the flower's bud or blossom (Fig. 2).

The motifs become a part of the mythological, symbolic and artistic sphere. As in the concept of

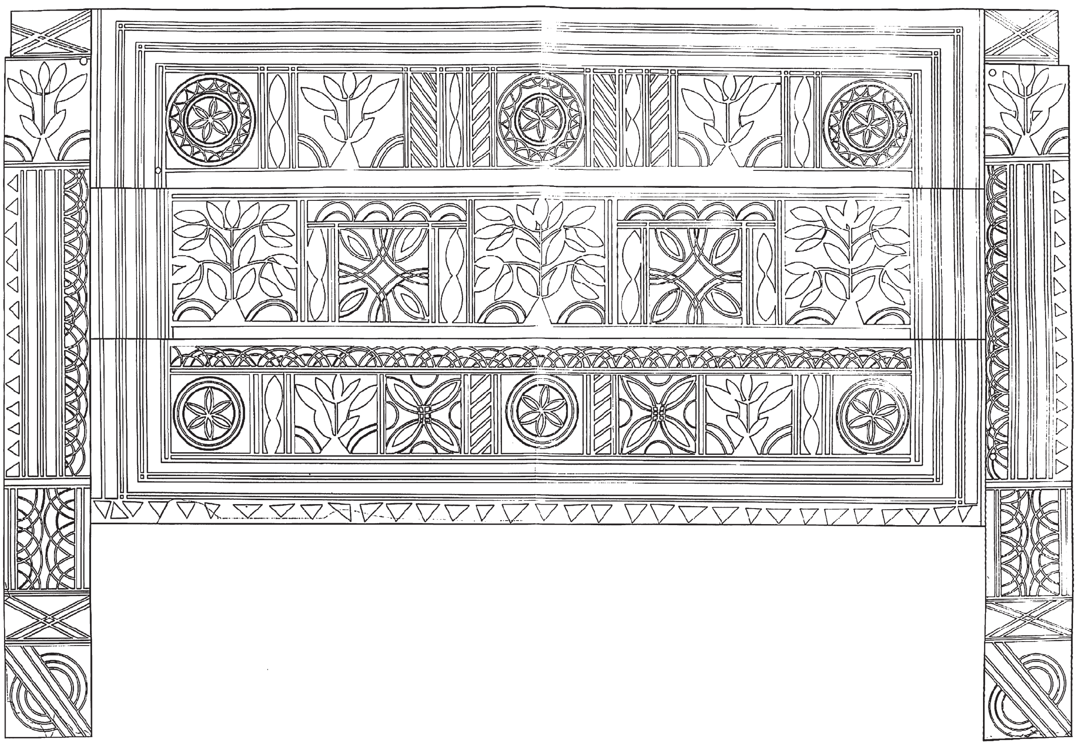

Figure 2 Carved decoration with a combination of geometrical and floral motifs on movable furniture, village of Dzepcishte, Tetovo[1]

Slika 2. Urezani ukras: kombinacija geometrijskih i cvjetnih motiva na pokretnom namještaju (selo Dzepciste, Tetovo)

[1] The drawing is taken from the collection composed for the project "EtnoPredmeti", for the Interior Architecture subject, 1993-2003, Faculty of Architecture, Skopje

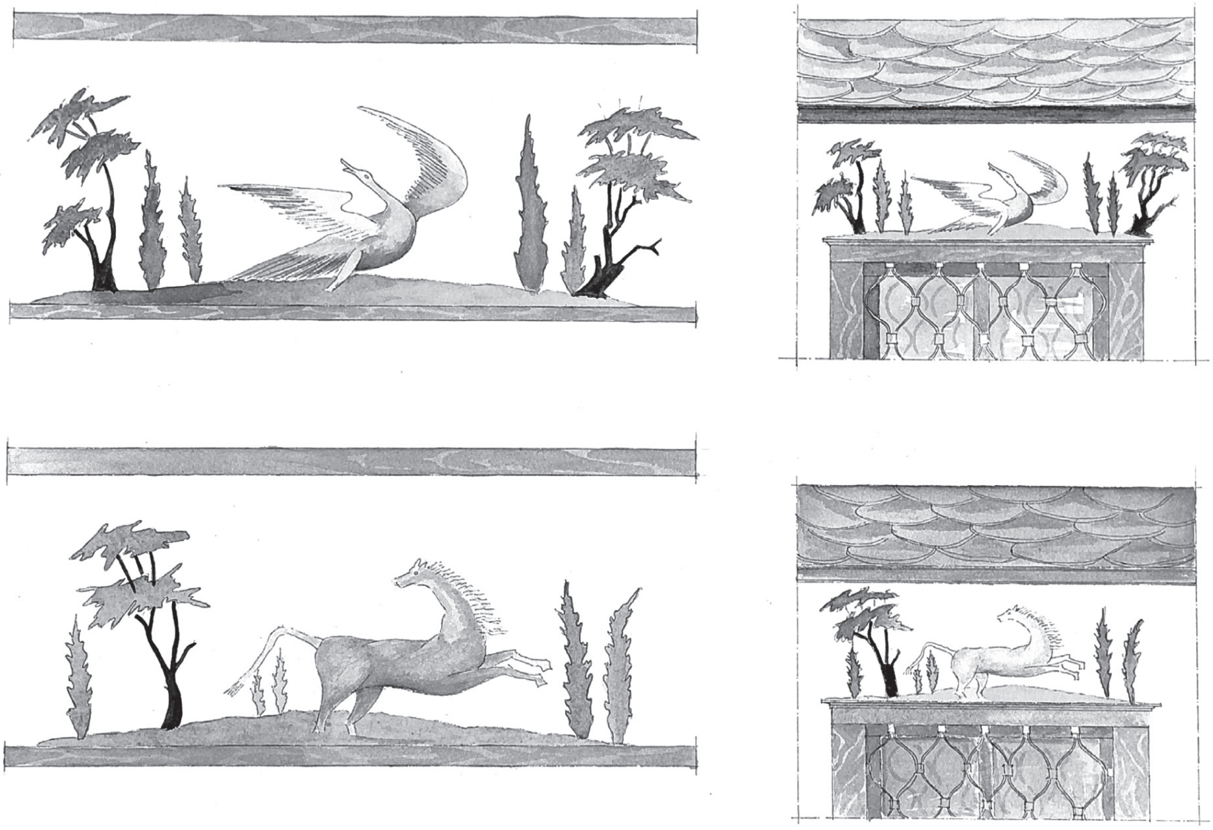

Figure 3 Decoration made by drawing, oilcolor painting, zoomorfic motifs, on house furniture in Veles[1]
Slika 3. Ukrasni crteži – zoomorfni motivi na namještaju izvedeni oslikavanjem uljnim bojama (kuća u Velesu)

supplementation, the partial and global phytomorphization of the female figure has a role of connecting her with the lower zones and elements of space (the Earth, the underground, the water) and to present the macro-cosmic aspect of what is feminine (Fig. 2). This primarily includes the birthing power of plants, but also all the other abstract categories that plants symbolize (fertility, food, life, abundance, and vital cycles in nature and humans). These types of images are the most frequent when it comes to furniture decoration. It is exactly their hyper-productivity that has contributed to the large degree of transformation of their primary prototypes, especially in the direction of their complete ornamentation. As a result, a particular issue today is whether or not a certain image of this type has kept its original mythologicalsymbolic meaning and according to which measurement, and whether the extreme intensity of phytomorphization of these images always reflects a high degree of their demythologization.

The examples of furniture and furnishings discover that even though the complicated ornamentation with plants keeps evolving around the old compositional scheme given by the female figure as it was known in the past, it is not of great importance for it to maintain a symbolic connection to the female figure or the categories that she represents, especially on a level of conscious findings, while on a functional level, i.e. in the sacral-magical character of ornaments, in some cases that connection is very important.

3.7 Zoomorphic decorative images
3.7. Zoomorfne ukrasne slike

The specific manifestation of the zoomorphic forms-pictures, present in the form of carvings and paintings on furniture, could not always be generalized, especially because of the local specifications of some specific ecological ambiance in which a zoological-cosmological symbolic relation like this has been born in and existed at some point. For a large part of mankind, the most frequent and universal are aquatic animals as well as reptiles, which usually represent water and soil, or the underground, and the lower zones of Space. At least in our territory and even further, this symbolic process is mostly represented by fish, snakes, lizards, frogs and turtles (Fig. 3).

4 CONCLUSION
4. ZAKLJUČAK

To understand the relationship between an individual and his/her surroundings, it is necessary to make a quick differentiation between the antique and the Christian contexts of this relationship. It can be obviously concluded that both the antique and the Christian contexts have left significant imprints on the cosmological images and performance of both movable and built-in furniture in Macedonia during the 19th century. The process of decoration has always begun with the three dimensional geometric projections of the cosmic space and shape, because these are the basic images that people have unconsciously reinterpreted again and again in the form of decoration on the furniture surface.

The horizontal projections of the cosmos on everyday appliances and furniture in antiquity (the second half of the first millennium B.C. until the first half of the first millennium A.D.), were projected in two different ways: more often as an artistic embellishment of the objects, delivered through geometric and figural motifs, and less often as basic geometric concepts of the objects or compositions. With the establishment of the Eastern Roman Empire, especially with the recognition and spreading of the new religion, the Balkan and the Mediterranean regions started to adopt a new aspect of understanding the universe, which science now classifies as being "typical for the spirit of the Orient." Starting in the 3rd century A.D. and continuing throughout the following centuries, this tendency, in its ultimate instance, has been manifested in the Christian cosmological scheme.

Thus, the concept of identification is the basic concept of presentation and understanding space.

With the development of rational human consciousness, the degree of correlation between what is identified (for example some occurrences in the macrocosmos) and its identifier (the symbols) decreases, which causes the process of intertwining to transition from the cognitive sphere into the sphere of styles and forms (recognized in the symbolical and artistic context).

When it comes to horizontal cosmological projections, it can be sais that they have survived in a lot of archaic forms, where they can be found on some pieces of movable furniture, (mostly chests, dressers and nightstands), in the form of artistic manifestations or carvings on the wood. Some everyday use objects such as textile, small wooden and ritualistic objects, are also decorated using horizontal cosmological projections.

The need for geometric display of cosmological pictures and cosmic phenomena in the form of decoration on furniture surface probably occurred as a result of a few factors:

- insufficient knowledge of primitive craftsman about art and artistic display of objects and occurrences;
- the need to accentuate the cosmological character of objects (figures);
- the acknowledgement of inherited and traditionally reinterpreted symbols.

The implementation of decorative wood carving and textile knitting made it easier for the craftsmen and women to display these symbols and designs on furniture.

From the geometric decoration aspect, the following forms and shapes are usually encountered on the furniture in Macedonian traditional houses from the 19-th century: quadrilateral, trapezoid, circle, triangle, and rhomb.

The phytomorphization can include all the female figure, turning her into a plant, so that her torso adopts the role of a trunk, her extremities adopt the form of bent branches, leafs or tendrils, while the neck and head take on the role of the flower's bud or blossom (Fig. 2).

The motifs that develop this process become a part of the mythological, symbolic and artistic sphere. As in the concept of supplementation, the partial and global phytomorphization of the female figure has a role of connecting her with the lower zones and elements of space (the Earth, the underground, the water) and to present the macro-cosmic aspect of what is feminine (Fig. 2). By analyzing the examples of furniture and furnishings, it has been discovered that even though the complicated ornamentation with plants keeps evolving around the old compositional scheme given by the female figure as it was known in the past, it is not of great importance for it to maintain a symbolic connection to the female figure or the categories that she represents, especially on a level of conscious findings, while on a functional level, i.e. in the sacral-magical character of ornaments, in some cases that connection is very important.

The most frequent and universal for a large part of mankind are aquatic animals as well as reptiles, which usually represent water and soil, or the underground, and the lower zones of Space. At least in our territory and even further, this symbolic process is mostly represented by fish, snakes, lizards, frogs and turtles (Fig. 3).

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Nastup studenata Drvnotehnološkog odsjeka Šumarskog fakulteta na Tjednu dizajna u Zagrebu (#tdzg 2016)

Uz Dan D, Tjedan dizajna Zagreb (#tdzg) najveće je događanje u Hrvatskoj posvećeno dizajnu. Održava se od 2014., a cilj mu je povezivanja dizajnera i gospodarstvenika te popularizacija dizajna u najširoj javnosti.

Od 3. do 8. svibnja 2016. na više od 4000 m² u Kući za ljude i umjetnost *Lauba* i u susjednoj zgradi *Hauba* te prvi put i na desetak lokacija u samom središtu grada održana je treća manifestacija Tjedna dizajna u Zagrebu, pod pokroviteljstvom gradonačelnika Zagreba, Turističke zajednice grada Zagreba i Hrvatske gospodarske komore. Partner regija #tdzg2016 bile su nordijske države Danska, Finska, Norveška i Švedska.

Glavni program Tjedna dizajna i ove je godine bio svojevrstan spoj nekoliko platformi u organizaciji Tine Marković i Daniela Tomičića iz tvrtke Skuderia – konferencije Auto®, originalne i odlične Produkteke, Konferencije kulturnih i kreativnih industrija (KIKI), Dana društvenih inovacija (DIDI), #tdzg EDUkativni programi te niza svakodnevnih pratećih događanja poput panela, stručnih konzultacija, projekcija filmova, modnih revija, poslovnih susreta i koncerata, zabavnog programa te događanja u središtu grada.

Naglasak ovogodišnjih akcija u *Laubi* bio je na Izložbi namještaja te na proizvodima za uređenje interijera i eksterijera. Uz najpoznatije i dizajnerski orijentirane domaće proizvođače namještaja i njihove *brandove* poput tvrtke Prostoria, Inkea (dizz concept), Modul, DIN Novoselac, Spin Valis, DI Čazma, ERA, Galeković Design, te uz dizajnere Filipa Gordona Franka, Svjetlanu Despot (Data by Despot), Zorana Šunjića (Kamen centar/Petrafom Dizajner) i prodajne tvrtke Themelie, BoConcept, Černelić i brojne druge, *Lauba* je i ove godine uistinu izgledala kao ekskluzivni (nažalost, nekadašnji) sajam Ambijenta „u malom“ (sl. 1.). U sklopu manifestacije održana je i izložba Zajednice za industrijski dizajn Pododjela za dizajn HGK-a (sl. 2.).

Hauba je nudila dizajnersko šarenilo podijeljeno prema tematskim štandovima (blokovima) – Expo, Market, Izložbe fakulteta i škola, a postavljena je i pozornica na kojoj su se održavale brojne revije i koncerti.

Kao i prethodnih godina, pozivu za sudjelovanjem na izlagačkom prostoru TDZG-a namijenjenom fakultetima i školama odazvao se i Šumarski fakultet, uz Studij dizajna, Grafički fakultet, Tekstilno-tehnološki fakultet, Sveučilište Sjever, Agoru, Callegari, Apuri, Profokus te Školu za primijenjenu umjetnost i dizajn iz Zagreba.

Petnaestak četvornih metara izlagačkog prostora Šumarskog fakulteta zauzeli su nastavni projekti koji su se provodili u akademskoj godini 2014./2015. na preddiplomskom studiju Drvne tehnologije (izborna skupina B) te na diplomskom studiju Oblikovanje proizvoda od drva. Sinergija kreativnosti, poznavanja svojstava materijala, načelâ oblikovanja i konstruiranja

Slika 1. Impozantna *Lauba*: izlošci dizajnerski orijentiranih proizvođača, dizajnera i trgovaca namještaja

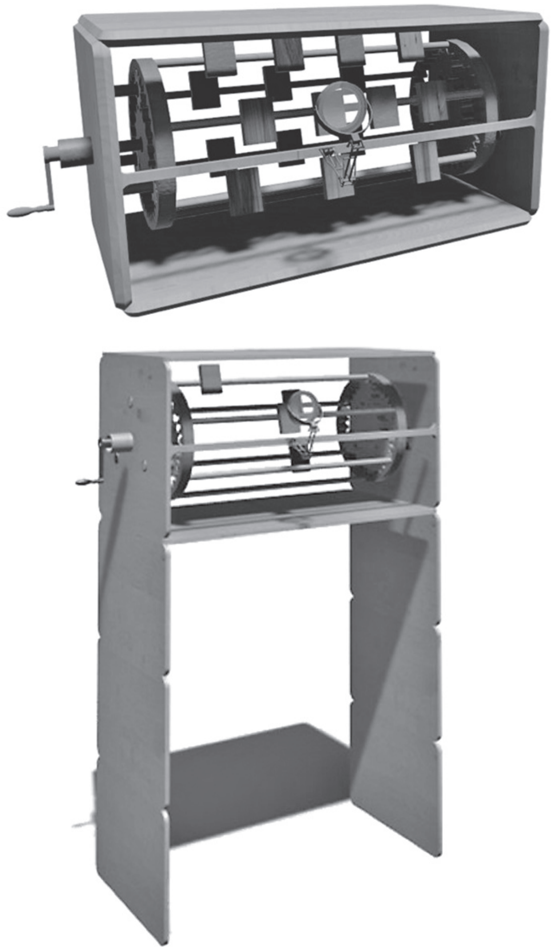
Slika 2. Izložba namještaja u *Laubi* – postav Zajednice za industrijski dizajn HGK-a

te tehnološke izvedivosti rezultirali su radovima objedinjenima u projektu *Oblikovanje namještaja za opremanje obrazovnih institucija Republike Hrvatske*, u suradnji s Drvnim klasterom *Slavonski hrast* iz Vinkovaca. Projekt je okupio radove studenata treće godine preddiplomskog studija Drvnotehnološki procesi, kolegija Oblikovanje namještaja (zadatak: *Oblikovanje školskog namještaja za opremanje srednjih škola RH*; studenti: Marta Badurina, Lovro Belina, Helena Borković, Zrinka Bridić, Ivana Hideg, Viktoria Jurina, Mihovil Karač, Franciska Klanfar, Igor Kolman, Ivan Lacković, Tin Lojen, Ivan Ražov, Vilim Redža, Valentino Slivar, Valentina Sunek, Josip Svilić, Melita Šomođi, Luka Zanić, Katalin Gyorgyevics; nastavnici: doc. dr. sc. Danijela Domljan i prof. dr. sc. Ivica Grbac) (sl. 3.), prve i druge godine diplomskog studija Oblikovanje proizvoda od drva, kolegija Namještaj i opremanje prostora te Metodologija industrijskog oblikovanja namještaja (zadatak: *Opremanje vijećnice Drvnotehnološkog odsjeka*; studenti: Lovro Belina, Zrinka Bridić, Ivana Hideg, Franciska Klanfar, Igor Kolman, Domagoj Mamić, Tomica Perković, Ivan Ražov, Valenino Slivar, Juraj Tomljanović; nastavnici: doc. dr. sc. Danijela Domljan i prof. dr. sc. Ivica Grbac) (sl. 4.) te kolegija Projektiranje proizvoda od drva (studenti: Ana Mišetić, Margareta Kovačević, Lana Jarža i Lucija Brglez, nastavnica izv. prof. dr. sc. Silvana Prekrat) (sl. 5.), uz izvannastavni projekt druge godine diplomskog studija (projekt: *Učionica 202*; studenti: Lana Jarža, Ana Mišetić, Valentino Slivar i Martino Grgić; voditeljica projekta: izv. prof. dr. sc. Silvana Prekrat) (sl. 6.).

U sklopu suradnje s Drvnim klasterom *Slavonski hrast* prototipove dvaju odabranih rješenja – višefunkcionalnog stola za Vijećnicu DTO-a (rad studenata V. Slivara, L. Beline, I. Ražova, sl. 7.) te radnog stola za računalnu učionicu (rad studenta V. Slivara) – od hrastovine je izradila stolarija Špurga d.o.o iz Županje.

Slika 3. Atmosfera u učionici za dizajn – timski rad studenata Drvne tehnologije i Studija dizajna na kolegiju Oblikovanje namještaja

Slika 4. Idejno rješenje uređenja Vijećnice DTO-a na kolegiju Namještaj i opremanje prostora, rad studenata Beline, L., Slivare, V., Ražova, I.



Slika 5. Lupa, rad studentice Lane Jarže u sklopu kolegija Projektiranje proizvoda od drva

Slika 6. Istraživački rad grupe studenata na projektu *Učionica 202*

Slika 7. Prototip višenamjenskog stola izrađen u stolariji Špurga d.o.o.

Međutim, po nečemu je ovogodišnji nastup Šumarskog fakulteta drugačiji od prethodnih. Prezentacija Fakulteta, kao i prethodnih godina, održana je u petak poslijepodne, plakati i prototipovi studentskih rješenja postavljeni su, kao i svih godina dosad, na predviđenome izlagačkom prostoru (sl. 8.), no nešto je ipak iznenadilo publiku i novinare!

S ponosom možemo istaknuti da su ove godine studenti smjera Oblikovanje proizvoda od drva nadmašili sami sebe, barem prema kasnijim izjavama entuzijastične grupe *Enable Table*, koja u početku nije vjerovala da se može pokrenuti, dogovoriti, ubrzati, povezati i iznjedriti odličan projekt o kojemu će pisati i novine! Prema riječima Korane Sutlić, novinarke *Jutarnjeg lista*, „…riječ je o prvoj generaciji studenata šumarstva koja je u dizajnerskom smislu izašla iz 'kutije'…" (Sutlić, 2016.).

A tko je grupa *Enable Table* i što je predstavila?

Projekt je započet kao izvannastavna aktivnost generacije kreativnih studenata smjera Oblikovanje proizvoda od drva, u suradnji s tvrtkom Bokart. Idejni pokretači projekta – direktor tvrtke Daniel Kvesić i doc. dr. sc. Danijela Domljan – osmislili su zadatak *Oblikovanje klub stolića od drva i stakla*, održali predavanje i čekali buđenje generacije…(sl. 9. i 10.).

Projekt je rezultirao samostalnim nastupom deset studenata na posebnome izlagačkom prostoru Expoa na kojemu su stolovi od drva i unikatnog stakla, izrađeni vlastitim snagama i uz pomoć brojnih tvrtki, plijenili pozornost posjetitelja i novinara (sl. 11.). Studenti Lovro Belina, Ivana Hideg, Lana Jarža, Igor Kolman, Margareta Kovačević, Domagoj Mamić, Tomica Perković, Ivan Ražov, Valentino Slivar i Juraj Tomljanović osmislili su postav i letak te samostalno izradili prototipove koji se ovih dana mogu pogledati u ulaznom predvorju nove zgrade Šumarskog fakulteta.

No uz sve iznimno pohvalne tekstove novinara objavljene u časopisima i tv emisijama te uz izjave o uspjesima naših studenata na *Facebook* stranicama,

Slika 8. Izložbeni prostor Šumarskog fakulteta u *Haubi* – zadovoljni studenti i mentorice nakon dobro obavljenog posla

Slika 9. Radna atmosfera na projektu, posjet kolega Daniela Kvesića (Bokart) i Vinka Postića (Maroon Creations)

Slika 10. Posjet tvrtki Bokart

Slika 11. Grupa studenata *Enable Table* na izložbenom prostoru Expoa u *Haubi*

Slika 12. Zahvala grupe *Enable table* na poleđini letka za TDZG

iskreno, ništa nas ne ispunjava većim ponosom od teksta zahvale angažiranim tvrtkama i osobama koji je objavljen na letku *Enable Tablea* (sl. 12.).

Hvala entuzijastičnoj grupi!

Više o Tjednu dizajna 2016. i nastupu studenata potražite na:

https://www.facebook.com/TDZG

www.tjedandizajna.com

https://www.facebook.com/Enable.Table/

Sutlić, K.: Od stolaca i lampi do Nordijske kuće , *Jutarnji list*, prilog „Kultura“, 4. svibnja 2016.; http://www.jutarnji.hr/kultura/od-stolaca-i-lampi-do-nordijske-kuce/3711753/

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doc. dr. sc. Danijela Domljan, magistrica dizajna

Zlatko Bihar

Obitelj, rodbina, prijatelji, suradnici i znanci, okupljeni u velikom broju, oprostili su se 7. lipnja 2016. od gospodina Zlatka Bihara, dugogodišnjega tehničkog suradnika Zavoda za znanost o drvu Šumarskog fakulteta Sveučilišta u Zagrebu.

Nakon završenog školovanja za drvnog tehničara u Drvnotehničkoj školi u Zagrebu, Zlatko Bihar počeo je raditi kao tehnički suradnik na Šumarskom fakultetu u veljači davne 1976. godine. Više od 40 godina naš kolega Zlatko obavljao je tehničke poslove u pripremi nastave, laboratorijskih i terenskih mjerenja te tehničke pripreme različitih publikacija za tisak, koji su uvijek bili nezaobilazni i vrlo važni za nesmetano obavljanje mnogih aktivnosti u sklopu djelatnosti Šumarskog fakulteta. Zlatkova tehnička naobrazba, pedantnost i poznavanje struke osobito su se očitovali u vremenu kad se ti poslovi još nisu obavljali na osobnim računalima. Njegova stručnost, znanje i vještine ogledale su se u svim aktivnostima koje su mu bile povjerene unutar nastave i rada sa studentima, u poslovima izdavačke djelatnosti, odgajanja asistenata i rada za dobrobit Fakulteta.

Katedra za tehnologiju drva na kojoj je počeo raditi tijekom vremena se preoblikovala u Zavod za znanost o drvu. Na tom su ga Zavodu upoznale mnoge generacije studenata drvne tehnologije i šumarstva, od kojih će ga mnogi pamtiti po uredno pripremljenim materijalima i uzorcima za nastavu i provođenje kolokvija o botaničkim nazivima vrsta drva te po redovitom sudjelovanju u terenskoj nastavi mnogobrojnih predmeta.

U izdavačkoj djelatnosti Fakulteta Zlatkov je doprinos velik, iako nije uvijek vidljivo potpisan, a utkan je u gotovo sva izdanja Fakulteta, posebice ona Drvnotehnološkog odsjeka.

Zlatko Bihar bio je tehnički urednik *Biltena Zavoda za istraživanja u drvnoj industriji* (*Bilten ZIDI*) gotovo cijelo vrijeme njegova izlaženja, od 1978. do 1989. godine. U suradnji s profesorom Stanislavom Bađunom pripremio je *Bibliografiju članaka, stručnih informacija i izvještaja objavljenih u časopisu Bilten Zavoda za istraživanja u drvnoj industriji za razdoblje od 1971. do 1982. godine*, koja je objavljena u *Biltenu ZIDI*, vol. 11(1983), br. 1, str. 8-46.

Tehničkim urednikom znanstvenog časopisa *Drvna industrija* postao je 1992., i taj je posao marljivo i kvalitetno obavljao sve dok se nije ozbiljno razbolio.

Zlatkov je doprinos kvaliteti i tehničkom uređenju časopisa *Drvna industrija* nemjerljiv i potpuno su ga svjesni samo dobri poznavatelji tehničke pripreme znanstvenih časopisa za tisak. Zlatko je vodio brigu i o decimalnoj klasifikaciji radova objavljenih u časopisu *Drvna industrija*, a u suradnji s profesorom Radovanom Despotom pripremio je i za *Drvnu industriju* objavio *Bibliografiju članaka, stručnih informacija i izvještaja objavljenih u Drvnoj industriji u volumenu 48 (1997 godina), UDK i ODK; Bibliografiju članaka, stručnih informacija i izvještaja objavljenih u Drvnoj industriji u volumenu 49 (1998 godina), UDK i ODK* te *Bibliografiju članaka, stručnih informacija i izvještaja objavljenih u Drvnoj industriji u volumenu 50 (1999 godina), UDK i ODK.*

Svojim odgovornim pristupom poslu, iznimnom pouzdanošću i poduzetnošću organizirao je i vodio brigu o tiskanju časopisa i uz srdačan osmijeh kolegama znanstvenicima prvi donosio svaki novi objavljeni broj *Drvne industrije*!

Uz doprinos *Biltenu ZIDI* i časopisu *Drvna industrija* Zlatko je uvelike pridonio da mnogi zbornici radova stručnih i znanstvenih savjetovanja tehnički uređeni ugledaju svjetlost dana. Njegovi crteži, grafikoni, tablice i slike već su tradicija izdavačke djelatnosti u drvnotehnološkoj struci i u nju su trajno ugrađeni. Objavljeni su i u brojnim magistarskim radovima, doktorskim disertacijama, skriptama i udžbenicima Šumarskog fakulteta.

Svojim nenametljivim savjetima, velikim tehničkim znanjem, inovativnošću, preciznošću i poznavanjem drva pridonosio je kvaliteti radova te je brojne poslove na Fakultetu odradio u tom duhu.

Vjerojatno je najvećem broju djelatnika ostao u sjećanju kao dugogodišnji šef Centralne inventurne komisije, ne spominjući i druge dužnosti koje je za dobrobit Fakulteta odradio zdušno i savjesno. Ono što će nas trajno podsjećati na kolegu Zlatka Bihara jest i trenutačni grb Šumarskog fakulteta koji je on izradio.

U doba stvaranja hrvatske države dao je svoj nesebičan doprinos njezinoj obrani i uspostavi, o čemu osim Spomenice Domovinskog rata koju mu je dodijelio prvi predsjednik Republike Hrvatske Franjo Tuđman svjedoče i vojne počasti iskazane na Zlatkovu posljednjem ispraćaju.

Zlatko je, nažalost, prerano otišao, a novi djelatnici Zavoda i Fakulteta moći će ga prepoznati i od njega učiti iz njegove prečesto nepotpisane ostavštine. Da, i iz toga, među ostalim, možemo iščitati njegovu izrazitu skromnost i samozatajnost! Mnogi kolege i prijatelji rado se sjećaju Zlatkovog pjevanja uz gitaru, a poznato je da je bio i vatreni dinamovac. Samo je nekolicina povlaštenih vidjela zbirku slika od drva s motivima obitelji i kućnih ljubimaca, izrađenih njegovom rukom.

Vjerujemo da će Zlatkovu umjetničku dušu na sudnjem danu krijepiti upravo bezgranična ljubav prema obitelji, sinu, struci i Fakultetu, a nama će uvijek u sjećanju ostati kao dobra duša Fakulteta i već za života svojevrsna legenda.

Naš *zlatni Zlatko* – Zlatkić, Zlatan, Zlajo, Aurelije (kako smo ga pokatkad znali zvati) bio je istinski kolega i prijatelj, srdačna, jednostavna i draga osoba.

Svima koji smo ga poznavali ostat će u trajnom sjećanju. Pozdravljamo se, ne zauvijek, već u vjeri do sljedećeg susreta.

Neka mu je laka naša hrvatska zemlja, neka mu dom bude nebo!

izv. prof. dr. sc. Tomislav Sinković
prof. dr. sc. Jelena Trajković

CHUKRASIA TABULARIS A. JUSS.

UDK: 674.031.757.291.2

NAZIVI

Vrsta drva *Chukrasia tabularis* A. Juss. pripada porodici *Meliaceae*. Trgovački je naziv te vrste chickrassy (Njemačka, Velika Britanija), chittagon wood (Velika Britanija), yinma (Burma, Njemačka), hoolanghik-grass (Cejlon), aglay, boga poma, boga porna, dalmara, chikrassi, pabba (Indija), voryong (Kambodža), lat hoa (Vietnam), chenana puteh, repoh (Malajska federacija), yom hin (Tajland).

NALAZIŠTE

Vrsta drva *Chukrasia tabularis* A. Juss. prirodno je rasprostranjena u južnoj i jugoistočnoj Aziji: u Burmi, Indiji, Indoneziji, Kambodži, Malajskoj Federaciji, Sri Lanki, Tajlandu i Vijetnamu. Raste u poluzelenim i trajno zelenim kišnim tropskim šumama.

STABLO

Na svom staništu stabla narastu od 10 do 25 (35) metara, dužina debla im je do 15 (25) metara, a prsni promjer do 0,9 metara. Deblo je pravilnoga cilindričnog oblika. Kora drva je uzdužno izbrazdana, crvenkastosmeđa, debljina joj je do 1 centimetar.

DRVO

Makroskopska obilježja

Drvo je rastresito porozno. Granice goda na poprečnom su presjeku uočljive golim okom. Pore i aksijalni parenhim oku su jedva vidljivi, a drvni se traci mogu uočiti samo uz pomoć povećala. Tekstura drva je jednolična i pravilna. Bjeljika je žuta do crvenkasta, širine do 5 centimetara. Srž je žutosmeđa do crvenkastosmeđa, a stajanjem na zraku potamni.

Mikroskopska obilježja

Raspored traheja je pojedinačan, pojavljuju se u paru ili u kratkim radijalnim nizovima. Ploča perforacije članaka traheja potpuna je. Promjer traheja iznosi 80...150 mikrometara, gustoća im je 10...15...20 na 1 mm^2 poprečnog presjeka. Volumni udio traheja iznosi oko 10 %. Traheje srži često su ispunjene tamnim sržnim tvarima. Aksijalni je parenhim paratrahealno vazicentričan i graničan. Volumni udio aksijalnog parenhima iznosi oko 7 %. Drvni su traci homogeni do heterogeni (rjeđe), visine 135...235...360 mikrometara, širine 37...50...60 mikrometara odnosno od 1 do 4 - 5 stanica. Gustoća drvnih trakova je 7...10...12 na 1 mm. Volumni udio drvnih trakova iznosi oko 20 %. U stanicama drvnih trakova i aksijalnog parenhima mogu se pronaći kristali prizmatičnog oblika. Drvna su vlakanca libriformska. Dugačka su 600...1000 mikrometara. Debljina staničnih stijenki vlakanaca iznosi 1,9...2,6...3,3 mikrometara, a promjer lumena im je 6,0...12,0...19,0 mikrometara. Volumni udio vlakanaca je oko 63 %.

Fizikalna svojstva

Gustoća standardno suhog drva, ρ_o	600...700...780 kg/m^3
Gustoća prosušenog drva, ρ_{12-15}	650...760...840 kg/m^3
Gustoća sirovog drva, ρ_s	oko 850 kg/m^3
Poroznost	48...54...60 %
Radijalno utezanje, β_r	3,9...5,2 %
Tangentno utezanje, β_t	6,0...7,4 %
Volumno utezanje, β_v	10,1...12,8 %

Mehanička svojstva

Čvrstoća na tlak	47,0...65,0 MPa
Čvrstoća na vlak, okomito na vlakanca	
- radijalno	oko 3,4 MPa
- tangencijalno	oko 5,2 MPa
Čvrstoća na savijanje	84,0...108,0 MPa
Čvrstoća na smicanje	
- radijalno	11 MPa
- tangencijalno	12 MPa
Tvrdoća (prema Brinelu), paralelno s vlakancima	57,0...88,0 MPa
Tvrdoća (prema Brinelu), okomito na vlakanca	
- radijalno	28,0...34,0 MPa
- tangencijalno	25,0...40,0 MPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Drvo se dobro strojno i ručno obrađuje. Dobro se ljušti, pili, reže, blanja i tokari. Čavle i vijke prima lako i drži dobro. Drvo nije potrebno prethodno bušiti. Dobro se lijepi i politira.

Sušenje

Dobro se suši na prirodan i umjetan način.

Trajnost i zaštita

U hrvatskoj normi HRN 350-2, 2005 ne mogu se pronaći podatci o trajnosti i zaštiti drva *Chukrasia tabularis* A. Juss. U literaturi se navodi da je bjeljika tog drva slabo trajna. No srž drva je trajna, otporna na insekte, gljive uzročnice truleži i atmosferske utjecaje. Slabo je otporna na morske štetnike, a djelomično je otporna na termite. Vrlo se teško impregnira.

Uporaba

Upotrebljava se za izradu furnira, furnirskih ploča, namještaja, parketa i obloga, a služi i kao konstrukcijsko drvo za unutarnju i vanjsku upotrebu pri srednjim opterećenjima te za izradu stuba i vrata. Rabi se i kao specijalno drvo za izradu glasovira i drvene ambalaže za čaj.

Sirovina

Drvo *Chukrasia tabularis* A. Juss. isporučuje se u obliku trupaca dužine 4 - 7 metara, najčešće srednjeg promjera 0,4 - 0,8 metara.

Napomena

Drvo nije na popisu ugroženih vrsta međunarodne organizacije CITES niti na popisu međunarodne organizacije IUCN Red list.

Tradicionalno, različiti se dijelovi stabla *Chukrasia tabularis* A. Juss. iskorištavaju u medicini kao analgetici, kao sredstva za liječenje proljeva i kao antipiretici.

Drvo sličnih svojstava imaju i ove vrste drveća: *Chukarsia velutina* Roem., *Aglaia gigantea* Pellegr., *Amoora cucullata* Roxb., *Entandrophragma angolense* C. DC., *Swietenia macropphylla* King.

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prof. dr. sc. Jelena Trajković
doc. 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. Kad je rad prihvaćen za objavljivanje, autori pristaju na automatsko prenošenje izdavačkih prava na izdavača te na zabranu da rad bude objavljen bilo gdje drugdje ili na drugom jeziku bez odobrenja nositelja izdavačkih prava.

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.

Svi prilozi podvrgavaju se jezičnoj obradi. Urednici će od autora zahtijevati da tekst prilagode preporukama recenzenata i lektora, te zadržavaju i pravo da predlože skraćivanje ili poboljšanje teksta. Autori su potpuno odgovorni za svoje priloge. Podrazumijeva se da je autor pribavio dozvolu za objavljivanje dijelova teksta što su već negdje objavljeni te da objavljivanje članka ne ugrožava prava pojedinca ili pravne osobe. Radovi moraju izvještavati o istinitim znanstvenim ili tehničkim postignućima. Autori su odgovorni za terminološku i metrološku usklađenost svojih priloga. Radovi se šalju elektroničkom poštom na adresu:

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.

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Web stranice

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

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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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