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Elastic and Strength Properties of OSB Layers

Elastičnost i čvrstoća slojeva OSB ploča

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ABSTRACT • *Experiments were conducted to determine the elastic and strength properties of the face and core layers of a commercial OSB/3 (oriented strand board) panel, 18 mm thick. Five elastic constants for each layer, as well tensile strength in three directions (0°, 45° and 90° with respect to the major OSB axis) were obtained in tension testing. Deformations of the samples were measured with the aid of resistance strain gauges. All the Young's moduli as well as the shear modulus of the face layer were distinctly higher than those of the core layer (2.18 – 2.23 and 2 times, respectively). The density of the face layer turned out to be 40 % higher than that of the core one. All the obtained results confirm that the face and core layers of the OSB/3 panel differ considerable in respect of density, elastic and strength properties but they have orthotropic properties.*

Key words: *elastic and strength properties, oriented strand board (OSB), orthotropy, Young's modulus, shear modulus*

SAŽETAK • *Istraživanja su provedena kako bi se odredila elastična svojstva i čvrstoća vanjskih i unutarnjih slojeva komercijalne OSB/3 ploče debljine 18 mm. Primjenom vlačnog testa dobivene su vrijednosti pet konstanti elastičnosti za svaki sloj, kao i vlačna čvrstoća u tri smjera (0°, 45° i 90° s obzirom na glavnu os OSB ploče). Deformacije uzoraka mjerene su mjernim instrumentima za otpornost materijala. Sve vrijednosti Youngova modula elastičnosti, kao i vrijednosti modula smicanja vanjskih slojeva, bile su značajno veće od vrijednosti dobivenih za unutarnje slojeve (2,18 – 2,23 puta veće za Youngove module elastičnosti i dvaput za module smicanja). Gustoća vanjskoga sloja bila je 40 % veća od gustoće unutarnjih slojeva ploče. Svi dobiveni rezultati potvrđuju da se vanjski i unutarnji slojevi OSB/3 ploče značajno razlikuju u smislu gustoće, elastičnih svojstava i čvrstoće, ali pokazuju i ortotropna svojstva ploče.*

Ključne riječi: *elastična svojstva i čvrstoća, ploče s orijentiranim iverjem (OSB), ortotropna svojstva, Youngov modul, modul smicanja*

1 INTRODUCTION
1. UVOD

Oriented strand board (OSB) made from hot-pressing strand mats, consisting of slender wood strands glued with water-resistant resins (OSB/3 and OSB/4 grades), usually are formed of three layers crossing at right angle. Strands in the upper and lower faces are oriented approximately along the major board axis, but in the core strands they are usually at 90° to this direction. OSB is often assumed to be an orthotropic material (Canadido *et al*., 1988; Wang and Chen, 2001; Zhu *et al*., 2005), but it is rather a three-layer cross laminate (Bodig and Jayne, 1982), and only on condition that the layers are strictly orthotropic and the number of the layers is big enough the laminate may be assumed to be orthotropic, too (Ashkenazi, 1978).

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The moduli of elasticity (MOEs) of the entire OSB panel mentioned in the PN-EN 300, PN-EN 310, PN-EN 12369-1 and PN-EN 789 standards are obtained in bending tests with the load perpendicular to the panel plane. Actually, for the OSB panel treated in bending perpendicularly to the plane as a layered system (Bodig and Jayne, 1982), the moduli of the various layers may be converted to a single modulus for the entire OSB specimen using so-called transformed cross section method. Therefore, OSB as a layered system can be modelled using an equivalent homogenous material for which the moduli of elasticity in directions of major and minor board axes are assumed to be constant throughout the entire cross section of the OSB panel. Obtained in such bending tests, the values of the OSB moduli of elasticity are completely incomparable with those obtained by the tension, compression or bending tests in the plane of the panel (Suzuki, 2000). MOE of the entire OSB sample in bending perpendicular to the panel plane in contrast to the in-plane bending is strongly, nonlinearly, affected not only by the strand orientation but by the face/core ratio, as well (Suzuki, 2000; Chen *et al*., 2008). Additionally, moduli obtained according to the above mentioned standards are useless for the design of the composite box- or I-beams, where OSB webs of those beams are in two-dimensional stress state (in plane stress), as a consequence of their in-plane bending. Therefore, the OSB moduli of elasticity estimated by the out-of-plane bending tests are only the apparent moduli (Carll and Link, 1988; Thomas, 2003). These effective OSB moduli of elasticity are influenced not only by the shape, size and distribution of strands (Nishimura *et al*., 2004), but also by the orientation of the strands, particularly in surface layers (Shupe *et al*., 2001; Wang and Chen, 2001). Therefore, the influence of these and many other factors on the effective MOE of OSB was often investigated but usually on plates manufactured in laboratory. Many theoretical models to investigate the influence of orientation level of strands or also of the vertical density profile and other factors on the effective MOE of OSB plates (Xu, 2000; Painter *et al*., 2006[a,b]) were developed, too. A methodology to explain the fundamental formation of the vertical density profile of OSB plates during the processing period was developed by Winistorfer *et al*. (2000) and by Wang and Winistorfer (2000). The industrially manufactured OSB have "U" (Böhm *et* al., 2011) or rather "M" shaped vertical density profile (Painter *et al*., 2006[a,b]) in numerical simulations assumed to be symmetrical about the mid-plane. Therefore, both the surface layers have a higher density than the internal one and consequently the OSB panel achieves higher bending strength and bending MOEs. To determine the variation in strength and elastic properties through the thickness of the OSB panel, Steidl *et al*. (2003) divided 23/32-inch-thick commercial southern pine OSB panel into 15 layers to obtain thin-layer specimens for tension and compression testing. The layer properties were used to predict the entire panel bending properties (apparent bending MOEs) but the experimental data were not as good as expected.

The objective of this study was to obtain experimentally all the elastic constants of the surface and inner layers of a commercial OSB panel, which are essential for the prediction of the elastic constants of entire OSB plate according to the laminate theory (Bodig and Jayne, 1982). The assumption was made that the OSB panel is a symmetric laminate consisting of three orthotropic layers crossing at right angle. More direct method of strain measurements with the aid of resistance strain gauges was chosen.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

All specimens were cut from one 1250 by 2500 mm, 18 mm thick commercial OSB/3 panel. The OSB/3 panel (bearing panel for use in wet conditions, according to the PN-EN 300 standard) was formed of three layers crossing at right angle. The inner layer (core) was bonded with the MDI (methylene-diphenyle-diisocyanate) adhesive, while the outer layers (faces) were bonded with the MUPF (melamine-urea-phenol-formaldehyde) resins. The OSB panel was made of flat, differently wide strands (generally of pine wood – *Pinus sylvestris* L.), 100 - 120 mm long and 0.6 mm thick and manufactured with the use of the Conti-Roll press by Kronopol-Żary, Poland. The faces/core weight ratio of the OSB/3 panel was about 50 / 50, in accordance with the manufacturer's data. The average density of the OSB/3 panel of 593 kg/m^3 was obtained in accordance with the PN-EN 323 standard just before the mechanical investigations at the average moisture content of 7.6 % obtained in accordance with the PN-EN 322 standard on the same specimens.

The preparation of the specimens for the experiments of elastic and strength properties consisted of two stages. In the first stage, 72 full-thickness test pieces 510 by 30 mm were cut from the OSB/3 panel: 25 pieces at 0°, 20 pieces at 90° and 27 at 45° with respect to the longer edge (major axis) of the OSB sheet. Five pieces of each orientation type, in total 15 pieces, were randomly selected from the larger group for the experiments of elastic properties. Similarly, another 15 pieces were randomly selected for the experiments of strength properties.

In the second stage, all the selected pieces were sawn into two separate specimens: the inner ones 5.5 mm thick from a core layer, symmetrical about the OSB mid-plane and the surface ones 3 mm thick, always from the same, upper face layer. Such thickness of the specimens was chosen because of a lack of the technical data about the thickness of individual layers of 18 mm thick OSB/3 plates. The thickness of both face layers was estimated to be between 2 and 3.5 mm (on the basis of our own experiments).

All the 30 specimens of three orientation types and of two separate layers, provided for the experiments of elastic properties, were equipped with two 120 ohm strain gauges of TFs-15/120 or HBM 10/120 LY 11 types situated at right angles to each other on the surface of each specimen in such a way that one of the

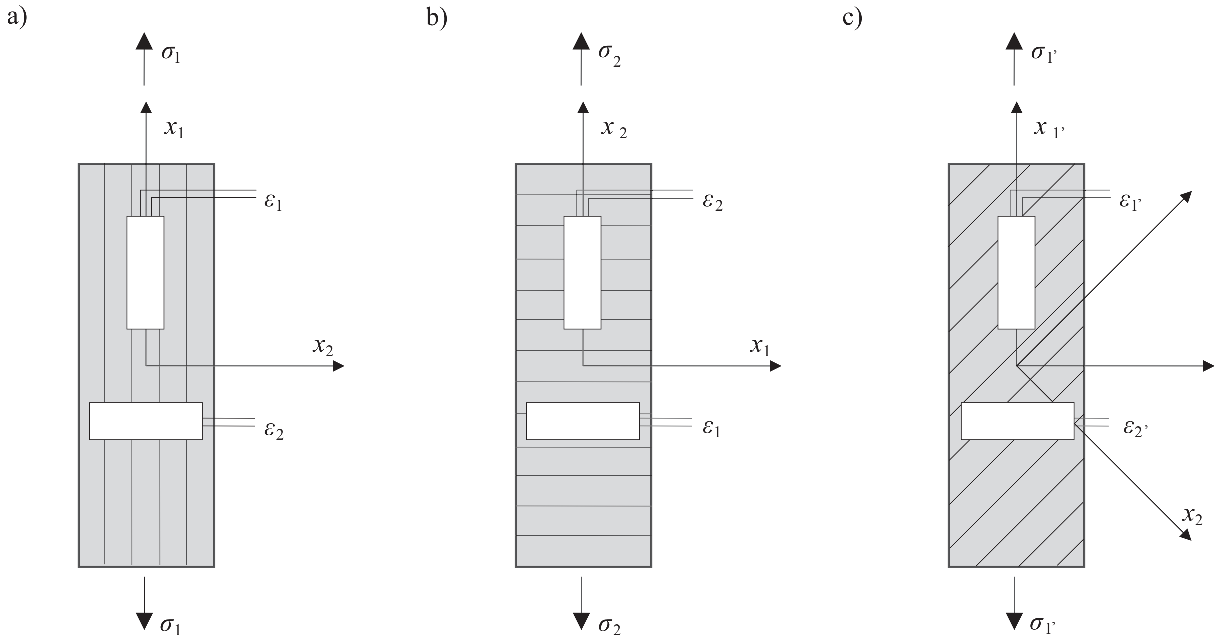

Figure 1 Scheme of loading and strain measurement for the tension tests of face specimens. Specimens orientation: a) at 0°; b) at 90°; c) at 45° with respect to the major OSB panel axis, x_1

Slika 1. Shema opterećenja uzoraka i mjerenja naprezanja pri vlačnom testu uzoraka vanjskih slojeva ploče. Orijentacija uzoraka: a) 0°; b) 90°; c) 45° u odnosu prema smjeru glavne osi OSB ploče x_1

strain gauges was situated parallel to the longer edge of this specimen (Fig. 1.). The specimens in the form of thin rectangular parallelepipeds were investigated in quasi-static tension tests. The gravity loading was realized by steel disks underslung to the bottom end of the specimen when the top end of the specimen was chucked directly in immovable grips of the FPZ 100/1 testing machine. Only the diagonal specimens (cut at 45° with respect to the OSB major axis) were fastened with the aid of special grips with a rod inserted into two bore-holes of 9 mm diameter, 40 mm from the ends of these specimens to enable shear strains without additional shear stresses. Before the basic tension tests, all the specimens were subjected to a mechanical preconditioning consisting in fivefold loading-unloading cycles (from the preload to the maximum load) to minimize the influence of plastic strains on the results of these experiments.

Three various levels of the maximum load were chosen, taking into consideration the cross-section of each specimen type (face or core), as well as their orientation (at 0°, 45° or 90° with respect to the OSB panel major axis). These load levels were chosen assuming that the stress level during the tension tests should not exceed 30 % of the tensile strength. Each specimen was subjected to a fivefold load, from the preload up to the maximal load, while the longitudinal and transverse unit strains were measured using strain gauges connected with a measuring amplifier Mikrotechna 1101 and two digital voltmeters.

Assuming that layers (laminae) of the OSB panel are homogenous orthotropic materials, then five elastic constants in a plane stress state are needed to establish the Hooke's law relationship between the stress and strain states for each of the layers. Four of them are independent: the Young's moduli in direction 1 and 2, E_1 and E_2; the shear modulus, G_{12} and the major Poisson's ratio, ν_{12}. The fifth elastic constant, ν_{21}, is a function of the other constants, and it may be determined from the relation: $\nu_{21}E_1 = \nu_{12}E_2$ (Ashton *et al*., 1969), regarding the symmetry of the stiffness matrix.

Since the assumption that the OSB layers are homogenous orthotropic materials was not evident in this study, it was decided to experimentally determine all the five elastic constants of each layer in three separate tension tests (Fig. 1). Figure 1 shows three types of tensile specimens cut out from the outer (face) layer of the OSB/3 panel.

The scheme of the tension tests on the inner (core) layer specimens was similar, but on account of different strand orientation in this core layer, which is perpendicular to the major OSB panel axis, x_1, it was no more the major axis of the orthotropic core layer – it was truly their minor axis.

Finally, destructive tension tests on another 30 specimens (15 face and 15 core specimens), with five specimens of each orientation type (0°, 45° and 90° with respect to the major OSB panel axis, x_1), were carried out using a FPZ 100/1 testing machine. The crosshead speed of 1.2 mm/min was selected so that the failure of the specimen occurred within 90 ± 30 seconds. Additionally, the density of the face and core layers was determined, on 25 specimens each time.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Two elastic constants: the Young's modulus, E_1, and the major Poisson's ratio, ν_{12}, of the face layer (Fig. 1a) and another two: the Young's modulus, E_2, and the minor Poisson's ratio, ν_{21}, (Fig. 1b) were calculated as follows:

Table 1 Elastic constants of the face layer of OSB/3
Tablica 1. Konstante elastičnosti vanjskog sloja OSB/3 ploča

Elastic constant *Konstanta elastičnosti*		**Mean** *Srednja vrijednost*	**Std. Dev.** *Stand. dev.*	**Coef. Var.** *Koef. var.*	**Specimens moisture content, %** *Sadržaj vode u uzorku, %*	**Air temperature, °C** *Temperatura zraka, °C*
Young's moduli *Youngov modul,* MPa	E_1	5148	976	19.0	6.9	24
	E_2	3721	628	16.9	6.9	25
	$E_{1'}$	4845	1615	33.3	6.9	25
Poisson's ratios *Poissonov omjer*	ν_{12}	0.204	0.122	59.8	6.9	24
	ν_{21}	0.234	0.156	66.6	6.9	25
	$\nu_{1'2'}$	0.364	0.075	20.6	6.9	25
Shear modulus *modul smicanja* MPa	G_{12}	1776	Calculated by the formula (3) / *izračunano prema jednadžbi (3)*			
		2263	Calculated by the formula (4) / *izračunano prema jednadžbi (4)*			
		2048	Calculated by the formula (5) / *izračunano prema jednadžbi (5)*			

$$E_1 = \frac{\sigma_1}{\varepsilon_1} \qquad \nu_{12} = -\frac{\varepsilon_2}{\varepsilon_1} \tag{1}$$

$$E_2 = \frac{\sigma_2}{\varepsilon_2} \qquad \nu_{21} = -\frac{\varepsilon_1}{\varepsilon_2} \tag{2}$$

while the shear modulus, G_{12}, was obtained in three ways:

directly, from the third tension test (Fig. 1c) as:

$$G_{12} = \frac{E_{1'}}{2\cdot(1+\nu_{1'2'})} \tag{3}$$

Where: $E_{1'} = \frac{\sigma_{1'}}{\varepsilon_{1'}} \qquad \nu_{1'2'} = -\frac{\varepsilon_{2'}}{\varepsilon_{1'}}$

and more indirectly – from all three tension tests (Fig. 1) as:

$$G_{12} = \frac{\sin^2\alpha \cdot \cos^2\alpha}{\frac{1}{E_{1'}} - \frac{\cos^4\alpha}{E_1} - \frac{\sin^4\alpha}{E_2} + \frac{2\nu_{12}}{E_1}\cdot\sin^2\alpha\cdot\cos^2\alpha} \tag{4}$$

and

$$G_{12} = \frac{\sin^2\alpha\cdot\cos^2\alpha}{\frac{1}{E_{1'}} - \frac{\cos^4\alpha}{E_1} - \frac{\sin^4\alpha}{E_2} + \frac{2\nu_{21}}{E_2}\cdot\sin^2\alpha\cdot\cos^2\alpha} \tag{5}$$

Where:
$\sigma_2, \sigma_2, \sigma_{1'}$ – normal stresses
$\varepsilon_1, \varepsilon_2, \varepsilon_{1'}, \varepsilon_{2'}$ – longitudinal and transverse unit strains
$E_1, E_2, E_{1'}$ – moduli of elasticity in the principal (x_1 and x_2) OSB panel directions and at a = 45° with respect to the major OSB panel axis, x_1, respectively
$\nu_{12}, \nu_{21}, \nu_{1'2'}$ – Poisson's ratios in principal (x_1, x_2) and rotated at a = 45° ($x_{1'}$, $x_{2'}$) axes, respectively

Obviously, the formulae (3-5) are valid only in the case when the material tested is orthotropic, in the strict sense (Ashkenazi, 1978).

The results obtained from the elastic tension tests are summarized in Tables 1 and 2. Table 1 presents the results of the tension tests on elastic constants of the outer (face) layer of the 18 mm thick OSB/3 panel, while Table 2 gives the results of similar tension tests for the inner (core) layer of this panel.

Table 1 clearly shows that the mean value of the Young's modulus of the OSB face layer in the major panel direction, E_1, is by above 38 % greater than E_2 (in the minor panel direction). The mean value of $E_{1'}$ Young's modulus in the $x_{1'}$ direction (Fig. 1c) turned out to be smaller than E_1 but greater by 30 % than E_2.

Table 2 Elastic constants of the core* layer of OSB/3
Tablica 2. Konstante elastičnosti za unutarnji sloj OSB/3 ploča

Elastic constant *Konstanta elastičnosti*		**Mean** *Srednja vrijednost*	**Std. Dev.** *Stand. dev.*	**Coef. Var.** *Koef. var.*	**Specimens moisture content, %** *Sadržaj vode u uzorku, %*	**Air temperature, °C** *Temperatura zraka, °C*
Young's moduli, MPa *Youngov modul,* MPa	E_1	1666	285	17.1	8.5	25
	E_2	2314	533	23.0	8.5	25
	$E_{1'}$	2221	785	35.3	8.5	25
Poisson's ratios *Poissonov omjer*	ν_{12}	0.202	0.145	71.8	8.5	25
	ν_{21}	0.226	0.080	35.4	8.5	25
	$\nu_{1'2'}$	0.239	0.080	33.5	8.5	25
Shear modulus, MPa *modul smicanja,* MPa	G_{12}	896	Calculated by the formula (3) / *izračunano prema jednadžbi (3)*			
		989	Calculated by the formula (4) / *izračunano prema jednadžbi (4)*			
		1037	Calculated by the formula (5) / *izračunano prema jednadžbi (5)*			

* The major OSB panel axis, x_1, is not the major axis of the core layer but it is their minor axis. / *Glavna os OSB ploče x_1 nije glavna os unutarnjeg sloja ploče, ali je njegova druga os.*

From amongst the Young's moduli determined for the OSB face layer, the $E_{1'}$ modulus produces the most scattered results.

The determination of the Poisson's ratios for OSB is significantly more difficult than the determination of the Young's moduli (Thomas, 2003) because it requires very sensitive measuring equipment and, additionally, is considerably affected by the OSB heterogeneous structure. The "major" Poisson's ratio, ν_{12}, produces the most scattered results, and the Poisson's ratio, $\nu_{1'2'}$, the least scattered results, as determined during the tension test on diagonal specimens (Fig. 1c). The value of $\nu_{1'2'}$ turned out to be much greater (by above 78 %) than ν_{12} and by above 55 % greater than ν_{21} (Table 1). The mean value of the shear modulus, G_{12}, of the face layer depending on the formula (3, 4 or 5) used, ranged from 1776 MPa to 2263 MPa.

Table 2 clearly shows that the mean value of the Young's modulus of the OSB core layer in the minor panel direction, E_2, is by above 39 % greater than E_1 (in the major panel direction). The mean value of $E_{1'}$ Young's modulus (in the $x_{1'}$ direction) turned out to be somewhat smaller than E_2 but by 33 % greater than E_1. Among the Young's moduli determined for the core OSB layer, this $E_{1'}$ modulus, like that for the face layer, produces the most scattered results. Table 2 clearly shows that the mean value of the shear modulus, G_{12}, of the core layer ranged from 989 MPa to 1037 MPa, depending on the formula (3, 4 or 5) used. Comparing the Young's moduli values of both the OSB panel layers (Tables 1 and 2), it is evident (taking into account the same strand orientation to the applied tension in testing) that the Young's moduli of the face layer are 2.18 – 2.23 times higher than those of the core layer.

The ratios of the E_1 (face) to the E_2 (core) and of the E_2 (face) to the E_1 (core) were practically identical and amounted to 2.22 and 2.23, respectively. Only the ratio of the E_1 (face) to $E_{1'}$ (core) was slightly lower and amounted to 2.18.

Similar relationship can be observed between the shear moduli values of both the OSB panel layers. The ratio of the G_{12} (face) to the G_{12} (core) amounted to 1.98 (taking into account values obtained from the formulae 3 or 5) and 2.29 (taking into account the formula 4). All the obtained Young's and shear moduli were, therefore, twice or more higher in the face layer than in the core layer.

This phenomenon was probably caused by greater density of the face layer than that of the core layer. The density measurements of OSB layers (each time on 25 samples) resulted in mean densities (taking into account the standard deviation) of 749 ± 22 kg/m^3 for the face layer and 535 ± 12 kg/m^3 for the core layer. Therefore, it turned out that the face layer density was 1.4 times greater than the core layer density. This face/core density ratio is in good accordance with the results of the numerical simulations of OSB vertical density profile carried out by Painter *et al.* (2006[a]). Taking into consideration earlier obtained OSB panel density of 593 kg/m^3, it was possible to estimate the thickness of each layer. These estimated values of 0.7 *h* for the core layer (where *h* - thickness of the OSB panel) and 0.15 *h* for the face layer are in good accordance with the data obtained on the basis of our own earlier, unpublished experiments.

Similar correlation between Young's moduli in tension and density of OSB layers was proved by Steidl *et al.* (2003). They explained the relatively high scatter of tensile properties of OSB layer (average coefficient of variation of 39 %) by the small specimen size used in their work. In this study, in spite of the smaller specimen size, the average coefficient of variation for all Young's moduli of both the OSB layers was considerably lower and amounted to 19 %. It was probably caused by the greater thickness of the face and core specimens (3 and 5.5 mm, respectively) than in the experiment of Steidl *et al.* (2003), where it was about 1.2 mm. The smaller thickness of the OSB specimens undoubtedly resulted in their higher non-homogeneity.

Specimens cut from an entire OSB panel parallel to their major axis, x_1, will indicate greater differentiation of elastic properties through the thickness than specimens cut perpendicular to this axis. The ratio of the E_1 (face) to the E_1 (core) amounted to 3.09, while the ratio of the E_2 (face) to the E_2 (core) only amounted to 1.61. This will be due to a combination of a denser face and the strands being oriented parallel or perpendicular to the applied tension. Steidl *et al.* (2003) came to similar conclusions.

The values of Poisson's ratios (except $\nu_{1'2'}$) turned out to be quite similar for both the layers. Similarly as for the face layer, $\nu_{1'2'}$ achieved the highest value of the Poisson's ratio for the core layer – obtained at 45° to the principal (x_1 and x_2) OSB panel directions.

In spite of identical test conditions (air temperature and relative humidity), the moisture content (MC) of face and core specimens, determined after the elastic tension testes were completed (Tables 1 and 2), turned out not to be identical. The MC of the core specimens (8.5 %) was somewhat higher than that of the face specimens (6.9 %). This phenomenon was probably caused by the lower density of the core layer and by some OSB processing factors, too. Neimsuwan *et al.*, (2008) established that a higher compression ratio leads to a slight decrease in strands equilibrium moisture content (EMC). They additionally stated that the strand EMC is affected by the platen temperature as well as by the wax and resin loading.

Table 3 summarises the results of the additional, destructive tension tests on the OSB face and core layers. It shows that the samples cut from the OSB face layer at 0° (to the major OSB axis, x_1) had the highest tensile strength, while the samples cut from the core layer at the same direction had the lowest tensile strength. The values of the mean tensile strength for all types of core samples (0°, 45° and 90°) turned out to be decidedly lower than those obtained for the face samples. All the tensile strength data in Table 3 are surprisingly low in comparison with the PN EN 12369-1 (2002) standard requirements for the OSB/3 (9.4 MPa at 0° and 7 MPa at 90°, respectively). This phenomenon was probably caused by the modified experiment

Table 3 Tensile strength of the layers of OSB/3
Tablica 3. Vlačna čvrstoća slojeva OSB/3 ploča

Layer *Sloj*	Angle to x_1 axis (sample type) *Kut u odnosu prema osi x_1*	Mean cross-section *Srednji poprečni presjek* mm²	Mean destructive force *Srednja sila loma* N	Tensile strength, MPa *Vlačna čvrstoća, MPa*		
				Mean *Srednji*	Std. Dev. *Stand. dev.*	Coef. Var. *Koef. var.*
upper face *vanjski sloj*	0º	85.26	950	11.15	1.74	15.6
	45º	86.60	506	5.84	0.75	12.8
	90º	91.06	561	6.15	0.76	12.3
core* *unutarnji sloj*	0º	167.34	642	3.84	0.20	5.2
	45º	168.86	737	4.37	0.46	10.4
	90º	167.36	766	4.58	0.54	11.8

* The major OSB panel axis, x_1, is not the major axis of the core layer but it is their minor axis. / *Glavna os OSB ploče x_1 nije glavna os unutarnjeg sloja ploče, ali je njegova druga os.*

procedure due to the use of very thin samples. Because of that, the increased non-homogeneity of these samples, in regard to the whole OSB panel, has probably increased the stress concentration and induced their premature failure.

Specimens cut from an entire OSB panel parallel to their major axis, x_1, will be indicate greater differentiation of strength properties through the thickness than specimens cut perpendicular to this axis.

In the first case, the ratio of the tension strength of the face to the core layer amounted to 2.9, while in the second case it was only 1.34. This was, similarly as for elastic properties, due to a combination of a denser face and the strands being oriented parallel or perpendicular to the applied tension. The first ratio is smaller and the second greater than those reported by Steidl *et al.* (2003).

4 CONCLUSIONS
4. ZAKLJUČAK

All the obtained results confirmed that the face and core layers of commercial OSB/3 panel, 18 mm thick, differ considerably with respect to density, elastic and strength properties. However, they show the characteristics of an orthotropic material with their strongest properties in the direction of the strand orientation. Due to the lack of the manufacturer's data on the thickness of individual layers of OSB panel, the thickness of each face layer was, experimentally, estimated between 2 and 3.5 mm. The density of the face layer was 40 % higher in comparison with that of the core layer. According to all three investigated directions (0°, 45° and 90°) used in this study, all the Young's moduli of the face layer were 2.18 - 2.23 times higher than those of the core layer. Similarly, the shear modulus of the face layer was twice higher than that of the core layer. Only the values of Poisson's ratios (except for $\nu_{1,2}$) were quite similar for both layers. In spite of the distinct differences between the values of all the elastic moduli obtained for both OSB/3 layers, the ratios of the E_1 to E_2 moduli for each layer were practically identical and amounted to 1.38 (in the core layer E_2 to E_1). This phenomenon is probably caused by a similar degree of strand alignment in both face and core layers. The tensile strength values for both OSB layers showed distinct differences, too. The ratios of the tension strength of face to core layer obtained in tension tests at 0°, 45° and 90° (with respect to the strand direction) were 2.43, 1.34 and 1.6, respectively.

Specimens cut from the entire OSB panel parallel to their major axis will indicate greater differentiation of elastic and strength properties through the thickness than specimens cut perpendicular to this axis. This phenomenon is caused by a combination of denser OSB face and identity of strands and tension directions.

This study enhances the understanding of the mechanical behaviour of OSB panels and may be useful to predict OSB panel bending, elastic and strength properties.

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Modelling of Drying Curves of Spruce, Beech, Willow and Alder Particles

Modeliranje krivulja sušenja iverja od drva smreke, bukve, vrbe i johe

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ABSTRACT • *Drying behaviour of spruce (Picea abies (L.) H. Karst.), beech (Fagus sylvatica L.), willow (Salix alba L.), and alder (Alnus glutinosa (L.) Gaertn.) particles was investigated in a convective dryer at constant air velocity of 0.01 m/s and at the drying air temperature of 25, 60, 80, and 150 °C. The results of the experiments have shown that the wood species and drying air temperature influence the drying behaviour. The experimental drying data of wood particles obtained were fitted to six empirical models. The effects of wood species and drying air temperature on the drying model parameters were determined. The accuracy of the models was measured using the determination coefficient (R^2), root mean square error (RMSE), and reduced chi–square (χ^2). The results showed that Lewis model, Henderson and Pabis model, and modified Page model, with the model parameters determined taking into account the effect of wood species and of drying air temperature, were found to satisfactorily describe the drying curves of spruce, beech, willow, and alder particles.*

Key words: *wood species, particles, drying kinetics, drying temperature, modelling*

SAŽETAK • *U radu su prikazani rezultati istraživanja procesa sušenja iverja od drva smreke (Picea abies (L.) H. Karst.), bukve (Fagus sylvatica L.), vrbe (Salix alba L.) i johe (Alnus glutinosa (L.) Gaertn.) u konvekcijskoj sušionici pri konstantnoj brzini zraka od 0,01 m/s i pri temperaturi zraka 25, 60, 80 i 150 °C. Rezultati pokusa pokazali su da vrsta drva i temperatura zraka utječu na tijek procesa sušenja drvnog iverja. Podaci dobiveni sušenjem iverja analizirani su s pomoću šest empirijskih modela. Određen je učinak vrste drva i temperature zraka na parametre modela sušenja. Točnost modela mjerena je veličinom koeficijenta determinacije (R^2), korijena srednje vrijednosti kvadrata pogreške (RMSE) i reduciranog hi-kvadrata (χ^2). Rezultati su pokazali da se krivulje sušenja iverja od drva smreke, bukve, vrbe i johe na zadovoljavajući način mogu opisati primjenom Lewisova modela, Hendersonova i Pabisova modela te modificiranoga Pageova modela s parametrima određenima tako da se uzmu u obzir utjecaj vrste drva i temperature zraka pri sušenju iverja.*

Ključne riječi: *vrsta drva, iverje, kinetika sušenja, temperatura sušenja, modeliranje*

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1 INTRODUCTION
1. UVOD

Drying of wood particles is one of the main steps not only in a particleboard production process but also in biofuel (pellets and briquettes) production process. For pellet production, the wood must be dried to the range 0.09-0.14 kg H_2O/kg d.m. (dry matter) moisture content (Ståhl *et al*., 2004). Consumption of high amount of energy, apart from environmental impacts, makes drying one of the most energy intensive operations with a great importance in particleboard, pellet and briquette manufacturing. Hence, reducing energy consumption, besides product quality, would be highly important for drying the raw materials used in industry (Zarea Hosseinabadi *et al*., 2012). Improvements in the wood drying process are accompanied by better understanding of the drying process (Kohantorabi *et al*., 2015).

Wood drying is a complex process of heat and mass transfer, which is conditioned by some phenomena, such as heat/moisture exchange between wood and environment, and heat/moisture movement in wood (Kajalavičius, 2008). It can be stated that this technological process is based on considerably complicated hydro-thermal process and, despite the noticeable effort of scientists and technologists, it has not yet been fully clarified (Dzurenda and Deliiski, 2012).

Investigation of drying kinetics is one of the best methods to get sufficient information about drying performance. Experimental data from the drying curves can be used in simulation of wood particle drying to optimize the particleboard and biofuel production processes (Zarea Hosseinabadi *et al*., 2012).

An important aspect of drying technology is the mathematical modelling of the drying process. Mathematical modelling provides a tool to enable drying rate and efficiency to be predicted under a range of conditions. Scientists developed various mathematical models on the basis of which it would be possible to predict wood moisture content under changing conditions and moisture movement in wood (Turner, 1996; Gigler *et al*., 2000; Truscott and Turner, 2005; Deliiski and Syuleymanov, 2006; Zarea Hosseinabadi *et al*., 2012). To account for the effect of drying variables on the drying model constants and coefficients, the predicted values were also correlated as a function of drying air temperature and air flow velocity (Zarea Hosseinabadi *et al*., 2012) or initial material load, particle shape and size (Kaleta and Górnicki, 2010). There is, however, no information on the investigation of the effect of wood species on the drying models constants and coefficients. Therefore, the aim of the present study was to investigate the effect of wood species and of drying air temperature on the drying model parameters.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Raw material
2.1. Sirovina

In this research, sawdust of spruce (*Picea abies* (L.) H. Karst.), beech (*Fagus sylvatica* L.), willow (*Salix alba* L.), and alder (*Alnus glutinosa* (L.) Gaertn.) was used in the drying experiments. Sawdust was obtained from a sawmill. The size distribution of raw material determined through screen analysis was as follows: the size of 86 % of all particles for spruce, 82 % for beech, 84 % for willow, and 77 % for alder was less than 10 mm and bigger than 0.5 mm. Sawdust particles totalling 14 % for spruce, 18 % for beech, 16 % for willow, and 23 % for alder passed through the 0.5 mm screen. The initial moisture content of samples ranged from: 0.45 to 0.49 kg H_2O/kg d.m. for spruce, 0.85 to 0.90 kg H_2O/kg d.m. for beech, 0.77 to 0.82 kg H_2O/kg d.m. for willow, 1.07 to 1.16 kg H_2O/kg d.m. for alder.

2.2 Drying procedure
2.2. Postupak sušenja

The drying experiments were carried out using Memmert UFP400 (MEMMERT GmbH+Co. KG, Schwabach, Germany) laboratory dryer. The drying experiments were conducted at the drying air temperature of 25, 60, 80, and 150 °C and airflow velocity of 0.01 m/s. Measurements of the moisture content changes carried out in the laboratory dryer were conducted in the following way. The sample was put on the tulle stretched on the metal frame (scale) and hung up to the electronic scales WPX 650 (RADWAG, Radom, Poland). The accuracy of the weighing was ±1 mg. Computer connected to the scales was an additional equipment of experimental stand. It recorded the mass of dried sample at regular intervals of 60 s. Measurements of mass changes were recorded up to the moment, when the mass changes of the sample were not observed. Experiments were replicated three times.

Air temperature inside the dryer was measured with ±0.1 °C accuracy using thermocouple TP–01b–W3 (NiCr–NiAl, CZAKI THERMO–PRODUCT, Raszyn, Poland), placed at the central part of dryer chamber. Temperature reading was done with EMT–08 meter (CZAKI THERMO–PRODUCT, Raszyn, Poland). The velocity of drying air was measured with ±3 % accuracy using Kestrel®4000 Packet Weather™ Tracker™ (Nielsen–Kellerman Company, Boothwyn, PA, USA).

The initial and final moisture contents of sawdust were determined using the oven method (ASAE, 1994).

2.3 Mathematical modelling of drying and data analysis
2.3. Matematičko modeliranje procesa sušenja i analiza podataka

Table 1 indicates the models used to describe the drying kinetics of wood particles, where *a*, *b*, *k*, *n* are constants of the models and *t* is the time. The dimensionless moisture ratio MR is given by

$$\mathrm{MR} = \frac{M_t - M_e}{M_0 - M_e} \tag{1}$$

Where M_t is the moisture content at *t*, M_e is the equilibrium moisture content, and M_0 is the initial moisture content. Moisture contents are on dry basis.

The models applied are empirical models. From the practical point of view, the simple models having

Table 1 Models applied to drying curves
Tablica 1. Modeli primijenjeni za krivulje sušenja

Model No. *Broj modela*	**Model equation** *Jednadžba modela*	Model name *Naziv modela*	**Reference** / *Izvor*
1	$MR = \exp(-k \cdot t)$	Lewis (Newton)	Lewis, 1921
2	$MR = a \cdot \exp(-k \cdot t)$	Henderson and Pabis	Henderson and Pabis, 1961
3	$MR = \exp(-k \cdot t^n)$	Page	Page, 1949
4	$MR = \exp[-(k \cdot t^n)]$	Modified Page	Overhults *et al.*, 1973
5	$MR = 1 + a \cdot t + b \cdot t^2$	Wang and Singh	Wang and Singh, 1978
6	$MR = a \cdot t^2$	Geometric	Chandra and Singh, 1995

no more than two parameters were chosen. Although empirical models neglect the fundamentals of drying, they are easy to use because such models give a direct relationship between average moisture content and drying time. Empirical models are very often used in practical drying.

In order to determine the moisture ratio as a function of drying time, drying curves obtained in the experiments were fitted to six different models (Table 1). A non-linear regression analysis was conducted to fit the models by the Lavenberg–Marquardt method using the computer program STATISTICA 10.

The goodness of fit of each model to the experimental data was evaluated from the coefficient of determination (R^2), the root mean square error (RMSE), and reduced chi – square (χ^2). High values of R^2 and low values of RMSE and χ^2 are needed to show a suitable model that describes the drying curve of wood particles (Zarea Hosseinabadi *et al*., 2012; Kaleta *et al*. 2013; Gómez-de la Cruz *et al*., 2015).

The effect of wood species and drying air temperature on the drying model parameters was investigated in the following way. The constants and coefficient of the models 1-6 involving the mentioned variables were determined by investigating the following type of dependences: summation $Y = f\,(wood\ species) + f\,(\mathrm{T})$, subtraction $Y = f\,(wood\ species) - f\,(\mathrm{T})$, multiplication $Y = f\,(wood\ species) \cdot f\,(\mathrm{T})$, division $Y = f\,(wood\ species)\,/\,f\,(\mathrm{T})$, where Y is the variable, T is the temperature. The effect of the drying air temperature was determined by considering the following type of equations: linear $f\,(\mathrm{T}) = A + B{\cdot}T$, rational $f\,(\mathrm{T}) = A + B{\cdot}T^{-1}$, logarithmic (natural) $f\,(\mathrm{T}) = A + B \cdot \ln(T)$, logarithmic (common) $f\,(\mathrm{T}) = A + B \cdot \log(T)$, and square $f\,(\mathrm{T}) = A + B{\cdot}T + C{\cdot}T^2$, where A, B, and C are the coefficients independent of wood species. The effect of wood species was determined by investigating the following equation: $f\,(wood\ species) = A_w$, where A_w is the coefficient which is independent of the drying air temperature.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Drying characteristics
3.1. Obilježja procesa sušenja

The drying of wood particles was affected by drying air temperature (Fig. 1). Each of the drying curves $M(t)$ represents an empirical formula, which approximates the results of three measurement repetitions of the moisture content changes with time. Each of the drying rate curves dM/dt was obtained by differentiation of the drying curves.

Fig. 1 shows that the higher the air temperature, the shorter was the drying time and the higher was the drying rate. The following explanation of the obtained experimental results can be presented. Heat transfer rate increases with increasing of drying temperature and, therefore, the water molecules move faster. Moreover, the moisture diffusion coefficient increases with increasing of discussed temperature. Consequently, the water migration inside the product accelerates with increasing of drying temperature (Kaleemullah and Kailappan, 2005; Kashaninejad *et al*., 2007; Zielińska and Markowski 2007; Zarea Hosseinabadi *et al*., 2012). The same trends as discussed for alder (Fig. 1) were obtained for spruce, beech, and willow particles. The decrease in drying time and increase in drying rate with the increase in drying air temperature have been also observed for particles of Scots pine (Bauer, 2003) and poplar particles (Zarea Hosseinabadi *et al*., 2012).

The initial moisture content of the investigated wood species was different. Therefore, in order to compare the course of their drying, the moisture ratio vs. time chart is presented in Fig. 2. It can be stated that the drying of wood particles was affected by wood species. Fig. 2 shows that the shortest drying time was observed for spruce particles and the longest for beech ones. This can be explained by different densities of beech, alder, spruce, and willow. Such an explanation,

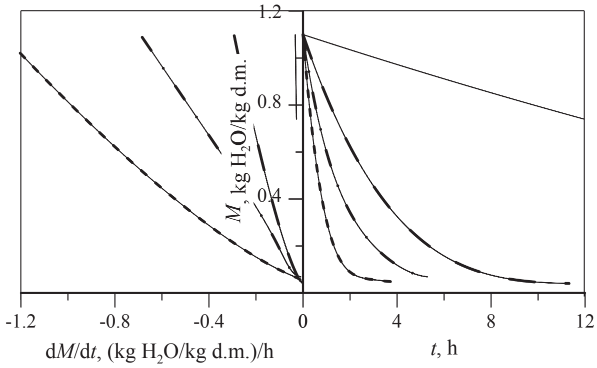

Figure 1 Moisture content vs. time and drying rate vs. moisture content for drying of alder particles at different air temperatures; – 25 °C, – – 60 °C, - · - 80 °C, - - - 150 °C
Slika 1. Odnos sadržaja vode i vremena sušenja te odnos brzine sušenja i sadržaja vode tijekom sušenja iverja od drva johe pri različitim temperaturama zraka: – 25 °C, – – 60 °C, - · - 80 °C, - - - 150 °C

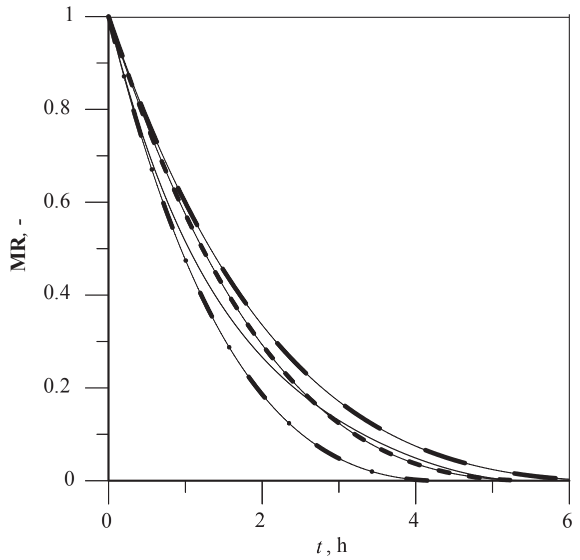

Figure 2 Moisture ratio vs. time for drying of different wood species particles at 80 °C air temperature; – alder, – – beech, - · - spruce, - - - willow
Slika 2. Odnos omjera sadržaja vode i vremena sušenja za iverje od različitih vrsta drva pri temperaturi zraka 80 °C: – joha, – – bukva, - · - smreka, - - - vrba

taking into account different densities of wood species, was given by Albrektas and Ukvalbergiené (2015) for the course of moistening process of oak, ash, and aspen wood. The explanation is as follows. In case of wood with lower density, cell cavities whose holes contain bound moisture have a relatively large internal surface. Consequently, such wood desorbs more moisture at the beginning of the drying. In present study, this can be noticed for spruce and alder. On the other hand, there is a smaller number of microcapillaries in low density wood and for this reason water migration from deeper layers becomes slower with drying duration. Desorption of moisture from wood of high density is slower and steadier. In the present study, such a situation was observed for beech particles. The same trends as discussed for drying at 80 °C were obtained at the air temperature of 25, 60, and 150 °C.

3.2 Evaluation of the models
3.2. Ocjena modela

The evaluation of the considered empirical models was conducted in the following way. The moisture content data obtained for different drying air temperatures were converted to the dimensionless moisture content expression and then curve fitting computations with the drying time were carried out using the six drying models considered above. Then the regressions were undertaken to account for the effect of wood species and drying air temperature on the drying model parameters of the six models. The effects of wood species and drying air temperature on the model parameters were also included in the models. The summation, subtraction, multiplication, and division dependences were tested. Regarding the air drying temperature, the following types of equation were used: linear, rational, logarithmic (natural), logarithmic (common), and square. The multiple combinations of the parameters that gave the highest R^2-values were included in the final model. The considered equations with the determined coefficients were then used to estimate the moisture content of spruce, beech, willow, and alder particles at any time during the process. Validation of the established models was made by comparing the computed moisture content with the measured ones in any particular drying run under certain conditions.

It turned out from the statistical analyses that the models 1, 2, and 4 (Table 2) with the model parameters determined with the following type of equations: 1) summation (or subtraction) and linear, rational or logarithmic (common), 2) multiplication and square, 3) division and linear or rational can be considered as appropriate for spruce, beech, willow, and alder particles. In case of calculating the model parameters using summation (or subtraction) and square type of equation, the models 1, 2, 3, and 4 can be assumed as suitable models for describing the drying process of the considered wood particles. It can be accepted that model 1 with the model parameters determined by division and logarithmic (common) equation gave acceptable results for drying characteristics of spruce, beech, willow, and alder particles. Models 1, 2, 4, and 5 with division and square model parameters seemed to be appropriate for the examined wood particles. Taking into account values of R^2, RMSE, and χ^2, however, it can be stated that the best results of the above cases were obtained by model 1, 2, and 4 with the model parameters determined by summation (or subtraction) and linear, rational, logarithmic (common) or square type of equations.

It can be concluded from the analysis that the effect of wood species and of drying air temperature on the drying model parameters can be considered individually (Table 3).

By substituting the coefficients given in Table 3 into parameter equations and then substituting the discussed equations into tested models, the course of drying curve can be predicted for spruce, beech, willow, and alder particles in the temperature range of 25 – 150 °C. Obtained results can be used in practice. From the practical point of view, the used drying models need to be accurate and simple in application. Therefore, models 1 and 2 can be recommended for practical applications. The results of statistical analysis for the recommended models are as follows: model 1 (Lewis (Newton) model): R^2 = 0.8347 – 0.9998, RMSE = 0.0203 – 0.3529, χ^2 = 0.0002 – 0.1250 and model 2 (Henderson and Pabis model): R^2 = 0.8287 – 0.9998, RMSE = 0.0200 – 0.3229, χ^2 = 0.0004 – 0.1044.

4 CONCLUSIONS
4. ZAKLJUČAK

Drying behaviour of spruce, beech, willow, and alder particles was investigated in a convective dryer. The effect of wood species and air drying temperature on the drying model parameters was investigated. Six empirical models were considered. The determination coefficient (R^2), root mean square error (RMSE), and

Table 2 Type of parameter equation and comparison of results of statistical analysis of modelling of drying of spruce, beech, willow, and alder particles
Tablica 2. Vrsta parametarske jednadžbe i usporedba rezultata statističke analize modeliranja procesa sušenja iverja od drva smreke, bukve, vrbe i johe

Type of parameter equation *Vrsta parametarske jednadžbe*	**Models No.** *Broj modela*	R^2	**RMSE**	χ^2
Summation (or subtraction) and linear	1	0.9511-0.9998	0.0203-0.1059	0.0002-0.0112
zbrajanje (ili oduzimanje) i linerna	2	0.9364-0.9991	0.0200-0.1072	0.0004-0.0115
$Y = A_W \pm (A + B \cdot T)$	4	0.8962-0.9920	0.0515-0.1213	0.0025-0.0148
Summation (or subtraction) and rational	1	0.9277-0.9980	0.0203-0.1270	0.0004-0.0161
zbrajanje (ili oduzimanje) i racionalna	2	0.9101-0.9990	0.0202-0.1287	0.0004-0.0166
$Y = A_W \pm (A + B \cdot T^{-1})$	4	0.8731-0.9631	0.0596-0.1421	0.0035-0.0203
Summation (or subtraction) and logarithmic (common)	1	0.9402-0.9988	0.0240-0.1163	0.0003-0.0135
	2	0.9242-0.9929	0.0248-0.1179	0.0004-0.0159
zbrajanje (ili oduzimanje) i logaritamska $Y = A_W \pm [A + B \cdot \log(T)]$	4	0.8903-0.9782	0.0529-0.1316	0.0028-0.0174
Summation (or subtraction) and square	1	0.9700-0.9997	0.0335-0.0868	0.0011-0.0075
zbrajanje (ili oduzimanje) i kvadratna	2	0.9603-0.9998	0.0295-0.0877	0.0009-0.0077
$Y = A_W \pm (A + B \cdot T + C \cdot T^2)$	3	0.8906-0.9759	0.0526-0.1252	0.0027-0.0157
	4	0.8949-0.9826	0.0478-0.1101	0.0022-0.0122
Multiplication square	1	0.8870-0.9992	0.0273-0.3529	0.0007-0.1250
množenje i kvadratna	2	0.8612-0.9986	0.0214-0.3183	0.0005-0.1014
$Y = A_W \cdot (A + B \cdot T + C \cdot T^2)$	4	0.8629-0.9750	0.0569-0.2753	0.0032-0.0763
Division and linear	1	0.9202-0.9991	0.0271-0.2839	0.0007-0.0809
dijeljenje i linearna	2	0.9292-0.9992	0.0202-0.2361	0.0004-0.0559
$Y = A_W / (A + B \cdot T)$	4	0.8198-0.9693	0.0694-0.3082	0.0048-0.0956
Division and rational	1	0.8450-0.9992	0.0271-0.2706	0.0007-0.0733
dijeljenje i racionalna	2	0.8287-0.9987	0.0201-0.2203	0.0004-0.0486
$Y = A_W / (A + B \cdot T^{-1})$	4	0.8195-0.9692	0.0605-0.3012	0.0036-0.0913
Division and logarithmic (common) *dijeljenje i logaritamska* $Y = A_W / [A + B \cdot \log(T)]$	1	0.9203-0.9992	0.0271-0.2763	0.0007-0.0766
Division and square	1	0.8347-0.9992	0.0276-0.3353	0.0007-0.1043
dijeljenje i kvadratna	2	0.9288-0.9986	0.0217-0.3229	0.0005-0.1044
$Y = A_W / (A + B \cdot T + C \cdot T^2)$	4	0.8303-0.9754	0.0481-0.2842	0.0023-0.0755
	5	0.8569-0.9743	0.0945-0.3344	0.0053-0.1122

R^2 - determination coefficient / *koeficijent determinacije*; *RMSE* - root mean square error / *korijen srednje vrijednosti kvadrata pogreške*; χ^2 - reduced chi-square / *reducirani hi-kvadrat*

Table 3 Coefficients of parameter equations for chosen models of drying of spruce, beech, willow, and alder particles
Tablica 3. Koeficijenti parametarskih jednadžbi izabranih modela procesa sušenja iverja od drva smreke, bukve, vrbe i johe

Model No. *Broj modela*	**Type of parameter equation** *Vrsta parametarske jednadžbe*	**Param-eter** *Param-etar*	A_w				*A*	*B*	*C*
			Spruce *Smreka*	**Beech** *Bukva*	**Willow** *Vrba*	**Alder** Joha			
1	Summation (or subtraction) and logarithmic (common) *zbrajanje (ili oduzimanje) i logaritamska* $Y = A_W \pm [A + B \cdot \log(T)]$	*k*	0.000929	0.001394	0.001858	0.000465	-0.420312	0.169434	-
2	Summation (or subtraction) and linear *zbrajanje (ili oduzimanje) i linearna* $Y = A_W \pm (A + B \cdot T)$	*k*	0.001319	0.001979	0.002639	0.000660	-0.066479	0.000220	-
		a	0.005172	0.007758	0.010344	0.002586	1.172629	-0.000321	-
4	Multiplication and square *množenje i kvadratna* $Y = A_W \pm (A + B \cdot T + C \cdot T^2)$	*k*	-0.000018	-0.000026	-0.000035	-0.000009	-2078.24	17.07	-0.03
		n	-0.003710	-0.005565	-0.007420	-0.001855	-1296.87	5.73	-0.01
5	Division and square *dijeljenje i kvadratna* $Y = A_W / (A + B \cdot T + C \cdot T^2)$	*a*	-16.711	-25.066	-33.421	-8.355358	220098.8	-1103.3	1.4
		b	0.106398	0.160	0.213	0.053199	2215636	-11353	14

reduced chi–square (χ^2) were examined for the applied models to compare their goodness of fit to the experimental drying data. It turned out that the effect of wood species and of drying air temperature on the drying model parameters can be considered individually (separated from one another). The following models: Lewis, Henderson and Pabis, and modified Page with the model parameters determined taking into account the effect of wood species and of drying air temperature were quite suitable for predicting the drying curve behaviour of spruce, beech, willow, and alder particles at the drying air temperature of 25, 60, 80, and 150 °C. For practical applications, Lewis model and Henderson and Pabis model can be recommended. Their goodness of fit to the experimental drying data is as follows: Lewis model: $R^2 = 0.8347 – 0.9998$, RMSE = 0.0203 – 0.3529, $\chi^2 = 0.0002 – 0.1250$ and Henderson and Pabis model: $R^2 = 0.8287 – 0.9998$, RMSE = 0.0200 – 0.3229, $\chi^2 = 0.0004 – 0.1044$.

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New Product Warranty: Empirical Evidence from Polish and Slovenian Furniture Industry

Jamstvo novih proizvoda: empirijsko iskustvo poljske i slovenske industrije namještaja

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ABSTRACT • *The aim of the study was to recognize the attitudes towards new product warranty issues in marketing practice of furniture manufacturers. The results of a survey conducted among 75 Polish and Slovenian furniture companies are presented, focusing on whether enterprises use the information concerning the length of warranty period offered for manufactured products in their marketing materials and in which cases they build their competitive strategy and strengthen their corporate identity based on warranty issues. Data collected through direct interviews and surveys was subjected to a comprehensive statistical analysis using statistical grouping method, cluster analysis and correspondence analysis. The results showed that most often the information on the length of warranty period is used commercially by manufacturers of furniture for children and kitchen furniture. The coexistence of variables connected with the offered warranty period for furniture products, the use of information concerning warranty in advertising materials, implementation of a long-term design management strategy, the development of a positive image of the company in the market based on the comprehensive visual identity project and the limited number of years when the company has been operating in the market was showed.*

Key words: *new products, product warranty, competitive advantage, empirical study, statistical analysis*

SAŽETAK • *Cilj istraživanja bio je upoznati mišljenja proizvođača namještaja o jamstvima proizvoda koji se pojavljuju u marketinškoj praksi. Prikazani su rezultati ankete provedene među 75 poljskih i slovenskih proizvođača namještaja. Naglasak ankete bio je na pitanju koriste li se poduzeća informacijama o duljini razdoblja jamstava što ih u svojim marketinškim materijalima nude za proizvode i u kojim slučajevima na jamstvima za proizvode grade svoju konkurentsku strategiju i jačaju svoj korporativni identitet. Podaci prikupljeni izravnim intervjuima i anketama podvrgnuti su sveobuhvatnoj statističkoj analizi uz pomoć statističke metode grupiranja, klasterske analize i analize korespondencije. Istraživanja su pokazala da se informacijama o trajanju jamstvenog roka najčešće komercijalno koriste proizvođači namještaja za djecu i proizvođači kuhinjskog namještaja. Iz analize rezultata potvrđena je i koegzistencija varijabli povezanih s ponudom jamstvenog roka za namještaj, s uporabom informacija vezanih za jamstvo u reklamnim materijalima, s provođenjem dugoročne strategije upravljanja dizajnom,*

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s razvojem pozitivne predodžbe o tvrtki na tržištu, stvorene na temelju sveobuhvatnog projekta izrade vizualnog identiteta, kao i s ograničenim brojem godina tijekom kojih tvrtka posluje na tržištu.

Ključne riječi: *novi proizvodi, jamstvo za proizvod, konkurentska prednost, istraživanje, statistička analiza*

1 INTRODUCTION
1. UVOD

In contemporary highly competitive economies of well developed countries both quality and reliability of the product, as well as the length and terms of the warranty period, are significant factors of competitive advantage. 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). Kotler (2000) indicated that together with other aspects such as e.g. external form of the product, its functionality, price, brand, material, etc., they comprise various levels of the product, affecting evaluation of a given product by potential consumers. Frequently, next to the core of the product, i.e. the set of basic benefits received by the consumer when purchasing a given goods, the decision of acquisition is determined by categories comprising the actual product, such as e.g. the price, quality, packaging, brand, and such additional benefits (added value) as e.g. extended warranty (Kotler, 2000; Kotler *et al.*, 2002). For this reason, when designing and launching new products, enterprises should consider these issues and adequately implement them in marketing activities (Menezes and Currim, 1992). Such an approach should be adopted particularly in the case of durable goods such as e.g. furniture (Udell and Anderson, 1968; Wiener, 1985) or automotive industry (Majeske *et al.*, 1997; Zhoua *et al.*, 2012). Increased interest in issues of reliability, quality and warranty can be observed in the furniture industry (Ratnasingam *et al.*, 1997; Gremyr *et al*, 2003; Smardzewski, 2005, 2009; Kłos and Fabisiak, 2010). Reliability is an essential feature determining the commercial success of a product and it is a significant element in the competitive strategy of the enterprise (Sander and Brombacher, 2000; Murthy and Djamaludin, 2002; Murthy, 2006; Murthy, 2007; Kłos and Fabisiak, 2013a, 2013b; Ojurović *et al*, 2013). It is of importance both for furniture producers (Vickery *et al.*, 1997) and consumers (Udell and Anderson, 1968; Sinclair and Hansen, 1993; Pakarinen and Asikainen, 2001; Ratnasingam, 2003; Chien *et al.*, 2005; Knauf, 2015). Numerous authors point out that quality is particularly demanded on wood products market (Schubert, 1979; Kozak and Maness, 2003). Taking the above into consideration, the aim of the study was to gather information concerning the attitudes towards quality, reliability and warranty issues in Polish and Slovenian companies manufacturing furniture, as well as the methods of applying knowledge on these aspects in the operation of furniture enterprises.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

It was decided to collect data concerning the above subject using questionnaire studies and direct interviews. The assumed population size was 100 furniture factories located in Poland and Slovenia. The analyzed sample of enterprises was selected on the basis of a quota selection method taking into account the size of the company and geographical structure. The aim of additional in-depth interviews was explanatory research to provide better understanding of the subject and remarks from the manufacturers' point of view as well as reasons staying behind their decisions concerning the studied issues. They were performed among 30 companies manufacturing case type furniture and much interested in the topic of product reliability. Polish companies constituted 60 % of this sample and Slovenian enterprises 40 %. Collected data were coded and then subjected to a statistical analysis with the use of STATISTICA 10.0 software. Data analysis was performed applying the statistical grouping method, taking into account the division of the units based on the criteria of country of origin and realization of a long-term strategy of brand creation. Stratified sampling, with respect to this criterion, was used to explore the hypothesis that those companies exhibit a greater awareness of the need to ensure quality and reliability of produced pieces of furniture and build a positive image in the market based on that. In turn, sampling was conducted taking into account the location of the company to discover whether there are differences between attitudes of furniture manufacturers in the analyzed countries. Moreover, cluster analysis was conducted. The method according to Ward (1963) was applied as the agglomeration algorithm, which makes it possible to estimate the distances between clusters using the analysis of variance approach, as it aims to minimize the sum square of deviations within clusters. Moreover, correspondence analysis was used to investigate the coexistence of variables concerning such characteristics as the age of the company, using the information on warranty in marketing materials, providing an extended warranty period for produced furniture and realization of a long-term strategy for design development and brand creation in the market.

Taking into consideration the percentage of returned questionnaires, their completeness and the number of direct interviews performed, it was decided to conduct further statistical analyses based on data gathered from 75 units. The distribution of the sample according to the level of employment was as follows: micro companies 4 %, small companies 35 %, medium companies 43 % and big ones 18 %. The distribution of the sample regarding geographic location of companies, according to the preliminary assumptions, represents the structure of furniture industry in the investigated countries based on national statistics.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Within the conducted study, it was first decided to determine whether, in the face of increasing competition, enterprises use information concerning the length of the warranty period in their marketing materials in order to focus the attention of potential customers on the additional benefits offered in connection with a given product. The conducted analysis showed that, both among the Polish and Slovenian companies participating in the study, the percentage of enterprises providing such information in their advertising materials was around 50 %. A detailed analysis conducted using statistical grouping methods, including data concerning the size of the enterprise, showed that none of the surveyed companies with the staff of max. 9 employees provided information on the length of the warranty period in their advertising materials (Figure 1). In contrast, the percentage of companies using such information to fight their market competition increased with an increase in the size of enterprise. In the case of companies with more than 250 employees it was as much as 75%.

It was also decided to specify whether the level of usage of information concerning the length of the warranty period in the marketing materials of furniture manufacturing companies varies depending on the type and purpose of produced furniture. It was shown that the analyzed problem was of greatest importance for the manufacturers of furniture for children and teenagers as well as kitchen furniture (Figure 2). All of the analyzed Polish and Slovenian companies producing such furniture informed their prospective customers on the warranty period offered for their furniture.

Information collected during in-depth direct interviews indicated that this was connected, among other things, with the very long period of use of kitchen furniture and with the particular focus of customers on safety issues in the case of furniture designed for children and teenagers. This is confirmed by the results of research conducted e.g. by Udell and Anderson (1968), which indicated that the effectiveness of the use of warranty in marketing is best when a given product is purchased rarely or it seems complicated to the consumers. Information on the length of the warranty period is included much less frequently in advertising materials of companies producing e.g. upholstered furniture.

Incorporation of information concerning warranty in marketing materials was also related to the degree of involvement of the company in actions associated with building their own brand i.e. activities connected with the brand development and its strengthening as well as having a visual identity project and the consistent development of a positive corporate image based on the long-term strategy for the development of design operations. Differences were found in the activity of furniture enterprises in this respect (Figure 3).

Conducted analyses showed that 82 % of the analyzed companies had their own brand, while only 69 % entities undertook actions connected with its development and strengthening. Investments in the purchase of

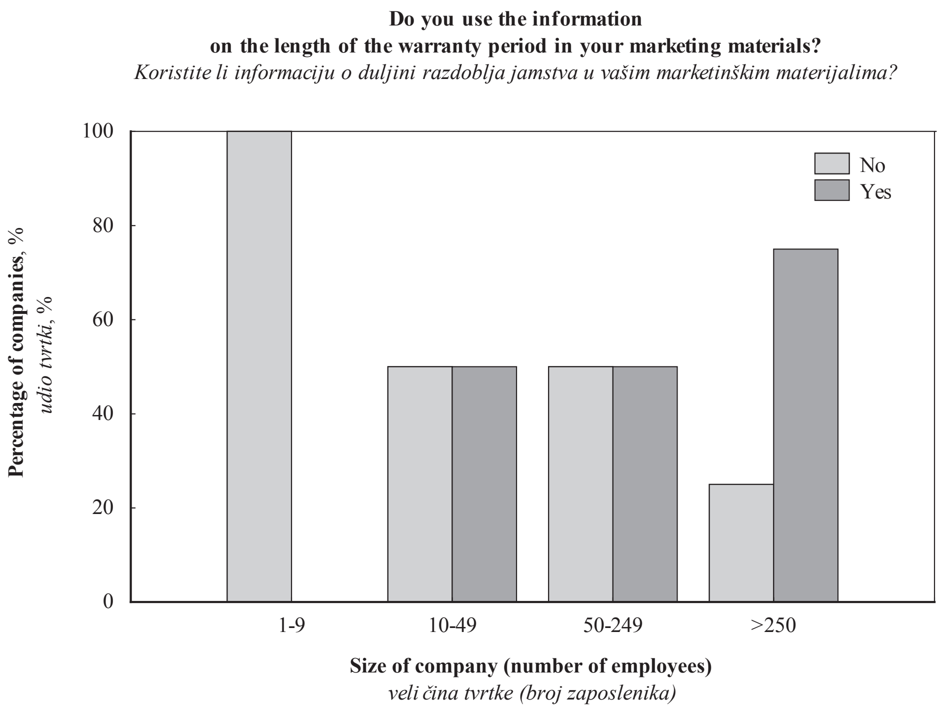

Figure 1 The distribution of analyzed enterprises in terms of their use of information on the length of the warranty period in their advertising materials depending on the size of enterprise
Slika 1. Raspodjela analiziranih poduzeća sa stajališta korištenja informacijama o duljini razdoblja jamstva za proizvode u reklamnim materijalima i ovisno o broju zaposlenih

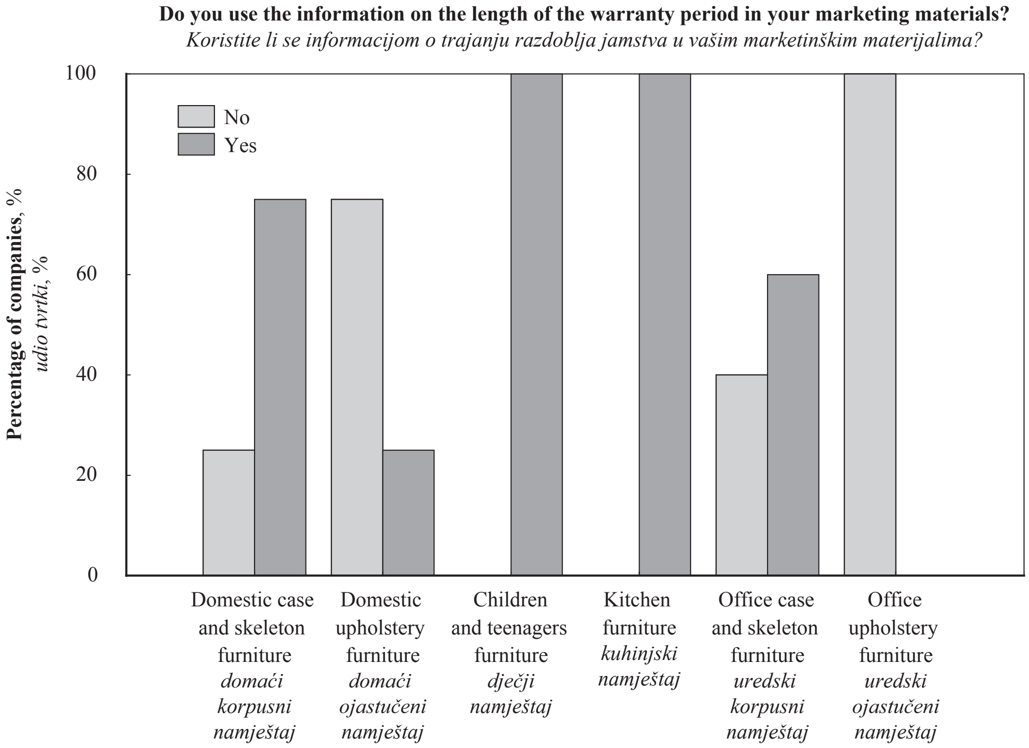

Figure 2 The distribution of analyzed enterprises in terms of use of information on the length of the warranty period in their advertising materials depending on the type of produced furniture
Slika 2. Raspodjela analiziranih poduzeća sa stajališta korištenja informacijama o duljini razdoblja jamstva za proizvode u reklamnim materijalima i ovisno o vrsti namještaja koji proizvode

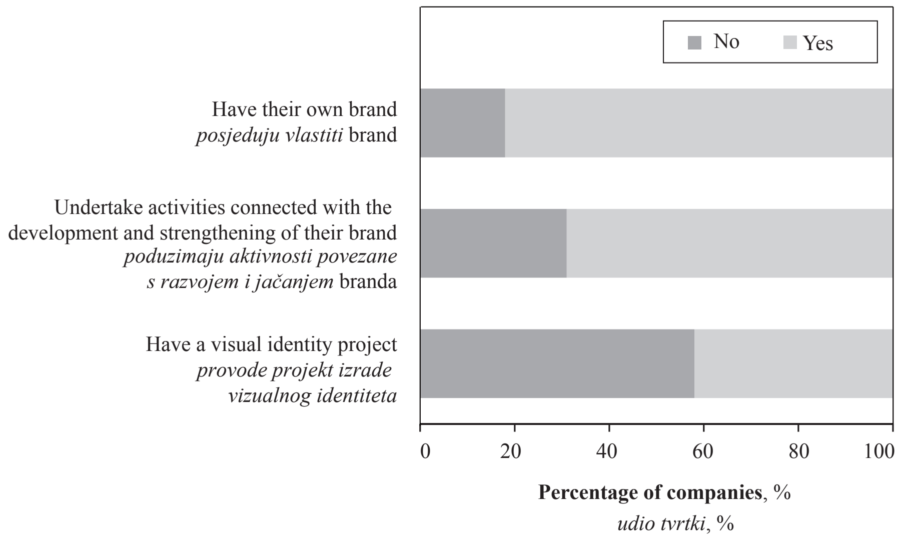

Figure 3 The distribution of analyzed furniture enterprises in terms of having their own brand, undertaking activities connected with the development and strengthening of their brand, having a visual identity project
Slika 3. Raspodjela analiziranih poduzeća za proizvodnju namještaja s obzirom na posjedovanje vlastitog *branda*, s obzirom na poduzimanje aktivnosti povezanih s razvojem i jačanjem tog *branda* te s provođenjem projekta izrade vizualnog identiteta

the visual identity project were only made by 42 % of the analyzed entities. Companies belonging to this group showed the greatest awareness of the benefits associated with the conscious creation of a brand and a positive corporate image in the market and also with the development of design operations. It was shown that this group of enterprises attained much better business results and received awards for high design value of their product range more frequently than the others. Observations presented above are confirmed by the chi-square test of independence for variables concerning the existence of the visual identity project in a given enterprise (variable *X*) and received awards for design (variable *Y*). The distribution of analyzed variables is presented in Figure 4 and in Table 1.

A verification procedure was conducted for the zero hypothesis specified as follows:

H_0: variables *X* and *Y* are independent in relation to the alternative hypothesis,

H_1: variables *X* and *Y* are not independent.

Results of the χ^2 test presented in Table 1 (χ^2 =24.5117 at p=0.00000) mean that it is admissible to

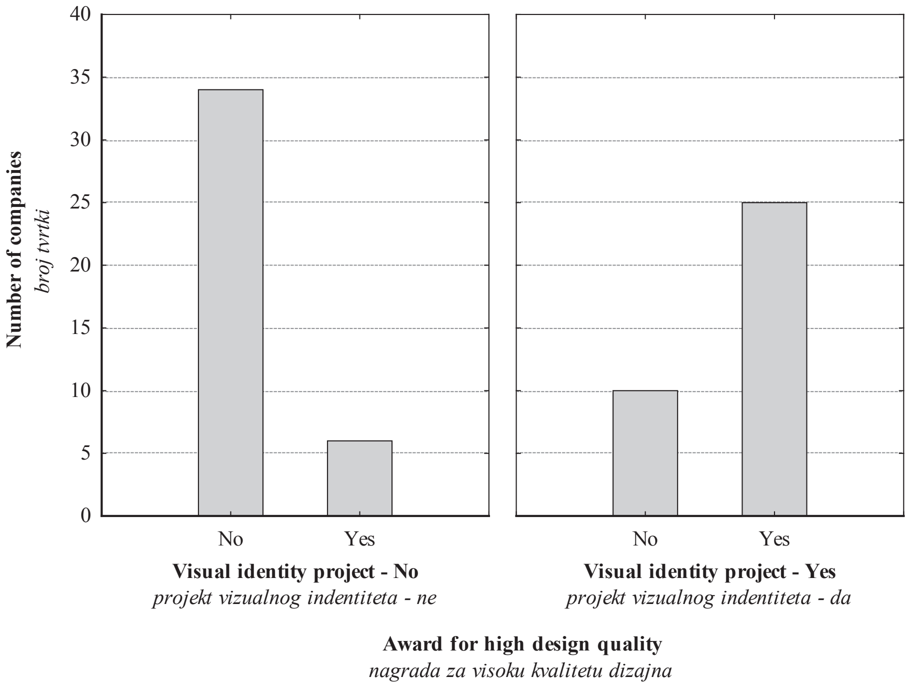

Figure 4 The distribution of analyzed furniture enterprises depending on their having a visual identity project and received awards for high design quality
Slika 4. Raspodjela analiziranih poduzeća za proizvodnju namještaja s obzirom na provedbu projekta izrade vizualnog identiteta i nagrada dobivenih za visoku kvalitetu dizajna namještaja

Table 1 Results of the chi-square independence test for variables: visual identity project and award for good design
Tablica 1. Rezultati χ^2-testa za varijable *projekt vizualnog identiteta* i *nagrada za dizajn proizvoda*

	χ^2	**Number of degrees of freedom** *Stupanj slobode*	**Level of significance** *Razina signifikantnosti*
χ^2 Pearson	24.5117	*Df* = 1	*p* = 0.00000
Contingency coefficient / *koeficijent kontingencije*	0.4963		
τ-b Kendall's coefficient / *Kendallov koeficijent*	0.5717		

reject the zero hypothesis on the independence of analyzed variables and to assume an alternative hypothesis on the existence of a relationship between investment by the enterprise in the visual identity project and receiving honors or awards for design. The value of the contingency coefficient C amounting to 0.4963 in the case of quality traits indicates a relatively strong correlation between variables. The existence of a strong positive relationship is also evidenced by the value of Kendall's τ-b coefficient (*b*=0.5717).

A detailed analysis of data coming from enterprises in both investigated countries showed that these companies used more frequently information on the length of the offered warranty period in their advertising materials. It should also be stressed here that enterprises without an active policy to establish their brand in the market did not present such information (Figure 5). The greatest percentage of companies, which built their competitive advantage using also information on the length of the warranty period offered for manufactured products, was found in the group of firms that invested in the visual identity project (Figure 6). These were enterprises that exhibited the greatest awareness of the benefits provided by the implementation of a comprehensive, clearly defined strategy of development and establishment of their own brand in the market, focusing on the quality and high design value of manufactured products. The above results were confirmed during the in-depth interviews with representatives of the studied units.

Data collected during comprehensive direct interviews showed that the more frequent presentation of information on the length of the warranty period for manufactured products in marketing materials was connected with the implementation of the strategy to create a positive image of the enterprise in the market based on customer trust and dedication to ensure high quality and reliability of products.

The chi-square test of independence was conducted for the analyzed variables. Verification was performed on the zero hypothesis specified as follows: H_0: variable *X* (information on the length of the warranty period for manufactured products incorporated in advertising materials of the company) and variable *Y* (creation of the brand based on the company visual identity project) are independent, in relation to the alternative hypothesis H_1: variables *X* and *Y* are not independent. Results of the test indicate that this dependence is significant at p = 0.07898 (χ^2 = 3.085714). Thus, we may reject the zero hypothesis on the independence of analyzed variables and accept the alternative hypothesis on the existence of a relationship be-

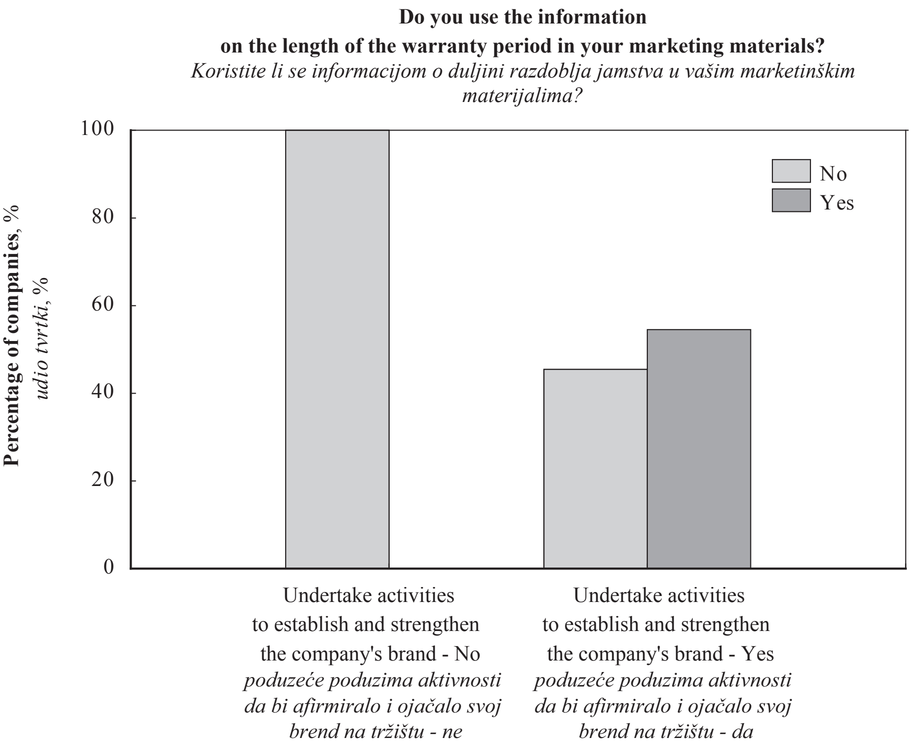

Figure 5 The distribution of analyzed enterprises in terms of their use of information on the length of the warranty period in their advertising materials depending on activities undertaken by the enterprise to establish and strengthen the position of its brand in the market
Slika 5. Raspodjela analiziranih poduzeća sa stajališta korištenja informacijama o duljini razdoblja jamstva za proizvode u reklamnim materijalima ovisno o aktivnostima koje poduzeća poduzimaju da bi afirmirali i ojačali svoj *brand* na tržištu

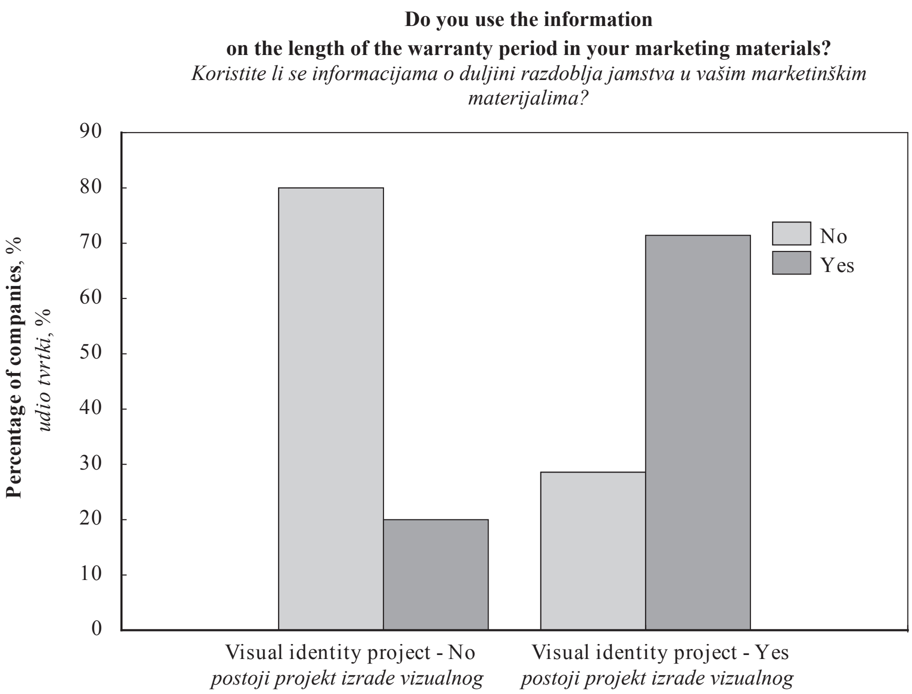

Figure 6 The distribution of analyzed enterprises in terms of the use of information on the length of the warranty period in their advertising materials depending on the existence of a visual identity project in the enterprise
Slika 6. Raspodjela analiziranih poduzeća sa stajališta uporabe informacija o duljini razdoblja jamstva za proizvode u reklamnim materijalima ovisno o postojanju projekta izrade vizualnog identiteta poduzeća

Table 2 Results of the chi-square independence test for variables: the use of information on the length of the warranty period in their advertising materials and development of the brand based on the company visual identity project
Tablica 2. Rezultati χ^2-testa za varijable korištenje informacijama o duljini razdoblja jamstva za proizvode u reklamnim materijalima i razvoj branda na temelju projekta izrade vizualnog identiteta poduzeća

	χ^2	**Number of degrees of freedom** *Stupanj slobode*	**Level of significance** *Razina signifikantnosti*
χ2 Pearson	3.0857	*Df*=1	*p*=0.079
Contingency coefficient / *Koeficijent kontingencije*	0.4523		
τ-b Kendall's coefficient / *Kendallov koeficijent*	0.5071		

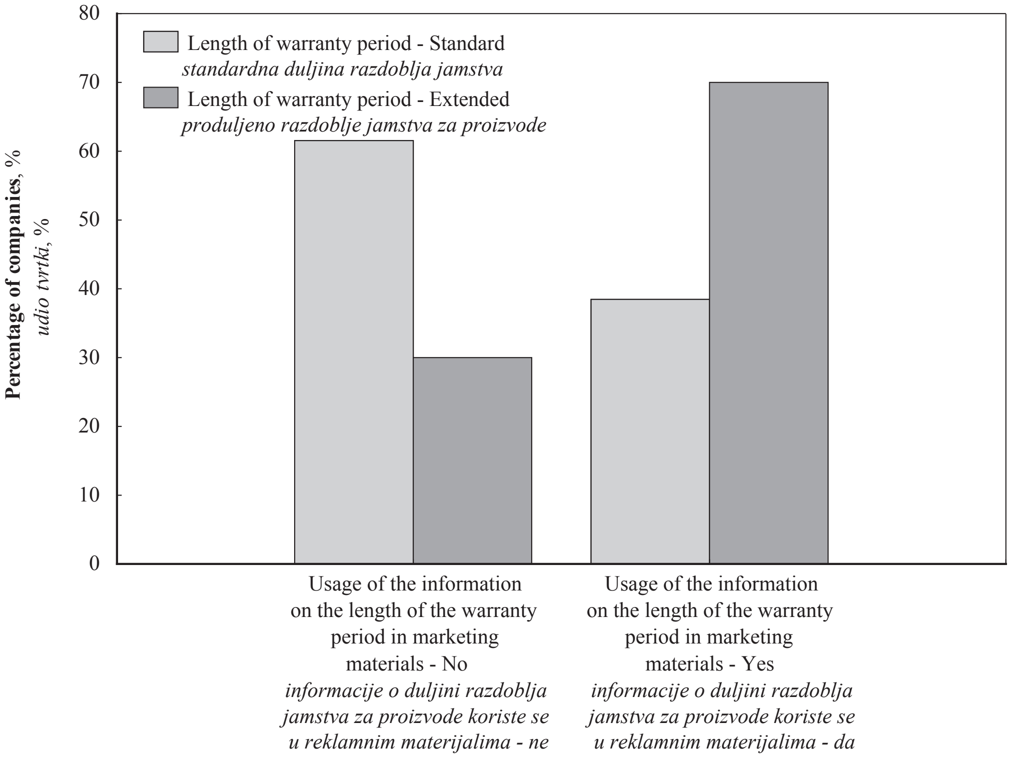

Figure 7 The distribution of analyzed enterprises in terms of the use of information on the length of the warranty period in their advertising materials depending on the offered length of warranty period
Slika 7. Raspodjela analiziranih poduzeća sa stajališta korištenja informacijama o duljini razdoblja jamstva za proizvode u reklamnim materijalima ovisno o ponuđenom razdoblju jamstva za proizvod

tween the incorporation of information on the length of the warranty period for manufactured products in the advertising materials of the company and the realization of a strategy connected with the establishment of the brand based on the company visual identity project. The moderate strength of the dependence between analyzed variables is indicated by the value of the contingency coefficient (C = 0.4522670). The strength and the positive direction of the discussed dependence have also been evidenced by Kendall's τ-b coefficient amounting to 0.5070925, which indicates a positive correlation between the investigated variables (Tab. 2).

It should also be mentioned here that, among companies using information on the length of the warranty period in their marketing activity, as many as 70 % offered an extended period of 3 up to 5 years (Figure 7).

In order to correctly define relationships between the discussed variables, the hierarchical classification of cluster analysis was applied, using Ward's method. This analysis included additionally the type of manufactured furniture. Results of cluster analysis show that, in the analyzed enterprises, two distinct main groups are found (Figure 8). The obtained results made it possible to accurately identify enterprises similar in terms of the dependence between the use of information concerning the length of the warranty period in advertising materials, the length of the offered warranty period and the type of manufactured furniture.

The first of the distinguished groups of enterprises is characterized by offering an extended warranty period for manufactured products, at the same time emphasizing in their advertising campaigns additional benefits consumers receive, connected with the extended length of the warranty period. This group includes most typically enterprises producing kitchen furniture as well as furniture for children and teenagers and non-upholstered furniture both for housing facilities and office interiors. The second group comprises companies offering a standard warranty period specified by the legal regulations. In contrast to the firms described above, these companies present this information in their marketing materials much less frequently.

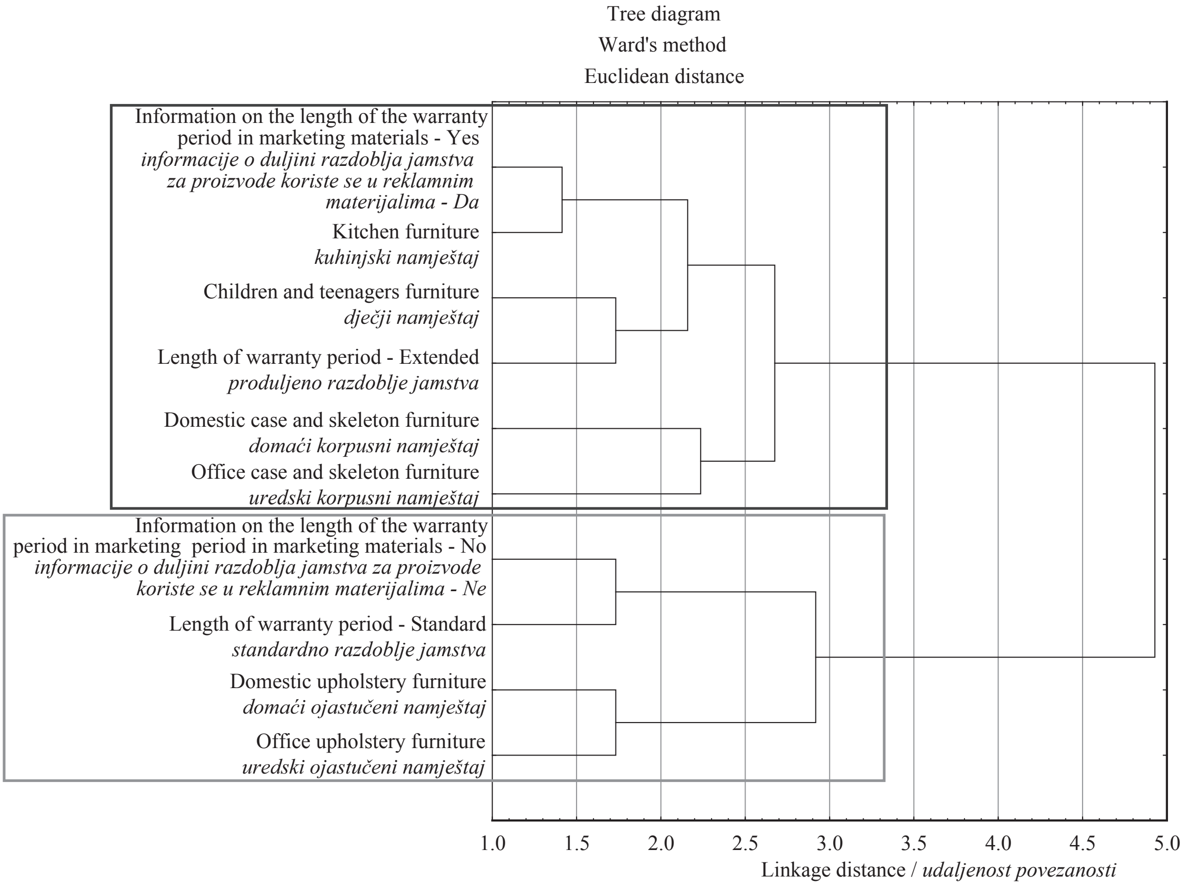

Figure 8 A graphic presentation of the results of cluster analysis for variables: incorporation of information concerning the length of the warranty period in advertising materials, the length of the offered warranty period and the type of manufactured furniture
Slika 8. Grafička prezentacija rezultata klasterske analize za ove varijable: korištenje informacijama o duljini razdoblja jamstva za proizvode u reklamnim materijalima i ponuđeno razdoblje jamstva za proizvod i vrstu namještaja

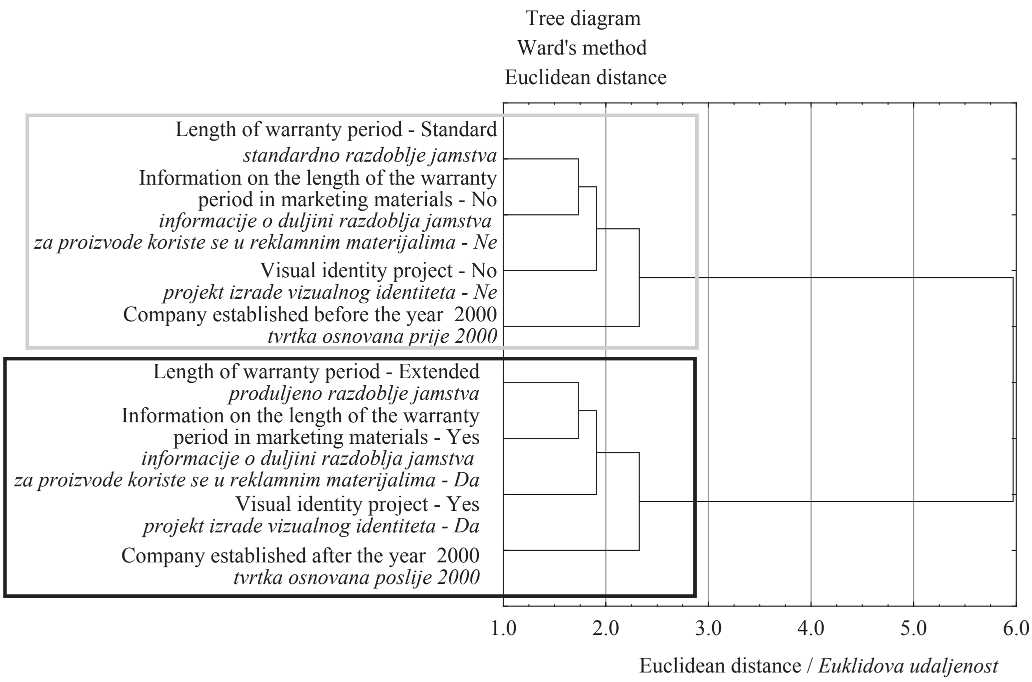

Figure 9 A graphic presentation of results of cluster analysis for variables: publishing information on the length of the warranty period in advertising materials, the length of the offered warranty period, having a visual identity project and the date when the company was established
Slika 9. Grafička prezentacija rezultata klasterske analize za ove varijable: objava informacija o duljini razdoblja jamstva za proizvode u reklamnim materijalima, ponuđeno razdoblje jamstva za proizvod, provedba projekta izrade vizualnog identiteta poduzeća i datum osnivanja poduzeća

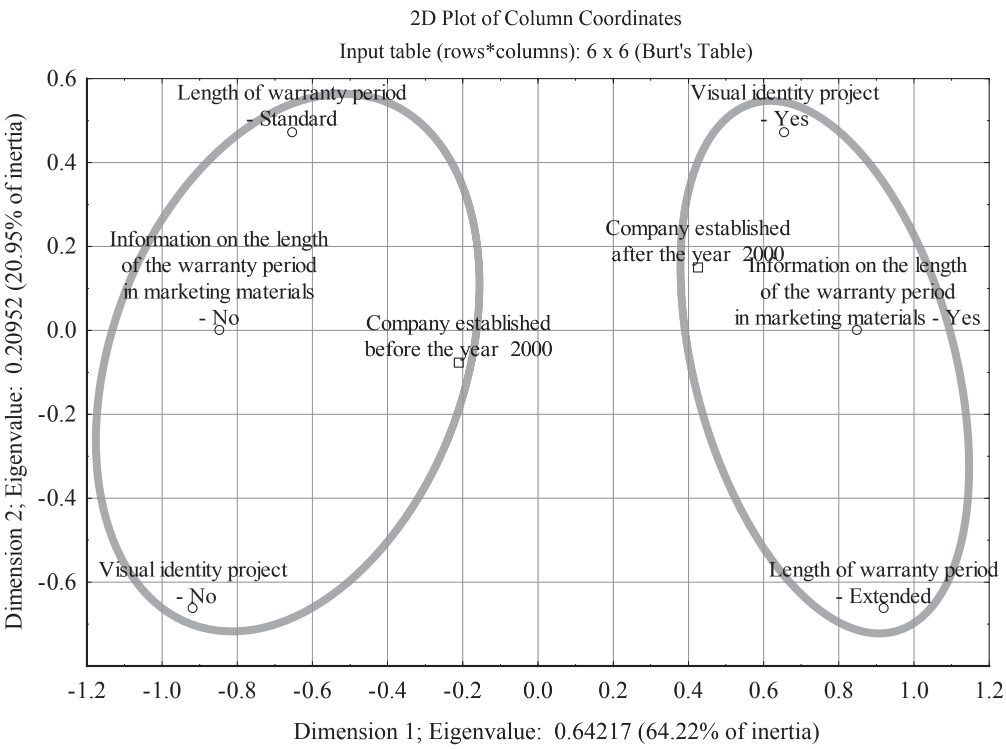

Figure 10 A graphic presentation of results of correspondence analysis for variables specifying the use of information concerning the length of the warranty period in advertising materials, the length of the offered warranty period, having a visual identity projects; additional points: the date when the company was established
Slika 10. Grafička prezentacija rezultata analize korespondencije za ove varijable: objavljene informacije o duljini razdoblja jamstva za proizvode u reklamnim materijalima, ponuđeno razdoblje jamstva za proizvod, provedba projekta izrade vizualnog identiteta poduzeća i za dodatnu varijablu – datum osnivanja poduzeća

The analysis was performed to identify the manner in which furniture enterprises establish their competitive edge and strengthen their positive image in the market based on quality, reliability and warranty for manufactured products. During this analysis, it was decided to focus additionally on whether the enterprise had a visual identity project and on the date the firm was founded. In order to verify the character of relationships between the above mentioned variants of analyzed variables, the hierarchical classification of cluster analysis was conducted using Ward's method (Figure 9). Results of cluster analysis suggest that two markedly distinct main groups may be distinguished in the investigated enterprises. One group comprises enterprises offering a standard warranty period, not mentioning that fact in their advertising campaigns. These companies frequently do not have a special visual identity project developed. Most firms in that group were established in the 1980s and 1990s. The other group is composed of enterprises using information on the length of the warranty period to fight competition in the market. At the same time, they offer a longer warranty period for manufactured products than that required by the legal regulations. They also have a visual identity project, thus realizing a long-term strategy of creation of their image in the market. This group comprises primarily enterprises established after the year 2000. This is confirmed by the results of investigations conducted by Innis and Unnava (1991), who suggest that the application of an extended warranty period and information of that fact in advertising materials may be particularly advantageous for new companies, still establishing their position in the market and striving to gain consumer loyalty and trust.

It was decided to apply a two-dimensional solution space. A graphic presentation of the results of correspondence analysis indicates differences between the 2 groups of enterprises (Figure 10). It confirmed the results of cluster analysis, as a result of which 2 groups of traits characterizing the investigated enterprises were identified, co-existing and connected with the use of information concerning the length of the warranty period in advertising materials, the length of the offered warranty period, having a visual identity project developed and the date when the company was founded. This confirms e.g. the results of a study by Innis and Unnava (1991), who showed that effectiveness of the use of a warranty as a tool in the creation of competitive edge is greater in the case of new brands, companies still striving to gain a stable position in the market.

4 CONCLUSION
4. ZAKLJUČAK

The results present the level of use of information concerning new product warranty in the marketing materials of furniture manufacturers operating in Poland and Slovenia.

Based on the conducted investigations, the following conclusions were drawn:

1. It was shown that information on the length of the warranty period was primarily presented in advertising materials by manufacturers of furniture for children and kitchen furniture (all of the investigated enterprises manufacturing such furniture). This is connected e.g. with the fact that customers expected a very long period of use of kitchen furniture, and were concerned about the safety of use in the case of furniture for children and teenagers. Information on the length of the warranty period was given much less frequently (e.g. 22 %) in the advertising materials of companies manufacturing upholstered furniture for housing facilities.

2. Among companies using in their marketing activity the information on the length of the warranty period, as many as 70 % offered an extended period covering 3 to 5 years. When offering an additional bonus in the form of extended warranty, they used it as a tool in the competitive fight in the market.

3. The study showed coexistence of variables connected with the offered warranty period, the use of information concerning warranty in advertising materials, implementation of a long-term strategy for design management and the development of a positive image of the company in the market based on the comprehensive visual identity project and the limited number of years since the company has been operating in the market.

4. No significant differences were shown between the selected Slovenian and Polish enterprises regarding the level of use of information concerning the length of warranty in their marketing activity. Both in the investigated Polish and Slovenian enterprises, it amounted to approx. 50 %.

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Chemical and Physical Properties of Pine Wood during Pyrolysis

Kemijska i fizikalna svojstva borovine tijekom pirolize

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ABSTRACT • *This paper examines the influence of temperature on several physical properties of wood. The results demonstrated that devolatilization during pyrolysis greatly affects the inner structure of wood, followed by changes in volume, mass, density and shape. The research showed that a decrease in wood density caused a significant increase in permeability. Data on pyrolytic gases, char composition and calorific value measurements of these products are also presented. The results showed that the lower heating value (LHV) of pyrolytic gas can reach 12 MJ/Nm3 at 600 °C and the higher heating value (HHV) of char can reach 34 MJ/kg for 700 °C. The analysis of the calorific values of pyrolytic gases and char showed that the thermal conversion of biomass can lead to the generation of good quality gaseous and solid fuels.*

Key words: *pyrolysis, pine wood, wood permeability, wood density, pyrolysis gas, thermogravimetric analysis*

SAŽETAK • *U radu se razmatra utjecaj temperature na neka fizikalna svojstva drva. Rezultati su pokazali da isplinjavanje tijekom pirolize uvelike utječe na unutarnju strukturu drva te na promjene njegova volumena, mase, gustoće i oblika. Analizom rezultata istraživanja može se zaključiti da smanjenje gustoće drva uzrokuje znatno povećanje propusnosti drva. U radu se prikazuju i podaci o pirolitičkim plinovima, sastavu ugljena i mjerenju njihovih kalorijskih vrijednosti. Rezultati su pokazali da donja ogrjevna vrijednost (LHV) pirolitičkog plina može dosegnuti 12 MJ/Nm^3 pri 600 °C, a gornja se ogrjevna vrijednost (HHV) ugljena kreće i do 34 MJ/kg pri 700 °C. Analiza kalorijskih vrijednosti pirolitičkih plinova i ugljena pokazala je da se toplinskom pretvorbom biomase mogu proizvesti kvalitetna plinovita i kruta goriva.*

Ključne riječi: *piroliza, drvo bora, propusnost drva, gustoća drva, pirolitički plin, termogravimetrijska analiza*

1 INTRODUCTION
1. UVOD

Biomass, such as pine wood, is a very common and generally accessible source of renewable energy. Traditionally, biomass has been utilized by direct combustion; however, the development of a biomass thermal conversion technology represents a promising alternative for energy production. Detailed reviews of other renewable energy solutions, such as hydrogeneration, pyrolysis and gasification, can be found in Demibras (2001) and McKendry (2002). Biomass processing is already a very popular topic in global research; many studies with different types of wood can be found in the literature (Qiang *et al.*, 2011; Gupta *et al.*, 2002; Bridgwater and Peacocke, 2000; Park *et al.*, 2010, Bellais *et al.*, 2003; Luo and Resende, 2014, Kim *et al.*, 2014). In addition, different temperature ranges and pyrolysis conditions have been studied. For example, Amutio *et al.* (2012) tested pinewood sawdust flash pyrolysis (con-

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tinuous mode) in a pilot plant with a conical spouted bed reactor in the narrow range from 400 °C to 600 °C. Martinez *et al.* (2014) tested co-pyrolysis of biomass with waste tires from 150 °C to 700 °C. Further, the influence of various heating rates during pyrolysis on the shape of pine wood (degree of shrinkage or swelling) was investigated by Patanottai *et al.* (2015).

During the pyrolysis process, the physical properties of wood change significantly. Changes of wood components, such as lignin, after thermal treatment were tested by Windeisen *et al.* (2008). Analysis of the effect of temperature on basic physical properties of wood, such as elementary composition, density, mass, specific heat and the calorific values of pyrolysis products, are numerous (Pattanotai *et al.*, 2014; Neves *et al.*, 2011; Kardaś *et al.*, 2014, Kluska, 2015).

Permeability and density of wood also change significantly. Measurements of permeability for different types of wood are available, but only for wood at room temperature (Tanaka *et al*, 2015; Redman *et al.*, 2012; Jinman *et al.*, 1991). Therefore, the permeability of wood, as a function of pyrolysis temperature, is not yet well understood. Similarly, analyses of the change in wood density during pyrolysis can be found in the reports of Brewer (2014) and Sommerville (2015). Since the numerical prediction of the pyrolysis process has also been intensively studied (Peters and Bruch, 2003), it is important to determine how the above parameters change with temperature for setting the boundaries of simulations and successfully predicting the outcome of the process. The change in the physical properties of wood during pyrolysis has an influence on the specific heat of wood (Gupta *et al.*, 2002; Gronli, 1996; Harada *et al.*, 1998).

This work thoroughly describes one type of biomass (pine wood) and provides detailed information on the pyrolysis process and the characteristics of its gaseous and solid products.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Wood samples
2.1. Uzorci drva

Samples used in this study were prepared from Scots pine (*Pinus sylvestris*), which is a very common type of wood in Poland. Although different analysis methods and equipment required different size and mass of wood samples, each one of them originated from the same cylindrical wood bar of 16 mm in diameter. In order to prepare the samples for elementary analysis, pine wood was ground in a knife mill and then in a centrifugal mill equipped with a sieve of 0.2 mm mesh diameter.

2.2 Pyrolysis
2.2. Piroliza

The high temperature reactor (Figure 1 Pyrolysis test stand) heats the core of the device to 900 °C and maintains that temperature to enable the thermal conversion of the biomass and waste materials.

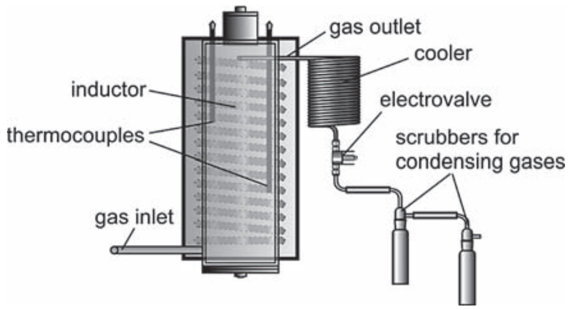

Figure 1 Pyrolysis test stand
Slika 1. Uređaj za pirolizu

The chamber is cylindrical with a 98 mm inner diameter. The active portion of the chamber, enveloped with a heating induction coil and thermal insulation, is located in the center of the device. It is equipped with ungrounded thermocouples fixed at 1/3 and 2/3 of the total height of the cylinder. Such an arrangement enables measuring and recording temperatures inside the reactor and inside the bed of the tested feed in real time during the experiment. The device was also equipped with a blow-through electrovalve to let in the process gas (argon) as well as a bleeder electrovalve to remove it. Argon is used in order to remove the air from the device before the process. The reactor works in a constant sweep of gas mode. The experiment was conducted on a group of 20 samples, from 20 °C to 900 °C.

2.3 Permeability measurement
2.3. Mjerenje propusnosti

2.3.1 Test stand
2.3.1. Ispitni uređaj

The test stand for measuring permeability consisted of the following devices: air compressor, differential pressure converter, steel container equipped with interchangeable steel sleeve (containing the biomass) and a bubble velocity meter (Figure 2 Permeability test stand). The upper part of the container is attached with screws and can be removed to place the interchangeable steel sleeve inside the container between two circular seals. This type of construction allows for the quick and easy replacement of biomass samples.

2.3.2 Sample preparation
2.3.2. Priprema uzoraka

At the beginning of the sample preparation process, each sample was of a cylindrical shape with a 16 mm diameter and was approximately 6 cm in height. A group of three samples was inserted into the stove and

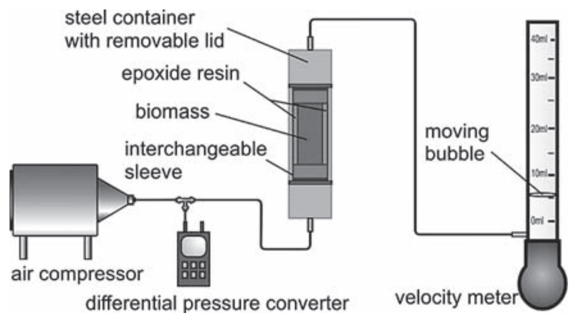

Figure 2 Permeability test stand
Slika 2. Ispitni uređaj za mjerenje propusnosti

heated to a given temperature in an oxygen-free atmosphere (the temperature was different for each group, from 50 °C up to 350 °C, at 50 °C intervals). After heating, the samples were removed from the stove and allowed to cool to room temperature. Each sample was inserted into the steel sleeve and fixed to it with epoxide resin (the samples were covered with varnish prior to this procedure to prevent the epoxide resin from percolating into the wood).

Dimensions of the samples varied as a result of the pyrolytic decomposition. Using a milling machine, each sample was leveled and adjusted so that each measurement was conducted on a 30 mm tall biomass cylinder. Different diameters (due to shrinkage during pyrolysis) were taken into consideration in the calculations.

2.3.3 Methodology and measurements
2.3.3. Metodologija i mjerenja

The method is based on blowing air (under pressure) into the container along the axial direction of the wood cylinder (which also is the direction of the wood grain) and measuring the air velocity after it crosses the wood cylinder.

The measurement of the wood permeability to air was indirect. It was calculated from Darcy's law:

$$K = \frac{u \cdot \mu \cdot l}{\Delta P} \quad (1)$$

Where ΔP is pressure difference, K permeability, μ is dynamic viscosity of the air, l is length (cylinder height), and u is velocity of the air flowing through porous media (in this case wood). The pressure difference was measured during the flow of the compressed air using a differential pressure converter (Figure 2 Permeability test stand). The velocity of the flow through wood cannot be measured directly; therefore, it was calculated based on the Law of Continuity, by measuring the time that it takes for a bubble to pass through the given volume of the velocity meter (constant and equal to 40 cm^3). For each measurement, the pressure value was set independently to obtain a measurable bubble velocity.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Wood sample elementary analysis
3.1. Elementarna analiza uzorka drva

The results of the technical and elementary analyses of pine wood are shown in Table 1 Technical and elementary analysis of biomass. The moisture content was determined using a MAC (Radwag) moisture balance and an elementary analysis was performed using a Thermo Scientific CHNS-O Flash 2000 elementary analyzer. The calorific value and calculation of the heating value were determined using a KL-11 calorimeter. The presented results agree with other published data (Neves *et al.*, 2011; Alauddin *et al.*, 2010, Yildiz *et al.*, 2015).

3.2 TGA analysis of pine wood
3.2. TGA analiza borovine

To analyze the thermal conversion rate and the temperatures at which they occur, a thermogravimetric analysis of the biomass samples was conducted. The results of the thermal decomposition of the biomass presented in this study were obtained by using the TA Instruments SDTQ600 thermogravimeter at different heating rates of 5 °C/min, 10 °C/min and 15 °C/min. The mean mass of the sample was 10 mg.

Table 1 Technical and elementary analysis of biomass
Tablica 1. Tehnička i elementarna analiza biomase

Heating value, MJ/kg *Ogrjevna vrijednost,* MJ/kg	19.59
Technical / *tehnička analiza*	%
Moisture / *sadržaj vode*	8.40
Volatiles / *hlapljivi spojevi*	67.90
Char / *ugljen*	21.40
Ash / *pepeo*	2.30
Elementary / *elementarna analiza*	%
C	45.00
H	6.40
O	47.30
N	1.30

The beginning of the devolatilization process occurs at 180 °C to 190 °C (Figure 3). The highest intensity devolatilization occurs at different temperatures for different heating rates (345 °C for the heating rate of 5 °C/min, 367 °C for 10 °C/min and 373 °C for 15 °C/min). Moreover, increase of the heating rate moves the thermogravimetric curve in the direction of higher temperatures. The obtained data is in good accordance with the literature (Alvarez *et al.,* 2015).

3.3 Pyrolytic gas analysis
3.3. Analiza pirolitičkih plinova

The pyrolytic gas analysis was conducted on SRI Instruments 310 gas chromatograph with ShinCarbon ST 80-100 packed column, thermal conductivity detector (TCD) and argon as a carrying medium.

The results of the pine wood pyrolysis (Figure 4) showed that, with an increase of the temperature to 600 °C, the CO content in the pyrolysis gases maintained a more or less constant value of 45 %, but decreased to 20 % at 900 °C. The content of CO_2 in the pyrolysis gas mixture decreased from 44 % at 300 °C to 27 % at 470 °C. After reaching 900 °C, the CO_2 content decreased

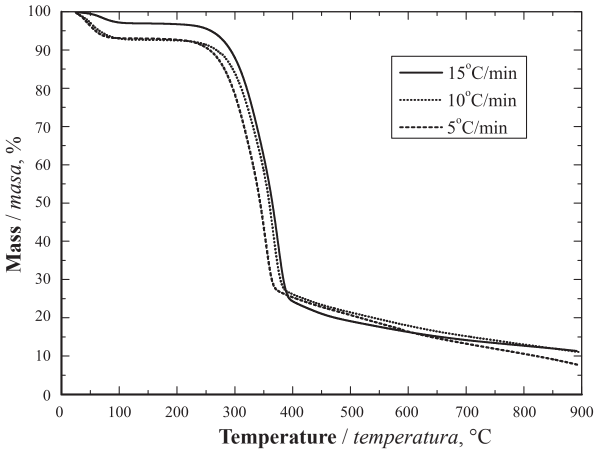

Figure 3 TGA analysis of pine wood
Slika 3. TGA analiza borovine

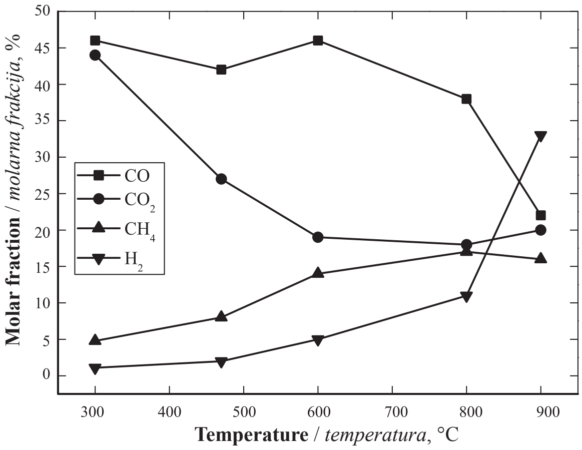

Figure 4 Influence of temperature on gas composition during pine wood pyrolysis
Slika 4. Utjecaj temperature na sastav plina tijekom pirolize borovine

even further to 20 %. The gas composition at 600 °C was very similar to the composition obtained by Amutio *et al.* (2012). Also, the results in the range of temperatures from 600 °C to 900 °C are in agreement with the work of Ningbo *et al.* (2015) as well as Song *et al.* (2014). We observed that high temperatures (above 600 °C) caused an intensive hydrogen release. In the final stage of the process, (900 °C), the content of H_2 was equal to 33 %. Additionally, the results showed that, with increasing temperatures (up to 700 °C), the methane content reached 16 % and then maintained a value of 15 %. Based on the analysis of the experimental results, it can be concluded that high temperatures move the pyrolysis process towards a gas composition with a high hydrogen content. The results also showed a high carbon oxide content in the range of temperatures from 400 °C to 800 °C (37 % to 45 %).

The results of the analysis of gas composition as a function of temperature in the pyrolysis process showed that the LHV depends on the temperature. The LHV of the pyrolytic gas mixture reached 8 MJ/Nm^3 at 500 °C and then increased to 12MJ/Nm^3 (Figure 5 Lower heating value of pyrolytic gases as a function of temperature5). These results are similar to other published data (Bridgwater and Peacocke, 2000; Neves *et al.,* 2011; Fabgemi *et al.*, 2011). At the lower range of temperatures, the LHV of the gases was determined by the carbon monoxide content (up to 45 % at 600 °C). The higher LHVs at higher temperatures are related to the high content of hydrogen and methane in the mixture.

3.4 Cylindrical chip mass, volume and density changes during pyrolysis
3.4. Promjene mase, obujma i gustoće cilindričnih uzoraka borovine tijekom pirolize

The results show a general decrease of the volume of wood cylinders with increasing temperatures (Figure 6). After decreasing to 2.22 cm^3 at 370 °C, an increase in the volume to 3.95 cm^3 at 420 °C is observed, followed by another decrease to 0.12 cm^3 at 520 °C. For higher temperatures, the volume decreases slowly from 2.6 cm^3 at 600 °C to 2 cm^3 at 900 °C. These fluctuations of volume are the result of difference in the radial shrinkage and swelling of the samples for these temperatures caused by the internal pressure during pyrolysis (Pattanotai *et al.,* 2014; Park *et al.*, 2010). The internal pressure in the cylindrical wood samples during pyrolysis at a high heating rate is higher than in the low rate of heating and helps to resist wood shrinkage in the radial direction (Pattanotai *et al.,* 2014). In the case of wood particles, the internal pressure produced is an important factor for the pyrolysis process. The pressure gradient causes the release of volatile components outside the particles. Moreover, high internal pressure can also partially crack the particles.

The largest loss of mass and volume, as a function of pyrolysis temperature, was observed in the range of temperatures from 240 °C to 370 °C (Figure 6). The final mass at 900 °C was 19 % of the initial mass of the pine wood cylinder samples, and the final volume at the same temperature was 30 %.

3.5 Elementary composition and LHV of char
3.5. Elementarni sastav i donja ogrjevna vrijednost ugljena

The measurements were conducted in a CHNS-O Flash 2000 elementary analyzer, while the calorific

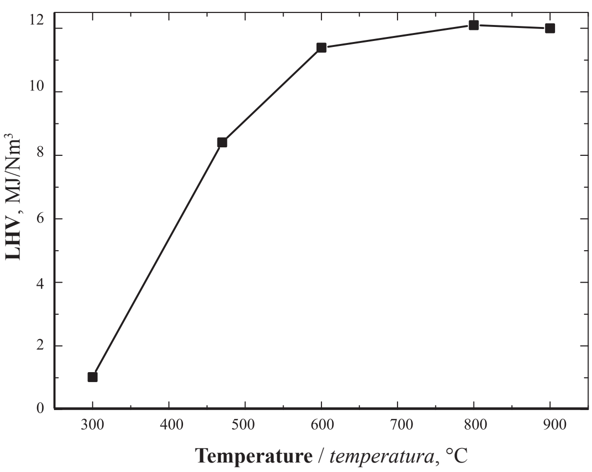

Figure 5 Lower heating value of pyrolytic gases as a function of temperature
Slika 5. Donja ogrjevna vrijednost pirolitičkih plinova u ovisnosti o temperaturi

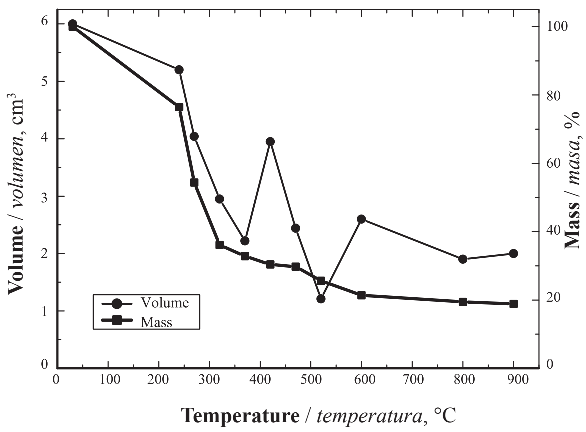

Figure 6 Pine wood mass and volume dependence on pyrolysis temperature
Slika 6. Ovisnost mase i obujma uzoraka borovine o temperaturi pirolize

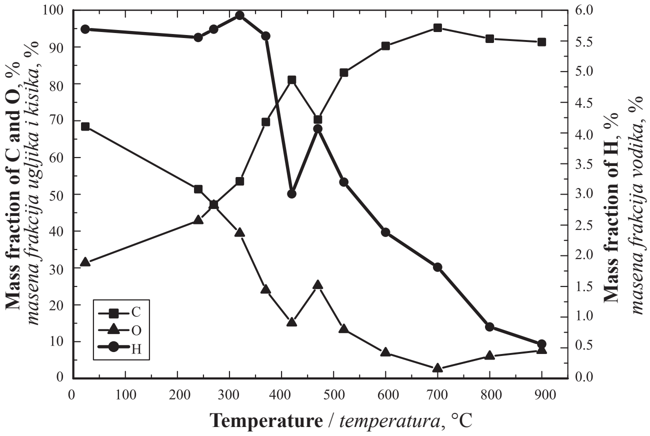

Figure 7 The influence of pyrolysis temperature on char composition
Slika 7. Utjecaj temperature pirolize na sastav ugljena

value and calculation of the heating value were determined using a KL-11 calorimeter.

Figure 7 shows how the char composition changes as a function of pyrolysis temperature. The carbon mass fraction increases with temperature, while the oxygen and hydrogen mass fractions decrease. The largest increase in carbon content, along with the largest decrease in oxygen content, occurred for the temperature range of 270 °C to 400 °C. This is because the wood devolatilization is the most intense within this range (Figure 3). Fluctuations of elementary composition of char (Figure 7) in the range of temperatures from 400 °C to 500 °C can be caused by irregular heating rate of particles during pyrolysis of packed bed. The bed consisted of 20 cylindrical samples. The heat could propagate with different rate depending on the sample location in the bed. Thus, at the temperature range representing the most intensive devolatilization (Figure 3), different rates of heating have a significant importance and may affect the elementary composition of char.

Due to wood volatiles leaving the solid particles, the mass fractions of carbon and oxygen significantly changed. In contrast, the hydrogen mass fraction, although small (5.5 % - 6 %), was relatively constant at lower temperatures and began to decrease at temperatures higher than 370 °C, down to 0.5 % at 900 °C. The obtained results agree with other published data (Neves *et al.*, 2011*;* Fabgemi *et al.*, 2011, Özbay *et al.*, 2015).

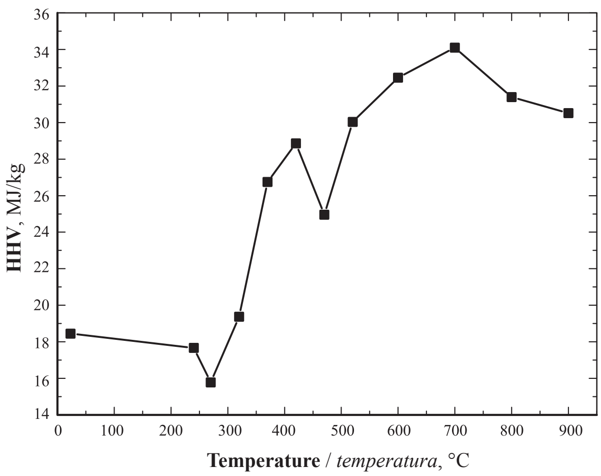

Figure 8 The influence of pyrolysis temperature on char higher heating value
Slika 8. Utjecaj temperature pirolize na gornju ogrjevnu vrijednost ugljena

Figure 8 shows the dependence of the HHV of char on pyrolysis temperature. As a natural result of the rapid carbon and oxygen content changes from 270 °C to 400 °C, the HHV of the char also rapidly changes at these temperatures. The initial HHV of char was 18.2 MJ/kg, and after the devolatilization process this value increased by nearly 60 % (up to 29 MJ/kg). The small decreases of HHV at 470 °C and from 700 °C to 900 °C are caused by the decreases of mass fraction of C and increases of mass fraction of O at the same temperatures (Figure 7). The char obtained during the pyrolysis process can increase in the HHV by a total of 87 % (at 700 °C) compared to the initial value. The obtained results are in a good accordance with the model (Figure 8) proposed by Channiwala *et al.,* (2002) as well as with other literature (Zhengang and Guanghua, 2015).

3.6 Permeability to air
3.6. Propusnost zraka

The permeability measurements were performed at room temperature for samples obtained at different pyrolysis temperatures (from 22 °C up to 350 °C) along the axial direction of the wood cylinder. Samples obtained at temperatures higher than 350 °C were cracked or too fragile to perform measurements of permeability. The pyrolysis caused irreversible changes in the wood structure and even after cooling the wood to room temperature, the permeability to air was different than before the process. The dependence of the wood permeability on the pyrolysis temperature is complex. From 50 °C to 150 °C, the permeability was smaller than for wood at room temperature. One possible explanation for this is that the wood resin blocks the pores at that range of temperatures, making it difficult for air to pass through (Figure 10). The inner structure of pine wood contains many long resin conduits along the trunk and branches, which are also connected with transverse conduits. The main component of the resin is a class of naturally occurring organic chemicals called terpenoids (among other compounds such as stilbenes, lignans, extractives). The melting point of these substances occurs at temperatures from 100 °C to 130 °C, and the vaporization temperatures are from 156 °C to 224 °C (Conolly, 1991). These values suggest that from 50 °C to 150 °C the resin movement caused by the heating process blocks the pores, and when the wood is cooled to room temperature the pores remained blocked (thus a decrease in permeability is observed). From 200 °C to 350 °C a large increase (up to ten times the initial value) in permeability is observed. This is caused by the loss of wood mass and by the increased size of its pores as a result of devolatilization. Since the resin components begin to evaporate at 156 °C, this may also contribute to an increase in permeability. Using the data presented in Figure 6, an approximation curve of wood

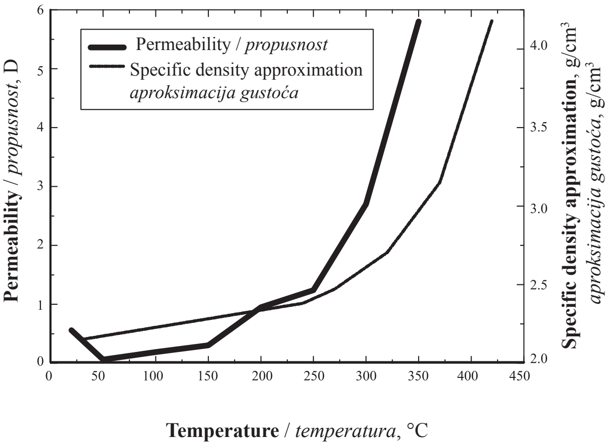

Figure 9 Characteristics of wood permeability and reverse approximation of density
Slika 9. Obilježja propusnosti drva i aproksimacija gustoće drva

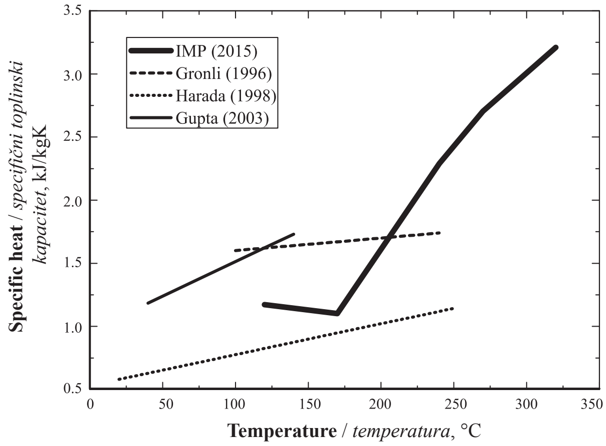

Figure 11 The influence of temperature on wood specific heat
Slika 11. Utjecaj temperature na specifičnu toplinu drva

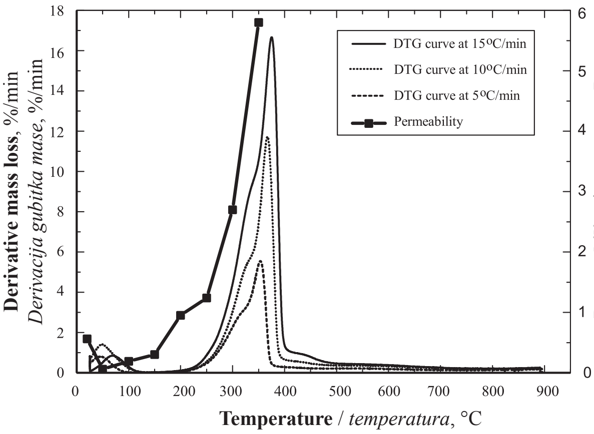

Figure 10 DTG and permeability curves for pine wood thermal decomposition
Slika 10. DTG i krivulje propusnosti za toplinsku razgradnju borovine

apparent density can be created, which can be further used to calculate reversed approximation curve. Figure 9 also shows that the permeability of wood is in accordance with the reversed approximation of apparent density in the range of temperatures from 25 ℃ to 350 ℃. This means that the decrease of wood density may cause an increase in permeability.

Figure 10 shows DTG curves for thermal decomposition of pine wood at heating rates of 5, 10 and 15 °C/min as well as permeability curve. Dramatic increase in permeability occurs for the same range of temperatures (starting at 250 ℃) as the most intensive degradation kinetics. The DTG curve for 15 ℃/min is in good accordance with literature data (Alvarez *et al.,* 2015).

3.7 Specific heat
3.7. Specifična toplina

The measurements of the specific heat of wood were conducted in a two-stage process. During the first stage, small wood samples were treated with temperatures from 70 °C to 320 °C inside a TA Instruments Q600 Thermogravimeter. The samples were heated up to the specified temperature at a rate of 20 °C/min in a nitrogen atmosphere and maintained at that temperature for 2 hours to reduce the moisture content. The second stage consisted of measuring the heat capacity of wood using a TA Instruments Q2000 Differential Scanning Calorimeter (DSC).

Each sample was closed inside a hermetic sample cell and heated to a temperature five degrees lower than corresponding temperature of that sample during the previous TGA pre-heating to avoid any chemical decomposition during measurement. The process was conducted with a heating rate of 5 °C/min in a nitrogen atmosphere. The average mass of wood samples during the DSC measurements was 3.35 mg.

The results are presented in Figure 11. From 120 °C to 170 °C, the specific heat was relatively constant at 1200 kJ/kgK, and for higher temperatures it rapidly increased to 3250 kJ/kgK. Gronli (1996) studied the specific heat of wood in the narrow range from 100 °C to 250 °C and Gupta *et al*. (2003) studied the specific heat of wood from 40 °C to 150 °C. The results of Gronli and Gupta show values 40 % - 50 % higher compared to the results obtained by the Institute of Fluid Flow Machinery PAS (IMP in Figure 11). Harada *et al.* (1998) tested the specific heat of wood from 20 °C to 250 °C and reported lower values. The specific heat of wood increases with temperature and the values obtained at the IMP are in agreement with the available literature.

4 CONCLUSION
4. ZAKLJUČAK

This paper provides information on pyrolytic gas properties as well as physical properties of pine wood such as permeability, density and specific heat and their interrelation over a wide range of temperatures. Pyrolysis causes a significant reduction in wood density, due to mass and volume changes. It was demonstrated that when the density of wood decreases, an increase in its permeability to gases is observed for the same range of temperatures. Permeability generally increases with temperature; however, from 50 °C to 150 °C, it reaches values lower than at room temperature. The density and volume of wood decreases with temperature, but from 350 °C to 500 °C some fluctuations were observed, especially in density. The LHV of pyrolytic gases reached 12 MJ/Nm^3 at 600 °C, while the HHV of char reached a maximum value of 34 MJ/kg at 700 °C. A large increase in the HHV of char, which was observed from 250 °C to 300 °C, is the result of the large increase in carbon content for the same range of temperatures. Thermal conversion of biomass can lead to the generation of good quality gaseous and solid fuels.

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Evaluation of Factors in Buying Decision Process of Furniture Consumers by Applying AHP Method

Vrednovanje činitelja u procesu donošenja odluke o kupnji namještaja primjenom AHP metode

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ABSTRACT • *There are not many wooden products that consumers would buy on pure impulse. Their decision regarding the purchase of a product normally undergoes a process of consideration – the more expensive the product, the more thorough the consideration. The consumer buying decision process consists of five stages: need recognition, search for information, alternatives evaluation, purchase decision and post-purchase behaviour. A company must establish what is important for consumers in each stage of this process. On the basis of these findings, the company must define the measures to influence consumers in individual phases. In this study, the analytic hierarchy process was used to analyse the buying behaviour of potential furniture buyers. Slovenian and Croatian marketing experts were asked about the habits, requests and needs of furniture buyers. The results of the research can serve as useful information for companies producing wooden products in the formulation of successful marketing strategies.*

Key words: *buyer decision process, buying behaviour, wood company, furniture, AHP*

SAŽETAK • *Ne postoji mnogo proizvoda od drva koje bi kupci kupili impulzivno, bez dodatnog poticaja i razmišljanja. Odluka potencijalnog kupca s obzirom na vrstu proizvoda obično prolazi kroz proces razmatranja, i to na način da je za skuplji proizvod razmatranje detaljnije. Proces donošenja odluke o kupnji nekog proizvoda ima pet faza: prepoznavanje potrebe, potraga za informacijom, vrednovanje alternativa, odluka o kupnji i ponašanje nakon kupnje. Tvrtka mora utvrditi što je njezinim potencijalnim kupcima (potrošačima) u svakoj fazi procesa donošenja odluke o kupnji važno. Na temelju toga, tvrtka mora odrediti mjere kojima će utjecati na potrošača u pojedinim fazama procesa razmatranja. Cilj ovog rada bio je vrednovati činitelje u procesu donošenja odluke o kupnji namještaja primjenom metode analitičkoga hijerarhijskog procesa (AHP). Vrednovanje pokazatelja navika, zahtjeva i potreba kupaca namještaja proveli su suradnici iz Slovenije i Hrvatske koji se bave istraživanjima i aktivnostima u području marketinga. Rezultati istraživanja mogu pomoći proizvođačima i/ili prodavačima namještaja u procesima definiranja uspješnih marketinških strategija.*

Ključne riječi: *proces donošenja odluke, ponašanje pri kupnji, tvrtke drvne industrije, namještaj, AHP*

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1 INTRODUCTION
1. UVOD

In a constantly changing environment, understanding the buying behaviour of consumers is of key importance for a company, if the company wishes to be efficient and successful. Furniture is a type of product that consumers select with a great deal of consideration and spend a lot of time before they finally decide to buy it (Oblak, 2012). The consumer buying decision process consists of five stages: need recognition, search for information, evaluation of alternatives, purchase decision, and post-purchase behaviour. The actual purchase is, therefore, only one stage in the buying decision process. The initial stages are essential in order to make a purchase; however, the consumer may stop the buying decision process at any point (Potočnik, 2002). This process is influenced by numerous factors. A company's marketing activities are an important factor. In order to prepare appropriate marketing strategies, the company must first identify and understand how consumers think in the individual stages of the buying decision process. It is, therefore, reasonable to analyse the influences on the purchasing behaviour of potential customers. Marketing professionals must understand the consumer's perception, which is not a simple task since consumers often make unexpected buying decisions. Marketing professionals must not just come up with simple ways to influence consumers, but must instead learn how the consumers really make their buying decisions (Kotler, 1994).

The objective of this article was to determine which stages within the buying process are the most important for marketing professionals; what encourages the need recognition in potential furniture buyers; where do they look for information on furniture; which criteria are the most important in the buying decision and which household member is the one that decides on the purchase in most cases. An additional objective was to determine if there were any differences between the Slovenian and Croatian markets, and what were the key differences between the buying decision process of Slovenian and Croatian furniture buyers. The results of the study should be interesting for manufacturers and sellers of furniture in Slovenia and Croatia as well as for all furniture manufacturers that sell their products on these two target markets.

2 CONSUMER BUYING DECISSION PROCESS
2. PROCES DONOŠENJA ODLUKE O KUPNJI

If companies want to be successful in the domain of sales, they must be familiar with the consumer's needs, and their perception and behaviour in the buying decision process. Companies must examine and understand the buying decisions of consumers.

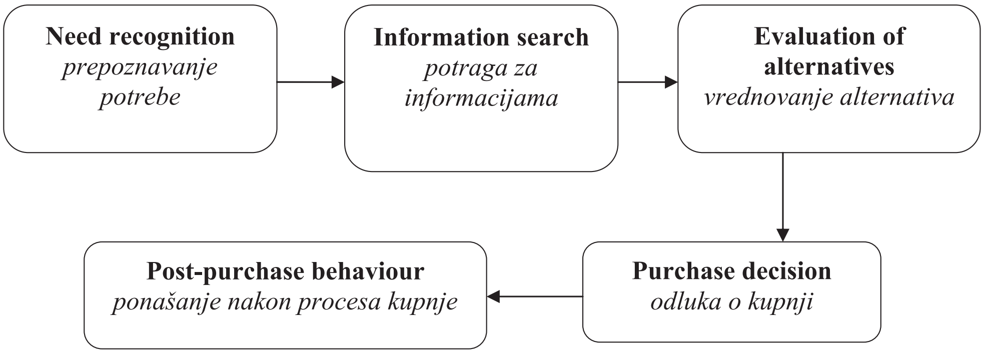

Figure 1 Consumer buying decision process
Slika 1. Proces donošenja odluke o kupnji

The buying decision process starts when the consumer recognizes a need or desire for a certain product. This is the first and determining stage in the consumer buying decision process. The company can and must actively participate in this process. First of all, it should be established whether the inactivity of buyers and their lack of interest in the company's products is a consequence of the absence of a need for these products or that they do have a need but are still not interested in making a purchase. In both cases, the company can trigger this stage through their activities. In the first case, they must prepare marketing strategies that create the need, and in the second case, they must prepare strategies that will encourage consumers to buy products that meet their need. In doing this, the marketing activities must draw the attention of consumers to the existing products that were unknown to them. There are many potential furniture buyers who are currently not considering a purchase, but the company could convince them to buy their products anyway with correctly prepared components of the marketing communications mix. Consumers who are already considering making a purchase but are not sure yet are even easier to convince. Also, there are always some consumers that are interested in buying a product even if they do not actually need it. It is a known fact that successful advertising and other marketing activities can convince certain consumers to buy furniture even if they do not need it.

The second step in the consumer buying decision process is the information search. When consumers feel the need for a particular product, they will search for information on various alternatives or variants. This information is usually related to price, quality, characteristics and the availability or delivery date of the product. The information on warranty, servicing, after-sales services, payment terms, etc. is also relevant. At this stage, the company can actively participate and submit product information to the consumer in a useful, accurate and easily understandable form. Consumers will first seek information from their relatives, friends and acquaintances. According to the studies performed, this information has a huge influence on the buying decision. The media are the second most important source of information (television, radio, the internet, journals, newspapers, etc.). The company's sales staff can play a decisive role in this phase of the buying decision process.

When the consumer has collected enough information, he/she enters the third stage of the buying decision process, in which he/she selects the products that could meet his/her need. The consumer will try to select the most suitable product from among these products or among alternative furniture suppliers. To that end, he/she will form the criteria according to which he/she compares the characteristics of each product. Some of these criteria are more important and have a greater value for the consumer. Usually the price and quality are the most important, while other criteria can also be decisive for some consumers (e.g. brand). In evaluating the alternatives, the sales staff can also play a very important role. Consumers have often not made up their mind and a good salesperson can use professional arguments to convince an indecisive consumer to buy a certain product.

Purchase is the fourth stage in which the consumer decides to buy the product. In some cases, negotiations on the sales conditions between the consumer and the salesperson take place at this stage, mostly regarding the price, terms of payment, warranty, delivery period, etc. If the purchase conditions are acceptable for the buyer, the actual purchase will take place. It is also interesting for companies to know which member of the household makes the decision on the purchase of furniture. This aspect is mostly important in terms of marketing communication.

When a consumer buys a product, he/she will start to evaluate it. This is the last, fifth stage in the consumer buying decision process. He/she compares the expectations and the actual effect of the product. The result of this is either satisfaction or dissatisfaction. The consumer's future buying decisions depend on this result. If the consumer is pleased with the product, he/she will continue to buy this company's products and also tell his/her friends and acquaintances about it. In the opposite case, he/she will also tell the others about his/her problems and bad choice of purchase.

3 MATERIAL AND METHODS
3. MATERIJAL I METODE

Based on the research objectives, a questionnaire was developed. The questionnaire was segmented into four sections in order to analyse the following questions:
1. What encourages the need recognition in potential furniture buyers?
2. Where do potential buyers search for information about furniture?
3. What are the most important criteria in deciding on the purchase of furniture?
4. Who makes the decision to purchase the furniture?

Five marketing experts from Slovenia and five marketing experts from Croatia were selected to participate in this study. The marketing experts were em-

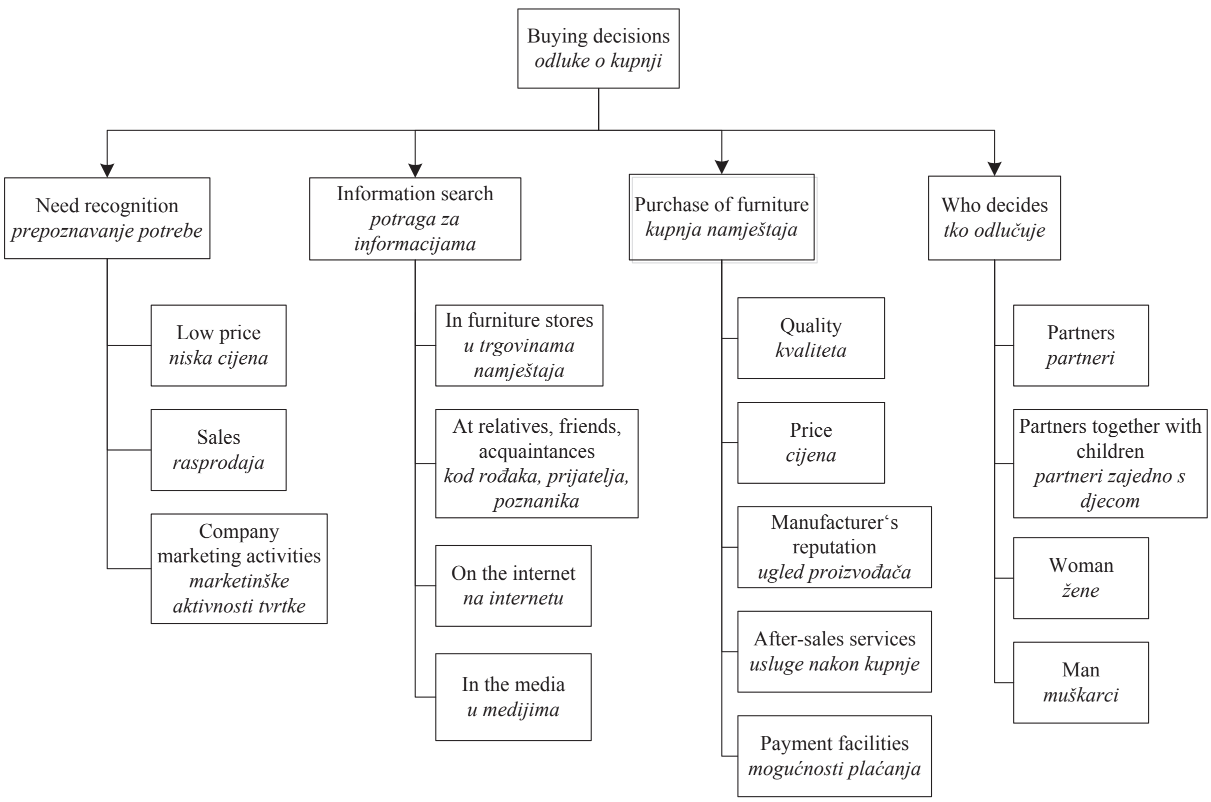

Figure 2 Factors affecting the consumer in the first four stages of the buying decision process
Slika 2. Činitelji koji utječu na kupca u prve četiri faze procesa donošenja odluke o kupnji

ployed to make pairwise comparisons of the factors in each stage regarding buying decision factors (shown in Figure 2). The Analytic Hierarchy Process (AHP) was the method used to analyse data in this study.

3.1 Analytic hierarchy process
3.1. Analitički hijerarhijski proces

Analytic Hierarchy Process (AHP) (Saaty, 1980) is a management approach to support multi-criteria decision making in complex real world problems. It has been used in numerous applications in various areas related to wood, furniture, sale and customers. Scholz and Decker (2007) measured the impact of wood species on consumer preferences for wooden furniture. Ojurović *et al.* (2013) performed analysis of the key factors of competitiveness in wood processing and furniture production. Motik *et al.* (2010) compared product lines in furniture industry regarding financial efficiency, risk and competition. Esmaili and Fazeli (2015) analysed criteria that influence the purchasing decision of a green product and compared indicators of green products and green promotions activities.

AHP supports rational decision making based on hierarchically structured problems. Pairwise comparisons represent the key phase in AHP. They enable decision maker to express his opinion and preferences about qualitative and quantitative factors. The relative importance of one factor over the other is measured on Saaty's 1-9 scale (Saaty, 2006) (Table 1).

AHP is also suitable for group decision making. The properly chosen decision makers with supplement knowledge, competences and experiences enable success of decision making process. There are different ways to form a group decision from individual decisions (Alonso *et al.*, 2010; Altuzarra *et al.*, 2007; Forman and Peniwati, 1998; Grošelj *et al.*, 2015; Srdjevic and Srdjevic, 2013). In this paper weighted geometric mean DEA (WGMDEA) method (Grošelj *et al.*, 2011) (1) is used to aggregate individual judgments into group vector of weights. The method is based on linear programming and data envelopment analysis and has been employed in several applications (Olšiakova *et al.*, 2016; Stasiak Betlejewska, 2015; Loučanova *et al.*, 2014).

Table 1 Fundamental scale of AHP (Saaty, 2006)
Tablica 1. Temeljna ljestvica AHP-a

Value a_{ij} *Vrijednost*	**Description** / *Opis*
1	Elements *i* and *j* are equally important *elementi „i" i „j" podjednako su važni*
3	Element *i* is slightly more important than element *j / element „i"umjereno je važniji od elementa „j"*
5	Element *i* is much more important than element *j / element „i"mnogo je važniji od elementa „j"*
7	Element *i* is proved to be more important than element *j / element „i"izrazito je važniji od elementa „j"*
9	Element *i* is absolutely more important than element *j / element „i"presudno je važniji od elementa „j"*
2, 4, 6, 8	Middle values/ *međuvrijednosti*

Individual pairwise comparisons of *m* decision makers and their reciprocal values for the inverse comparisons are presented in the pairwise comparison matrices, $A_k = \left(a_{ij}^{(k)}\right)_{n\times n}$, $k=1,..., m$.

The consistency of judgments is measured by the consistency ratio $CR_A = CI_A / RI_n$, where consistency index $CI_A = \frac{\lambda_{A,\max} - n}{n-1}$ depends on the principal eigenvalue of matrix A, $\lambda_{A,\max}$, and the random index RI_n (Saaty, 2006), which depends on the size of the matrix A. CR_A<0.1 is considered acceptably consistent.

Group vector of weights $w = (w_1, ..., w_n)$ is derived from individual comparison matrices A_k by solving *n* linear programs and then normalizing the weights.

$$\max \quad w_0 = \sum_{j=1}^{n} \sqrt[m]{\prod_{k=1}^{m}\left(a_{0j}^{(k)}\right)} x_j$$

$$\text{subject to } \sum_{j=1}^{n}\left(\sum_{i=1}^{n} \sqrt[m]{\prod_{k=1}^{m}\left(a_{ij}^{(k)}\right)}\right) x_j = 1$$

$$\sum_{j=1}^{n} \sqrt[m]{\prod_{k=1}^{m}\left(a_{ij}^{(k)}\right)} x_j \ge n x_i, \; i = 1,...,n$$

$$x_j \ge 0, \; j = 1,...,n.$$

4 RESULTS AND DISCUSSION
4. REZULTATI I RASPRAVA

Results of the AHP method are given in Table 2. Weight vectors are calculated using WGMDEA method separately for Slovenian and Croatian experts, as well as the total weight vectors for both groups. Additionally, the most important factors that influence consumer in the first four stages of the buying decision process were established (Figures 3, 4, 5, and 6).

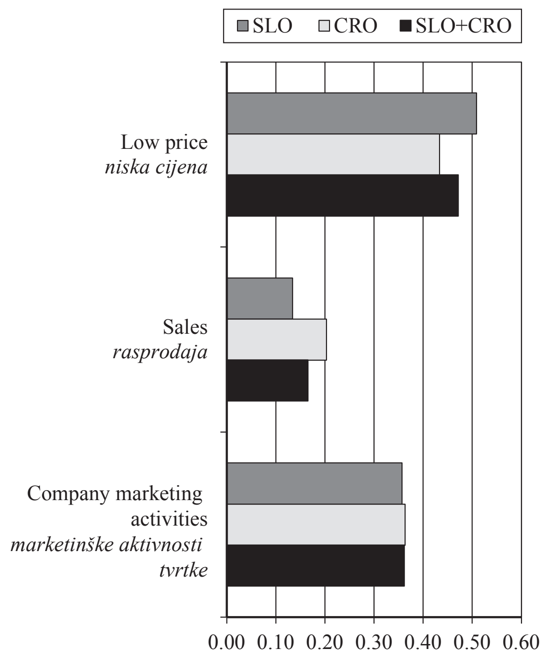

Figure 3 Factors that encourage the need recognition in potential furniture buyers
Slika 3. Činitelji koji potiču na prepoznavanje potrebe potencijalnih kupaca namještaja

Table 2 Weights of decision making factors for all 4 groups for: a) Slovenian experts (SLO); b) Croatian experts (CRO); and c) Slovenian and Croatian joint results (SLO + CRO)
Tablica 2. Težina/važnost svih četiriju činitelja kupnje prema mišljenju: a) slovenskih stručnjaka (SLO); b) hrvatskih stručnjaka (CRO); c) objedinjeni rezultati slovenskih i hrvatskih stručnjaka (SLO + CRO)

		SLO	CRO	SLO+CRO
Need recognition *Prepoznavanje potrebe*	Low price / *niska cijena*	0.51	0.43	0.47
	Sales / *rasprodaja*	0.13	0.20	0.17
	Company marketing activities / *marketinške aktivnosti tvrtke*	0.36	0.36	0.36
Information search *Potraga za informacijama*	In furniture stores / *u trgovinama namještaja*	0.27	0.24	0.26
	At relatives, friends, acquaintances *kod rođaka, prijatelja, poznanika*	0.06	0.13	0.09
	On the internet / *na internetu*	0.54	0.39	0.47
	In the media (TV, radio, printed) *u medijima (na televiziji, radiju, u tiskanim medijima)*	0.13	0.25	0.18
Purchase of furniture *Kupnja namještaja*	Quality / *kvaliteta*	0.42	0.13	0.25
	Price / *cijena*	0.28	0.46	0.38
	Manufacturer's reputation / *ugled proizvođača*	0.05	0.08	0.07
	After-sales services (delivery, assembly) *usluge nakon kupnje (dostava, montaža)*	0.14	0.10	0.13
	Payment facilities / *mogućnosti plaćanja*	0.12	0.23	0.18
Who decides *Tko odlučuje*	Partners / *partner*	0.41	0.24	0.32
	Partners together with children / *partner i djeca*	0.13	0.12	0.13
	Women / *žene*	0.40	0.57	0.49
	Men / *muškarci*	0.05	0.06	0.06

It is evident, as shown in Figure 3, that low price was found to be the major factor of need recognition for buying furniture in Slovenia as well as in Croatia. According the assessment of Slovenian market experts, the weight of this factor was 50.9 %, and according to Croatian experts, this weight was 43.4 % (Table 2). The marketing activities of the company got a slightly lower influence on the need recognition in potential furniture buyers (weight of 35.7 % in Slovenia and 36.3 % in Croatia). Sales were the last of the three most important factors that encourage the recognition of a need for furniture in customers (weight of 13.4 % in Slovenia and 20.3 % in Croatia).

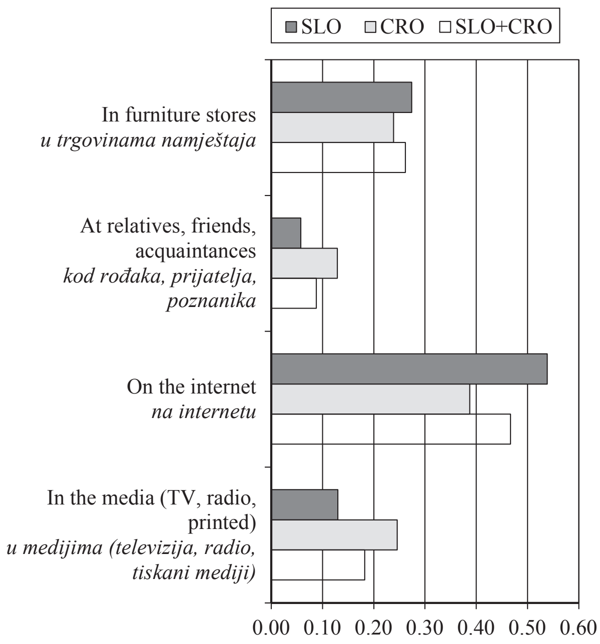

Figure 4 Where do potential buyers search for information about furniture
Slika 4. Mjesta na kojima potencijalni kupci traže informacije o namještaju

Figure 4 shows where customers, who have identified the need to purchase furniture, seek for information. In both countries, the potential buyers first seek information on the Internet. In Slovenia, this weight was almost twice as high as the next one. The weight of the Internet was 53.8 % and furniture shops, that were the second most important factor, obtained only a weight of 27.4 %. The media (TV, radio, printed) was noted as the third most important place where consumers seek information, noting a weight of 13.0 %. Consumer's relatives, friends, and acquaintances (with a weight of 5.8 %) were found to be as the fourth important factor regarding the place where consumers seek information about furniture in Slovenia.

In Croatia, the Internet was established as the most important place for seeking information (weight of 38.7 %), the media were in the second place (weight of 24.6 %), furniture shops in the third place with an almost equal weight (23.8 %) and relatives, friends and acquaintances with a weight of 12.9 % were the fourth most important place where potential buyers sought for information on furniture, but this last weight was more than twice as high as in Slovenia.

With regard to the most important criteria for purchasing furniture, according to the experts' opinion, Slovenian and Croatian consumers vary considerably. In Slovenia, the most important criterion was quality (weight of 41.6 %) and in Croatia, it was price (weight of 46.0 %). In Croatia, payment facilities (weight of 22.7 %) were more important than quality (weight of 13.1 %). Furthermore, after-sales services (weight of 10.2 %) were the fourth and the manufacturer's reputation (weight of 7.9 %) was placed the fifth. In Slovenia, the price was in second place with a weight of 27.5 %,

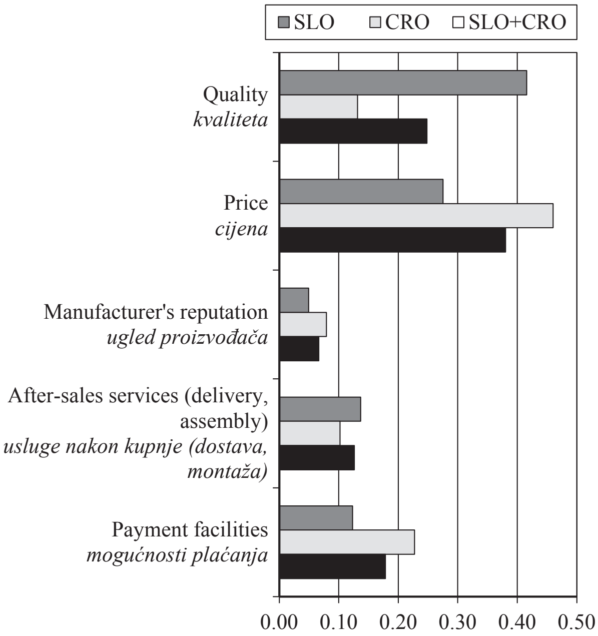

Figure 5 The most important criteria for the purchase of furniture
Slika 5. Najvažniji kriteriji kupca pri kupnji namještaja

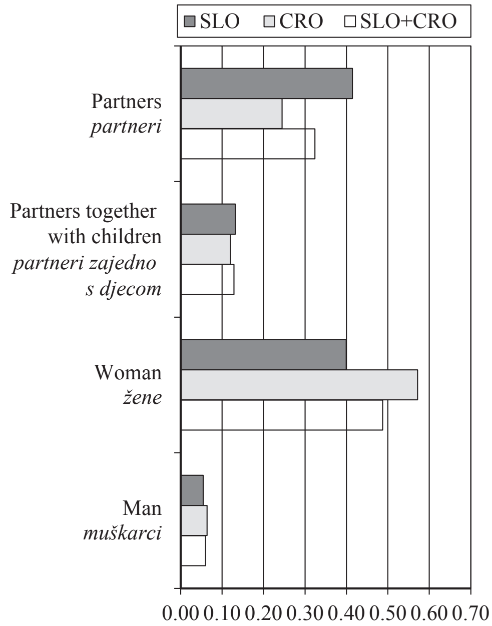

Figure 6 Decision makers on the purchase
Slika 6. Donositelji odluke o kupnji

after-sales services was in the third place with a weight of 13.7 %. Payment facilities took the fourth place with a weight of 12.3 % and the manufacturer's reputation was in the fifth place with a weight of 4.9 %.

In Slovenia, the decision to purchase furniture was mostly made by both partners jointly (weight of 41.4 %), while in Croatia it was mostly made by women (weight of 57.2 %). Decisions made solely by women were in the second place in Slovenia (only a slightly lower weight of 40.0 %), decisions made by partners together with their children were in the third place (weight of 13.2 %), and decisions made solely by men were in the fourth place (weight of 5.4 %). In Croatia, decisions made by both partners were in the second place with a weight of 24.5 %, decisions made by both partners with their children were in the third place with a weight of 12.0 % and decisions made solely by men were in the fourth place (weight of 6.4 %). The partners mostly made their decision together with their children when they were deciding to buy furniture for the children's bedroom.

5 CONCLUSION
5. ZAKLJUČAK

In the study, the influences on joint decision making in the purchase of furniture in Slovenia and in Croatia were established. Additionally, the experts were asked about consumers' needs, desires and habits at every stage of their buying decision process. In this way, very interesting answers, which could be helpful to manufacturers and sellers of furniture seeking to satisfy the consumer's needs and effectively formulate their marketing mix, were acquired.

Furthermore, important differences between the buying behaviour of potential furniture buyers in Slovenia and in Croatia were identified. Consumers in both countries were mostly stimulated to buy furniture due to low prices; slightly less due to the company's marketing activities and least of all due to the sales staff. The buying behaviour was also no different in the stage of the initial search for information on furniture. The Internet was, normally, found to be the first source of information and consumers would often also seek information in the furniture shops. However, they would less often seek information in the media and from their relatives, friends and acquaintances.

The results referred to the most important criteria for making a purchase show to be particularly interesting. In Slovenia, the quality of the product was found to be the most important; followed by price at the second place, after-sales services at the third place, and payment facilities at the fourth place. In Croatia, the criteria were arranged in a completely different order. The price was in the first place, followed by payment facilities, quality of products was in the third place and after-sales services in the fourth place.

In Slovenia, the decision to purchase furniture was mostly made together by both partners, while in Croatia it was mostly made by women. The partners often made a decision together with their children, especially when deciding about purchasing children's bedroom furniture. Additionally men would choose furniture by themselves very rarely.

The results of the study indicated that there were differences between the buying behaviour of potential furniture buyers in Slovenia and in Croatia. These findings could be helpful to furniture companies operating in these two target markets in the process of designing their marketing strategies.

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A Mid-Recession and Post-Recession Comparison of Chain-of-Custody Certification in the U.S. Value-Added Wood Product Manufacturing Sector

Usporedba CoC certifikacije u sektoru proizvođača finalnih drvnih proizvoda u SAD-u tijekom recesije i u postrecesijskom razdoblju

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ABSTRACT • *In this paper we examine changes in perceptions, attitudes, and participation in chain-of-custody (CoC) certification in the U.S. value-added, or secondary wood products sector between the period of the Great Recession (2007) and post-recession (2014). Data were collected for two studies conducted in 2008 (for 2007 annual data) and 2015 (for 2014 annual data) using web-based surveys administered by various value-added wood product associations on behalf of the researchers. Results show that understanding of CoC certification, purchases of certified raw materials, and costs to sell certified products increased over this period. The primary reasons for getting involved in certification changed from market driven (growing markets, increasing sales, and expanding market share) to customer driven (customer request) suggesting that respondents were attempting to use certification to become more competitive during the recession when many companies in the U.S. went out of business and employment in the sector declined. Nearly 100 % of respondents in both studies said that they planned on continuing sales of certified wood products.*

Key words: *chain-of-custody certification, value-added wood products, United States*

SAŽETAK • *U radu je opisano istraživanje promjena u percepciji, stajalištima i sudjelovanju u certifikaciji lanca sljedivosti (CoC) u sektoru proizvođača finalnih odnosno sekundarnih proizvoda od drva u SAD-u u razdoblju od velike recesije (2007.) do postrecesije (2014.). Podaci su prikupljeni iz dvaju istraživanja koja su provedena u 2008. (godišnji podaci za 2007.) i 2015. (godišnji podaci za 2014.). Istraživanja su realizirana uz pomoć web-anketa što su ih za istraživače provele različite udruge proizvođača finalnih drvnih proizvoda. Rezultati pokazuju da*

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su se razumijevanje CoC certifikata, kupnja certificiranih sirovina te prodajna cijena certificiranih drvnih proizvoda u navedenom razdoblju povećali. Glavni su se razlozi za uključivanje proizvođača u certificiranje promijenili i nisu više potaknuti tržištem (rastućim tržištima, povećanjem prodaje i širenjem tržišnog udjela) već zahtjevima kupaca. To upućuje na zaključak da se ispitanici pokušavaju koristiti certifikatom kako bi postali konkurentniji u vrijeme recesije, kada su mnoge tvrtke u SAD-u obustavile poslovanje, a zapošljavanje se u sektoru smanjilo. Gotovo 100 % ispitanika u obje studije izjasnilo se kako planiraju nastaviti prodaju certificiranih proizvoda od drva.

Ključne riječi: *CoC certifikat, finalni drvni proizvodi, SAD*

1 INTRODUCTION
1. UVOD

Concerns regarding tropical deforestation and the need for sustainably managed forest resources led to the emergence of forest certification programs in the early 1970s (Espinoza *et al.*, 2013, 2012; Marx and Cuypers, 2010; Vlosky *et al.,* 2009). Since that time, several factors such as government regulations, environmental activism, corporate social responsibility, and "green" investors, have influenced the growth of forest certification around the world (Cashore *et al.*, 2004; Maletz and Tysiachniouk, 2009).

Forest certification primarily aims to confirm that management of a specific forest area conforms to standards set by third party organizations. The major programs used by U.S. forest landowners and wood products manufacturers are Forest Stewardship Council (FSC), Sustainable Forestry Initiative (SFI) and Program for the Endorsement of Forest Certification (PEFC), and to a lesser degree, Scientific Certification Systems (SCS) (FSC, 2016; PEFC, 2014; SFI, 2015b; Vlosky *et al.*, 2003). In addition to third-party certification, the existence of first and second party certifications are acknowledged and often classified under self-regulation title (Marx and Cuypers, 2010).

Forest certification standards can be summarized under the three main categories, namely, performance based standards, system-based standards, and the ones that are a combination of the first two types. For instance, FSC is a performance based system in which forest resource is being compared to pre-set performance indicators, while within the scope of a system-based standard, the primary focus is on the adoption of predefined procedures. On the other hand, PEFC and SFI schemes employ combined certification standards and expect applicants to conform to the requirements of them (Espinoza *et al*., 2012). Dovetail Partners has released a report addressing various aspects and differences of FSC and SFI programs. The authors concluded that the differences between the standards of these two certification schemes are present and varying from region to region (Fernholz *et al*., 2015; Fernholz *et al*, 2010). However, the distinction ratio has been degrading to a lesser degree in recent years, especially after last revisions of both FSC and SFI standards occurred in 2012 and 2010, respectively (Fernholz et al., 2015; FSC, 2016; SFI, 2015b) . It is also emphasized that the choice between FSC and SFI program totally depends on case-specific considerations involving economic, social and environmental factors (Fernholz *et al.*, 2015; Fernholz *et al.*, 2012; Fernholz *et al.*, 2010). Sustainable forest management (SFM) criteria of PEFC are based on internationally recognized standards and indicators developed as a result of joint effort of government agencies all over the world. Thus, this organization functions like an umbrella that incorporates diversity of certification systems that pledge to meet its rigorous criteria under the same roof (Bowers *et al.*, 2014; Espinoza *et al.*, 2012; Moore *et al.*, 2012; PEFC, 2015).

In addition to the forest management component of certification, most certification schemes also provide chain-of-custody certification (CoC). The main purpose of CoC is to ensure that certified product is being processed in accordance with the guidelines and rules of specific certification program throughout the supply chain, from forests to the final consumer, by tracking and monitoring the material as it is formed into a pre-decided end item such as upholstered furniture, kitchen cabinets or wood flooring materials (Berg and Lovaglio, 2012; Espinoza *et al.*, 2012; Vlosky *et al.*, 2009).

Annual progress reports of FSC and PEFC show the trends of Chain of Custody (CoC) certificates issued by these certification programs. The most recent reports of FSC indicates that 5,257 CoC certificates have been issued to companies in U.S. and Canada as of end of 2015, a 5 % increase from the previous year (FSC, 2016). In addition, 439 CoCs, 260 in U.S. and 79 in Canada, have been issued by SFI by the end of 2014 (SFI, 2015a, 2015b).

This paper focuses on certification in the context of downstream members of the wood products supply chain that includes value-added or secondary products. Secondary products use primary products as input for re-manufacturing and include furniture, cabinetry, doors, flooring and millwork, whereas primary products are produced directly from logs such as lumber and plywood. The largest demand sector for both primary and secondary wood products is new home construction, also termed housing starts. Housing can be single family or multifamily, including apartments, condominiums and townhomes. The secondary wood product sector follows because new homes include floors, doors and millwork. Also, when people move into new homes, they typically purchase new furniture.

According to Federal Reserve Economic Data (FRED), seasonally adjusted annual housing starts in the U.S. reached a peak of 2.2 million in the 2005-2006 period. Accordingly, the wood products industry was extremely healthy with record production and employment. However, the "Great Recession" of 2007-2008 marked two consecutive years of significant reductions in housing starts, severely harming the U.S. forest

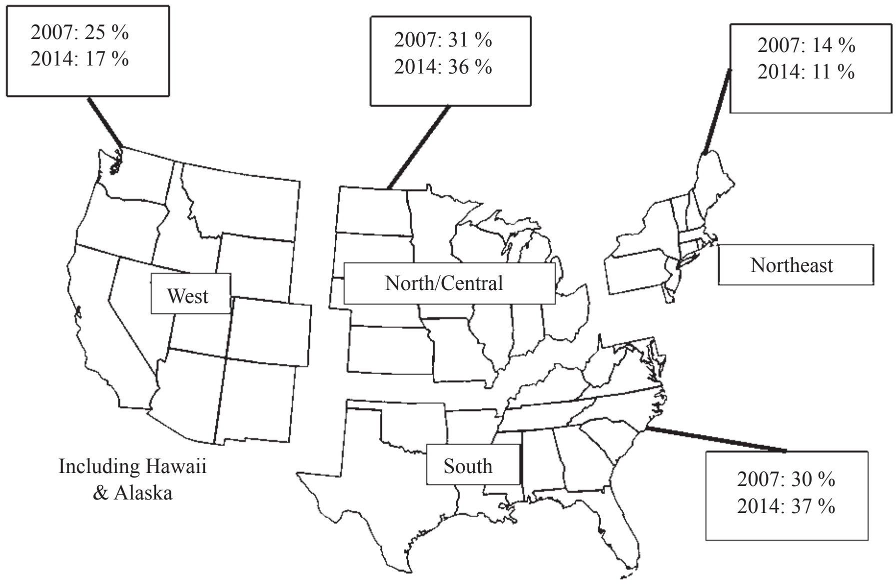

Figure 1 Respondent corporate headquarter locations (percent of respondents) (2007: *n* = 464; 2014: *n* = 251)
Slika 1. Lokacije korporacijskih sjedišta ispitanika (postotak ispitanika) (2007.: *n* = 464; 2014.: *n* = 251)

products sector, both primary and secondary. Housing starts have never fully recovered. As such, we wanted to see if there may be any underlying effects of the recession on certification adoption and structure for the value-added, secondary wood products sector.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

In 2008 and 2015, we conducted studies (for annual data from the previous years, 2007 and 2014) to identify value-added wood industry perspectives and participation in certification and to see what has changed in the industry since the "Great Recession". The data are from the previous years from when the studies were conducted, i.e., 2007 and 2014. We used SurveyMonkey® a web-based survey program. The data are presented for the previous years (the years that respondents were asked to report on). The questionnaires were sent by partner associations to their members on our behalf[1]. These associations required anonymity for their members and as such, controlled the dissemination of the surveys. Hence, only one "mailing" was sent for each time period. The associations did include a cover letter encouraging the recipients to participate in the studies.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Respondent demographics
3.1. Demografska slika ispitanika

There were 464 and 251 respondents in 2007 and 2014, respectively. Due to the methods used, we could not determine response rates for the studies. In addition, although the same sector was surveyed, respondent companies, key respondents and response rates were different for each period. However, frequencies of respondent geographic locations (Figure 1) and frequencies of raw materials used by respondents (Figure 2) in the two time periods are not statistically different. For both years, the majority of respondents were in the South and North/Central regions of the U.S. and composite panels were the most used raw material followed by North American hardwood lumber and North American plywood and veneer. The pattern of respondent company size shifted between 2007 and 2014 from smaller companies. Sixty-one percent and 41 % of respondent companies had 50 or less employees in 2007 and 2014, respectively. In 2007, 27 % of respondents had more than 100 employees and increasing in 2014 to 46 % of respondents.

3.2 Understanding and knowledge - certification concepts and certifiers
3.2. Razumijevanje i znanje – koncepti certificiranja i certifikatori

We first asked respondents to rate their level of understanding of forest management and Chain-of-Custody certification using a 5-point Likert scale anchored on 1 = Do not Understand at All; 3 = Somewhat Understand; 5 = Completely Understand. Using 2-tailed t-tests, we found that with regard to Forest Management certification, the overall level of understanding was high and there was no statistical difference in mean responses at $\alpha = 0.05$ level of significance (4.1 and 4.2 for 2007 and 2014, respectively). The level of understanding of Chain-of-Custody certification did see a statistically significant increase at $\alpha = 0.01$ from 3.9 in 2007 to 4.2 in 2014. This is the type of certification that value-added wood products manufacturers are involved in.

We then asked about respondent understanding of the three major certification programs' objectives, Forest Stewardship Council (FSC), Sustainable For-

[1] Association for Retail Environments (A.R.E.); Architectural Woodwork Institute (AWI); Business and Institutional Furniture Manufacturer Association (BIFMA); Kitchen Cabinet Manufacturers Association (KCMA); and the National Hardwood Flooring Association (NHFA).

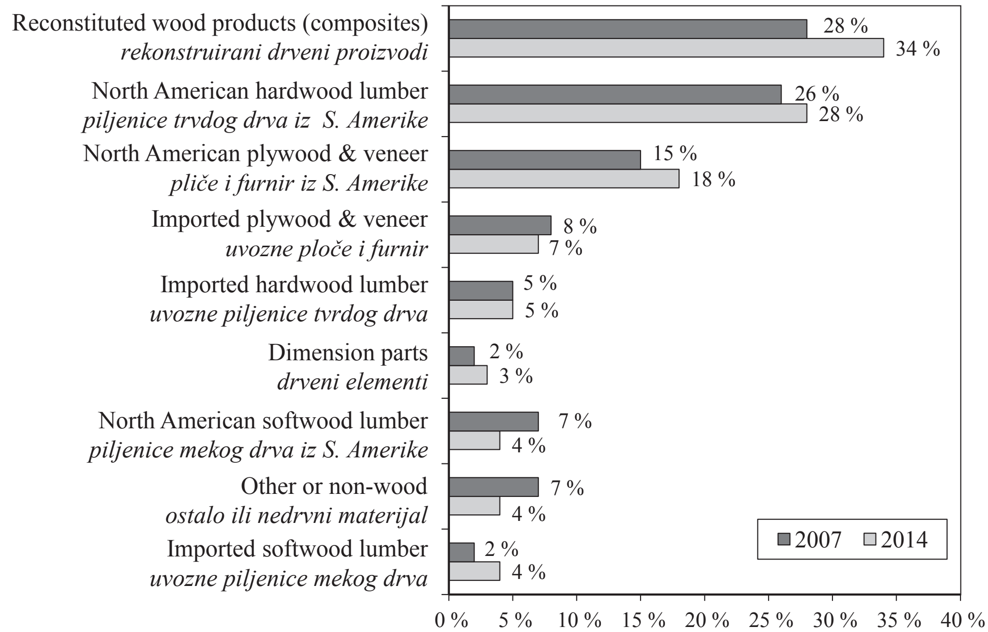

Figure 2 Raw materials used by respondents (percent of respondents) (multiple responses possible) (2007: n = 464; 2014: n = 251)
Slika 2. Sirovina kojom se koriste ispitanici (postotak ispitanika; mogući su višestruki odgovori) (2007.: n = 464; 2014.: n = 251)

estry Initiative (SFI), and Program for the Endorsement of Certification (PEFC). From 2007 to 2014, respondent mean understanding of PEFC and SFI declined significantly at α = 0.01 (PEFC: 3.3 to 2.5; SFI: 3.4 to 2.9). For FSC, the average level of understanding increased significantly at α = 0.01 from 3.7 to 4.2.

We also wanted to know what all respondents thought about their certification business practices and perceptions in general. Using Likert Scale anchored on 1 = Strongly Disagree; 3 = Somewhat Agree; 5 = Strongly Agree, the level of agreement from respondents that seek out suppliers of certified wood raw materials has increased marginally from 2007 to 2014 (Figure 3). The level of agreement regarding the belief that their customers would pay a premium for certified wood products decreased marginally (2.6 to 2.5) and the level of agreement that they would pay a premium for certified wood raw materials remained flat at 2.5. The final question posed to all respondents was whether they have actually purchased certified raw materials over the previous year. In this case, the average levels of agreement were higher than the midpoint and the increase in the level of agreement was significant at α = 0.01, increasing from 3.3 in 2007 to 4.0 in 2014.

3.3 Respondents with certification
3.3. Ispitanici s certifikatom

The percent of respondents that sold certified wood products increased from 12 % in 2007 (n = 11/152 that responded) to 83 % in 2014 (n = 76/92 that

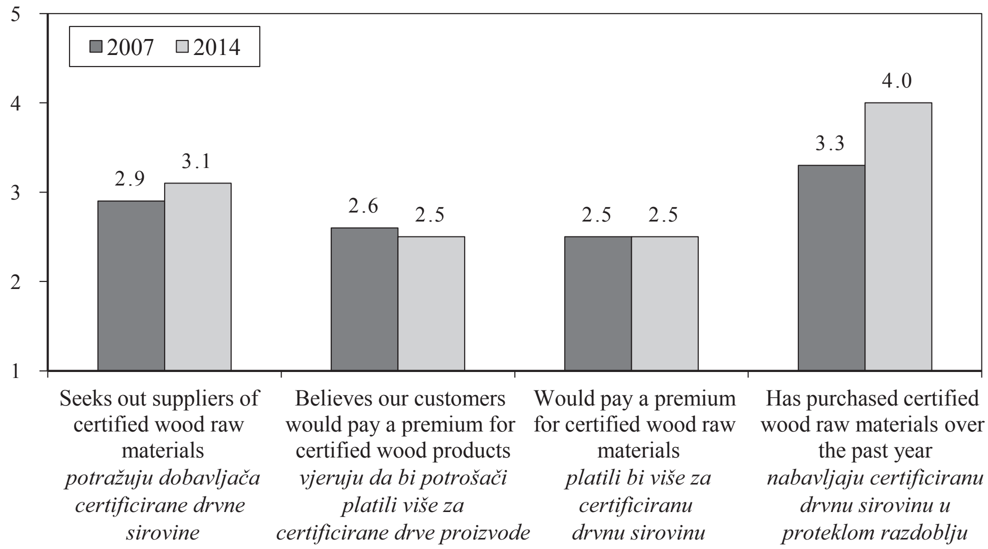

Figure 3 General certification concepts (2007: n = 454; 2014: n = 153) (Scale: 1 = Do Not Agree at all; 3 = Somewhat Agree; 5 = Completely Agree)
Slika 3. Opći koncepti certificiranja (2007.: n = 454; 2014.: n = 153) (ljestvica: 1 – uopće se ne slažem; 3 – uglavnom se slažem; 5 – potpuno se slažem)

Table 1 Certification plans for the future (percent of respondents without certification)
Tablica 1. Budući planovi certificiranja (postotak ispitanika bez certifikata)

	2007 (n = 269)	2014 (n = 63)
Obtain chain-of-custody certification within 1 year? *Planirate li dobiti CoC certifikat unutar jedne godine?*	11 %	10 %
Obtain chain-of-custody certification within 2 years? *Planirate li dobiti CoC certifikat unutar dvije godine?*	10 %	2 %
Monitor developments and obtain chain-of-custody certification if needed? *Pratite li razvoj i planirate li dobiti CoC certifikat ako vam bude potreban?*	58 %	60 %
Ignore chain-of-custody certification? / *Ignorirate li CoC certifikat?*	20 %	29 %

responded), a significant increase at α = 0.01 using Pearson Chi-Square test (χ^2 = 0.000). As certification becomes an increasingly important part of the business structures for respondents, their level of understanding of CoC certification processes increased commensurately. Using a 5-point Likert scale of understanding (1 = Poor, 2 = Fair, 3 = Good, 4 = Very Good, 5 = Excellent), in 2007, 65 % of respondents said they had a Very Good or Excellent understanding of certification. In 2014, 80 % of respondents had this level of understanding. This difference was significant at α = 0.01 (p = 0.000) using a 2-tailed t-test.

For the respondents that indicated that they did not sell certified wood products at the time that the surveys were conducted, we asked what their plans were for the future (Table 1). The vast majority of respondents for both studies said they were going to monitor the situation and obtain Chain-of-Custody (CoC) certification if necessary (2007: 58 %; 2014: 60 %). The percent of respondents that said they were planning on getting CoC within one year was similar for both 2007 and 2014 as was the percent of respondents that said they were simply going to ignore certification completely. The response with the biggest disparity was for respondents that were going to obtain CoC within two years, decreasing from 10 % of respondents in 2007 to 2 % in 2014.

Why did respondents get involved in certification? Figure 4 shows that responding to customer requests became the primary reason over time, a shift from attempts to build markets and sales. All of the other possible reasons declined from 2007 to 2014. The authors suggest that this is due to the "Great Recession" that prompted respondents to try most anything to be more competitive during these turbulent economic times. These pressures appear to have waned in the intervening years since the recession.

The percent of respondents with Chain-of-Custody certification jumped almost 600 % from 2007 to 2014 with 12 % and 83 % of respondents stating that this was the case, respectively. This was a significant increase at α = 0.01 using Pearson Chi-Square test (χ^2 = 0.000). For both years, Forest Stewardship Council (FSC) certification was most prevalent for 83 % and 85 % of respondents in 2007 and 2014, respectively (Figure 5). Other certification programs used by respondents were Sustainable Forestry Initiative (SFI), Program for the Endorsement of Forest Certification

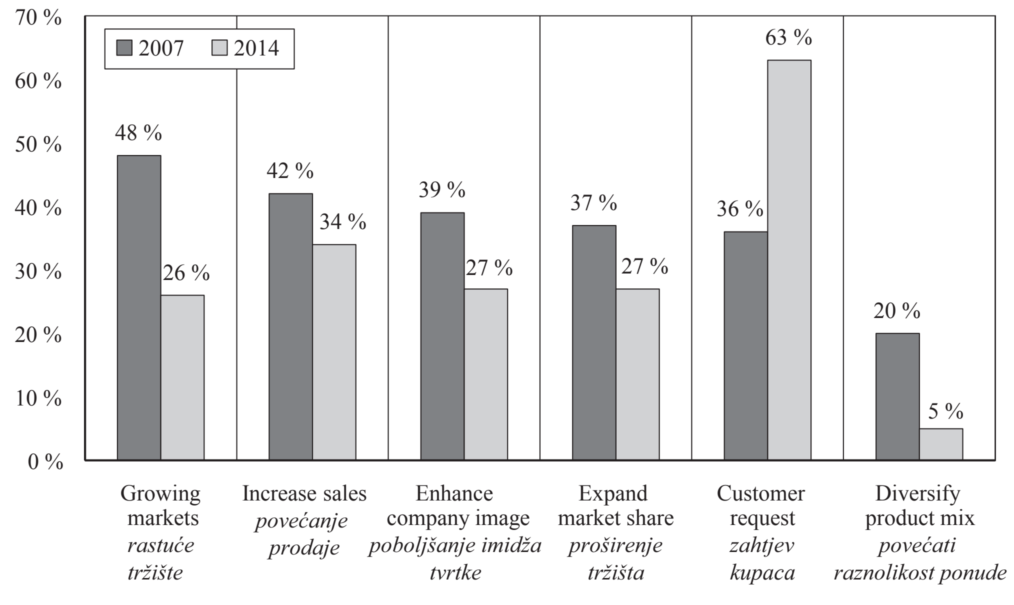

Figure 4 Why respondents became involved in certification (percent of respondents) (multiple responses possible) (2007: n = 193; 2014: n = 99)
Slika 4. Razlozi uključivanja ispitanika u certificiranje (postotak ispitanika; mogući su višestruki odgovori) (2007.: n = 193; 2014.: n = 99)

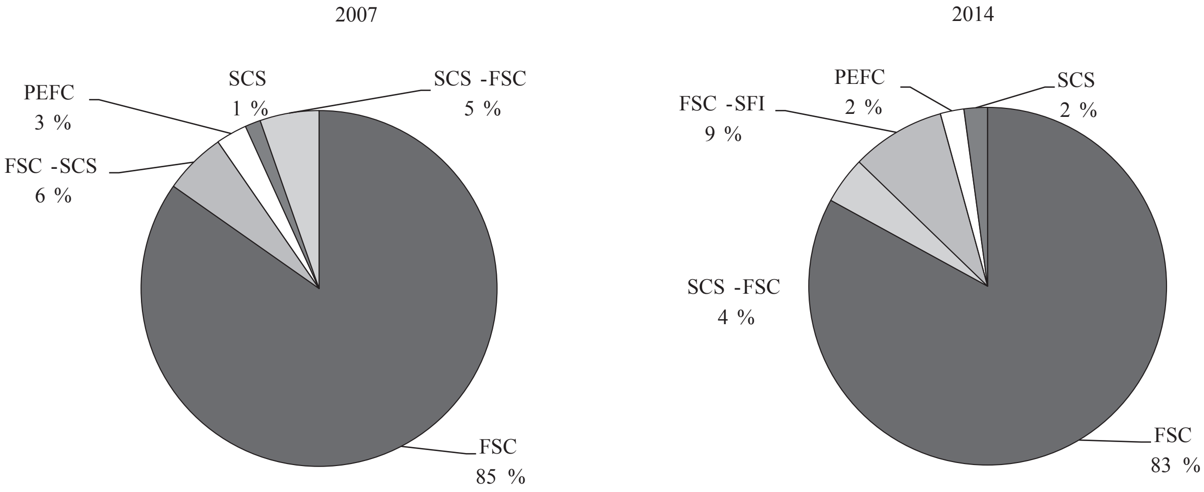

Figure 5 Chain-of-custody certification program used by respondents (percent of respondents) (2007: *n* = 193; 2014: *n* = 99)
Slika 5. Programi CoC certificiranja kojima se koriste ispitanici (postotak ispitanika) (2007.: *n* = 193; 2014.: *n* = 99)

(PEFC), Scientific Certification Systems (SCS), or combinations of these programs.

3.4 Certified raw material purchases
3.4. Nabava certificirane sirovine

On the wood raw material supply side, on average, the percent of wood products purchase costs attributed to certified products increased from 20 % in 2007 to 33 % in 2014, a statistically significant difference at $\alpha = 0.05$ ($p = 0.012$) using a 2-tailed t-test. The percent of respondents requesting that their wood raw material suppliers become certified increased marginally from 50 % to 51 % in 2007 to 2014. As shown earlier, customer demands for certified wood products are increasing, so it is no surprise that respondents are pressuring their suppliers to provide certified raw materials. With multiple responses possible, over the two time periods, respondent sourcing of certified raw material internationally (27 % to 35 % of respondents) and direct purchases from domestic suppliers (61 % to 73 % of respondents) increased with a decline sourced from U.S. brokers/wholesalers (50 % to 46 %). In addition, in 2007, 74 % of respondents said they paid a premium for certified wood raw materials increasing to 89 % of respondents in 2014.

Respondents were asked about the problems or challenges they face when purchasing certified wood product materials. Table 2 shows that Overpriced Products and Inconsistent Supply have been ranked #1 or #2 for the three time periods. Supplier Service, Delivery, and Contracts as well as Product Quality do not appear to be significant issues.

Table 2 The top 5 problems faced when purchasing certified wood raw materials (ranked: 1 = worst problem to 5 = least worst problem) (2007: *n* = 193; 2014: *n* = 99)
Tablica 2. Najčešćih pet problema s kojima se ispitanici suočavaju pri nabavi certificirane drvne sirovine (rang: 1 – najveći problem, 5 – najmanji problem) (2007.: *n* = 193; 2014.: *n* = 99)

	2007 RANK	**2014 RANK**
Overpriced products *Previsoke cijene proizvoda*	1	1
Inconsistent supply / *Nepouzdana opskrba*	2	2
Inconsistent quantities / *Nestalne količine*	3	
Inadequate service / *Neadekvatna usluga*	4	
Late delivery /*Kasna isporuka*	5	3
Product quality / *Kvaliteta proizvoda*		5
Contract fulfillment / *Ispunjenje ugovora*		4

3.5 Selling certified products
3.5. Prodaja certificiranih proizvoda

On the sales side of the supply chain, the percent of total company sales, on average, attributed to certified products increased marginally from 21 % in 2007 to 22 % in 2014. The volume of certified products sold by respondents generally decreased over the previous five years for each study period. In 2007, 4 % of respondents said sales had decreased in the previous 5 years, while in 2014, 18 % of respondents said sales decreased. The percent of respondents saying that certified wood products sales increased in the previous 5 years declined from 56 % of respondents in 2007 to 40 % in 2014. The percent of respondents that saw no change was 40 % and 42 % of respondents in 2007 and 2014, respectively.

The customer base for certified wood products remained fairly consistent between time periods with Institutional Customers, State Governments, Custom Woodworking Jobs, and Municipalities ranked highest (Figure 6). With regard to the geographic market profile, the only major change (significant at $\alpha = 0.01$ using a 2-tailed t-test) was the decrease in the percent of sales to In-State markets, which declined from 27 % to 11 % of respondents (Figure 7). Local Markets and those in Other States increased, while Export markets remained the same at 8 % of respondent markets.

In 2007, 61 % of respondents received a premium for certified wood products relative to the non-certified alternative. In 2014, this had dropped to 42 % of respondents receiving such a premium. When asked if their company incurred any additional costs

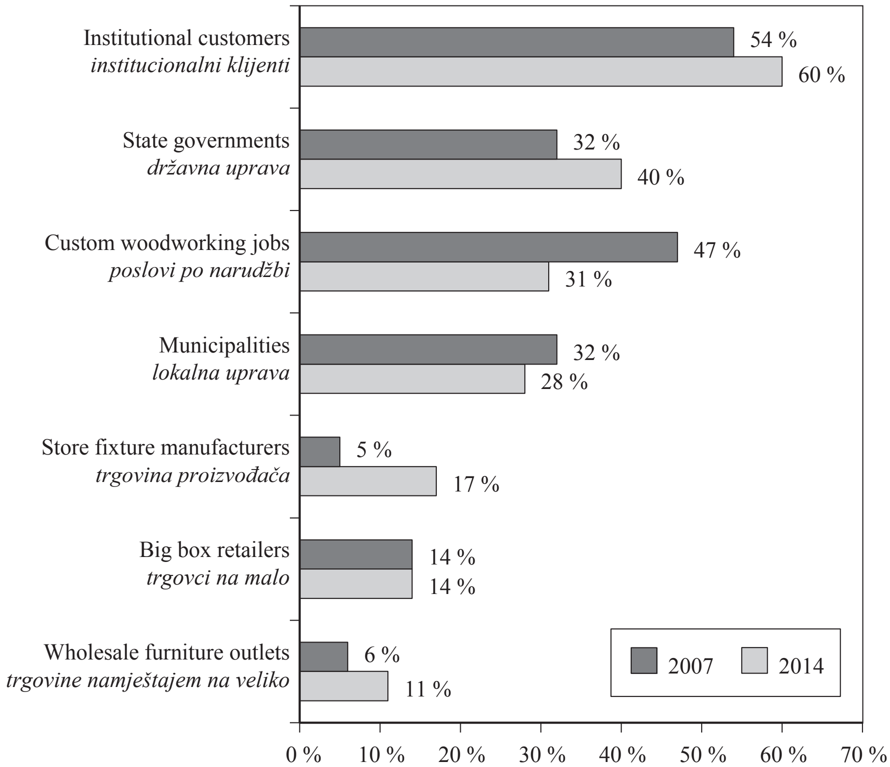

Figure 6 Customers for certified wood products (% of respondents) (multiple responses possible) (2007: *n* = 193; 2014: *n* = 99)
Slika 6. Kupci certificiranih drvnih proizvoda (postotak ispitanika; mogući su višestruki odgovori) (2007.: *n* = 193; 2014.: *n* = 99)

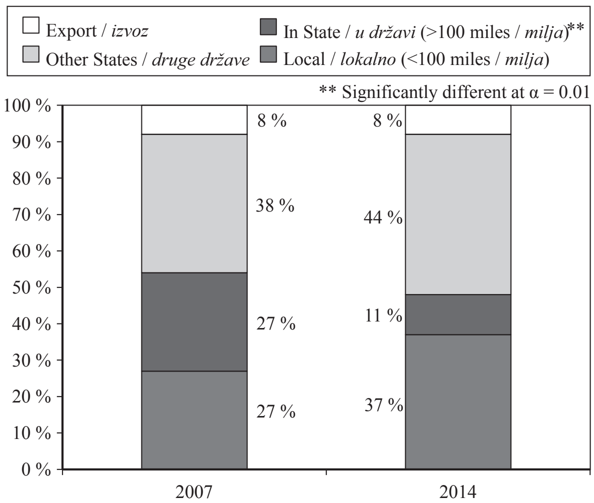

Figure 7 Geographic locations of **c**ustomers for certified wood products (percent of respondents) (multiple responses possible) (2007: *n* = 130; 2014: *n* = 99)
Slika 7. Zemljopisne lokacije kupaca certificiranih drvnih proizvoda (postotak ispitanika; mogući su višestruki odgovori) (2007.: *n* = 130; 2014.: *n* = 99)

to provide certified products to their customers, the percent of respondents saying this was the case increased from 77 % of respondents in 2007 to 90 % of respondents in 2014.

The final questions asked respondents to look ahead into the future with regard to their plans to sell certified wood products. Overwhelmingly, respondents in both years said they planned to continue selling certified products (97 % and 98 % of respondents in 2007 and 2014, respectively). However, in 2007, 84 % of respondents saw their sales volume of certified products increasing in the future, while in 2014, only 45 % of respondents felt this to be the case; in 2007, 14 % of respondents saw sales as remaining the same in the future, while 43 % in 2014 believed this to be true. This suggests a slowing in the rate of growth for certified wood products for existing companies.

4 CONCLUSION
4. ZAKLJUČAK

The U.S. forest products industry has not fully recovered from the recession of 2007-2008. In this comparative temporal study, we found that certification understanding, awareness and participation increased between this recessionary period and 2014. In examining possible effects of the recession, results show that the primary motivational factors for certification participation shifted from market driven to customer driven. In the quest to find new markets, expand existing markets, or simply remain in business, the provision of certified "green" products may have been part of respondent competitive strategies. This strategy seems to have created pressure on margins for the sale of certified products. For example, the percent of respondents receiving premiums for certified wood products declined by 31 %, while the percent of respondents paying a premium for certified raw materials increased by 20 %. Certification has matured and expanded since its inception. Results suggest that certification continues to be an important part of doing business for the value-added wood products sector in the U.S. with almost all respondents in both studies having plans to continue selling certified wood products.

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Interrelationship between Static and Dynamic Strength Properties of Wood and its Structural Integrity

Međusobna ovisnost statičkih i dinamičkih svojstava čvrstoće drva i njegova strukturnog integriteta

Original scientific paper • Izvorni znanstveni rad
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ABSTRACT • *Various biotic and abiotic agents affect the performance of wood products. Chemicals, thermal energy, radiation, as well as different organisms have the potential to alter the optical, haptic and functional performance of wood. These effects come along with a change of structural integrity of wood, which in turn affects its strength properties. Therefore, a test was developed to quantify the structural integrity of wood in terms of its Resistance to Impact Milling (RIM). In a High-Energy Multiple Impact (HEMI) – test, steel balls were used in a heavy vibratory mill for crushing wood samples. Thousands of single events were captured by analyzing the fragments. Based on the degree of integrity and the percentage of fine fragments (< 1mm), an indicator has been defined to detect structural changes on cell wall level with high sensitivity.*
The aim of this study was to investigate the variation of structural integrity within and between ten different wood species in comparison with some strength properties according to standardized test protocols and in dependence of wood density. HEMI-tests, bending tests, and impact bending tests were performed with matched specimens. Wood density turned out to have only a subsidiary effect on structural integrity, but is dominanting standard strength properties. Thus, RIM was found to be only slightly correlated with the impact bending strength (IBS) and bending strength (MOR). On the other hand, the method shows clear insensitivity to natural variation in anatomy of wood.

Key words: *bending strength, High-Energy Multiple Impact (HEMI) tests, impact bending strength, modulus of elasticity, Resistance to Impact Milling (RIM)*

SAŽETAK • *Na svojstva proizvoda od drva utječu brojni biotički i abiotički činitelji. Kemikalije, toplinska energija, zračenja i različiti organizmi mogu promijeniti optička, haptička i funkcionalna svojstva drva. Te učinke prate i promjene strukturnog integriteta drva, što pak utječe na njegovu čvrstoću. Stoga je razvijen test za kvantificiranje strukturnog integriteta drva s obzirom na njegovu otpornost na udarce (RIM). Za provedbu testa višestrukih udar-*

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aca visoke energije (HEMI test) upotrijebljene su čelične kuglice u teškome vibracijskome mlinu za drobljenje uzoraka drva. Analizom fragmentiranog drva obuhvaćeno je više tisuća pojedinačnih događaja. Na temelju stupnja integriteta i postotka sitnih čestica (< 1 mm) definiran je pokazatelj vrlo visoke osjetljivosti koji otkriva strukturne promjene na razini stanične stijenke.
Ova je studija usmjerena na istraživanje varijacija strukturnog integriteta unutar i između deset različitih vrsta drva u usporedbi s odabranim svojstvima čvrstoće prema standardiziranim ispitnim testovima te u ovisnosti o gustoći drva. HEMI testovi, testovi savijanja i testovi ispitivanja žilavosti provedeni su na odgovarajućim uzorcima. Pokazalo se da gustoća drva ima samo sekundarni utjecaj na strukturni integritet, a da dominantnu ulogu imaju standardna svojstva čvrstoće. Rezultati su pokazali da je RIM slabo povezan sa žilavošću materijala (IBS) i čvrstoćom na savijanje (MOR). No predstavljeni je pokazatelj nedvojbeno neosjetljiv na prirodne varijacije u građi drva.

Ključne riječi: *čvrstoća na savijanje, test višestrukih udaraca visoke energije (HEMI), žilavost materijala, modul elastičnosti, otpornost na udarce (RIM)*

1 INTRODUCTION
1. UVOD

Various biotic and abiotic agents are affecting the performance of wood and wood based products. Chemicals, thermal energy, radiation, as well as different organisms have the potential to alter the optical, haptic and finally functional performance of wood (e.g. Berger *et al.*, 2006; Sandak *et al.*, 2015; Willems *et al.*, 2015). Many of these effects come along with a change of the structural integrity of wood, which in turn affects its strength properties. Therefore, a test was developed to determine the structural integrity of wood in terms of its resistance to impact milling. A High-Energy Multiple Impact (HEMI) – test has been designed using steel balls in a heavy vibratory mill for crushing wood samples. The development work started after realizing that bending and impact bending strength tests were not suitable for quality control of – in this case – thermally modified wood (Brischke *et al.*, 2006a). They suffered from insufficient reliability and reproducibility and required a high number of carefully selected and precisely manufactured replicate samples. Consequently, time and costs became unacceptably high for industrial quality control (Rapp *et al.*, 2006).

The aim was to overcome the drawbacks of standard strength testing, but keeping the advantage of examining a highly sensitive wood property such as its dynamic strength, which is strongly affected by structural changes of the material. Instead of using multiple replicates, the number of events affecting the wood should be multiplied. After a first attempt to use a shotgun to apply several hundred pellets at a time on wooden boards – which might cause significant security problems in the lab – a heavy vibratory ball mill was used for crushing wood samples (Brischke *et al.*, 2006a). The Resistance to Impact Milling (*RIM*), which can vary between 0 and 100 %, is used here as a measure of wood structural integrity.

Heat treatment of wood goes along with a drastic strength loss (e.g. Esteves and Pereira, 2008). In particular, the dynamic strength properties are affected, and so is *RIM*. Excellent correlation was obtained between *RIM* and the severity of thermal modification expressed as decrease in mass (*dm*) or in terms of color changes (Brischke *et al.*, 2006a, 2012; Rapp *et al.*, 2006). As shown for 14 different wood species by Welzbacher *et al.* (2012), the treatment intensity can be estimated from *RIM* with fairly high precision.

Different kinds of chemical modification were also examined. Their very different effects on the structural integrity of wood were found to be detectable. While furfurylation and treatments with DMDHEU (dimethylol dihydroxyethyleneurea) and melamine resin led to a significant decrease in *RIM*, hydrophobation with oils and waxes increased the structural integrity (Brischke *et al.*, 2012). Impregnation with oil and wax obviously did not weaken the wood structure, but increased the *RIM*, which might be explained by hydraulic effects (e.g. Ulvcrona *et al.*, 2006). Furthermore, a remarkably reduced amount of fine fragments indicated ‘adhesion effects’, which might also have a positive effect on the structural integrity.

Hydraulic effects have also been observed on water saturated samples by Brischke *et al.* (2014), when testing different wood species used in the marine environment. While the structural integrity decreased with increasing moisture content in the hygroscopic range, it increased again up to full water saturation due to hampered short term compression of the wooden cells when the lumens were filled with water.

The HEMI test was furthermore used to detect incipient decay (Brischke *et al.*, 2006b). Brown and white rot had clearly different effects on the structural integrity. Partly, differences were found even on fungal species level (Brischke *et al.*, 2008). Fungal decay was found to be detectable before significant mass loss was determined. Furthermore, Huckfeldt *et al.* (2010) showed that drilling cores taken from full size structures can also be used for HEMI tests for early detection of fungal degradation. Samples from archaeological objects, such as the Vasa shipwreck in Stockholm, Sweden, were investigated with the HEMI method (Rapp *et al.*, 2008).

Gamma radiation, which is a common method for sterilization of wood samples, e.g. for laboratory resistance tests, did negatively affect the structural integrity of wood (Despot *et al.*, 2007). Degradation of cellulose through radiation led to significantly reduced *RIM*. On the other hand, the HEMI method was found to be almost unaffected by wood density, weathering effects (e.g. cracking) and blue stain (Brischke *et al.* 2009), which requires further testing.

Previous tests with different wood-based materials indicated that *RIM* and mechanical properties, such as impact bending strength and bending strength, are only poorly correlated, although both are negatively affected e.g. by heat, fungal decay or radiation, but are obviously affected by different structural features (Welzbacher *et al.*, 2011; Brischke *et al.*, 2014).

Therefore, in this study, the structural integrity of different wood species was determined on samples, which had previously been submitted to standard impact bending tests. Furthermore, matched specimens were subjected to three-point-bending tests to determine the modulus of elasticity (*MOE*) and the modulus of rupture (*MOR*).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Wood
2.1. Drvo

Specimens were prepared from European-grown wood species, i.e. four softwoods and six hardwoods as shown in Table 1. Specimens for impact bending and bending tests were cut from the same planks; HEMI test specimens were cut from impact bending test specimens after the tests to match them exactly in axial direction.

2.2 Determination of oven-dry density
2.2. Određivanje gustoće apsolutno suhog drva

The oven-dry density was determined on HEMI test specimens since they were axially matched with the impact bending test specimens. The specimens were oven dried at 103 °C till constant mass, weighed to the nearest 0.01 g and the dimensions were measured to the nearest 0.01 mm. The oven dry density was calculated according to the following equation:

$$\rho_0 = \frac{m_0}{v_0}, \quad \frac{\text{g}}{\text{cm}^3} \tag{1}$$

Where ρ_0 is the oven-dry density, m_0 is the oven-dry mass, and V_0 is the oven-dry volume of specimens.

2.3 Strength tests
2.3. Ispitivanje čvrstoće

Impact bending tests were performed on 300 x 20 x 20 mm³ specimens using a Otto-Wolpert pendulum impact machine according to DIN 52 189-1 (DIN 1981). The static bending tests were run to determine the bending strength (modulus of rupture *MOR*) and the modulus of elasticity (*MOE*) of wood according to DIN 52 186 (1978). Three-point bending tests were performed on 360 x 20 x 20 mm³ specimens with concentric force parallel to the grain on a universal testing machine Zwick/Roell Z100. Before the mechanical strength tests, all samples were conditioned in a standard climate at 20 °C and 65 % relative humidity until constant mass was achieved.

2.4 High-energy multiple impact (HEMI) – tests
2.4. Testovi višestrukih udaraca visoke energije (HEMI testovi)

The development and optimization of the High-Energy Multiple Impact (HEMI) - test have been described by Rapp *et al.* (2005) and Brischke *et al.* (2006a, b). In the present study, the following procedure was applied: 20 oven-dried specimens of 10 (ax.) x 5 x 20 mm³ were placed in the bowl (140 mm in diameter) of a heavy-impact ball mill (Herzog HSM 100-H; Herzog Maschinenfabrik, Osnabrück, Germany), together with one steel ball of 35 mm diameter for crushing the specimens. Three balls of 12 mm diameter and three of 6 mm diameter were added to ensure impact with smaller wood fragments. The bowl was shaken for 60 s at a rotary frequency of 23.3 s^{-1} and a stroke of 12 mm. The fragments of the 20 specimens were fractionated on a slit sieve according to ISO 5223 (1996) with a slit width of 1 mm using an orbital shaker at an amplitude of 25 mm and a rotary frequency of 350 min^{-1} for 2 min. The following values were calculated:

$$I = \frac{m_{20}}{m_{\text{all}}} \cdot 100, \quad \% \tag{2}$$

Where the degree of integrity *I* is the ratio of the mass of 20 biggest fragments m_{20} to the mass of all fractions m_{all} after crushing.

Table 1 Wood species under test
Tablica 1. Ispitivane vrste drva

Wood species *Vrsta drva*	Botanical name *Botanički naziv*	Number replicates[1] *Broj ponavljanja*		
		HEMI tests *HEMI test*	**Bending tests** *Test savijanja*	**Impact bending tests** *Test ispitivanja* žilavosti
Norway spruce / *norveška smreka*	*Picea abies* Karst.	30	38	60
Siberian larch / *siberijski ariš*	*Larix sibirica* Ledeb.	50	59	60
Douglas fir / *duglazija*	*Pseudotsuga menziesii* Franco.	25	29	25
Scots pine / *obični bor*	*Pinus sylvestris* L.	10	10	10
Beech / *bukva*	*Fagus sylvatica* L.	10	10	10
Poplar / *topola*	*Populus nigra* L.	10	10	10
Hornbeam / *grab*	*Carpinus betulus* L.	10	10	10
English oak / *hrast lužnjak*	*Quercus robur* L.	10	10	10
Ash / *jasen*	*Fraxinus excelsior* L.	10	10	10
Robinia / *bagrem*	*Robinia pseudoacacia* L.	10	10	10

[1] One replicate sample in HEMI tests consisted of 20 single specimens. / *Jedno ponavljanje mjerenja HEMI testovima obuhvaća 20 pojedinačnih uzoraka.*

Table 2 Oven-dry density, mechanical properties, and structural integrity measures for different wood species (*ODD* – oven-dry density, *MOR* – modulus of rupture, *MOE* – modulus of elasticity, *IBS* – impact bending strength, *RIM* – resistance to impact milling, *I* – degree of integrity, *F* – fine percentage)
Tablica 2. Gustoća apsolutno suhog drva te mehanička svojstva i mjere strukturnog integriteta različitih vrsta drva (*ODD* – gustoća apsolutno suhog drva, *MOR* – modul loma, *MOE* – modul elastičnosti, *IBS* – žilavost, *RIM* – otpornost na udarce, *I* – stupanj cjelovitosti, *F* – postotak sitnih čestica)

Wood species *Vrsta drva*	***ODD*** g/cm³	***MOR*** N/mm²	***MOE*** N/mm²	***IBS*** KJ/m²	***RIM*** %	***I*** %	***F*** %
Norway spruce *norveška smreka*	0.43 (0.05)	91.5 (9.9)	10379 (1303)	29.2 (9.3)	76.0 (2.9)	23.4 (5.0)	6.5 (2.6)
Siberian larch / *siberijski ariš*	0.57 (0.04)	123.1 (17.1)	12247 (1532)	40.8 (17.3)	78.0 (1.7)	32.4 (5.0)	6.8 (1.7)
Douglas fir / *duglazija*	0.55 (0.05)	113.2 (23.9)	12380 (2490)	45.4 (16.4)	83.0 (4.1)	41.3 (12.2)	3.2 (2.1)
Scots pine / *obični bor*	0.55 (0.02)	103.5 (11.3)	12637 (953)	34.1 (10.2)	78.5 (1.4)	28.8 (2.7)	5.0 (2.1)
Beech / *bukva*	0.71 (0.03)	140.8 (15.4)	12924 (1174)	62.8 (12.7)	86.9 (0.9)	52.4 (2.4)	1.6 (0.5)
Poplar / *topola*	0.37 (0.02)	72.9 (7.6)	8368 (566)	18.2 (8.6)	80.2 (2.1)	40.3 (3.1)	6.6 (1.9)
Hornbeam / *grab*	0.70 (0.07)	128.3 (9.0)	9062 (1569)	55.5 (7.3)	87.8 (1.0)	55.8 (4.0)	1.6 (0.5)
English oak / *hrast lužnjak*	0.66 (0.03)	97.3 (9.7)	9655 (729)	32.6 (8.4)	76.8 (2.7)	37.0 (6.5)	9.9 (1.6)
Ash / *jasen*	0.63 (0.02)	133.5 (12.5)	13477 (1448)	74.1 (12.1)	85.9 (1.2)	49.4 (4.7)	1.9 (0.6)
Robinia / *bagrem*	0.77 (0.02)	161.3 (23.5)	13457 (1089)	80.8 (40.0)	86.5 (1.0)	51.2 (3.4)	1.7 (0.5)

$$F = \frac{m_{\text{fragments<1mm}}}{m_{\text{all}}} \cdot 100, \quad \% \qquad (3)$$

Where the fine fraction *F* is the ratio of the mass of fragments < 1 mm to the mass of all fractions m_{all} multiplied by 100.

$$RIM = \frac{(I - 3 \times F) + 300}{400}, \quad \% \qquad (4)$$

Where *RIM* is the resistance to impact milling as a measure for the structural integrity of the material.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The results of various mechanical tests are summarized in Table 2. A wide range of density and different strength related properties was covered with Poplar showing lowest density and mechanical strength and Robinia with the best property values. However, Beech and Hornbeam showed similar or even higher *RIM* compared to Robinia. Compared to other mechanical properties, *RIM* differed significantly less between wood species. In contrast, *I* and *F* showed much higher variations than the resulting *RIM*, which points to the anatomical peculiarities of different wood species. For instance, high *F* values were found for softwoods, which also showed generally lower *IBS*, and English oak showed the highest *F* value of all. The softwoods are characterized by weak earlywood portions that alternate with latewood areas, whereby the transition from one tissue to the other can be more or less abrupt (e.g. Schweingruber, 2012). English oak, however, suffers from very thick parenchyma rays and large early wood vessels, which in combination might explain both, low *RIM* and *IBS*.

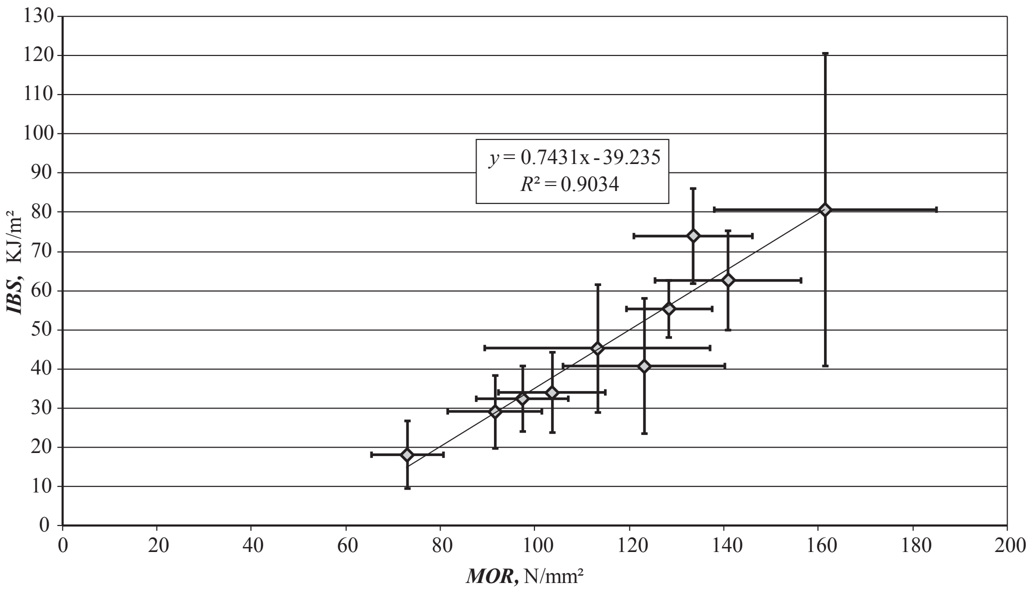

Figure 1 Relationship between modulus of rupture (*MOR*) and impact bending strength (*IBS*). (Dots represent mean values of wood species; Standard deviations are indicated by error bars.)
Slika 1. Odnos između modula loma (*MOR*) i žilavosti drva (*IBS*) (točke označuju prosječne vrijednosti za pojedine vrste drva, a standardne su devijacije prikazane linijama pogrešaka)

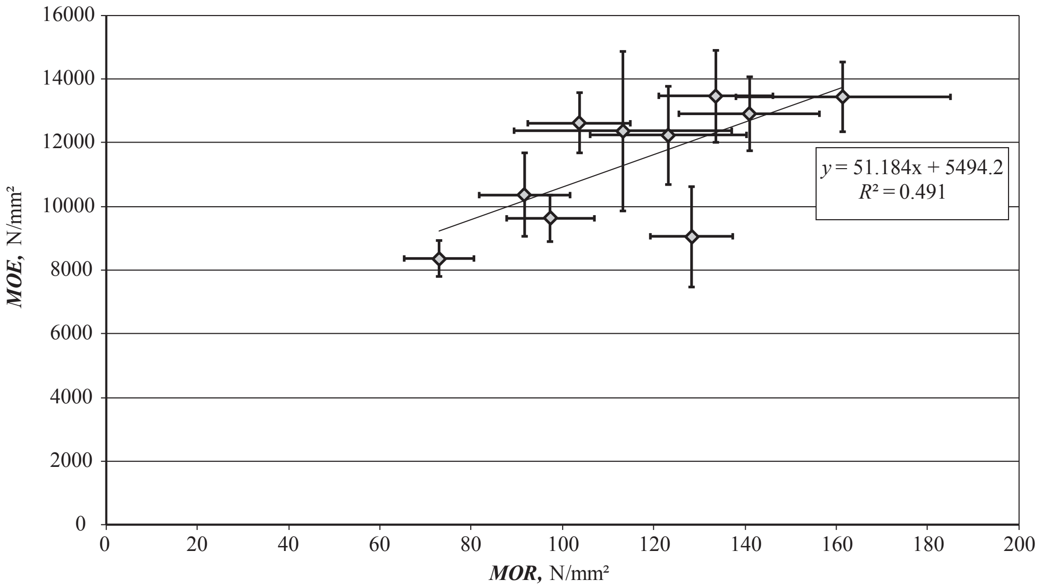

Figure 2 Relationship between modulus of rupture (*MOR*) and modulus of elasticity (*MOE*) (Dots represent mean values of wood species. Standard deviations are indicated by error bars.)
Slika 2. Odnos između modula loma (*MOR*) i modula elastičnosti drva (*MOE*) (točke predočuju prosječne vrijednosti za pojedine vrste drva, a standardne devijacije prikazane su linijama pogrešaka)

RIM showed very little variation for all tested wood species. The percentage standard deviation (coefficient of variation, *COV*) was between 1 and 5 %, which coincides with previous studies e.g. by Brischke *et al.* (2014). In contrary, *IBS* showed *COV* between 20 and 50 %. The two basic measures, *F* and *I,* used for calculating *RIM,* suffered from significantly higher variation. *I* showed *COV* up to 30 %, *F* scattered even more with a *COV* up to 66 %. However, in combination and expressed a RIM according to equation 4, the high variations are eliminated.

As expected, an excellent correlation was established between *IBS* and *MOR* (R^2 = 0.9034, Figure 1. Rather unexpected, the correlation between *MOE* and *MOR* was poor (R^2 = 0.491, Figure 2 and stands in contrast to earlier studies, e.g. by Young and Evans (2003), Niemz and Sonderegger (2003), and Lachenbruch *et al.* (2010), who found *MOE* and density clearly correlated, as well as the micro fibril angle and *MOE.*

The reason for *MOR* and *IBS* being so well correlated indicates a density dependency, which is illustrated in Figure 3. If only the mean values for different wood species are considered, *IBS* and *MOR* are well correlated with density, while *RIM* and *MOE* are not (Figure 3). However, if single values within one species are considered, as exemplarily shown for Norway spruce and Siberian larch in Figure 4, no correlation is achieved, neither between *RIM* nor *IBS* and density. This coincides with previous studies, where *RIM* appeared to be unaffected by density within one wood

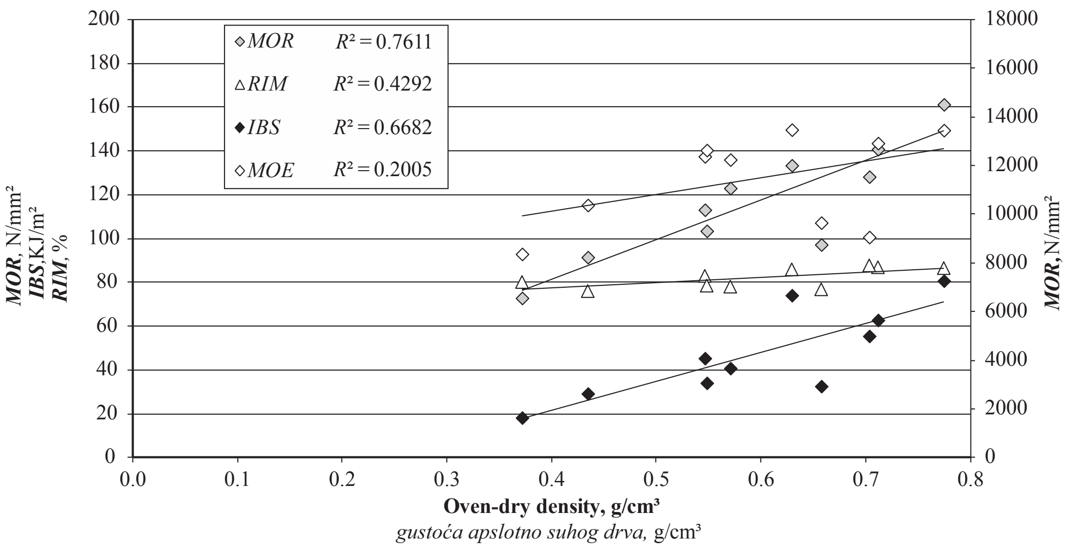

Figure 3 Relationship between oven-dry density and modulus of rupture (*MOR*), modulus of elasticity (*MOE*), impact bending strength (*IBS*), and resistance to impact milling (*RIM*) (Dots represent mean values of wood species)
Slika 3. Odnos između gustoće apsolutno suhog drva i modula loma (*MOR*), modula elastičnosti (*MOE*), žilavosti drva (*IBS*) i otpornosti na udarce (*RIM*) (točke označuju prosječne vrijednosti za pojedine vrste drva)

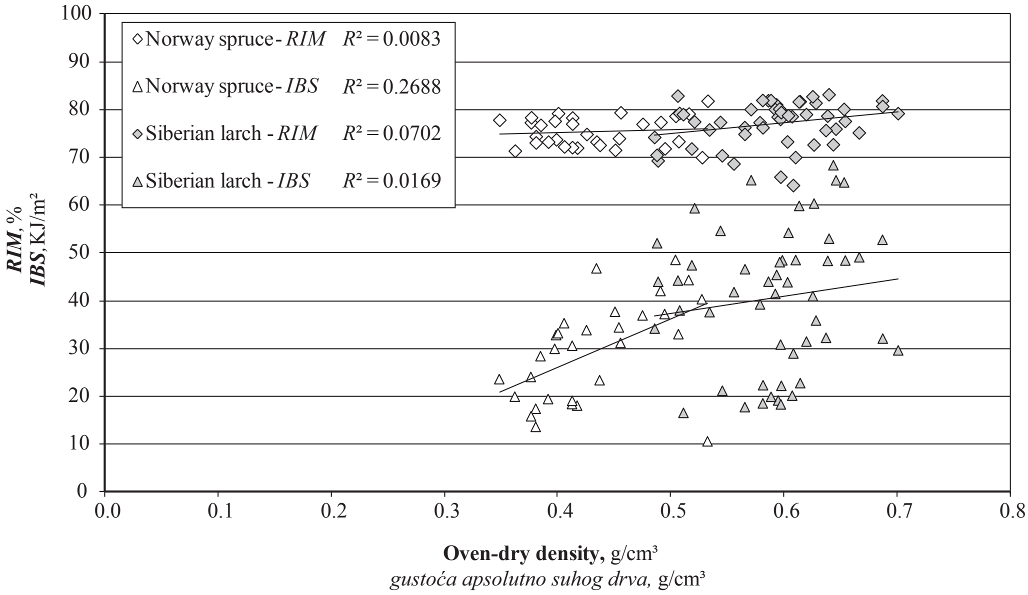

Figure 4 Relationship between oven-dry density and impact bending strength (*IBS*) and resistance to impact milling (*RIM*) for two different softwood species (Dots represent single values of replicate samples.)
Slika 4. Odnos između gustoće apsolutno suhog drva i žilavosti drva (*IBS*) te otpornosti na udarce (*RIM*) za dvije vrste mekog drva (točke predočuju vrijednosti pojedinačnih mjerenja)

Table 3 Coefficient of determination R^2 for different combinations of wood properties tested
Tablica 3. Koeficijent determinacije R^2 za različite kombinacije istraživanih svojstava drva

	RIM	*IBS*	*MOR*	*MOE*	Density
RIM	-	0.670	0.556	0.105	0.429
IBS		-	0.903	0.046	0.668
MOR			-	0.491	0.761
MOE				-	0.201
Density					-

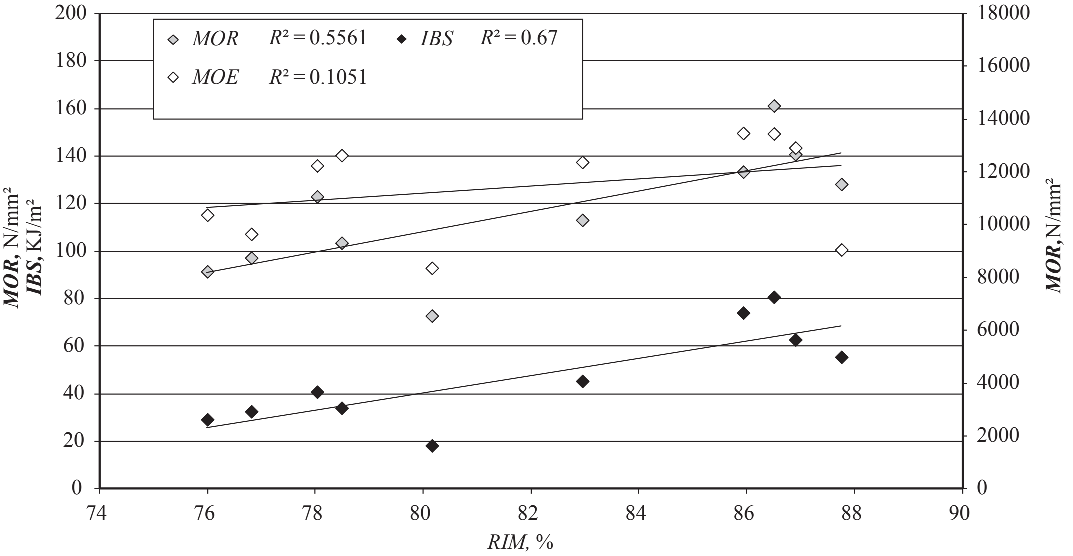

Figure 5 Relationship between resistance to impact milling (*RIM*) and modulus of rupture (*MOR*), modulus of elasticity (*MOE*), and impact bending strength (*IBS*) (Dots represent mean values of wood species.)
Slika 5. Odnos između otpornosti na udarce (*RIM*) i modula loma (*MOR*), modula elastičnosti (*MOE*) i žilavosti drva (*IBS*) (točke označuju prosječne vrijednosti za pojedine vrste drva)

species (Brischke *et al.*, 2009), but also across different wood species (Brischke *et al.*, 2014). Consequently, other anatomical characteristics need to be responsible for the significant differences in structural integrity between wood species. Nevertheless, as shown in Figure 5, *MOR* (R^2 = 0.5561) and *IBS* (R^2 = 0.67) seem to be correlated with *RIM*, but *MOE* (R^2 = 0.1051) is obviously not. An overview of cross-correlation of the investigated wood properties is given in Table 3.

Density is the dominating parameter for the majority of strength properties of wood, but numerous further factors have the potential to affect different strength and elasto-mechanical properties of wood. Fiber length, composition, size and amount of rays, lignin content, the micro fibril angle, and others lead to intra- and inter-species specific variation of wood properties (Niemz and Sonderegger, 2003) and are not necessarily the same for different wood properties such as the investigated parameters in this study. Dynamic strength properties, such as *IBS* and *RIM,* are affected by anatomical abnormalities, which can easily overrule the influence of wood density (Ghelmeziu, 1937; von Pechmann, 1953; Niemz and Sonderegger, 2003).

4 CONCLUSIONS
4. ZAKLJUČAK

Wood density seems to have only a subsidiary effect on the structural integrity of wood as determined in high-energy multiple impact (HEMI) tests. Furthermore, the *RIM* seems only slightly correlated with standard strength properties of wood such as *IBS* and *MOR*. More likely, anatomical features within one wood species, and in particular between wood species, have stronger effects on the structural integrity of wood and thus on its brittleness. Consequently, future studies need to include microscopic studies to further elaborate the effect of anatomical characteristics such as micro fibril angles and cell and tissue volume ratios.

The limited transferability of *RIM* to established strength properties of wood comes along with its insensitivity to natural variation in anatomy of wood. This retrieves the advantage of a high discriminatory power for detecting structural changes, e.g. caused by fungal decay or cell wall modification.

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Determination of Screw Withdrawal Resistance of Some Heat-Treated Wood Species

Određivanje otpora toplinski obrađenog drva izvlačenju vijaka

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ABSTRACT • *In this study, the screw withdrawal resistance of heat-treated hornbeam (Carpinus betulus L.), black pine (Pinus nigra Arnold) and Uludağ fir (Abies bornmuellerinana Mattf.) was determined according to the ASTM D 1761 standard. For this purpose, wood materials were heat treated at 150, 170, 190 and 210 °C for 3 h. After the heat treatment, the screw withdrawal resistance of the wood was determined in radial, tangential and transverse directions. As a result, the screw withdrawal resistance values decreased with increasing heat treatment temperature and the lowest resistance was obtained in the wood heat-treated at 210 °C. In terms of wood species, the highest screw withdrawal resistance was found in hornbeam (Carpinus betulus L.), while the lowest value was observed in black pine (Pinus nigra Arnold). Additionally, in terms of the cross-sectional direction, the highest screw withdrawal resistance was determined in the tangential direction, while the lowest resistance value was observed in the transverse direction.*

Key words: *heat treatment, black pine, hornbeam, Uludağ fir, screw withdrawal resistance*

SAŽETAK • *Ovim je istraživanjem određena veličina otpora drva izvlačenju vijaka na uzorcima od toplinski obrađenog drva graba (Carpinus betulus L.), crnog bora (Pinus nigra Arnold) i turske jele (Abies bornmuelleriana Mattf.), u skladu s normom ASTM D 1761. Za tu svrhu drvni su materijali toplinski obrađeni pri 150, 170, 190 i 210 °C tijekom tri sata. Nakon toplinske obrade određen je otpor drva izvlačenju vijaka na radijalnome, tangencijalnome i poprečnom presjeku drva. Rezultati istraživanja pokazali su da se vrijednosti otpora drva izvlačenju vijaka smanjuju s povećanjem temperature njegove toplinske obrade, a najmanji otpor zabilježen je za drvo toplinski obrađeno pri 210 °C. S obzirom na vrstu drva, najveći otpor izvlačenju vijaka izmjeren je na uzorcima od drva graba (Carpinus betulus L.), a najmanja je vrijednost izmjerena za uzorke od drva crnog bora (Pinus Nigra Arnold). S obzirom na presjek drva, najveći je otpor izvlačenju vijaka izmjeren na tangencijalnome, a najmanji na poprečnom presjeku drva.*

Ključne riječi: *toplinska obrada, crni bor, grab, turska jela, otpor izvlačenju vijaka*

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1 INTRODUCTION
1. UVOD

In recent years, as a result of increasing environmental consciousness, consumers have started to question the possible toxic effects of wood-modification applications using chemicals on the environment. This phenomenon has paved the way for developing alternative modification methods to preserve wood material – an eco-friendly and sustainable source. Heat treatment using adjustable treatment parameters is one of them i.e. an alternative modification method to chemical use that increases the wood dimensional stability and enhances its resistance against biological attack by reducing hygroscopicity and generating molecules toxic to fungi (Hill, 2006; Wang and Cooper, 2005). In this method, wood materials are heated in an oxygen-free environment at a temperature between 150 and 250 ºC. The heat treatment processes have been known for a very long time and they include several different methods. The main differences between the heat treatment processes are to be seen in the process conditions (process steps, oxygen or nitrogen, steaming, wet or dry process, the use of oils, steering schedules, etc.) (Militz, 2002). The heat-treated wood materials have very broad application areas ranging from outdoor uses such as sidings, doors, windows and garden furniture to indoor uses such as floors, paneling, baths and saunas (Viitaniemi, 2000). The dimensional stability and biological resistance of heat-treated wood materials increases, while their mechanical resistance decreases, which makes their use in load-bearing systems limited (Bekhta and Niemz, 2003; Esteves and Pereira, 2009; Korkut, 2008; Yildiz 2002; Korkut and Guller, 2008). The color of wood changes, and changes in mechanical properties have also been observed as a result of the heat treatment. Changes observed in physical and mechanical properties of heat-treated wood materials influence their performance in applications either positively or negatively (Ayan and Ciritcioğlu, 2012).

Some factors of the wood material, especially species and thickness, have some effects on the rigidity and durability of the wood structure elements. The screws are commonly used as joint components of the wood construction in engineered wood structures and, since each wood species has its own properties, they also have different screw withdrawal resistance. Therefore, the determination of this withdrawal resistance for some wood species is important for wood applications (Aytekin, 2008). The durability and stability of each structure depends on the performance of the fasteners. The screws are one of the fasteners widely used in the woodworking and furniture industries. Therefore, the knowledge regarding the withdrawal resistance of screws for wooden building elements will provide useful information about the durability and stability of the whole system (Celebi and Kilic, 2006). The number of screws, pilot-hole diameters, screw depth and material cross-sections should be taken into consideration in wood or wooden material applications (Faherty and Williamson, 1998; Koch, 1972).

Poncsák *et al*. (2006), investigated the effect of high heat treatment temperature on screw withdrawal resistance of birch (*Betula papyrifera*). They indicated that some decreases in screw withdrawal resistance were observed as a result of high temperature. Kocaefe *et al*. (2008) investigated the effects of heat treatment on technological properties of jack pine (*Pinus banksiana* Lamb.) and aspen (*Populus tremuloides* Michx.). They stated that screw withdrawal resistance of heat-treated jack pine decreased, but this decrease was not significantly different from the control samples. Also, screw withdrawal resistance of heat-treated aspen was found to be relatively higher than that of untreated samples. Kariz *et al*. (2013) determined the screw withdrawal resistance in the radial and tangential direction on the heat-treated spruce (*Picea abies* Karst.) at 150, 170, 190, 210, and 230 °C. The results indicated that there was a greater decrease in screw withdrawal resistance for heat treatment conditions, and they concluded that the size of deformation around the screw increased at higher temperatures based on the analysis of the images of the deformed surface left by the screws.

The amount of use and application areas of heat-treated wooden materials has substantially increased. Most of the joints use screws. Thus, the determination of screw withdrawal resistance of heat-treated wood materials is of importance in terms of high efficiency and strength of the structure. The aim of this study is to determine screw withdrawal resistance of the samples produced from heat-treated hornbeam (*Carpinus betulus* L.), black pine (*Pinus nigra* Arnold) and Uludag fir (*Abies bornmuelleriana* Mattf.).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Hornbeam (*Carpinus betulus* L.), black pine (*Pinus nigra* Arnold), and Uludağ fir (*Abies bornmuellerinana* Mattf.) were selected randomly from timber merchants as test materials because of their wide use in industry. Special emphasis was given for the selection of wood materials; non-deficient, proper, knotless, and normally grown (without zone line, reaction wood, decay, or damage caused by wood decay fungi) materials were selected. The samples were cut into in the dimensions of 60 (thickness) x 60 (width) x 780 (length) mm before the heat treatment, including radial, tangential and transverse cross-sections. The wood samples were conditioned to 12 % moisture contents (MC) in a conditioning device at 20 °C (± 2) and 65 % (± 5) relative humidity for two months before being planed and cut into small specimens.

2.1 Preparation of test samples and their heat treatment
2.1. Priprema uzoraka i njihova toplinska obrada

The small clear specimens were cut into 50 x 50 x 150 mm pieces for withdrawal tests before the heat treatment. Then they were completely dried at a temperature of 103±2 ºC until they had a constant weight. Completely dried samples were taken from the drying

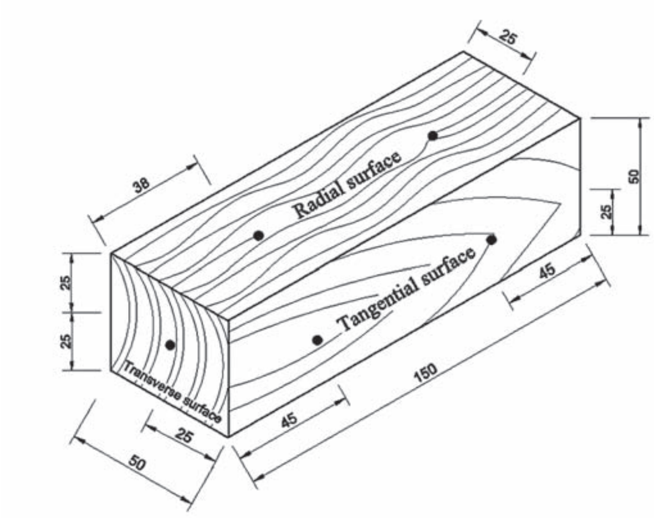

Figure 1 Test samples used for screw withdrawal resistance and screw positions
Slika 1. Uzorak drva za određivanje otpora izvlačenju vijaka s prikazom njihova položaja

oven and weighed on an electronic balance to the precision of 0.01 g. The heat treatment applications were conducted in a temperature controlled small heating unit. 4 different temperatures (150, 170, 190 and 210 °C and for 3 h.) were applied to specimens under atmospheric pressure and in the presence of air. After heat treatment, treated and control samples were conditioned to 12 % moisture contents (*MC*) in a conditioning chamber at 20 °C (± 2) and 65 % (± 5) relative humidity to reach equilibrium moisture content. The test samples used for screw withdrawal resistance tests, and screw positions are shown in Fig. 1. (ASTM D 1761, 2000).

The screws were driven into pilot holes, 70 % of the core diameter of the screw and 15 mm depth, drilled on the face of the specimens. Six wood screws (4 x 50) for each sample were used for the withdrawal tests (Fig. 1). All of the screws were embedded 32 ± 0.5 mm deep in the surface of the test samples. The withdrawal resistance was determined in the radial, tangential, and transverse directions. Screw-withdrawal resistance tests were carried out using the universal test equipment, in accordance with the ASTM D 1761 standard. During the tests, the loading rate was 2 mm/min for all tests. Ten test samples for the withdrawal resistance tests were prepared for each group. The screw-withdrawal resistance values were calculated according to Equation 1.

$$\sigma_s = \frac{F_{max}}{2 \cdot \pi \cdot r \cdot h} \quad (1)$$

Where:
σ_s – screw-withdrawal resistance, N/mm^2
F_{max} – maximum load, N
$2 \cdot \pi \cdot r \cdot h$ – surface area of the screw exposed to friction, mm^2.

Weight loss (*WL*) after heat treatment was calculated according to Equation 2.

$$WL = \frac{M0 - M1}{M0} \cdot 100 \quad (2)$$

Where *WL* is weight loss (%), M_0 is the initial oven dried mass of the wood sample before the treatment and M_1 is the oven dried mass of the same sample after the treatment.

2.2 Analysis of data
2.2. Analiza podataka

MSTATC statistical software package was used for the statistical evaluation of the results and to show the effects of the type of wood material and the temperature of heat treatment on screw-withdrawal resistance. The interactions between these factors were determined using multivariate analysis of variance (MANOVA). The comparisons were made using the critical values obtained from the LSD (least significant difference) test, and the factors causing the differences were identified.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The average values and standard deviations of weight loss (*WL*), density, and equilibrium moisture content (*EMC*) of heat-treated and control wood are given in Table 1.

As shown in Table 1, the weight loss values generally exhibited a decrease with increasing heat treatment temperature. The highest weight loss values were obtained from heat-treated at 210 ºC for black pine, hornbeam, and Uludağ fir (4.91 %, 6.98 %, and 3.72 %, respectively). The weight loss of the wood is one of the most important features in heat treatment and is commonly referred to as an indication of the quality. The weight loss depends on the wood species, heating medium, temperature, and treatment time (Esteves and Pereira, 2009). Alén *et al*. (2002) studied the weight loss of heat-treated spruce at temperatures between 180 °C and 225 °C during 4 to 8 h and found 1.5 % weight loss at 180 °C for 4h and 12.5 % at 225 °C for 6h. Similar results were also found in previous studies (Yildiz, 2002; Ozcifci *et al*. 2009; Malek *et al*. 2013). The weight loss of the heat-treated wood samples is due to the degradation of the wood polymers depending on the heat treatment temperature and treatment time, the hemicelluloses generally being the most thermally-sensitive wood components (Poncsák *et al*. 2006; Yildiz *et al*. 2006).

As shown in Table 1, the oven-dried density values decrease with increasing heat treatment temperature for three wood species. The heat-treated wood samples at a temperature of 210 °C gave the lowest air-dried density values when compared with other conditions studied. While the maximum effect of the heat treatment was recorded at 210 °C, the minimum effect was recorded at 150°C. Gunduz *et al.* (2009) studied the effects of heat treatment on the density properties of hornbeam. Their research indicated that the minimum density loss of 0.76 % occurred at treatment conditions of 170 °C for 4 h, whereas the maximum density loss of 16.12 % occurred at treatment conditions of 210 °C for 12 h. Another study showed a similar reduction of air-dried density for heat-treated Anatolian black pine wood (Akyildiz *et al*. 2009).

Table 1 Average values of WL, density and EMC of heat-treated wood
Tablica 1. Prosječne vrijednosti gubitka mase, gustoće i ravnotežnog sadržaja vode toplinski obrađenog drva

Wood species *Vrsta drva*	**Heat treatment temperature** *Temperatura toplinske obrade*	***WL*** %			**Density** g/cm^3			***EMC*** %		
		X	*sd*	*N*	*X*	*sd*	*N*	*X*	*sd*	*N*
Black pine *crni bor*	Control	-	-	-	0.511	0.016	10	13.35	0.788	10
	150 °C	1.12	0.106	10	0.506	0.012	10	10.41	0.612	10
	170 °C	2.11	0.127	10	0.501	0.018	10	9.78	0.422	10
	190 °C	3.18	0.143	10	0.494	0.017	10	8.12	0.476	10
	210 °C	4.91	0.175	10	0.484	0.018	10	6.89	0.246	10
Hornbeam *grab*	Control	-	-	-	0.653	0.014	10	11.83	0.433	10
	150 °C	1.22	0.105	10	0.646	0.015	10	9.17	0.274	10
	170 °C	2.34	0.191	10	0.634	0.011	10	8.44	0.251	10
	190 °C	3.93	0.397	10	0.623	0.014	10	7.23	0.211	10
	210 °C	6.98	0.434	10	0.601	0.015	10	5.11	0.212	10
Uludağ fir *turska jela*	Control	-	-	-	0.426	0.011	10	12.42	0.363	10
	150 °C	0.91	0.111	10	0.422	0.012	10	10.16	0.319	10
	170 °C	1.76	0.222	10	0.417	0.011	10	9.83	0.315	10
	190 °C	2.79	0.131	10	0.411	0.013	10	7.67	0.298	10
	210 °C	3.72	0.135	10	0.407	0.012	10	6.26	0.191	10

WL - weight loss / *gubitak mase*; *EMC* - equilibrium moisture content / *ravnotežni sadržaj vode*; *X* - average value / *prosječna vrijednost*; *sd* - standard deviation / *standardna devijacija*; *N* - the number of test samples / *broj uzoraka*

Also, Korkut and Bektaş (2008) conducted research on heat-treated Uludağ fir (*Abies bornmuellerinana* Mattf.) and Scots pine (*Pinus sylvestris* L.) and confirmed that the air-dried density values decreased. The conversion of hemicelluloses into volatile products and evaporation of some extractive substances play an important role in decreasing density values after heat treatment (Esteves *et al*., 2008).

Table 1 shows the results of equilibrium moisture content (EMC) of black pine, hornbeam, and Uludağ fir treated at four different temperatures (150, 170, 190, and 210 °C) for 3 hours. Treatment at 150 °C resulted in the lowest values for the EMC. The wood samples heat treated at a temperature of 210 °C have the lowest EMC value of 5.11 % for hornbeam wood when compared with other species studied. On the other hand, the highest EMC value was 10.41% for black pine wood at a temperature of 150 °C. In addition, a lower effect of heat treatment was observed when the samples were treated at 150 °C. Accessibility of hydroxyl groups to water molecules becomes difficult due to the increasing cellulose crystallinity, as a result of the degradation of amorphous cellulose. This phenomenon causes a decrease in the EMC value (Bhuiyan and Hirai, 2005; Boonstra and Tjeerdsma, 2006). The hydrolysis of hemicellulose into less hygroscopic furfural polymers causes a decrease in the EMC value (Boonstra, 2008). The results of the multivariate analysis of the screw

Table 2 Results of the Analysis of Variance
Tablica 2. Rezultati analize varijance

Direction *Smjer*	**Factor** / *Činitelj*	**Degrees of Freedom** *Stupanj slobode*	**Sum of Squares** *Zbroj kvadrata*	**Mean of Squares** *Srednja vrijednost kvadrata*	**F value** *Vrijednost F*	**Level of significance** *Razina signifikantnosti* ($P \leq 0.05$)
Radial radijalni	Factor A	2	3104.977	1552.488	45026.8203	0.0000
	Factor B	4	410.528	102.632	2976.6372	0.0000
	Interaction A*B	8	404.066	50.508	1464.8908	0.0000
	Error	135	4.655	0.034		
	Total	149	3924.226			
Tangential *tangencijalni*	Factor A	2	2265.917	1132.959	42944.0058	0.0000
	Factor B	4	444.288	111.072	4210.1104	0.0000
	Interaction A*B	8	209.299	26.162	991.6657	0.0000
	Error	135	3.562	0.026		
	Total	149	2923.066			
Transverse *poprečni*	Factor A	2	2810.115	1009.057	34193.6653	0.0000
	Factor B	4	201.161	50.290	1704.1708	0.0000
	Interaction A*B	8	78.031	9.754	330.5276	0.0000
	Error	135	3.984	0.030		
	Total	149	2301.291			

Factor A - wood species / *vrsta drva*; Factor B - heat treatment temperature / *temperatura toplinske obrade*

Table 3 Comparative test results for the effect of wood species for radial, tangential, and transverse directions (N/mm²)
Tablica 3. Rezultati usporednog testa za mjerenje utjecaja vrste drva pri radijalnome, tangencijalnome i poprečnom presjeku drva

Wood species *Vrsta drva*	**Radial*** *Radijalni*		**Tangential**** *Tangencijalni*		**Transverse***** *Poprečni*	
	X	HG	*X*	HG	*X*	HG
Black pine / *crni bor*	16.26	C	16.78	C	14.92	C
Hornbeam / *grab*	25.95	A	25.31	A	22.78	A
Uludağ fir / *turska jela*	16.34	B	17.37	B	15.08	B

LSD: *0.07287, **0.06372, ***0.06845; X - average value / *prosječna vrijednost*; HG: homogeneous group / *homogena skupina*. Different letters in HG column refer to significant differences among wood species at 0.05 confidence level. / *Različita slova u stupcu označenome s HG potvrđuju postojanje signifikantne razlike između vrsta drva pri razini signifikantnosti 0,05*.

withdrawal resistance for the heat-treated and untreated (control) wood materials for the radial, tangential, and transverse directions are shown in Table 2.

The results of the analysis of variance indicated that the effects of the wood species, heat-treatment temperature and their interactions were found to be statistically significant ($P \leq 0.05$) for the radial, tangential, and transverse directions. The comparative LSD test results for different wood species are given in Table 3.

As shown in Table 3, the highest screw withdrawal resistance was achieved in the hornbeam (*Carpinus betulus* L.) wood, followed by Uludağ fir (*Abies bornmuellerinana* Mattf.) and black pine (*Pinus nigra* Arnold), respectively. The highest resistance values for black pine and Uludağ fir were found in the tangential direction, while the lowest value was observed in the transverse surface. This may be caused by the arrangement of wood cells and fiber angle orientations. The screw withdrawal resistance of the radial direction of the hornbeam wood was found slightly higher than that of its tangential direction. Regarding wood species, the maximum screw withdrawal resistance was determined in hornbeam wood. This may be due to its high density. The density of hornbeam wood was the highest among the three species of the present study (Table 1). In fact, the highest screw withdrawal resistance was also found in hornbeam wood, in radial, tangential, and transverse directions. It may, therefore, be concluded that density and species may have a decisive importance for screw withdrawal resistance. In literature, Bal *et al*. (2015) stated that there was a strong relationship between the screw withdrawal resistance and the density of wood and that the screw holding resistance of the higher density beech plywood was higher than that of other lower density plywood panels. Akyildiz and Malkoçoğlu (2001) reported that the screw withdrawal resistance increased with increasing density of wood. The comparative LSD test results for the heat treatment temperatures are given in Table 4.

As shown in Table 4, the highest screw withdrawal resistance in radial, tangential, and transverse directions was found in the heat treated samples at 150°C, while the lowest value was found in the heat treated samples at 210 °C. Table 4 clearly shows that increasing heat treatment temperature reduces the screw withdrawal resistance. The reason for screw withdrawal resistance decreasing after heat treatment may be caused by the mass losses as a result of the degradation of hemicelluloses and by degradation of wood (Viitanen *et al*. 1994; Fengel and Wegener, 1989). Also, the density plays an important role in the mechanical strength of wood. Gašparík *et al.* (2015) investigated the effect of the heat treatment on screw withdrawal resistance of wood. They reported that screw withdrawal resistance of the heat-treated wood decreased depending on lower density and moisture content of wood, which resulted from heat treatment. The results of the LSD test for a comprehensive comparison of the effects of wood species, surface section, and heat treatment temperature on the screw withdrawal resistance are shown in Table 5.

Table 4 Comparative test results for the effect of heat treatment temperatures for radial, tangential, and transverse directions (N/mm²)
Tablica 4. Rezultati usporednog testa za mjerenje utjecaja temperature toplinske obrade pri radijalnome, tangencijalnome i poprečnom presjeku drva

Heat treatment temperature *Temperatura toplinske obrade*	**Radial*** *Radijalni*		**Tangential**** *Tangencijalni*		**Transverse***** *Poprečni*	
	X	HG	*X*	HG	*X*	HG
Control	21.16	A	21.29	A	18.57	B
150 °C	20.94	B	21.40	B	18.73	A
170 °C	20.36	C	20.29	C	17.98	C
190 °C	18.09	D	18.82	D	17.10	D
210 °C	17.03	E	17.00	E	15.57	E

LSD: *0.09438, **0.08227, ***0.08837; *X* - average value / *prosječna vrijednost*; HG: homogeneous group / *homogena skupina*. Different letters in HG column refer to significant differences among wood species at 0.05 confidence level. / *Različita slova u stupcu označenome s HG potvrđuju postojanje signifikantne razlike između vrsta drva pri razini signifikantnosti 0,05*.

Table 5 Comprehensive comparison analysis of wood species, direction section, and heat treatment temperature on screw withdrawal resistance (N/mm^2)
Tablica 5. Cjelovita analiza utjecaja vrste drva, presjeka drva i temperature toplinske obrade drva na otpor izvlačenju vijaka (N/mm^2)

Wood species *Vrsta drva*	**Heat treatment temperature** *Temperatura toplinske obrade*	**Radial*** *Radijalni*		**Tangential**** *Tangencijalni*		**Transverse***** *Poprečni*	
		X	HG	*X*	HG	*X*	HG
Black pine *crni bor*	Control	17.50	F	18.46	F	16.21	G
	150 °C	17.28	G	18.23	G	16.37	F
	170 °C	16.45	I	16.87	K	15.43	H
	190 °C	15.17	L	16.12	M	14.01	M
	210 °C	14.89	M	14.24	N	12.58	N
Hornbeam *grab*	Control	29.98	A	28.74	A	24.16	B
	150 °C	29.23	B	28.35	B	24.59	A
	170 °C	27.88	C	26.12	C	23.44	C
	190 °C	22.19	D	23.12	D	22.32	D
	210 °C	20.48	E	20.21	E	19.38	E
Uludağ fir *turska jela*	Control	16.01	J	17.57	I	15.35	HI
	150 °C	16.32	I	17.63	I	15.22	IJ
	170 °C	16.76	H	17.89	H	15.07	JK
	190 °C	16.91	H	17.23	J	14.98	K
	210 °C	15.72	K	16.55	L	14.77	L

*LSD: 0.1629, **:0.1425, ***: 0.1531, *X* - average value / *prosječna vrijednost*; HG: homogeneous group / *homogena skupina*. Different letters in HG column refer to significant differences among wood species at 0.05 confidence level. / *Različita slova u stupcu označenome s HG potvrđuju postojanje signifikantne razlike između vrsta drva pri razini signifikantnosti 0,05*.

The screw withdrawal resistance of wood species decreased with increasing temperature. Generally, in terms of direction, the lowest screw withdrawal resistance was found in transverse direction. The reason lies in the fact that the screws drawn perpendicularly in the surfaces were also in the direction of grain configuration of test samples. Therefore, it was concluded that it would be useful to take into consideration the effects of grain direction on withdrawal resistance.

Hornbeam was the most affected by heat treatment, while Uludağ fir (*Abies bornmuellerinana* Mattf.) was the least affected. In other words, screw withdrawal resistance in hornbeam decreased much more compared to other wood species. The reason for this was probably caused by degradation of hemicelluloses. The chemical composition of wood varies from species to species. In general, hardwoods contain more hemicellulose than softwoods (Baeza and Freer 2001). The degradation of the hemicelluloses starts to take place at a relatively low temperature (between 160 and 260 ºC). Also, the degradation of the hemicelluloses increases with heat treatment temperature and treatment time (Poncsák *et al*. 2006, Yildiz *et al*. 2011). The **s**oftwoods are more thermally stable than hardwoods, which is the result of their hemicellulose content and compositional differences (Fengel and Wegener, 1989). Perçin (2015) studied screw withdrawal resistance of laminated samples produced from heat-treated oak (*Quercus petraea* Liebl.) at 140, 170, 200 and 230 °C for 2 h and reinforced with carbon fibers. As a result, increasing heat treatment temperature decreased the screw withdrawal resistance of test samples. A study by Baltaci (2010) investigated the effects of heat treatment on screw withdrawal resistance of several wood species. He applied heat treatment to Scots pine, Oriental beech, Uludağ fir, and Carolina poplar at 120, 160, 200 ºC for 2 to 6 h. The highest screw withdrawal resistance was found in oriental beech, while the lowest resistance was found in Uludağ fir. Kariz *et al*. (2013) reported that heat treatment affected the screws withdrawal capacity of wood because of various factors, one of which was the decrease in density that resulted from high heat treatment temperature. The heat treatment resulted in a decrease in density, and this reduction in density became even more pronounced as the temperature of the heat treatment increased. Therefore, a relationship was observed between the decrease in density and the decrease in screw withdrawal resistance (Aytin *et al*. 2015).

4 CONCLUSIONS
4. ZAKLJUČAK

According to the results, the screw withdrawal resistance decreased with the increasing heat treatment temperature. In terms of the cross sectional direction, the lowest screw withdrawal resistance was found in transverse surface. In terms of wood species, the highest screw withdrawal resistance was found in hornbeam (*Carpinus betulus* L.), while the lowest resistance value was found in black pine (*Pinus nigra* Arnold). Screw withdrawal resistance was most affected by heat treatment when hornbeam (*Carpinus betulus* L.) was used. Screw-withdrawal resistance in heat-treated wood decreased with increasing temperature. Thus, it can be suggested that appropriate wood species should be selected for applications where heat-treated wood are to be used, and heat treatment should be carried out at appropriate temperatures.

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Green Logistics in the Context of Sustainable Development in Small and Medium Enterprises

Zelena logistika u kontekstu održivog razvitka u malim i srednjim pogonima

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ABSTRACT • *Forestry and wood-processing industry are sectors based on renewable ecological natural resources of wood raw material. Wood mass processing should be based on sustainable development, which involves the economic and social development based on environment preservation. Green logistics, which leads to change in creating the product value, characterizes different possibilities to measure and minimize the ecological impact of logistics activities and puts emphasis on sustainable ecological orientation, is closely related to sustainable development. The aim of this article is to investigate the issue of green logistics of forestry and wood processing in small and medium enterprises in Slovakia. To reach this goal, an empirical research was carried out, the objective of which was to determine the level of understanding, as well as the implementation of green logistics activities, and to identify its potential for future implementation in small and medium enterprises in selected branches. The research has revealed that as many as 28.8 % of enterprises claim not to have had any experience with green logistics within their enterprise. The greatest barrier for the implementation of green logistics appears to be the high input costs, which was confirmed by 62 % of the enterprises. On the basis of the research results, a model of implementation of green logistics concept in Slovak small and medium forestry and wood-processing enterprises has been proposed, as an element of sustainable development.*

Keywords: *green logistics, sustainable development, small and medium enterprises (SMEs), forestry, wood processing, model*

SAŽETAK • *Šumarstvo i drvoprerađivačka industrija u Slovačkoj sektori su koji se temelje na obnovljivim, ekološkim, prirodnim resursima, odnosno na drvu kao osnovnoj sirovini. Prerada drvne mase trebala bi biti osnova održivog razvoja, što podrazumijeva ekonomski i socijalni razvoj utemeljen na očuvanju okoliša. Zelenu logistiku, koja donosi promjene u određivanju vrijednosti proizvoda, karakteriziraju različite mogućnosti mjerenja i smanjenja utjecaja logističkih aktivnosti na ekološki sustav, pri čemu je naglasak na održivoj ekološkoj orijentaciji, tijesno povezanoj s održivim razvojem. Istraživanje opisano u radu odnosi se na aspekte zaštite okoliša u malim i srednjim poduzećima za šumarstvo i preradu drva u Slovačkoj u kontekstu održivog razvoja i zelene logistike. Kako bi se ostvario glavni cilj istraživanja, provedeno je iskustveno istraživanje radi određivanja razine razumijevanja i implementacije aktivnosti zelene logistike te mogućnosti njezine buduće implementacije. Istraživanje*

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je pokazalo da 28,8 % poduzeća u svom dosadašnjem radu nije imalo nikakvih iskustava sa zelenom logistikom. Najveću prepreku uvođenju zelene logistike čine visoki troškovi implementacije, što je potvrdilo 62 % anketiranih poduzeća. Na osnovi rezultata istraživanja predložene su nove mogućnosti razvoja koncepta zelene logistike u slovačkim malim i srednjim pogonima u šumarstvu i drvoprerađivačkoj industriji kao dijela održivog razvoja poduzeća.

Ključne riječi: *zelena logistika, održivi razvoj, mala i srednja poduzeća (SMEs), šumarstvo, drvoprerađivačka poduzeća, model*

1 INTRODUCTION
1. UVOD

People's concern for environmental issues and sustainable development has been rising around the world and, therefore, businesses are pushed into taking responsibility for their products and services (Benčiková, 2013). Within this context, logistics in an enterprise should represent an effort to synchronize, coordinate, and optimize the flow of information and materials, in order to satisfy the needs of customers at an adequate cost and the lowest possible negative impact of corporate activities on the environment. The relation between the logistics processes and the ecological objectives forms the basis of green logistics (Nováková and Kusý, 2010).

Out of a number of authors (Hu and Hsu, 2003; Bjorklund *et al*., 2012; Brandenburg and Rebs, 2015; Tognetti *et al*., 2015), the most relevant opinions related to green logistics are presented by Lun *et al*. (2015), who defined it as a study of the impact on the environment, with the aim to measure and minimize the ecological impact of logistics activities.

Green logistics can be divided into four basic subsystems – green procurement logistics, green production logistics, green distribution logistics, and reverse logistics. In an enterprise, green procurement logistics is focused on the market orientation (market research, choosing the right suppliers, cooperating with partners in order to achieve environmental objectives, etc.), as well as on the orientation on physical tasks, i.e. those related to the flow of materials and products. Green production logistics is a sum of logistics tasks and measures needed to prepare and carry out the production process. It includes such activities that are connected with the flow of information, raw and other materials, reducing the amount of packaging material, and utilizing the renewable sources of energy. Green distribution logistics is a set of operations, which enable the goods or services to be shipped from the point of production to the customer, at the right amount, quality, location, time, and price. These are e.g. using electronic invoicing, loading the goods, optimizing the transportation routes, choosing ecological ways of transportation, but also lowering the CO_2 emissions. Out of all logistics activities, distribution is the one that is most subject to various accidental influences, which requires a flexible structure so as to effectively respond to these influences (Sheu *et al*., 2005). Reverse logistics can be defined as a process of repeated acquiring of recyclable and renewable material, waste and reprocessed items from the point of consumption, as well as their use for repairs, readjustments, disposal, or storage (Gunasekaran and Spalanzani, 2012). This is mainly waste separation and recycling.

European markets, the Slovak economy is directly dependent on, require development of fields of industry, which have a certain specific position in the market (Bikár and Kmet'ko, 2015). Within the framework of the Slovak economy, this position is undoubtedly held by wood processing and forestry, which is the result of their comparative advantages. Wood processing and forestry of the Slovak Republic are relatively independent of the supply of raw material, and they can always show active balance of the foreign market. Wood processing and forestry, considering the positive state of raw material, good geographical location, and the acceptable energetic demand of wood processing, represent an important part of the Slovak national economy, and suggest good conditions for further development of small and medium enterprises (Sedliačiková *et al*., 2016).

One of the ways how to increase the productivity of the wood processing and forestry industry and enable the increase of export of our production (mainly in wood processing and forestry), is building small and medium enterprises operating in the field of wood processing and forestry via effective allocation of investment costs into production programs, which will increase the utilization of production capacities, lower the material and energetic demands, and enable know-how in the field of environmental management of small and medium enterprises.

Small and medium enterprises (SMEs) are a crucial part of economic potential in most countries of the world, and this is not different in the Slovak Republic (Lesáková, 2012). A clear and explicit definition of terms "small" and "medium" does not exist. Approaches to defining SMEs are, therefore, different from author to author (Vavrová, 2014; Nováková, 2003; Ojurović *at al*., 2013). Small and medium-sized enterprises (SMEs) represent 99.8 % of all businesses in the EU. Defining a SME is essential, as the access to finance and the EU support programs are targeted specifically at these enterprises. Small and medium-sized enterprises are defined in the European Commission Recommendation 2003/361. The main factors determining whether an enterprise is a SME are: staff headcount, and total turnover or balance sheet. According to the EC recommendation, SMEs represent those enterprises in which the staff headcount is less than 250, whose annual turnover does not exceed 50 million Euros, and/or total balance sheet does not exceed 43 million Euros.

Current theoretical knowledge and practical experience of wood processing and forestry SMEs in Slovakia were investigated using a questionnaire to evaluate their perception of how the activities of green logistics can contribute to their operations. The results provided reliable feedback of the level of application of green logistics activities. The main objective of the research was to suggest an algorithm of implementation of green logistics activities into wood processing and forestry SMEs in Slovakia, based on the results of analysis of the implementation of the chosen green activities, as well as the obstacles to implementation of the 'green practice'.

This research, which is based on a random sample of wood processing and forestry SMEs, reports on green logistics activities, and focuses on the current state in the awareness as well as the use of green logistics and its potential in improving processes in enterprises.

2 RESEARCH METHOD
2. METODA ISTRAŽIVANJA

The research has been conducted in two phases. In the first phase, in 2014, the researchers conducted a secondary research aimed at the analysis of the domestic and foreign literature in order to compare the opinions of different authors concerning the given problem, as well as to develop theoretical foundations for the questionnaire. The second phase, carried out in the second half of 2014, was based on a primary research, which was done through the questioning method – a questionnaire. The main objective of the research was to find out how small and medium enterprises in wood processing and forestry industry in Slovakia perceive the activities of green logistics. To verify the assumptions, the following methods and tools were used: method of inference statistics (Chi-square test, the Friedman test, and the Wilcoxon test), Pareto analysis as a tool of decision making, methods of descriptive statistics (relative frequency, cumulative relative frequency, as methods of distribution description) and data visualization (graphs, frequency tables). The representativeness of the sample was tested using the Chi-square test, by the chosen variables. Friedman test was used to analyze the significance of differences between related samples, and the Wilcoxon test assessed the agreement between the responses in two different samples. Pareto analysis was used to identify the key activities of green logistics, and the key barriers of its implementation.

2.1 Data collection
2.1. Prikupljanje podataka

The data collected was specifically designed to determine the current level of use of green logistics activities in wood processing and forestry SMEs in Slovakia. The questionnaire was designed in two parts:
Part A – 4 questions: Type of enterprise (A1 – A3)
Part B – 5 questions: Green logistics (B1 – B5)

Part A was aimed at determining the characteristics of the enterprise size (small or medium), form of the enterprise (trade, production) and the market the enterprises operate in (local, regional, national, European, and global). Part B focused on identifying the state and the level of implementation of green logistics activities in selected wood processing and forestry SMEs in Slovakia, as well as on identifying the potential interest of the selected wood processing and forestry SMEs concerning the topic of this paper.

2.2 Sample size
2.2. Veličina uzorka

The questionnaire was distributed among 500 randomly selected wood processing and forestry industry SMEs in Slovakia, out of which 309 questionnaires have been filled in and returned. For the purposes of this research, 248 correctly and fully filled in questionnaires have been used to evaluate the results. The representativeness of the sample according to the selected attribute (size of the enterprise, determined on basis of the number of employees) has been proved, as the p-value was higher than the level of significance ($\alpha = 0.05$). Overall, 240 small and 8 medium enterprises have participated in the research, 132 small and 3 medium enterprises being in the field of wood processing. The forestry industry was represented by 108 small and 5 medium enterprises. Of this number, 45 % was trade and 55 % was the production SMEs. The turnover in most enterprises (37.2 %) was between 10,001-100,000 Euros, while these enterprises mostly operate on regional markets (28 %). Local market is represented by 24 % of respondents, national market by 25.2 %, European by 19.2 % and the global market by 3.6 % of the analyzed enterprises.

2.3 Methods of research analysis
2.3. Metode analize rezultata istraživanja

The survey data were analyzed by descriptive methods, graphic visualization, and statistical analysis. Question B1, aimed at determining the agreement, was evaluated on the basis of the Likert scale, where 1 meant the weakest agreement, and 7 meant the strongest agreement with the statement. Likert scale is not only used to determine the content of the attitude but also its approximate strength. The question was focused on the meaning that the term "green logistics" had for wood processing and forestry SMEs in Slovakia. In questions B2 and B3, the addressed enterprises were asked to select one option from the list. The questions were aimed at finding out if the implementation of green logistics is important for wood processing and forestry SMEs in Slovakia, and if the activities of green logistics are implemented in specific enterprises. The responses to the first three questions of Part B were evaluated by relative frequencies in frequency tables.

To evaluate the responses to questions B4 and B5, the authors have used the Friedman and Wilcoxon tests. Question B4 was aimed at finding out which activities of green logistics the enterprise plans to implement, while the respondents could select from 15 different activities. The enterprises had the following options: 1 – not planning anything, 2 – planning long-term, 3 – planning short-term, and 4 – already implementing. Question B5 focused on what wood processing and forestry SMEs perceive as the greatest barriers to green logistics implementation. Respondents were asked to select three most preferred options on the given list.

Since questions B4 and B5 were structured as multiple-choice responses, the results were interpreted by relative frequencies as a percentage of responses and as a proportion of the addressed enterprises – percentage of cases. Considering the fact that these are ordinal variables, Friedman and Wilcoxon tests were used to verify the agreement of the levels of different dependent samples. The Friedman test is the non-parametric alternative to the one-way ANOVA test (Analysis of Variance) with repeated measures. It is used to test the differences between groups when the dependent variable being measured is ordinal. It can also be used for continuous data that has violated the assumptions necessary to run the one-way ANOVA with repeated measures (e.g. data that has marked deviations from normality). In case the hypothesis concerning the agreement of the levels of different dependent choices is denied, it is possible to compare the pairs of choices aiming at the identification of the significant differences between the levels of responses, i.e. to continue testing with the use of the Wilcoxon test. The Wilcoxon signed-rank test is the nonparametric test equivalent to the dependent t-test. As the Wilcoxon signed-rank test does not assume normality in the data, it can be used when this assumption has been violated and the use of the dependent t-test is inappropriate. It can be used to compare two sets of ordinal data. Pareto analysis has also been used as a statistical technique in decision making used for selecting a limited number of tasks that produce significant overall effect. This analysis uses the Pareto Principle (also known as the 80/20 rule) meaning that by doing 20 % of the work you can generate 80 % of the benefit of doing the entire work. In terms of quality improvement, a large majority of problems (80 %) are produced by a few key causes (20 %). This is also known as the vital few and the trivial many. All statistical analysis and graphic presentations were done using the SPSS statistical program package.

3 RESULTS AND DISCUSSION
3. REZULTATI ISTRAŽIVANJA I RASPRAVA

3.1 Results of empirical research
3.1. Rezultati iskustvenog istraživanja

On the basis of descriptive statistics, it has been established that wood processing and forestry SMEs in Slovakia mostly agree with the statement that ‘green logistics is an ecological way to transport materials and goods, and to use packaging which does not hurt the environment’ (B1). As many as 42 % of the questioned enterprises have responded that the implementation of green logistics is necessary for wood processing and forestry SMEs in Slovakia in order to remove or reduce the negative effects of business on the environment (B2). A very interesting finding is that 45.2 % of the addressed enterprises do implement the activities of green logistics, but, on the other hand, this is not standardized within their corporate documents. Moreover, 28.8 % of the enterprises claim that so far they have not had any experience with the activities of green logistics (B3).

Table 1 Friedman test, question B4
Tablica 1. Friedmanov test, pitanje B4

Rank *Tvrdnja*		**Mean Rank** *Srednja vrijednost*
B4a	- using alternative fuel / *upotreba alternativnoga goriva*	6.81
B4b	- adjustment of vehicles to achieve lower consumption *prilagodba vozila radi smanjenja potrošnje*	8.15
B4c	- ecological style of driving / *ekološki način vožnje*	10.01
B4d	- use of ways of transport with low negative impact on the environment *način transporta s manjim negativnim učinkom na okoliš*	8.52
B4e	- optimizing the transport routes / *optimiziranje transportnih putova*	10.99
B4f	- making the loading of the transported goods more efficient *uspostava učinkovitijeg načina utovara proizvoda*	11.24
B4g	- using sustainable sources of energy *iskorištavanje održivoga (obnovljivog) izvora energije*	7.66
B4h	- gathering information about energy consumption and CO_2 *prikupljanje podataka o utrošku energije i ispuštenom* CO_2	6.95
B4i	- reduction of the amount of packaging material *smanjenje količine materijala za pakiranje*	10.27
B4j	- certification in the field of ecology and environment *posjedovanje certifikata s područja ekologije i zaštite okoliša*	6.18
B4k	- implementing lowering the CO_2 emissions into primary corporate objectives *politika smanjenja emisija* CO_2 *kao jednoga od primarnih ciljeva poduzeća*	6.32
B4l	- cooperation with stakeholders in order to achieve the environmental goals *suradnja s vlasnicima radi postizanja ekoloških ciljeva*	6.75
B4m	- cooperation with customers in order to achieve the environmental goals *suradnja s korisnicima (kupcima) radi postizanja ekoloških ciljeva*	6.92
B4n	- environmental education for employees / *izobrazba uposlenih o zaštiti okoliša*	7.31
B4o	- environmental education for customers / *izobrazba korisnika (kupaca) o zaštiti okoliša*	5.91

Table 2 Friedman test, question B4
Tablica 2. Friedmanov test, pitanje B4

Test Statistics - Friedman Test *Statističke vrijednosti testa - Friedmanov test*	
N	250
Chi-Square / χ^2	840.327
df	14
Asymp. Sig.	0.000

Application of the Friedman test (Tables 1 and 2) has confirmed that the given activities of green logistics are not of the same importance to the enterprises with regard to the time frame of planning their implementation (p-value = 0.0). Based on the data collected in the primary research, the Wilcoxon sign rank test was used to establish which activities are not of the same importance. On the basis of the Friedman and the Wilcoxon tests, it is possible to claim that in the field of green logistics, wood processing and forestry SMEs in Slovakia put most emphasis on optimizing the transport routes (B4e) as well as making the loading of the transported goods more efficient (B4f).

The activities of green logistics, such as the use of alternative fuel in transportation (B4a), use of sustainable sources of energy (B4g), gathering information about energy consumption and CO_2 emissions (B4h), certification in the field of ecology and environment (B4j), cooperation with partners and customers in order to achieve the environmental goals (B4m), and environmental education of the employees (B4n) and customers (B4o), show the lowest planning activity. This finding has proved that the enterprises only provide some of the activities of green logistics and do not perceive it as a tool that can help them achieve competitive advantage and thus ensure their stable position in the market.

This has also been proved by Pareto analysis (Fig. 1), on the basis of which the key activities of green logistics in wood processing and forestry SMEs in Slovakia have been identified. Out of 15 suggested activities, those that the enterprises plan to implement in a short-term period of time, or are already implementing, were identified 1,020 times. As it is clear from the Lorenzo curve (curve of cumulative relative frequencies expressed as a percentage), according to wood processing and forestry SMEs in Slovakia, 60.88 % responses related to activities which the enterprises are either planning to implement in a short time or are already using, concern the following activities of green logistics: making the loading of the transported goods more efficient (B4f), optimizing the transport routes (B4e), reduction of the amount of packaging material (B4i), ecological style of driving (B4c) and use of ways of transport with low negative impact on the environment (B4d). Making the loading of the transported goods more efficient (B4f) was chosen by 77 % of the enterprises (percentage of cases) as the activity which they are either planning to implement in a short-term period of time or are already implementing.

On the other hand, only 21.08 % of the addressed enterprises are planning to educate, or are already educating their employees (B4n). By selecting and planning education of the employees properly, it is possible to ensure implementation of processes of green logistics, such as: choice of environmentally suitable suppliers, effective allocation of the production equipment in the enterprise, ecological style of driving, gathering information about emissions and energy consumption, reduction of the amount of packaging material, and cooperation with customers. These are often financially demanding and can save the enterprise the costs related to transportation, manipulation with the material, production, and last, but not least, loss of a customer.

Evaluation of the question related to finding out the barriers to implement the processes of green logistics (B5) was also very important. Friedman test (Tables 3-4)

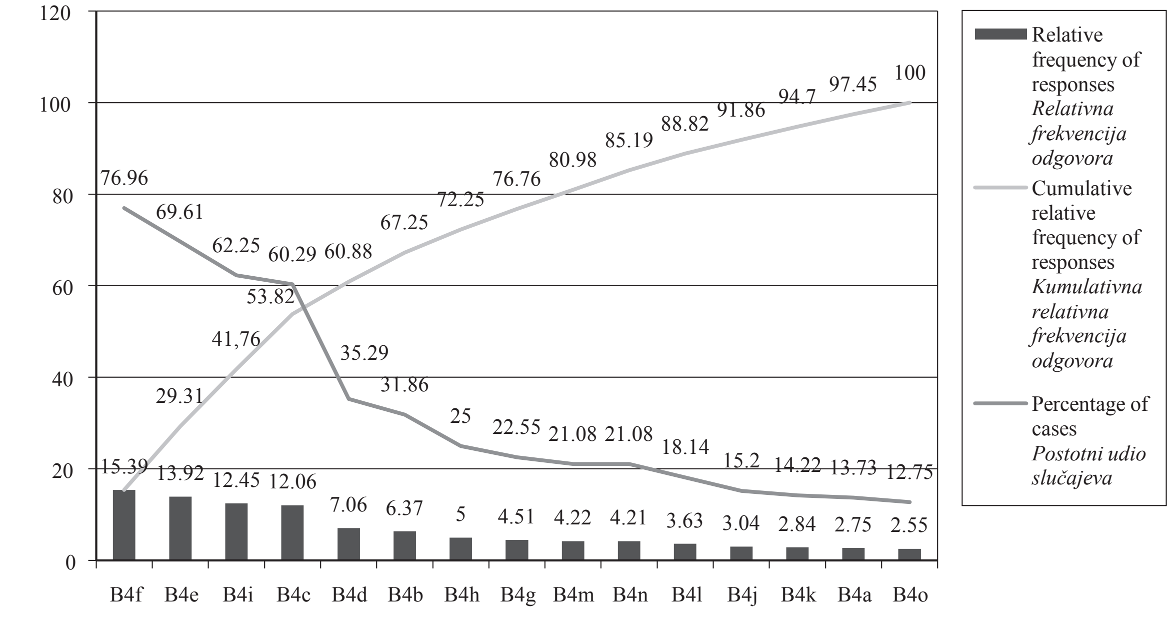

Figure 1 Pareto analysis, question B4
Slika 1. Paretova analiza, pitanje B4

Table 3 Friedman test, question B5
Tablica 3. Friedmanov test, pitanje B5

Rank *Tvrdnja*		Mean Rank *Srednja vrijednost*
B5a	- high input costs / *visoki troškovi uvođenja zelene logistike*	8.80
B5b	- uncertain return on the invested sources / *nesigurnost povrata uloženih sredstava*	7.53
B5c	- high operational costs / *visoki operativni troškovi*	6.45
B5d	- insufficient financial resources / *nedostatak financijskih sredstava*	7.72
B5e	- lack of qualified workforce / *nedostatak kvalificirane radne snage*	6.01
B5f	- insufficient knowledge of green logistics / *nedovoljno znanje o zelenoj logistici*	6.85
B5g	- lack of interest of customers / *nedostatna zainteresiranost korisnika (kupaca)*	5.05
B5h	- insufficient support from the government / *nedostatna potpora vlasti*	7.77
B5i	- weak support of transportation companies and distributors *slaba potpora transportnih poduzeća i distributera*	5.53
B5j	- lack of interest in SMEs / *nedostatna zainteresiranost malih i srednjih poduzeća*	5.89
B5k	- limited access to technologies lowering the negative impact on the environment *ograničen pristup tehnologijama za smanjenje negativnog utjecaja na okoliš*	5.34
B5l	- lack of opportunities to educate employees in the field of environment *nemogućnost izobrazbe uposlenih o zaštiti okoliša*	5.05

Table 4 Friedman test, question B5
Tablica 4. Friedmanov test, pitanje B5

Test Statistics - Friedman Test *Statističke vrijednosti testa - Friedmanov test*	
N	250
Chi-Square / χ^2	581.491
df	11
Asymp. Sig.	0.000

has proved that small and medium enterprises do not consider the barriers mentioned in the questionnaire to be of the same importance (*p*-value = 0). Wilcoxon test has proved (*p*-value = 0) that for the enterprises, the greatest obstacle to implement the processes of green logistics is the high input costs (B5a). The second biggest barrier appears to be the lack of support from the government/state (B5h), uncertain return on the investments (B5b), and lack of financial resources (B5d). On the other hand, the smallest barrier, as perceived by the respondents, proves to be the lack of interest from the customers (B5g) and insufficient possibilities to educate the employees in the field of environment (B5l).

Pareto analysis (Fig. 2) has confirmed the results of the Friedman and the Wilcoxon tests. When evaluating question B5, the barriers of implementation of green logistics were assessed from the point of view of frequency in segmentation according to the individual Slovak SMEs. Subsequently, relative frequency and cumulative relative frequency of responses were calculated and expressed in percentage. It can be claimed that as many as 77.18 % of the chosen barriers in implementing green logistics are represented by high input costs, (B5a), lack of support from the government (B5h), insufficient financial sources (B5d), uncertain return on investments (B5b), and insufficient knowledge of the problems of green logistics (B5f). Almost 60 % of barriers, as identified by the enterprises, are

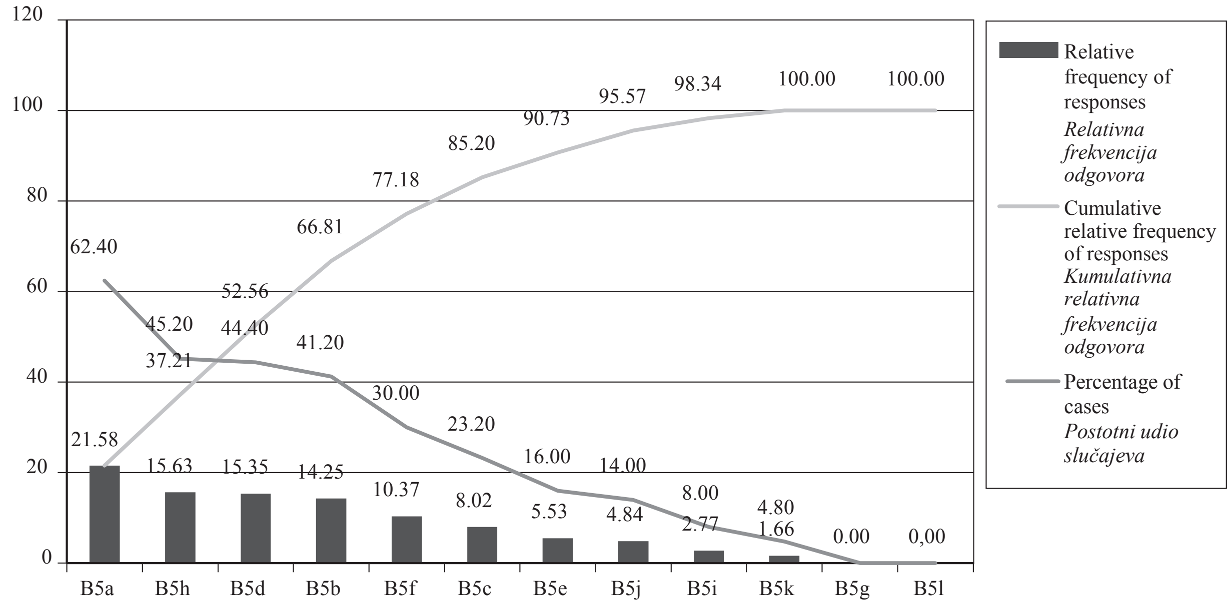

Figure 2 Pareto analysis, question B5
Slika 2. Paretova analiza, pitanje B5

financial barriers, and 40 % are non-financial. This has also been confirmed by 62.4 % enterprises that have identified high input costs as the greatest barrier (B5a).

On the basis of the research results, it may be stated that wood processing and forestry SMEs in Slovakia are currently engaging only in a minimum number of activities of green logistics. Benčiková (2013) suggests that the trend in educating managers in Slovakia is to focus primarily on managerial and financial skills, rather than issues related to the psychological, cultural or environmental well-being of an enterprise. High input investment is considered as the biggest barrier by the respondents. At the same time, the enterprises do not plan to educate their employees in this field within a short-term period, which would in fact make the processes the employees are responsible for more effective. Activities of green logistics are often financially inexpensive, but the lack of interest in education in this field leads to ineffective performance of the processes in an enterprise and results in loss of financial resources, which could be invested in activities of green logistics. Creation, development, use and evaluation of knowledge is crucial for the enterprise to ensure its further development, as well as in terms of gaining and maintaining the competitive advantage (Minárová, 2014).

3.2 Proposal of development of green logistics in wood processing and forestry SMEs

3.2 Prijedlog razvoja zelene logistike u malim i srednjim poduzećima

Within the past few years, considerable pressure has been put on the wood processing and forestry SMEs to make them more involved in the initiatives of green logistics. When making their purchases, customers are more and more interested in the question if SMEs are providing their activities with regard to the environment (Lipušček *et al.*, 2010).

At present, it is important to 'think green'. But conversely, the available resources of wood processing and forestry SMEs in Slovakia are limited. As a result of the lack of financing opportunities, wood processing and forestry SMEs depend on other capital sources such as bank loans or other alternative sources of finance. Current developments require new innovative approaches in entrepreneurship to be competitive (Sedliačiková *et al.*, 2016). Not all activities of green logistics are financially demanding. The main goal of this research was to find out how SMEs in Slovakia approach the implementation of the initiatives of green logistics. On the basis of the research results, an algorithm of implementation of green logistics for Slovak wood processing and forestry SMEs was proposed (Table 5), which can help SMEs in putting emphasis on added environmental value (voluntary environmental activities exceeding the frame of the basic responsibilities mandated by the legislation). This not only offers higher environmental protection but also increases the competitive advantage of the enterprises.

The stakeholders and their requirements represent the foundation for implementing the initiatives of green logistics in wood processing and forestry SMEs. The main barriers to implement the initiatives of green logistics are not only the financial and economic factors, but also the perception of stakeholders, who expect these initiatives on one hand, but on the other, they are not willing to pay for green initiatives. At the same time, their requirements in the given field are unclear and vague.

At present, the wood processing and forestry industries are facing numerous environmental issues and challenges. They are directly influenced by climate change, competition in obtaining the wood resources, changing consumer demands, increasing economic competition, and the growing complexity of production processes. Despite these problems, a great innovation opportunity for traditional forestry and wood sector that uses renewable natural resources in a sustainable and responsible way is to increase the quality and the level of finalizing the wood processing, as well as to increase the effectiveness of energy use of wood processing waste. By implementing the activities of green logistics, growing effectiveness of production can be achieved, and hence also the industry's sustainability. Wood processing and forestry represent not only an important part of a developing economy, but also of the whole society, with a new prospective direction based on biotechnologies. The use of wood as a renewable resource is of a great importance for the whole society, because: wood and wooden products sequester carbon and lower its volume in the atmosphere; wooden products are made in an energy-efficient production system, with lowest possible emissions when compared to other building materials; waste wood from the sawmills can be used to produce wood-based panels; and finally, wooden products may be reused, recycled, and in the end of their life cycle, they can be used as a source of bioenergy.

Based on the results of the empirical research, it can be concluded that there is no unified algorithm for the implementation of green logistics activities in Slovak wood processing and forestry SMEs. The model of algorithm for the implementation of green logistics activities proposed in this paper includes seven basic steps. The findings suggest that the implementation of this algorithm can help managers to define which green practices within their organization require more attention and which green practices may be given less attention. This ranking assists managers in allocating resources and financial investments appropriately. As Seroka-Stolka (2014), Farahani *et al.* (2010) and Neto *et al.* (2009) concluded that the generally rising attention that is paid to the greener solutions does not exclude logistics. It plays a very important role, as it is one of the main pollution sources and resource user. As reported by Hu and Hsu (2003) and Govindana *et al.* (2015), green supply chain management practices can create benefits to enterprises in the form of reduced waste, better resource use, economic advantages, and decrease in costs. Thus green supply chain management practices play an important role in undergoing sustainable development of enterprises and in improving social, environmental and economic benefits. The

Table 5 Algorithm of implementation of activities of green logistics
Tablica 5. Algoritam uvođenja aktivnosti zelene logistike

1.	**External analysis - stakeholder view** *Vanjska analiza - sa stajališta vlasnika*
	The goal of this step is to obtain information about the activities of green logistics, which are valuable for the given enterprise, from the stakeholders who can: / *Cilj tog koraka jest prikupljanje informacija o aktivnostima zelene logistike važnima za poduzeće od vlasnika:* - provide information related to creating an action plan of improvement in the field of environment / *koji daju informacije o pripremi plana za poboljšanja u području zaštite okoliša* - support the enforcement of the final decision / *koji podržavaju provođenje završne odluke* - assist in determining the criteria and various solutions to individual alternatives of the action plan in environmental improvement / *koji pomažu u određivanju kriterija i različitih rješenja do pojedinih varijanti akcijskog plana poboljšanja zaštite okoliša* - decide about the right choice and its implementation / *koji odlučuju o pravom izboru i njegovoj implementaciji.* Development of wood processing and forestry is based on the requirements of stakeholders and on sustainable use of wood resources. The main objective of this step is to obtain information on the needs of all stakeholders and focus the initiatives of green logistics towards satisfying such needs that are specific for the customer segment in the wood processing and forestry industry. At the same time, risks that are characteristic of this field of industry must be identified. / *Razvoj u šumarstvu i preradi drva temelji se na zahtjevima vlasnika i održivom iskorištavanju drvnih resursa. Glavni cilj tog koraka jest prikupljanje informacija o potrebama svih vlasnika i usmjeravanje postupaka inicijative zelene logistike na zadovoljenje tih potreba, karakterističnih za šumarstvo i preradu drva. Istodobno se trebaju odrediti i svi rizici u tim industrijskim granama.* The right implementation of Step 1 leads to the removal of barriers B5 g, h, i. / *Pravilna implementacija 1. koraka vodi uklanjanju barijera B5 g, h, i.*
2.	**Internal analysis - enterprise view** *Unutarnja analiza - sa stajališta poduzeća*
	It is the analysis of the SME's opportunities to provide new services in the environmental area, and thus differentiate from its competitors. The main goal of this step is the analysis of disposable resources of the enterprise. It is essential to create a new offer of green logistics activities for customers, from the point of view of the current situation in an enterprise. In order to support the obligation of an enterprise to lower the impact of its corporate activities on the environment, the enterprises are encouraged to ensure an efficient cooperation between the individual departments and organize staff training related to ecological problems. The right implementation of Step 2 leads to the removal of barriers B5 a, b, c, d, e, j. *Riječ je o analizi mogućnosti malih i srednjih poduzeća da pruže nove usluge u području zaštite okoliša i po tome budu različiti od konkurencije. Glavni cilj tog koraka jest analiza resursa* što ih *poduzeće ima na raspolaganju. Nužno je stvoriti novu ponudu aktivnosti zelene logistike prema kupcima, posebice sa stajališta trenutačne situacije u poduzeću. Kako bi se poduprle obveze poduzeća za snižavanje utjecaja njegovih aktivnosti na okoliš, predlaže se da poduzeća osiguraju dobru suradnju među pojedinim odjelima i organiziraju edukaciju osoblja vezanu za ekološke probleme. Pravilna implementacija 2. koraka vodi uklanjanju barijera B5 a, b, c, d, e, j.*
3.	**Identification of opportunities - creating a new value system** *Identifikacija mogućnosti - stvaranje novog sustava vrednovanja*
	On the basis of findings from the internal and external audits and their comparison, SMEs will identify their strengths and weaknesses, and estimate potential environmental risks. The main aim of this step is to create an action plan of improvement in the environmental area, which includes the potential of development in initiatives of green logistics. These are activities, such as: *Na osnovi vanjske i unutarnje analize te njihove usporedbe, mala i srednja poduzeća identificirat* će *svoje prednosti i slabosti te odrediti potencijalne rizike koje imaju za okoliš. Glavni cilj tog koraka jest priprema akcijskog plana poboljšanja u području zaštite okoliša koji će obuhvatiti mogući razvoj aktivnosti zelene logistike. To su aktivnosti poput:* - employee training in the field of environment (e.g. ecological style of driving, etc.) - removes barriers B5 e, l. / *obrazovanja uposlenih o zaštiti okoliša (npr. o ekološkom načinu vožnje i sl.) - uklanjanje barijera B5 e, l* - careful management and monitoring of energy consumption and CO_2 emissions - removes barriers B5 b, c, k. / *briga menadžmenta i praćenje iskorištavanja energije i emisije CO_2, uklanjanje barijera B5 b, c, k* - decrease in the material demands of production - removes barriers B5 c, d, g, k. / *smanjenje upotrebe materijala u proizvodnji*, *uklanjanje barijera B5 c, d, g, k* - choice of environmentally suitable suppliers - removes barriers B5 c, d. / *odabir ekološki prihvatljivih dobavljača*, *uklanjanje barijera B5 c, d* - waste separation and recycling - removes barriers B5 c, d, g, k. / *odvajanje otpada i recikliranje*, *uklanjanje barijera B5 c, d, g, k* - optimizing the transportation routes - removes barriers B5 c, d, i. / *optimiziranje transportnih putova*, *uklanjanje barijera B5 c, d, i* - monitoring the use of vehicles (load, way of parking, maximum use of capacity) - removes barriers B5 c, d, i / praćenje *iskorištenosti vozila (utovara, načina parkiranja, maksimalnog korištenja kapaciteta)*, *uklanjanje barijera B5 c, d, i* - prevention program of vehicle maintenance in order to decrease the consumption and environmental pollution - removes barriers B5 a, c, d, k / *program prevencije u održavanju i uporabi vozila kako bi se smanjilo njihovo korištenje i onečišćenje okoliša*, *uklanjanje barijera B5 a, c, d, k*

Table 5 Algorithm of implementation of activities of green logistics
Tablica 5. Algoritam uvođenja aktivnosti zelene logistike

	- reduction in the amount of packaging material - removes barriers B5 b, c, d, g. */ smanjenje količine materijala za pakiranje, uklanjanje barijera B5 b, c, d, g* - decreasing water consumption by means of simple water recycling methods - removes barriers B5 a, b, c, d *smanjenje upotrebe vode i primjena jednostavnih metoda recikliranja, uklanjanje barijera B5 a, b, c, d* - energy-efficient production, use of renewable sources of energy - removes barriers B5 c, d, g, k *energetski učinkovita proizvodnja, korištenje obnovljivih izvora energije, uklanjanje barijera B5 c, d, g, k* - purchasing environmentally efficient technologies - removes barriers B5 c, d, k *nabava ekološki učinkovite tehnologije, uklanjanje barijera B5 c, d, k* - digitalization (less paper in the offices) - removes barriers B5 c, d, g *digitalizacija (uz manje količine papira u uredima), uklanjanje barijera B5 c, d, g.*
4.	**Development of human resources towards the environment** *Razvoj ljudskih potencijala prema zaštiti okoliša*
	The main objective is to ensure organization support and suitable human resources. It is essential to plan the training and to educate the employees in order to increase their awareness of and knowledge in the field of green logistics. The right implementation of Step 4 leads to the removal of barriers B5 e, f, l. *Glavni je cilj tog koraka osigurati potporu organizaciji i adekvatne ljudske potencijale. To je nužno pri planiranju i obrazovanju uposlenika kako bi se povećala svijest i znanje o zelenoj logistici.* *Pravilna implementacija 4. koraka vodi uklanjanju barijera B5 e, f, l.*
5.	**Implementation of green logistics activities into an enterprise** *Uvođenje aktivnosti zelene logistike u poduzeće*
	The right implementation of Step 5 leads to the removal of barriers B5 b, c, e, f, g, i, j, k, l. *Pravilna implementacija 5. koraka vodi uklanjanju barijera B5 b, c, e, f, g, i, j, k, l.*
6.	**Evaluation of the environmental behavior of the enterprise** *Vrednovanje odnosa poduzeća prema okolišu*
	Based on the environmental norms of quality management, it was proposed to organize evaluation in these three areas: *Na osnovi normi za zaštitu okoliša u upravljanju kvalitetom, predlaže se vrednovanje triju područja:* - Management - described by indicators of managers' behavior (Management Performance Indicators MPI) *menadžmenta - opisivanje pokazatelja menadžerskog ponašanja (MPI)* - Operation - described by operational indicators (Operational Performance Indicators OPI) */ proizvodnje - opisivanje pokazatelja rada (OPI)* - Environment - described by indicators of the status of environment (Environmental Condition Indicators ECI) *okoliša - opisivanje pokazatelja stanja zaštite okoliša (ECI).* The right implementation of Step 6 leads to the removal of barriers B5 a, b, c, d. *Pravilna implementacija 6. koraka vodi uklanjanju barijera B5 a, b, c, d.*
7.	**Feedback** *Povratne informacije*
	The objective is to ensure the flow of information on the progress and quality level of the activities of green logistics. *Glavni je cilj tog koraka osiguranje protoka informacija o razvoju i kvaliteti razine aktivnosti zelene logistike.*

adoption of cleaner solutions generally implies an increase in costs, which has also been confirmed by our research. As Gonzáles-Benito and Gonzáles-Benito (2006) investigated, companies aiming to decrease the environmental impact of their logistics networks should then look for good trade-offs between environmental impact and costs. The game is, therefore, smartly compromising the two Ps: Planet and Profit (Neto *et al.*, 2009). Lai and Wong (2012), Zhang *et al*. (2015), Santos *et al*. (2015) and Shulga *et al*. (2016) pointed out that green logistics can be seen by manufacturing enterprises not as a 'problem', but more as an 'opportunity'. Due to rising costs of materials and scarcity of resources, such as rare metals, it can be a profitable source for manufacturers to recycle expensive materials from used products.

4 CONCLUSIONS
4. ZAKLJUČAK

Our research has established a substantial amount of information about possibilities of implementation of green logistics activities in wood processing and forestry SMEs, which would reduce the environmental impact of their products and processes, and improve their performance.

In our study sample (the wood processing and forestry SMEs), the level of understanding, as well as the implementation of green logistics activities were generally low, because 28.8 % of respondents stated that they have not yet encountered any activities of green logistics in their enterprise.

Based on the Friedman and Wilcoxon tests, it may be stated that within the field of green logistics, Slovak wood processing and forestry SMEs are most active in optimizing the transportation routes and making the loading of the transported goods more effective.

With the use of Pareto analysis, it has been established that more than a third of the barriers to implement green logistics, as indicated by the enterprises, are represented by high input costs and lack of support by the government/state.

If small and medium enterprises for wood processing and forestry wish to make their processes more ecological, they must first focus on including the initiatives of green logistics into the enterprise strategy, which will improve their implementation in the whole enterprise and will have a positive effect on creating new products and services. It is also important to ensure the orientation on customers, in order to use green knowledge and competencies in satisfying the needs of the current and potential customers, as well as managing and controlling the initiatives of green logistics in accordance with the official statement of the enterprise in the field of green investments.

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Iva Ištok obranila doktorski rad

Iva Ištok, mag. ing. techn. lign., obranila je 7. listopada 2016. na Šumarskom fakultetu Sveučilišta u Zagrebu doktorski rad *Anatomska svojstva juvenilnog drva bijele topole* (*Populus alba* L.) *uz rijeku Dravu*. U povjerenstvu za obranu rada bili su prof. dr. sc. Jelena Trajković (Šumarski fakultet, Sveučilište u Zagrebu), dr. sc. Tomislav Sedlar (Šumarski fakultet, Sveučilište u Zagrebu) i dr. sc. Nenad Potočić, viši znanstveni suradnik (Hrvatski šumarski institut, Jastrebarsko). Javnom obranom doktorskog rada Iva Ištok stekla je akademski stupanj doktorice znanosti s područja biotehničkih znanosti, znanstvenog polja Drvna tehnologija, znanstvene grane Drvni materijali. Mentor rada bio je doc. dr. sc. Bogoslav Šefc.

ŽIVOTOPIS

Iva Ištok rođena je 26. lipnja 1983. godine u Zagrebu. Osnovnu školu i prva dva razreda jezične gimnazije pohađala je u Krapini. Godine 2000. upisuje Program međunarodne mature (IBDP) u XV. gimnaziji u Zagrebu, u kojoj je 2002. maturirala. Diplomirala je 2009. na Šumarskom fakultetu, Drvnotehnološkom odsjeku, te stekla titulu diplomirane inženjerke drvne tehnologije, kasnije izjednačenu s onom magistre inženjerke drvne tehnologije. Tijekom studija dobila je državnu stipendiju Ministarstva znanosti obrazovanja i sporta te Dekanovu i Rektorovu nagradu. Dana 10. siječnja 2011. zapošljava se na Šumarskom fakultetu Sveučilišta u Zagrebu kao znanstvena novakinja u suradničkom zvanju asistentice u Zavodu za znanost o drvu. Kao asistentica održava vježbe kolegija Anatomija drva na Drvnotehnološkom i Šumarskom odsjeku. Akademske godine 2011./2012. upisuje poslijediplomski doktorski studij Drvna tehnologija. Kao istraživačica sudjelovala je od 2011. do 2013. u projektu Ministarstva znanosti, obrazovanja i sporta pod nazivom *Trajnost ekološki zaštićenog i modificiranog drva*, a od 2013. do 2015. radi u međunarodnom IPA IIIc projektu pod nazivom *Povećanje konkurentnosti hrvatske industrije drvenih podova na EU tržištu*. Sudjeluje u radu COST akcije FP1106 *Studying Tree Responses to extreme Events: a SynthesiS*. U sklopu te akcije od 18. rujna do 14. prosinca 2012. boravila je na znanstvenom usavršavanju na Oddelku za lesarsvo Biotehniške fakultete u Ljubljani. U lipnju 2015. sudjeluje u radionici *Quantitative wood anatomy – from sample to data* u Centru za istraživanja planinskog okoliša u San Vito di Cadoreu, Italija, a od rujna 2014. do lipnja 2016. aktivno sudjeluje u prijavi i provedbi projekta *Promocija poduzetništva i obrta u šumarskom i drvnom sektoru*, financiranoga sredstvima Europskoga socijalnog fonda. Do sada je kao autorica ili suautorica objavila osam znanstvenih i stručnih radova, a kao neposredna voditeljica sudjelovala je u izradi jednoga završnog rada.

PRIKAZ DOKTORSKOG RADA

Doktorski rad Ive Ištok sastoji se od 283 stranice (XXV + 258) te sadržava 162 slike, 171 tablicu i 170 citiranih naslova literature. Rad je ovako strukturiran:

Podaci o mentoru
Bibliografska kartica
Bibliographic data
Sadržaj
Popis slika
Popis tablica
1. Uvod (9 str.),
2. Problematika istraživanja (13 str.)
3. Cilj istraživanja (3 str.)
4. Materijal i metode istraživanja (22 str.)
5. Rezultati i rasprava (176 str.)
6. Zaključci (2 str.)
7. Literatura (15 str.)
Prilog
Životopis.

U uvodnom dijelu doktorskog rada istaknuto je značenje roda *Populus*, a bijela topola (*Populus alba* L.) izdvojena je kao predmet istraživanja. U istom su poglavlju opisane strukturne karakteristike drva topola i širok spektar njegove uporabe. Nadalje, istaknuta je važnost istraživanja i poznavanja anatomskih svojstava drva topole radi njegove široke primjene. Detaljno je opisana problematika varijabilnosti i razlika u anatomskim svojstvima drva različitih vrsta topole iz dosadašnjih istraživanja, s posebnim naglaskom na problematici varijabilnosti svojstava unutar zone juvenilnog drva. S obzirom na porast primjene gnojidbe u plantažnom uzgoju brzorastućih stabala, iznesene su i dostupne ograničene spoznaje o utjecaju gnojidbe dušikom na anatomska svojstva drva topole. Za definiranje smjera i opsega ovog istraživanja vrlo je važno bilo nekoliko spoznaja. Bijela topola uzgojno je zanimljiva kao vrsta otporna na sušu i tolerantna na varijacije razine podzemnih voda, ali je unutar roda *Populus* najmanje istraživana te je njezina vrijednost kao sirovine uglavnom nepoznata. Dok o brojnim vrstama topole danas postoji poprilično veliko znanje, anatomska svojstva drva potencijalno uzgojno zanimljivih klonova poput 'L-12' i 'Villafrance' do sada nisu uopće istraživana. Usto, nedovoljno su istražena i nisu kvantificirana anatomska svojstva drva bijele topole iz prirodnih populacija. Također, svojstva juvenilnog drva potrebno je što bolje okarakterizirati radi njegova što učinkovitijeg iskorištavanja. U temeljito istraživanje potreba za gnojidbom potrebno je uključiti i istraživanje o utjecaju gnojidbe na kvalitetu drva. S obzirom na iznesenu problematiku istraživanja, a radi upotpunjavanja dosad nedostatnih podataka i znanstvenog unapređenja razumijevanja varijacija i razlika u anatomskim svojstvima juvenilnog drva bijele topole iz prirodnih populacija i juvenilnog drva klonova bijele topole, kao i da bi se detaljnije okarakterizirao utjecaj gnojidbe dušikom na anatomska svojstva drva topola, postavljene su odgovarajuće hipoteze i ciljevi istraživanja. Kako bi se ostvarili zadani ciljevi, u istraživanju je primijenjen postupak maceracije za izradu preparata maceriranog materijala, a izrađeni su i histološki preparati poprečnoga i tangencijalnog presjeka. Postupak maceracije proveden je za potrebe mjerenja duljine drvnih vlakanaca, dok su histološki preparati poprečnoga i tangencijalnog presjeka izrađeni radi mjerenja ostalih anatomskih svojstava. Istražena su anatomska svojstva juvenilnog drva dvaju klonova bijele topole ('L-12' i 'Villafranca') te bijele topole iz prirodnih populacija s lokaliteta na području Osijeka i Varaždina, i to njihove varijacije od srčike prema kori, kao i razlike unutar klona i unutar populacija bijele topole te razlike ovisno o lokalitetima. U juvenilnom drvu pet stabala klona 'L-12' i pet stabala bijele topole s lokaliteta na području Osijeka te sedamnaest stabala klona 'Villafranca' i pet stabala bijele topole s lokaliteta na području Varaždina izmjerene su duljine drvnih vlakanaca i dvostruke debljine njihovih stijenki, promjeri i udjeli lumena drvnih vlakanaca, promjeri i udjeli lumena traheja i udjeli drvnih trakova. Kao postotni ostatak udjela lumena drvnih vlakanaca, udjela lumena traheja i udjela drvnih trakova u juvenilnom drvu svih stabala izračunani su udjeli stijenki stanica drva. Dobiveni rezultati anatomskih svojstava juvenilnog drva klonova uspoređeni su sa svojstvima juvenilnog drva bijele topole s istog lokaliteta. Istražen je i utjecaj gnojidbe dušikom na anatomska svojstva juvenilnog drva klona 'Villafranca'. Za istraživanje značajnosti varijacija i razlika u anatomskim svojstvima juvenilnog drva u statističkoj je obradi primijenjen model analize varijance ponovljenih mjerenja i model univarijantne analize varijance za istraživanje značajnosti utjecaja gnojdibe dušikom u svakoj pojedinoj godini primjene. Na drugom stupnju analize varijance unutar modela univarijatne analize varijance upotrijebljen je *post hoc test* (*Tukey test*) višestrukog uspoređivanja pojedinih parova tretiranja.

Provedenim istraživanjem ostvareni su svi zadani ciljevi te je iz njega proizašlo nekoliko zaključaka. Utvrđene su statistički značajne varijacije anatomskih svojstava juvenilnog drva od srčike prema kori, a za pojedina svojstva i ovisno o podrijetlu drva s dvaju lokaliteta, one se razlikuju i po veličini tog značaja. Sukladno hipotezi, utvrđene su značajnije razlike za pet anatomskih svojstava juvenilnog drva unutar prirodnih populacija bijele topole u usporedbi s razlikama među lokalitetima. Za dva anatomska svojstva te su razlike unutar prirodnih populacija bijele topole u usporedbi s razlikama među lokalitetima jednakog značaja. Suprotno tome, utvrđene su i znatnije razlike među lokalitetima u usporedbi s razlikama unutar prirodnih populacija bijele topole samo za jedno svojstvo. Razlike u pojedinim anatomskim svojstvima juvenilnog drva obaju klonova i juvenilnog drva bijele topole s istog lokaliteta nisu jednako značajne. U juvenilnom drvu različitog podrijetla s lokaliteta na području Osijeka te su razlike podjednako i statistički značajne i bez značaja. Međutim, u juvenilnom drvu različitog podrijetla s lokaliteta na području Varaždina te su razlike u najvećoj mjeri statistički značajne. Utvrđeno je da svaka od tri razine gnojidbe dušikom različito utječe na promjenu anatomskih svojstava juvenilnog drva klona 'Villafranca' u svakoj godini primjene. Značajne promjene anatomskih svojstava drva zabilježene su u 2004. godini, dok one u 2005. ipak nisu značajne. Najviše anatomskih svojstava drva značajno je promijenjeno nakon srednje razine gnojidbe dušikom. Na temelju navedenoga, nijedna od četiri postavljene hipoteze nije u potpunosti potvrđena.

OCJENA DOKTORSKOG RADA

Doktorski rad Ive Ištok, mag. ing. techn. lign., izvorno je i samostalno znanstveno djelo i stoga u potpunosti zadovoljava zahtjeve izrade doktorske disertacije. Istraživanje obuhvaća provedbu postavljenih ciljeva i donosi nove spoznaje o anatomskim svojstvima drva bijele topole (*Populus alba* L.) i njezinih klonova te nova znanja o varijacijama tih svojstava unutar klonova i unutar prirodne populacije, unutar lokaliteta i među dvama lokalitetima. Ujedno donosi i nova znanja o utjecaju gnojidbe dušikom na anatomska svojstva drva klona 'Villafranca'. Diskusija je potpuno utemeljena na rezultatima te je logično podijeljena s obzirom na postavljene ciljeve i hipoteze. Posebna je pozornost usmjerena na pojedinačne skupine rezultata koji proizlaze iz ispitivanja. Rezultati su primjereno uspoređeni s podacima iz dostupne literature. Zaključci su pravilno, logično i izravno izvedeni iz rezultata ispitivanja i diskusije. Rezultati ovog istraživanja doprinos su selekciji klonova ‹L-12› i ‹Villafranca› glede anatomskih svojstava njihova drva, a dodatnim istraživanjima moguće je i detaljnije istražiti kvalitetu drva. Izravan su znanstveni doprinos ovog istraživanja kvantificirani podaci o anatomskim svojstvima juvenilnog drva bijele topole te podaci o njihovoj varijabilnosti unutar istog staništa i među različitim staništima. Anatomska svojstva drva vrlo su važan parametar kvalitete drva. Rezultati ovog istraživanja moći će se uzeti u obzir pri kultiviranju bijele topole te u procjeni učinka brzog rasta na juvenilnost i kvalitetu plantažnog drva bijele topole. Usporedba anatomskih svojstava juvenilnog drva bijele topole iz prirodnih populacija i klonova iz pokusnih nasada pokazuje postoje li, i u kojoj mjeri, poboljšanja anatomskih svojstava u oplemenjenom materijalu. Detaljno istražen utjecaj gnojidbe dušikom na anatomska svojstva najpoznatijega i najrasprostranjenijeg klona bijele topole 'Villafranca' pokazuje značajan utjecaj određenih razina gnojidbe dušikom, koji je moguće tumačiti kao pozitivan ili negativan, ovisno o zahtjevima i specifičnoj namjeni sirovine. Cjelokupan rad sastoji se od zaokruženih tematskih cjelina koje se mogu logično oblikovati kao zasebni znanstveni radovi za objavljivanje.

doc. dr. sc. Bogoslav Šefc

In memoriam – prof. dr. sc. Vladimir Bruči

Dana 8. studenoga 2016. zatekla nas je bolna vijest o odlasku našega dragog profesora, učitelja i prijatelja prof. dr. sc. Vladimira Bručija.

S tugom i tihom sjetom prisjećamo se njegova svijetlog lika kroz djela stvorena predanim radom, djela koja su oplemenila njegov životni put i pridonijela prosperitetu drvnotehnološke struke i Šumarskog fakulteta. Rođen je 23. kolovoza 1935. u Zagrebu, gdje je završio osnovnu školu i gimnaziju. Na Šumarski fakultet, Drvnoindustrijski smjer, upisao se 1954., a diplomirao je 28. veljače 1960. te stekao akademsko zvanje dipl. ing. drvne industrije. Nakon povratka s odsluženja vojnog roka najprije se 1961. zapošljava u Zagrebačkoj tvornici pokućstva kao inženjer pogona i glavni konstruktor. Tijekom 1962. odlazi u Tvornicu šperploča DIP-a Vrginmost, te nakon usavršavanja od voditelja odjeljenja i voditelja smjene postaje upravitelj Tvornice. Dana 1. srpnja 1963. vraća se trajno u Zagreb i ponovo se zapošljava u Zagrebačkoj tvornici pokućstva, u Analitičko-planskom odjelu. Od 1. prosinca 1963. radi na Šumarskom fakultetu kao asistent vrsnog prof. dr. sc. Juraja Krpana, na predmetu Industrija furnira i ploča. Zbog iznenadne smrti prof. Krpana prof. Bručiju, tada asistentu predavaču, povjerena je kompletna nastava na VI., VII./1 i VII./2 stupnju studija, kao i mentorstvo pri izradi diplomskih, magistarskih i doktorskih radova. Naslov magistra znanosti stječe 1969. obranivši magistarski rad *Spajanje furnira*, a doktorom znanosti postaje 1976. obranivši disertaciju naslova *Utjecaj vlage iverja i temperature prešanja u proizvodnji troslojnih ploča iverica na vrijeme prešanja i svojstva gotovih ploča*. Za višeg predavača izabran je 1975., za docenta 1977., a za izvanrednog profesora 1981. Redovitim profesorom postaje 1987., a u znanstveno-nastavno zvanje najviše razine – u zvanje redovitog profesora u trajnom zvanju, promaknut je 1998.

U znanstvenome, nastavnome i stručnom radu bavio se tehnologijom klasičnih i vatrootpornih ploča iverica, razvojem novih tipova ploča na bazi drva, sirovinskom bazom za proizvodnju ploča od usitnjenog drva, problematikom naknadnog oslobađanja formaldehida iz drvnih ploča te filozofijom šumsko-drvnoindustrijskog kompleksa.

Uspješno je provodio sve tri misije koje su danas temelj budućnosti Sveučilišta – visoko obrazovanje, istraživanje te inovacije i transfer znanja.

Radio je u povjerenstvima za izradu normi za furnire i ploče, kreator je Naredbe o obveznom atestiranju ploča iverica, a bio je i prvi predsjednik TO 89 – Furniri, drvne ploče i drvni poluproizvodi. Suosnivač je i voditelj Laboratorija za ploče iverice, ovlaštenoga za certificiranje ploča iverica rješenjem Državnog zavoda za normizaciju i mjeriteljstvo od 15. svibnja 1995. Izradio je brojne elaborate, studije i ekspertize. Vodio je niz znanstvenih i razvojnih projekata, domaćih i stranih (u Italiji i Sloveniji) vezanih za problematiku furnira, drvnih ploča i kemijskih komponenata za drvne ploče, a osobito je intenzivno radio na problematici slobodnog formaldehida.

Izradio je niz elaborata, studija i ekspertiza, od kojih su najvažniji:
- pokus loženja parnog kotla
- određivanje kapaciteta sušionica furnira i konačne vlage
- analiza radnih uvjeta pri upotrebi formaldehidnih ljepila
- ispitivanje efikasnosti rada sušionica furnira sa sapnicama
- stručno mišljenje o materijalima hidroakustičkog bazena
- studija korištenja drvnoindustrijskih ostataka
- recenzija tehnološkog projekta tvornice furnira
- recenzija investicijskog programa rekonstrukcije pogona, i dr.

Bio je aktivni sudionik brojnih domaćih i međunarodnih znanstvenih i stručnih skupova. Objavio je stotinjak znanstvenih, stručnih i drugih radova te dvije sveučilišne knjige. Pod njegovim mentorstvom izrađena su i obranjene su četiri doktorske disertacije, sedam magistarskih radova i brojni diplomski radovi. Bio je višegodišnji predstojnik Zavoda za mehaničku preradu drva te suosnivač Zavoda za ploče i kemijsku preradu drva. Akad. god. 1988./89. i 1989./90. bio je prodekan Drvnotehnološkog odsjeka. Sudjelovao je u radu brojnih znanstvenih i stručnih udruga. Nosilac je Spomenmedalje Sveučilišta u Zagrebu te Spomenice Domovinskog rata.

Prof. dr. sc. Vladimir Bruči osjećao je da je rođen za velike domete, u njegovim mislima nazirala se neka nova filozofija i vizija suvremenog razvoja drvnotehnološke struke i gospodarstva. Bio je spreman na odricanje i neizvjesnost te se otisnuo u znanstvene bujice zapadne civilizacije. Glavni mu je cilj bio SAD, a potom najnaprednije zemlje zapadne Europe. Njegove vrhunske kvalitete nepopravljivog entuzijasta potvrđene su dodjelom triju najprestižnijih stipendija, kojima se malo koji znanstvenik iz Hrvatske, ali i iz šireg okruženja, može pohvaliti, a to su:
- stipendija Republike Finske

- stipendija Alexandera von Humboldta (SR Njemačka)
- Fulbrightova stipendija (SAD).

Navedene stipendije omogućile su mu specijalizaciju i usavršavanje na elitnim europskim i svjetskim sveučilištima, u institutima, razvojnim centrima, tvrtkama i sl., kao što su:

- akad. god. 1971./72., Finska
  - Institut za tehnička istraživanja Helsinki-Otamiemi (Valtion Teknillinen Tutkimnslaitos, Otamiemi)
- akad. god. 1979./80., SR Njemačka
  - Institut für Holzforschung der Universität München
  - Wilhelm Klauditz Institut, Braunschweig
  - Fachhochschule Rosenheim
  - Institut für Fenstertechnik, Rosenheim
- akad. god. 1981./82., SAD
  - University of California
  - USDA Forest Products Laboratory
  - University of Wisconsin, Madison
  - University of Lewiston, Idaho.

U Lewistonu, Idaho, u tvrtki Potlatch, radio je na eksperimentalnom dijelu projekta *Surface Activated Bonding Systems*. Na prestižnim američkim sveučilištima i institutima održao je nekoliko vrlo zapaženih predavanja. U Minnesoti i Wisconsinu stručno je iskustvo stjecao u velikim korporacijama proizvođača ploča (Louisiana-Pacific, Blandin Wood Products, Superwood i Northwood).

Bio je rado viđen znanstvenik i sudionik najvećega svjetskog skupa o furnirima i drvnim pločama u SAD-u, Pullman, Washington, u ravnopravnoj konkurenciji s najvećim svjetskim znanstvenicima.

U Italiji je bio savjetnik u Internacionalnom centru za drvo C. I. L. u Trstu.

Vizija razvoja drvne struke, gospodarstva i društva u cjelini prof. Bručija bila je ispred njegova vremena, teško prihvatljiva običnom smrtniku i gotovo je pripadala znanstvenoj fantastici. Bilo je pitanje je li moguće slijediti njegovu viziju i ima li to uopće smisla, nije li to samo vizija neostvarivog sna. Vrijeme koje je uslijedilo nakon preranog umirovljenja prof. Bručija potvrdilo je ne samo održivost svih njegovih dotad neshvaćenih razvojnih i životnih teza, već i prosperitet koji donosi njihova primjena.

Svijetli lik i djela prof. dr. sc. Vladimira Bručija ostat će trajno u našim mislima i srcima, a brojne generacije studenata još će se dugo sjećati velikog vizionara i jednoga od najvećih doajena drvnotehnološke znanosti.

Neka mu je vječna slava i hvala za sve što je učinio za našu struku i naš Fakultet!

prof. dr. sc. Vladimir Jambreković

Staudtia stipitata Warb.

NAZIVI

Staudtia stipitata Warb. naziv je drva botaničke vrste iz porodice *Myristicaceae.* Trgovački su nazivi te vrste i niové (Njemačka, Francuska, Velika Britanija, Belgija), memenga (Angola), m'bou, mogoubi, ohobe (Gabon), bokapi, bopé, bopé bambake, ekop, m'bonda (Kamerun), bosasa, kamashi, menge-menga, sunzu, susumenga, wanga (Kongo).

NALAZIŠTE

Stabla *Staudtia stipitata* Warb. nalazimo u zapadnoj i srednjoj Africi. Područja rasprostranjenosti tog drveća su Kongo, Nigerija, Kamerun, Gabon i Angola. Rastu ponajprije u području tropskih nizinskih trajno zelenih kišnih šuma i u području suptropskih kišnih šuma dubokih pjeskovitih tala.

STABLO

Naraste od 25 do 30 (35) metara, dužina debla mu je 20 – 25 metara, a prsni promjer do 1,0 (1,3) metra. Stabla su cilindričnog oblika. Kora mladog drva je glatka, na zrelom je drvu pločasta i raspucana, pepeljasto siva do crvenkasta. Debljina kore je od 0,5 do 1,0 centimetra. Sadržava lateks.

DRVO

Makroskopska obilježja

Drvo je rastresito porozno. Bjeljika i srževina međusobno se razlikuju. Bjeljika je široka, žućkasta do svjetlosmeđa. Netom ispiljena srž narančastosmeđe je boje. S vremenom potamni i postane crvenosmeđa. Svježe posječeno drvo intenzivnog je mirisa. Pore, aksijalni parenhim i drvni traci uočljivi su samo povećalom.

Mikroskopska obilježja

Traheje su pretežito pojedinačno raspoređene, a pojavljuju se u paru i u skupinama. Promjer traheja iznosi 85...120...165 mikrometara, gustoća im je 5...7...8 na 1 mm^2 poprečnog presjeka. Volumni udio traheja iznosi oko 15 %. Traheje su često ispunjene tilama i smeđim sržnim tvarima. Aksijalni je parenhim apotrahealno marginalan, širok od 1 do 2 stanice, paratrahealan. Volumni udio aksijalnog parenhima je oko 7 %. Drvni su traci heterogeni, visoki 330...700...1200 mikrometara te široki 15...30...43 mikrometara, odnosno od 1 do 2 odnosno 3 stanice. Gustoća drvnih trakova je 10...11...13 na 1 mm poprečnog presjeka. Volumni udio drvnih trakova iznosi oko 26 %. Drvna su vlakanca libriformska, a dugačka su 300...650...1700 mikrometara. Debljina staničnih stijenki vlakanaca iznosi 2,15...3,5...4,5 mikrometara, a promjer lumena 7,0...12,0...16,0 mikrometara. Volumni je udio vlakanaca oko 52 %.

Fizička svojstva

Gustoća standardno suhog drva, ρ_o	700...850...950 kg/m^3
Gustoća prosušenog drva, ρ_{12-15}	750...900 ...1000 kg/m^3
Gustoća sirovog drva, ρ_s	900...1100 kg/m^3
Poroznost	oko 44 %
Radijalno utezanje, β_r	5,2...5,9 %
Tangentno utezanje, β_t	6,3...7,1 %
Volumno utezanje, β_v	9,0...11,8...16,7 %

Mehanička svojstva

Čvrstoća na tlak	79...111 MPa
Čvrstoća na vlak, okomito na vlakanca	2,4...3,0...4,0 MPa
Čvrstoća na savijanje	150...161...193 MPa
Čvrstoća na smik	oko 6,0 MPa
Tvrdoća (prema Brinellu), okomito na vlakanca	36...41 MPa
Modul elastičnosti	16,2...18,5 GPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Drvo se dobro ručno i strojno obrađuje. Piljenje je otežano i zahtijeva upotrebu pile sa zupcima od tvrdog materijala te velik utrošak energije. Dobro se savija, reže, blanja i ljušti. Prije upotrebe vijaka i čavala drvo je potrebno predbušiti. Dobro se lijepi i površinski obrađuje, no prije obrade površinu je potrebno obraditi otapalima.

Sušenje

Drvo se dobro suši i prirodnim načinom i u sušionicama, no treba izbjegavati visoke temperature sušenja.

Trajnost i zaštita

Prema normi HRN 350-2, 2005, srž drva vrlo je otporna na gljive uzročnice truleži (razred otpornosti 1) i otporna na termite (razred otpornosti D). Srž je slabo permeabilna (razred 4). Po trajnosti drvo pripada razredu 4 i stoga se može koristi u dodiru s tlom i vodom.

Uporaba

Upotrebljava se kao furnirsko drvo, za izradu rezanoga i ljuštenog furnira, za proizvodnju namještaja, kao konstrukcijsko drvo za srednja i velika opterećenja, za izradu stubišta, parketa i ograda, za brodogradnju te za proizvodnju vagona i mostova. Od njega se mogu izrađivati i sportske naprave, ručke alata, crtaći pribor, četke i tokareni drvni elementi.

Sirovina

Drvo na tržište dolazi u obliku trupaca dužine 4,0 do 8,0 metara, najčešće srednjeg promjera od 60 do 90 centimetara.

Zbog sličnih svojstava na svjetskom se tržištu pod istim trgovačkim nazivom često pojavljuje i vrsta *Staudtia kamerunenesis* Warb.

Napomena

Staudtia stipitata Warb. nije na popisu ugroženih vrsta međunarodne organizacije CITES, niti na popisu međunarodne organizacije IUCN Red list. Drvo sličnih svojstava imaju i vrste *Staudtia kamerunenensis* Warb. i *Staudtia* spp.

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

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Broj slika mora biti ograničen samo na one koje su prijeko potrebne za objašnjenje teksta. Isti podaci ne smiju biti navedeni i u tablici i na slici. Slike i tablice trebaju biti zasebno obrojčane, arapskim brojkama, a u tekstu se na njih upućuje jasnim naznakama ("tablica 1" ili "slika 1"). Naslovi, zaglavlja, legende i sav ostali tekst u slikama i tablicama treba biti napisan hrvatskim i engleskim jezikom.

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Primjer

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Primjeri

Krpan, J., 1970: Tehnologija furnira i ploča. Drugo izdanje. Zagreb, Tehnička knjiga.

Wilson, J. W.; Wellwood, R. W., 1965: Intra-increment chemical properties of certain western Canadian coniferous species. U: W. A. Cote, Jr. (Ed.): Cellular Ultrastructure of Woody Plants. Syracuse, N.Y., Syracuse Univ. Press, pp. 551- 559.

Ostale publikacije (brošure, studije itd.)

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

Web stranice

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

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Wilson, J.W.; Wellwood, R.W. 1965: Intra-increment chemical properties of certain western Canadian coniferous species. U: W. A. Cote, Jr. (Ed.): Cellular Ultrastructure of Woody Plants. Syracuse, N.Y., Syracuse Univ. Press, pp. 551-559.

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