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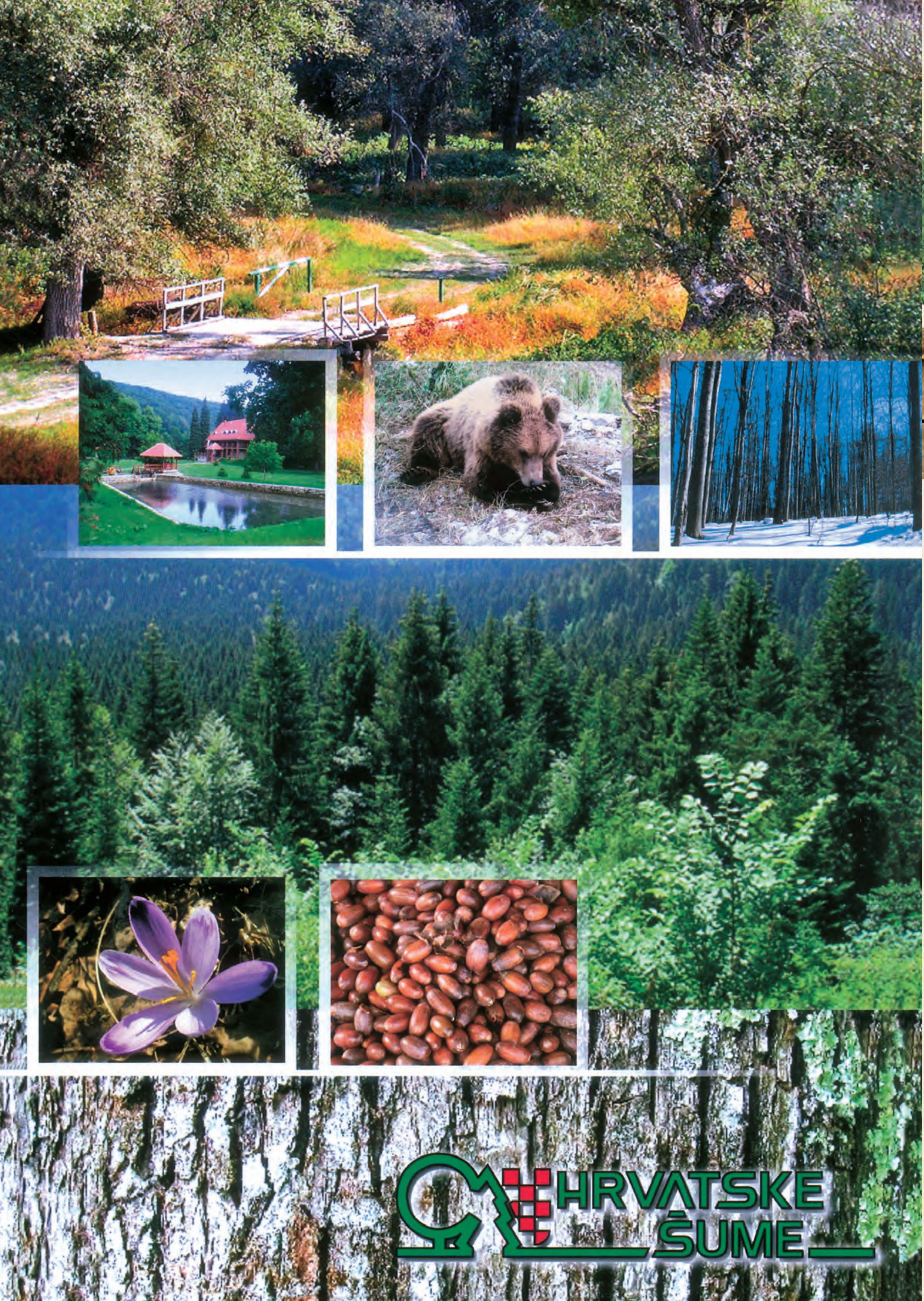
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Majid Kiaei[1]

Effect of Cultivation Methods on Wood Static Bending Properties in Alnus Glutinosa

Utjecaj načina uzgoja crne johe na njezina statička savojna svojstva

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ABSTRACT • *This study was carried out to determine radial variation of wood density, modulus of elasticity (MOE), modulus of rupture (MOR) and stress at elastic limit in plantation and natural alder (Alnus glutinosa) forests in north of Iran. Testing samples were taken at breast height of the stem and at three radial positions (10, 50 and 90 % of radius) for both cultivation methods (natural and plantation forests) to determine wood mechanical strength properties according to the ASTM standard. Analysis of variance indicated that cultivation methods (natural and plantation forest), radial position and interaction between planting position and radial direction had no significant effects on the modulus of elasticity (MOE), modulus of rupture (MOR) and stress at elastic limit in alder wood. Only the radial position had a significant effect on the wood density. Wood density was increased along radial direction from the pith to the periphery for both planting conditions. Overall, the mechanical strength properties in plantation forest were slightly higher than in natural forest. The relationship between wood density and mechanical properties were analyzed by linear regression. A positive relationship was found between wood density and mechanical properties for both planting conditions. These relationships were stronger in plantation forest than in natural forest.*

Keywords: *Alnus glutinosa, modulus of elasticity, modulus of rupture, Fiber stress at elastic limit, cultivation methods (natural and plantation forest)*

SAŽETAK • *Istraživanje je provedeno kako bi se u radijalnome smjeru utvrdile varijacije gustoće drva, modula elastičnosti (MOE), modula loma pri savijanju (MOR) i naprezanja na granici elastičnosti drva crne johe (Alnus glutinosa) iz plantažne i prirodne šume johe sa sjevera Irana. Ispitni uzorci uzeti su na prsnoj visini stabala s tri radijalne pozicije (10, 50 i 90 % radijusa) iz oba načina uzgoja (iz prirodne i plantažne šume) kako bi se utvrdila mehanička svojstava drva prema standardu ASTM. Analiza varijance pokazala je da način uzgoja crne johe (prirodna i plantažna šuma), radijalni položaj, kao i interakcija između položaja samog stabla i položaja uzorka u radijalnome smjeru nisu imali statistički značajnog utjecaja na modul elastičnosti, modul loma pri savijanju, kao ni na naprezanje na granici elastičnosti. Radijalni položaj uzoraka imao je značajnog utjecaja samo na gustoću drva. Gustoća drva povećavala se u radijalnom smjeru od srčike prema kori, bez obzira na način uzgoja šuma. Općenito, ispitivana mehanička svojstva drva crne johe iz plantažne šume bila su nešto bolja od mehaničkih svojstava drva iz prirodne šume. Odnos između gustoće drva i ispitivanih mehaničkih svojstava analiziran je linearnom regresijom. Utvrđen je pozitivan odnos između gustoće drva i ispitivanih mehaničkih svojstava za oba*

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načina uzgoja šuma. Ti odnosi između gustoće drva i ispitivanih mehaničkih svojstava jače se očituju u drvu johe iz plantažnog uzgoja nego iz prirodnog uzgoja.

Ključne riječi: *Alnus glutinosa, modul elastičnosti, modul loma pri savijanju, naprezanje na granici elastičnosti, prirodna i plantažna šuma*

1 INTRODUCTION
1. UVOD

The *Alnus glutinosa* is diffuse-porous hardwood species from *Betulaceae* family, which accounts for about 9 percent of the growing stock in Northern forests according to the Iranian forest organization. Alder wood is soft or semi-hard, and light density (moisture content of 15 %) hardwood (0.4 – 0.67 g/cm^3). In our forests, there are two species of this fast growing wood: *Alnus subcordata* and *Alnus glutinosa*. These species have good nailing ability, good adhesiveness, they are highly colorable and have low durability. They are mostly used for box-making, water structures, boat-making, furniture, plywood and veneer (Parsapajouh, 1998).

Wood quality can be measured directly by submitting timber to a large number of technical tests. However, many of wood traits such as strength and elasticity properties are related to density. This parameter is suitable for predicting wood quality (Panshin and De Zeeuw, 1980). For a specific species, the wood density is very variable among trees due to genetic and environmental differences (Zahner, 1968). The relation between density and site index depends on difference in growth rate, which is a very complex issue (Taylor and Wooten, 1937). Wood density varied along longitudinal and radial directions from bottom to the up and from pith to bark (Zhang and Zhong, 1990). Variations of wood density may be directly related to variation in cell wall percentages and changes in cell wall thickness, cell diameter and tissue proportions (Zahner, 1968).

A research on the comparison of wood properties of planted big-leaf mahogany in Martinique Island with naturally grown Mahogany from Brazil, Mexico and Peru (there are two age groups such as young trees [<40 years old] and old trees [>40 years old] for plantation trees) indicated that wood density of plantation trees (young and old trees) was lower than that of natural forest trees. Although the density of natural forest wood was higher than that of plantation trees, the difference in modulus of elasticity (*MOE*) was not significant. The static bending strength (*MOR*) of young and old trees was significantly lower than that of natural forest trees (Langbour *et al*., 2011). The mean values of dried density, basic density, volumetric shrinkage, volumetric swelling, fiber saturation point, modulus of elasticity and modulus of rupture for Turkish alder wood *(Alnus glutinosa)* were respectively determined as 0.454 g/cm^3, 0.399 g/cm^3, 12.62 %, 13.78 %, 32.87 %, 8.61 GPa and 77.53 MPa (Korkut and Guller, 2008).

There were no information about mechanical strength properties and other characteristics and differences between plantation-natural forests for *Alnus glutinosa* species in Iran. Therefore, the aims of this study of *Alnus glutinosa were*: a) to examine wood density, modulus of elasticity, modulus of rupture and stress at elastic limit along radial direction from pith to bark for both planting conditions (natural and plantation forest), and b) to investigate the relationship between wood density and static bending strength for both cultivation methods (a species grown in two different ways).

2 MATERIAL AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Study material comes from six alder trees (*Alnus glutinosa*) sampled from two planting conditions in the eastern part of Mazandaran province (Savadkouh region) in the north of Iran. These planting conditions were plantation and natural forests. Logs and discs were cut at breast height for each tree. Selected trees with straight trunks, normal branching and no disease or pest symptoms were felled. From each selected tree, a log 50 cm long was extracted at breast height diameter (*dbh*). The plantation alder trees were 20 years of age and natural forest trees 20-22. The mean values of annual ring width in the plantation alder trees and natural alder forest were 6.95 and 6.86 mm, respectively. In this region, the average air temperature was 11.2 °C and the sum of annual rainfall was 386 mm/year. The altitude was 120 m for plantation forest and 350 m for natural forest. The soil of this region is similar for both planting conditions.

2.2 Methods
2.2. Metode

2.2.1 Static bending properties
2.2.1. Svojstva pri statičkom ispitivanju na savijanje

Wood samples for testing were taken along the radial direction from pith to bark (three positions from pith 10, 50, 90 % of radius) in four geographical directions of trees to determine static bending properties according to the ASTM–D143-94 standards. The dimensions of samples were 25×25 mm in cross section and 410 mm in longitudinal direction. The length span of 360 mm was required to determine the modulus of elasticity (*MOE*), modulus of rupture (*MOR*) and stress at elastic limit. The prepared samples were then conditioned at the temperature of 20±2 °C and at 65±5 %

relative humidity until the specimens reached an equilibrium moisture content of about 12 %. Three different static bending strength parameters, fiber stress at elastic limit (*FS* at *LP* in MPa), modulus of rupture (*MOR* in MPa) and modulus of elasticity (*MOE* in MPa) were computed using the equations (1), (2) and (3):

$$FS \text{ at } LP = 3 \cdot P \cdot l \,/\, 2 \cdot b \cdot h^2 \quad (1)$$

$$MOR = 3 \cdot P_{max} \cdot l \,/\, 2 \cdot b \cdot h^2 \quad (2)$$

$$MOE = P \cdot l^3 \,/\, 4 \cdot D \cdot b \cdot h^3 \quad (3)$$

Where

P – load at the limit of proportionality, kN,
P_{max} – maximum load, kN,
l – span of the test specimen, mm,
b – breadth of the test specimen, mm,
h – depth of the test specimen, mm,
D – deflection at the limit of proportionality, mm.

Finally, the specimens were examined to determine wood oven-dry density based on the ISO-3131 standard (20 × 20 × 20 mm). The samples were oven-dried at 103 ± 2 °C to 0 % moisture content. After cooling in desiccators, the oven-dry weights of the specimens were measured. The values of the wood oven-dry density were calculated using the following equation (4):

$$\rho_0 = \frac{m_0}{V_0} \quad (4)$$

Where

ρ_0 – density in absolutely dry condition,
m_0 – weight in absolutely dry condition,
V_0 – volume in absolutely dry condition.

2.2.2 Statistical analysis
2.2.2. Statistička analiza

To determine the effect of cultivation methods (natural and plantation trees) and radial direction on the static bending properties and wood density, statistical analysis was conducted using the SPSS programming method in conjunction with the analysis of variance (ANOVA) techniques. A linear regression model was used to analyze the relationship among the various properties for both cultivation methods in alder wood.

3 RESULTS OF RESEARCH
3. REZULTATI ISTRAŽIVANJA

3.1 Wood density
3.1. Gustoća drva

Radial variation of wood density for plantation forest and natural forest are shown in Table 1. Analysis of variance (ANOVA) indicated that the effects of cultivation methods (*F*= 0.169, sig = 0.685), and their interaction between cultivation methods and radial position (*F*= 4.253, sig = 0.026, *P*<0.05) had no significant effect on wood density. There are, however, significant differences in wood density among radial samples (*F*= 0.488, sig = 0.620). The average wood density in plantation forest was slightly higher than that in natural alder forest. Wood density increased in the radial direction from pith to bark for both planting conditions. The average wood density in plantation and natural alder trees was 0.396 and 0.391 g/ cm^3, respectively.

3.2 Modulus of elasticity (*MOE*)
3.2. Modul elastičnosti (*MOE*)

Radial variation of modulus of elasticity (*MOE*) for plantation forest and natural forest are shown in Table 2. Analysis of variance (ANOVA) indicated that the effects of cultivation methods (*F* = 0.911, sig = 0.349), radial position (2.528, sig = 0.101) and their interaction

Table 1 Mean values (coefficients of variation) of wood density in plantation and natural alder forests
Tablica 1. Srednje vrijednosti i koeficijenti varijacije (CV, %) gustoće drva crne johe iz plantažne i prirodne šume

Radial direction *Pozicija u radijalnome smjeru*	**Natural forest** *Prirodna šuma*	**Plantation** *Plantažna šuma*
Pith / *srčika*	0.37 (3.24)	0.388 (5.67)
Middle / *sredina*	0.392 (8.16)	0.385 (6.75)
Bark / *kora*	0.412 (8.49)	0.414 (6.03)
Mean / *aritmetička sredina*	0.391	0.396

Table 2 Mean values (coefficients of variation) of modulus of elasticity (*MOE*) in plantation and natural alder forests
Tablica 2. Srednje vrijednosti i koeficijenti varijacije modula elastičnosti (*MOE*) drva crne johe iz plantažne i prirodne šume

Radial direction *Pozicija u radijalnome smjeru*	**Natural forest** *Prirodna šuma*	**Plantation** *Plantažna šuma*
Pith / *srčika*	5.85 (19.14)	6.59 (10.68)
Middle / *sredina*	5.88 (6.75)	6.24 (5.83)
Bark / *kora*	7.04 (6.87)	7.04 (11.57)
Mean / *aritmetička sredina*	6.25	6.62

Table 3 Mean values (coefficients of variation) of modulus of rupture (*MOR*) in plantation and natural alder forests
Tablica 3. Srednje vrijednosti i koeficijenti varijacije (CV, %) modula loma pri savijanju drva crne johe iz plantažne i prirodne šume

Radial direction *Pozicija u radijalnome smjeru*	**Natural forest** *Prirodna šuma*	**Plantation** *Plantažna šuma*
Pith / *srčika*	42.27 (12.56)	44.34 (12.49)
Middle / *sredina*	45.61 (11.90)	47.57 (7.60)
Bark / *kora*	46.61 (19.05)	53.29 (17.35)
Mean / *aritmetička sredina*	44.83	48.4

Table 4 Mean values (coefficients of variation) of fiber stress at elastic limit in the plantation and natural alder forests
Tablica 4. Srednje vrijednosti i koeficijenti varijacije (CV, %) naprezanja na granici elastičnosti drva crne johe iz plantažne i prirodne šume

Radial direction *Pozicija u radijalnome smjeru*	**Natural forest** *Prirodna šuma*	**Plantation** *Plantažna šuma*
Pith / *srčika*	16.91 (12.65)	17.73 (12.46)
Middle / *sredina*	18.25 (11.89)	19.02 (7.62)
Bark / *kora*	17.64 (21.48)	21.31 (17.31)
Mean / *aritmetička sredina*	17.60	19.35

(F = 0.343, sig = 0.713) had no significant effect on *MOE*. The average *MOE* in plantation forest (6.62 GPa) was slightly higher than that in natural alder forest (6.25 GPa). The average *MOE* varied from pith to bark from 5 to 7 GPa for natural alder stems and varied from 6 to 7 GPa for plantation alder stems.

3.3 Modulus of rupture (*MOR*)
3.3. Modul loma pri savijanju drva (*MOR*)

Radial variation of modulus of rupture (*MOR*) for plantation forest and natural forest are shown in Table 3. Analysis of variance (ANOVA) indicated that the effects of cultivation methods (F= 1.974, sig = 0.173), radial position (F=2.511, sig= 0.102) and their interaction (F= 0.388, sig = 0.683) had no significant effect on *MOR*. The average *MOR* in plantation forest (48.40 MPa) was slightly higher than that in natural alder forest (44.83 MPa). With natural alder stems, the increment of *MOR* from pith to bark was, on average, 42 to 47 MPa, and with plantation alder stems from 44 to 54 MPa.

3.4 Fiber stress at elastic limit
3.4. Naprezanje vlakanaca na granici elastičnosti

Radial variation of fiber stress at elastic limit for plantation forest and natural forest are shown in Table 4. Analysis of variance (ANOVA) indicated that the effects of cultivation methods (F= 2.854, sig = 0.104), radial position (F=1.614, sig= 0.220) and their interaction (F= 0.879, sig = 0.428) weren't significant on the fiber stress at elastic limit. The fiber stress at elastic limit averaged 16.91 MPa in the pith part, 18.25 MPa in middle part, and 17.64 MPa in bark part, for natural alder stems. This factor was respectively determined 17.73, 19.02 and 21.31 MPa for plantation alder stems.

3.5 Relationship between wood density and various wood properties
3.5. Odnos između gustoće drva i ispitivanih mehaničkih svojstava

The dependence of static bending properties (modulus of elasticity, modulus of rupture and fiber stress at elastic limit) on the oven-dry density was modeled using simple regression equations (Figure 1). The correlation coefficient between wood density and *MOE*, *MOR*, and stress at elastic limit in plantation alder wood (R^2=0.613, 0.488 and 0.302, respectively) was higher compared to natural alder wood (R^2=0.505, 0.296 and 0.042, respectively). Furthermore, the correlation coefficient between wood density and *MOE* was considerably higher than the relationship between wood density-*MOR* and wood density-fiber stress at elastic limit. Overall, positive relationships were found between wood density and different static bending strength properties of wood for both planting conditions.

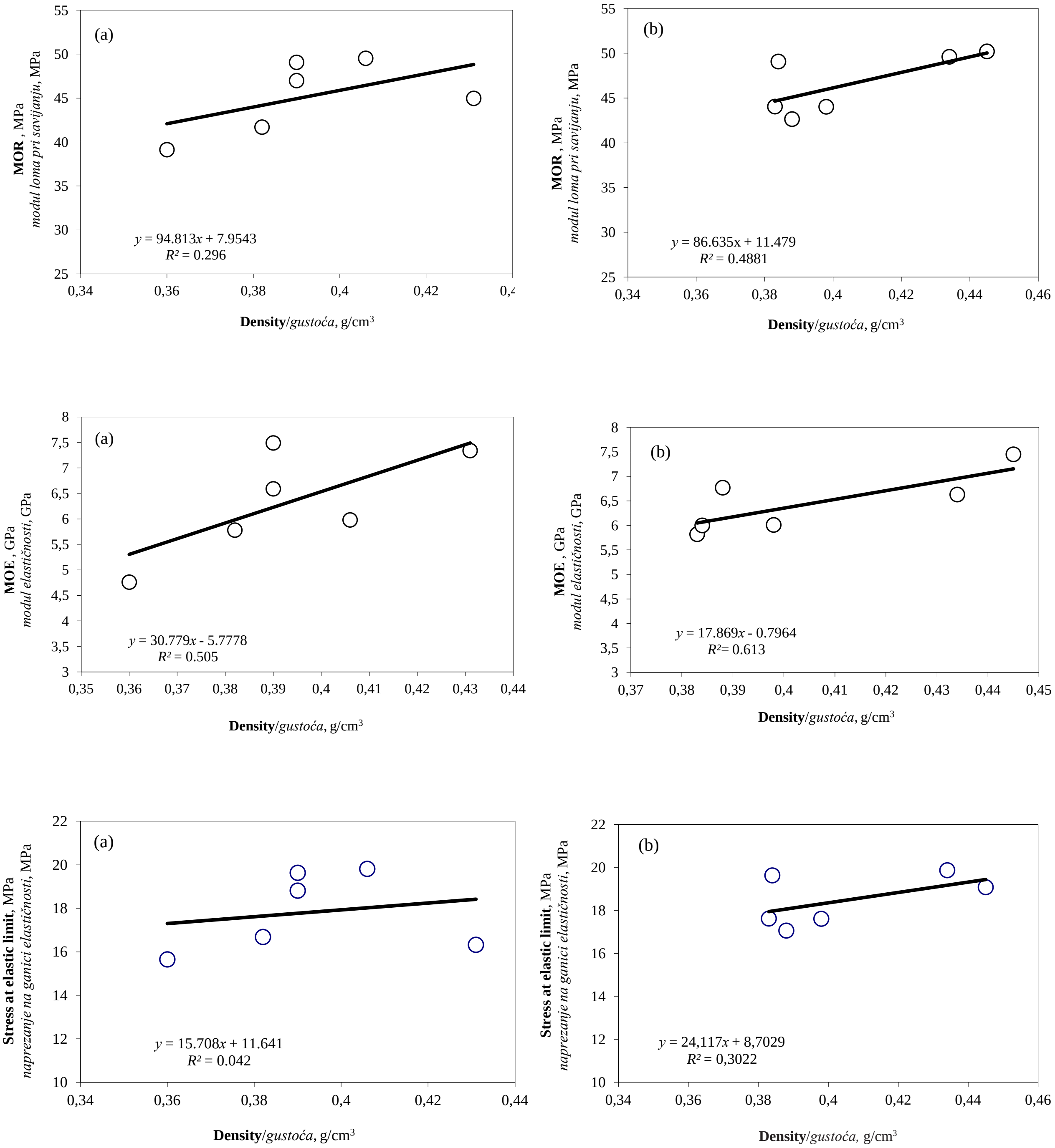

Figure 1 Relationship between wood mechanical properties and density of alder wood: a) from natural forest; b) from plantation

Slika 1. Međusobni odnos testiranih mehaničkih svojstava i gustoće drva johe: a) iz prirodne šume; b) iz plantažne šume

4 DISCUSSION
4. RASPRAVA

Many researchers suggest that trees growing in plantations produce wood of the lowest properties, such as wood density and other wood variables (Zobel and Sprague, 1998). For example, *Terminalia amazonia* trees from natural forests in Panama (Llach, 1971), Nicaragua (González, 1973), Bolivia, Venezuela and Colombia (Keenan and Tejada, 1987), and Honduras (Shupe *et al.,* 2005), among others, were reported to have superior mechanical properties to those from the forest plantations evaluated by Moya and Munoz (2010) study. Furthermore, *Swietenia macrophylia* trees from natural forests had better mechanical strength properties than plantation mahogany trees (Langbour *et al*. 2011). *Alnus glutinosa* tress from natural forests in Turkey (Korkut and Guller, 2008; Guller and Ay, 2001) were reported to have superior mechanical strength properties to those from the forest plantations and natural forests evaluated in the present study. The wood density of Turkish natural alder wood (0.454 g/cm^3) was higher than that of Iranian natural (0.391 g/cm^3) and plantation (0.396 g/cm^3) alder forests. These values were found for modulus of rupture and modulus of elasticity of alderwood in Turkey and in the present study. The mentioned properties were 77.53 MPa and 8.61 GPa for Turkish alder stems (Korkut and Guller, 2008; Guller and Ay, 2001). In addition, the wood mechanical properties of Iranian *Alnus glutinosa* are lower than those of *Alnus acuminata* in Costa Rica country (Moya and Munoz, 2010). These divergent results suggest a probable influence of site and environmental condition on wood quality. Zobel and Van Buijtenen (1989) suggest that large structure variations are produced by changes in climate, site and management characteristics, as a product of these extrinsic factors influencing various activities. Our study indicated that there are no significant differences between natural and plantation forests in the wood density and static bending properties. The wood density, modulus of rupture, modulus of elasticity and stress at elastic limit were slightly higher in plantation alder wood than in natural alder wood.

Some researchers have reported that different properties of wood increase with age or distance from the pith (in diffuse porous species). This is supported by the fact that juvenile wood is usually known to be of a lower density than mature wood (Zobel and Van Buijtenen, 1989; Heräjärvi, 2004; Hrázský and Král, 2010; Kord *et al*., 2010). Our study indicated that the radial direction had no significant effect on the static bending of natural and plantation alder stems. This phenomenon can be related to the fact that the transition stage of juvenile wood to mature wood did not happen in natural and plantation alder trees due to their low age.

A positive correlation between wood density and static bending (*MOE*, *MOR* and stress at elastic limit) was found in both planting conditions. Similar trend has also been reported by several researchers for different hardwood and softwood species (Zhang, 1997; Betkas *et al.*, 2002; Heräjärvi, 2004). The values of correlation coefficients between wood density and different mechanical strength properties were higher in plantation forest than in natural alder forest.

5 CONCLUSIONS
5. ZAKLJUČCI

The present research determined the static bending properties of natural and plantation alder stems in the Savadkouh – Mazandaran region. The following conclusions were obtained from this study:

1. There are no significant differences between cultivation methods (natural and plantation alder stem) in wood density, MOE, MOR and stress at elastic limit.
2. Radial variation of wood strength indicated that the MOE, MOR and stress at elastic limit increased with increasing cambial age in both planting conditions, and that these differences were not significant. The effect of radial variation on the wood density was significant.
3. The interaction between radial direction and cultivation methods had no significant effect on the wood density, MOE, MOR, and fiber stress at elastic limit
4. Positive relationship between wood density and mechanical properties was found in natural and plantation alder stems. According to correlation coefficients, these relationships are stronger in plantation alder forest than in natural alder forest.
5. Wood density is an important parameter of wood quality. Wood quality of plantation forest is similar to the quality of natural forest when referring to alder wood. So plantation alder wood may be used in the same way as natural alder wood in different wood industries.

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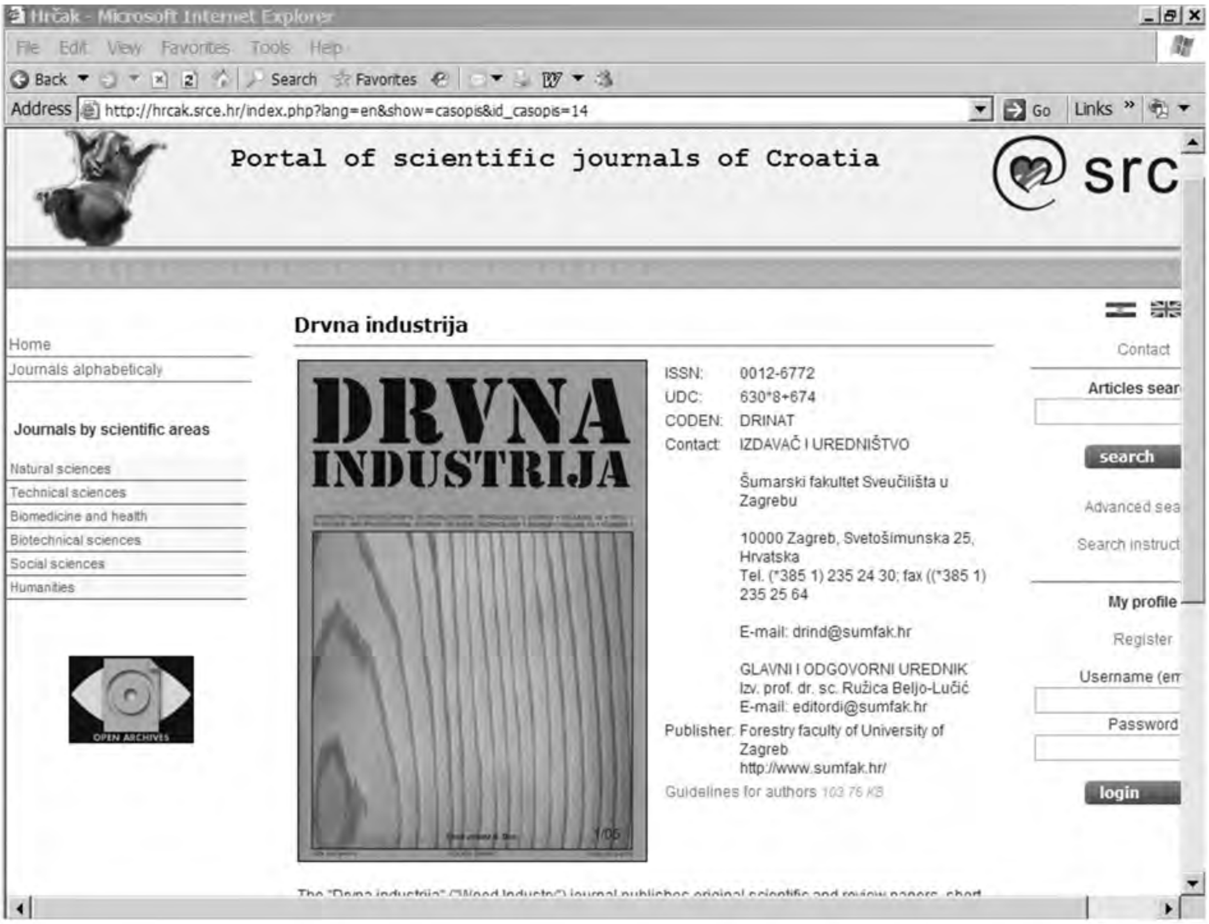

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Miha Humar[1], Boštjan Lesar[2]

Performance of Native and Copper-Ethanolamine-Treated Wood Exposed to Seawater at Port of Koper, Slovenia

Rezultati izlaganja nezaštićenog drva i drva zaštićenog bakar-etanolaminom utjecaju morske vode u luci Koper, Slovenija

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ABSTRACT • *The application of wood in seawater is one of the most challenging. Impregnated wood is exposed to leaching and to various marine borers, Limnoria sp. and Teredo sp. being the most important ones. The present research investigated the durability of pine wood impregnated with copper-amine based preservative solution (Silvanolin) of different concentrations exposed to the seawater according to EN 275 standard. Performance of Silvanolin treated wood was compared to the performance of reference wood (Quercus sp., Castanea sativa, Larix decidua). After 10, 18 and 32 months of exposure, specimens were removed and assessed. The results show clearly that the reference wood species were completely degraded after 10 months of exposure. On the other hand, it became evident that Silvanolin prolonged the service life of wood exposed to the sea. The specimens impregnated with the lowest concentration of preservative solution (c_{Cu} = 0.31 %) were slightly decayed. The specimens, impregnated with higher concentrations of copper (c_{Cu} > 0.31 %), showed almost no defects after expsore to marine borers.*

***Keywords**: marine borers, Limnoria sp., Teredo sp., EN 275, cooper based preservative, Adriatic Sea*

SAŽETAK • *Primjena drva u morskoj vodi jedna je od najizazovnijih primjena drva. Impregnirano drvo izloženo je ispiranju te raznim morskim štetnicima, pri čemu su Limnoria sp. i Teredo sp. među najštetnijima. U radu je prikazano istraživanje trajnosti borova drva impregniranoga zaštitnom otopinom na bazi bakar-amina (Silvanolin) različitih koncentracija i izloženoga morskoj vodi prema normi EN 275. Izgled drva zaštićenog Silvanolinom uspoređen je s izgledom referentnoga drvnog materijala (Quercus sp., Castanea sativa, Larix decidue). Nakon 10 , 18 i 32 mjeseca izlaganja morskoj vodi, uzorci su izvađeni te ocijenjeni. Iz dobivenih se rezultata može jasno vidjeti da su uzorci referentnog drva nakon 10 mjeseci bili potpuno razgrađeni. Nasuprot tome, pokazalo se da Silvanolin produžuje vijek trajanja drva u moru. Uzorci impregnirani otopinom zaštitnog sredstva najmanje koncentracije (c_{Cu} = 0,31 %) blago su istrunuli. Uzorci impregnirani otopinom zaštitnog sredstva s većom koncentracijom bakra (c_{Cu} > 0,31 %) nisu pokazali gotovo nikakva oštećenja nakon izlaganja morskim štetnicima.*

***Ključne riječi:** morski štetnici, Limnoria sp., Teredo sp., EN 275, zaštitna sredstva na bazi bakra, Jadransko more*

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1 INTRODUCTION
1. UVOD

Wooden material is widely used in the sea due to its abundance that means renewable material, elastic properties, low production costs and easy plantation. Wood in sea water applications is exposed to a variety of physical factors and wood-decaying organisms. They use wood as food or as shelter. Besides erosion, wood in sea water applications is primarily endangered by *Teredo* sp., *Limnoria* sp. and Pholades (Sen *et al.,* 2010). These organisms cause failure of unprotected wood in rather short time between one and two years (Cragg, 1989; 1999; Westin *et al.*, 2004; Lesar and Humar, 2011). In order to protect wood against degrading organism in sea water applications, it must be impregnated with effective biocides. In the past, mainly chromated copper arsenate (CCA) or/and creosote was used for impregnation (Eaton and Hale, 1993). Double treatment (two-step impregnation process – the first step is impregnation with CCA according to the full cell process, dry CCA treated wood is impregnated with creosote according to the full or empty cell process) was the most effective (Wilkinson, 1979; Cragg, 1989). During the implementation of the Biocidal Products Directive (98/8/EC, 1998) in 2006, the use of chromium based wood preservatives was considerably limited or even banned in some EU countries. On the other hand, the use of creosote was only allowed in class 3 applications (2011/71/EU, 2011). In spite of legislation issues, copper based biocides still belong to the most important active ingredients in wood preservatives in Europe. The main reason for their wide use is a good ratio between efficacy and toxicity, and the fact that most of the competitive products have been banned. Therefore, copper is still allowed to be used in all classes, including use class 5 (sea water applications) (EN 335, 2006). In order to meet legislation requirements, chromium compounds in wood preservatives were replaced with amines, predominately ethanolamine. Unfortunately, fixation of copper-ethanolamine based wood preservatives is not as efficient as the fixation of copper-chromium ones (Humar *et al.*, 2001; Cooper and Ung, 2009). Additionally, public perception of the use of biocides is sometimes negative (Despot *et al.*, 2008). Therefore, biocidal solutions are replaced with biocide free alternatives like naturally durable wood species (Connell, 2004). The aim of this study was to elucidate the performance of copper-amine treated wood in the northern Adriatic Sea and compare it to the performance of naturally durable and reference wood species. There are few reports about the presence of marine borers in the Northern Adriatic. As wood is endangered by marine borers, wood has not been traditionally used for sea water applications. So, to the best of our knowledge, this is the first report regarding the performance of wood in sea water applications in Northern Adriatic.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Testing was performed according to the standard procedure described in the European Standard EN 275 (2004). The two goals of this experiment were: (1) to determine the performance of naturally durable and reference wood species; and (2) to determine the performance of wood impregnated with commercial copper-ethanolamine based aqueous solution (Silvanolin, Silvaprodukt) in sea water conditions (use class 5).

To determine the performance of naturally durable species, specimens (200 mm × 75 mm × 25 mm) made of European oak (*Quercus* sp.), European larch (*Larix decidua*) and sweet chestnut (*Castanea sativa*) heartwood were prepared. In parallel Scots pine (*Pinus sylvestris*) sapwood specimens of the same dimensions were prepared. They were vacuum-pressure impregnated according to the full cell procedure (30 min vacuum at 10 kPa; 3 h pressure at 900 kPa; 15 min vacuum at 20 kPa) with copper-ethanolamine solution of five different concentrations (Table 1). Commercial solutions consisting of copper hydroxide-carbonate, ethanolamine, quaternary ammonium compound, boric acid and octanoic acid were used. Detailed composition of preservative solution is available in the patent of Humar and Pohleven (2008). Ratios between all active ingredients were the same in all treating solutions, only the concentration varied. For comparison, specimens were impregnated with reference copper and chromium based solution, as prescribed by the standard EN 275 (2004). For each treatment/wood species, 10 specimens were prepared. After impregnation, the uptake of preservative solution was determined gravimetrically. Retention was determined through comparison of the oven dry masses before and after impregnation. Retention shows the quantity of wood preservatives introduced into wood, excluding water.

After a month of conditioning at temperature of 20 °C and 70 % relative humidity, specimens were mounted to a specially designed stand and exposed to seawater in the Port of Koper, Slovenia, at the depth of 6 m. The average sea temperature in Koper is 15.8 °C, minimum temperature in February is 8 °C, and maximum in August is 24 °C. The average salinity is between 37 ‰ and 38 ‰, and can reach 35 ‰ in summer (Rejec Brancelj, 2011). Impregnated pine wood specimens together with respective controls (non-impregnated pine wood specimens) were exposed to seawater on Oct. 10, 2009. The assessment of the specimens was performed after 18 months and 32 months. Naturally, durable and reference specimens were exposed on June 22, 2011 and assessed after 10 months of exposure. Scots pine wood specimens were used as control for both experiments. Natural durable specimens were exposed in the second step, due to limited space in test rack. As they were exposed almost throughout the whole year, the time of exposure should not have a significant impact on the performance.

The assessment was performed visually. First, surfaces of the specimens were mechanically cleaned of algae and other fouling organisms. Then specimens were split with a band-saw, and the presence of bore holes in the interior of the specimens was visually examined and valuated with marks: 0 (no destruction), 1 (little destruction), 2 (moderate destruction), 3 (violent destruction) and 4 (severe damage, tunnels cover more than 50 % of the specimens surface), according to the standard EN 275. The assessment was performed separately for *Limnoria* sp. and separately for *Teredo* sp. damages. The standard EN 275 prescribes the assessment to be performed by X-ray scanning. As there was no such device available in the offshore territory of the Port of Koper, destructive testing was performed. Therefore, more specimens were exposed in parallel, enabling destructive evaluation. The evaluated specimens were destroyed, while parallel specimens remained in the sea for further testing.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

In the present research, Scots pine sapwood was used for impregnation with copper based wood preservatives. Pine sapwood is very easy to impregnate (EN 350-1, 1994), which can be seen in high uptakes of preservative solutions. All impregnated specimens retained between 421 kg/m^3 (Silvanolin E) and 453 kg/m^3 (Copper-chromium based solution) of preservative solutions (Table 1), indicating that specimens were completely impregnated with wood preservatives. Differences between preservatives were insignificant (Table 1). As expected, more prominent differences were observed with retention. The ratio between the lowest and the highest retention was 1:13. Furthermore, retention data clearly indicates that even the preservative solution of the highest concentration was able to penetrate the wood to the same depth as the preservative solution of the lowest concentration.

All specimens were completely overgrown with different fouling organisms like algae and mussels, after 18 months of exposure (Figure 1). This clearly indicates the biodiversity of the northern part of the Adriatic Sea. After short-term exposure, the interior of all control specimens were completely destroyed, and on the other hand, the surface (outer 1 mm to 2 mm shell) of the specimens remained almost intact. Detailed analysis of the damages revealed that boreholes were made by *Teredo* sp. as well as by *Limnoria* sp. Similar damages of untreated Scots pine were determined after exposure in the North Sea (Westin *et al*., 2004; Larsson-Brelid and Westin, 2010), Mediterranean Sea in Turkey (Sen *et al.,* 2010) and southern Portuguese coast (Williams *et al*., 2007). This comparison revealed that the chosen field test site (Port Koper) is biologically active. According to the statements of Kiersgaard (2011), *Limnoria* and *Teredo* species prefer warmer locations, meaning that the Adriatic Sea should offer better conditions than the North Sea. However, it should be taken into consideration that these tests are preliminary, and therefore huge variations are possible depending on years of exposure. Other factors affecting the development of *Teredo* and *Limnoria* are salinity and temperature. In rainy and cold weather, the development of *Teredo* species is considerably slowed down, as severe late summer and autumn rainfalls reduce the salinity of the water.

Next to the pine sapwood specimens, specimens of heartwood of naturally durable and reference wood species were exposed. Sapwood of Scots pine was completely deteriorated after 10 months of exposure. Similar to pine sapwood, non-treated specimens of heartwood of European oak, sweet chestnut and European larch were completely deteriorated as well (Table 2, Figure 2). Damages caused by *Teredo* sp. were more frequent and more visible than damages caused by *Limnoria* sp. This result clearly indicates that domestic wood species from central Europe, despite their good natural durability, do not offer sufficient resistance against marine boring organisms (when used in class 5 applications without good biocidal protection). Data from the literature reveal that conditions for wood in sea water applications in the northern part of the Adriatic Sea are even more severe than the ones in the southern Mediterranean. For example, Sen and coworkers (2010) reported that oak and sweet chestnut perform better than pine sapwood in the Turkish part of

Table 1 Composition, uptake and retention of preservative solutions
Tablica 1. Sastav, upijanje i zadržavanje otopine zaštitnog sredstva

Preservative solution *Otopina zaštitnog sredstva*	**c_{Cu} in preservative solution** *Koncentracija bakra u zaštitnom sredstvu* %	**Uptake of preservative solution** *Upijanje otopine zaštitnog sredstva* kg/m^3	**Retention** *Zadržavanje* kg/m^3
CC 1	1.2	453	5.4
CC 5	5.0	442	22.1
Silvanolin A	0.31	447	19.0
Silvanolin B	0.625	436	37.0
Silvanolin C	1.25	437	74.1
Silvanolin D	2.5	427	144.8
Silvanolin E	4.0	421	230.1

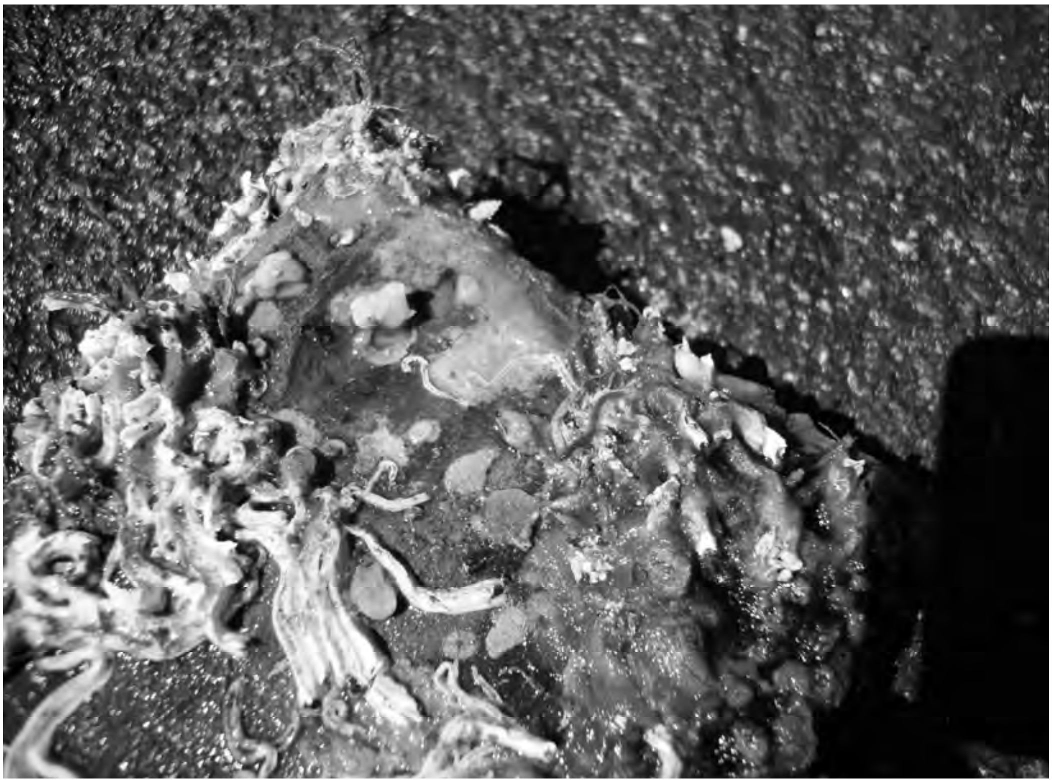

Figure 1 Visual appearance of specimens after 10 weeks of exposure in Adriatic Sea
Slika 1. Izgled uzoraka nakon 10 dana izlaganja u Jadranskome moru

the Mediterranean Sea, and do not deteriorate as fast as in the Port of Koper.

Contrary to naturally durable wood species, Silvanolin treated wood performed much better, if sufficient retention has been applied. After 18 months of testing, there were no signs of damage in wood that retained at least 37 kg/m^3 of Silvanolin compounds (Silvanolin B; c_{Cu} = 0,625 %). On the other hand, 18 months was sufficient to see the first signs of deterioration in wood containing 19 kg/m^3 of copper-amine compounds (Silvanolin A; c_{Cu} = 0.31 %) (Figure 3). This deterioration continues, and after 32 months, this wood was almost completely degraded (Table 3). However, retention of 37 kg/m^3 of Silvanolin B was insufficient to prevent degradation for 32 months, as the first signs of degradation were noted. Therefore, higher concentrations have to be used to ensure proper protection against marine borers. The majority of the damage on copper treated wood was caused by *Teredo* sp. These results indirectly proved that copper remained in wood even after 32 months of exposure. During 18 months of exposure, control-scots pine wood specimens were completely deteriorated as well. This indicates the susceptibility of the material to and presence of active marine borers.

Reference material (CC1 and CC 5), impregnated with copper-chromium based solutions was protected at both reference concentrations (Table 3). Similar results are reported by Westin and co-workers (2004). They reported that the life cycle of specimens, impregnated with CCA target retention of 4 kg/m^3, is around 3.2 years, while specimens retaining 18 kg/m^3 of CCA

Table 2 Performance of different untreated wood species exposed to seawater for 10 months in the Port of Koper according to the EN 275 standard (2004)
Tablica 2. Ocjena izgleda različito zaštićenih uzoraka drva nakon 10 mjeseci izlaganja morskoj vodi u luci Koper; prema normi EN 275 (2004)

Wood species *Vrsta drva*	**Mean rating of deterioration after 10 months of exposure** *Srednja ocjena propadanja uzoraka nakon 10 mjeseci izlaganja*		
	Teredo	***Limnoria***	**Total /** *ukupno*
Pinus sylvestris (softwood)	4	1.6	4
Larix decidua (heartwood)	4	3.8	4
Castanea sativa (heartwood)	3.75	3.1	4
Quercus sp. (heartwood)	4	4	4

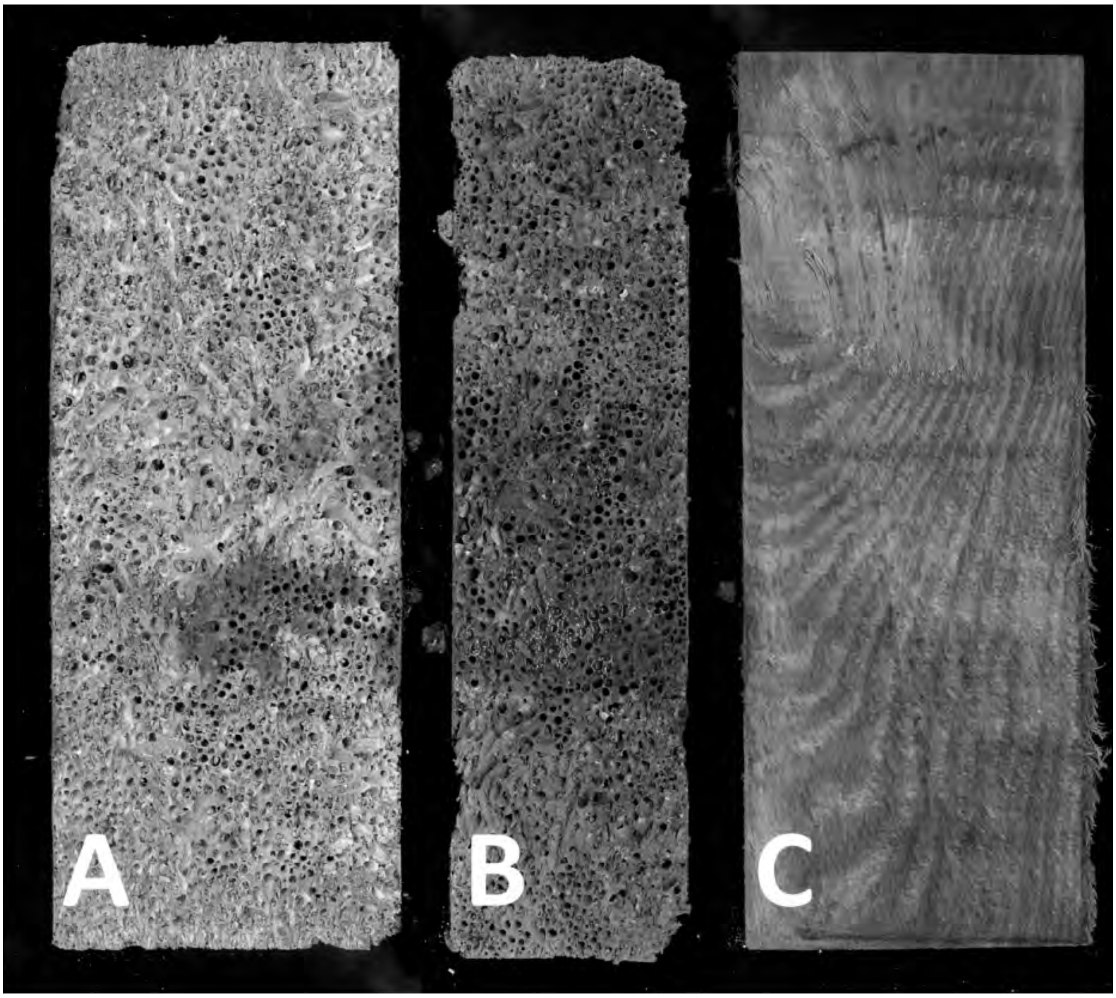

Figure 2 Cross-sections of specimens exposed in the Port of Koper: (A) untreated Scots pine sapwood and (B) untreated sweet chestnut heartwood exposed for 10 months; (C) Scots pine sapwood impregnated with Silvanolin C (c_{Cu} = 1.25 %) exposed for 32 months
Slika 2. Poprečni presjek uzoraka izlaganih u luci Koper: (A) nezaštićeno drvo bjeljike bora i (B) nezaštićeno drvo srži kestena nakon 10 mjeseci izlaganja; (C) drvo bjeljike bora impregnirano Silvanolinom C (c_{Cu} = 1,25 %) nakon 32 mjeseca izlaganja morskoj vodi

Table 3 Decay of Scots pine sapwood impregnated with commercial copper-ethanolamine solutions of different concentrations, after 18 months and 32 months of exposure in seawater of the Port of Koper, determined according to EN 275 (2004)
Tablica 3. Propadanje drva bjeljike bora impregniranoga komercijalnom otopinom bakar-etanolamina različitih koncentracija, nakon 18 mjeseci i 32 mjeseca izlaganja utjecaju morske vode u luci Koper; sukladno normi EN 275 (2004)

Preservative solution *Otopina zaštitnog sredstva*	**c_{Cu} in preservative solution** *Koncentracija bakra u zaštitnom sredstvu* %	**Mean rating of deterioration after 18 months of exposure** *Srednja ocjena propadanja uzoraka nakon 18 mjeseci izlaganja*			**Mean rating of deterioration after 32 months of exposure** *Srednja ocjena propadanja uzoraka nakon 32 mjeseca izlaganja*		
		Teredo	***Limnoria***	**Total** *Ukupno*	***Teredo***	***Limnoria***	**Total** *Ukupno*
Control	0	4	1.6	4	/	/	/
CC	1.2	0	0	0	0	0	0
CC	5	0	0	0	0	0	0
Silvanolin A	0.31	2	0.7	2	3	0.5	3
Silvanolin B	0.625	0	0	0	1	0	1
Silvanolin C	1.25	0	0	0	0	0	0
Silvanolin D	2.5	0	0	0	0	0	0
Silvanolin E	4	0	0	0	0	0	0

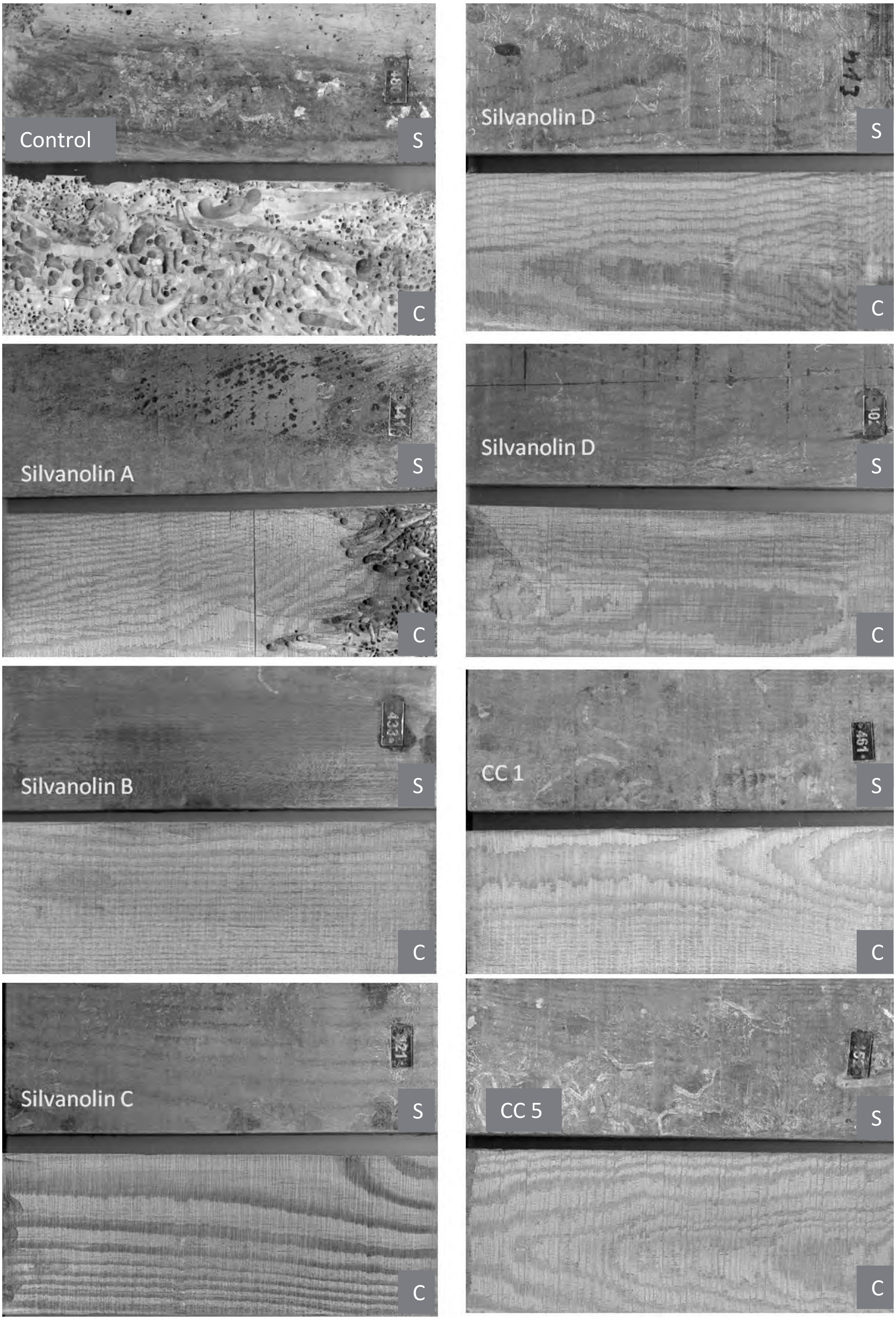

Figure 3 Surface (*S*) and Cross-sections (*C*) of copper treated specimens exposed in the Port of Koper, Slovenia for 18 months
Slika 3. Površina (*S*) i poprečni presjeci (*C*) uzoraka zaštićenih bakrom nakon 18 mjeseci izlaganja u luci Koper, Slovenija

remained health even after 10 years of exposure in the North Sea.

If these results are compared to outdoor applications (use class 3 and 4), it is evident that almost ten to twenty times higher retentions are required in use class 5. For example field testing studies clearly showed that retention of 4 kg/m^3 of Silvanolin (Silvanolin A) was enough to ensure the service life of at least 7 years in above ground applications (Humar and Thaler, 2012).

4 CONCLUSIONS
4. ZAKLJUČCI

Wood in the northern Adriatic Sea is endangered by marine borers. Untreated controls of Scots pine sapwood and naturally durable heartwood of European oak, European larch and sweet chestnut were completely degraded in 10 months of exposure. On the other hand, impregnation of wood with copper-ethanolamine solution ensures good protection against marine borers if sufficient concentrations are applied.

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Analiza stanja tvrtki u proizvodnji namještaja u Republici Hrvatskoj

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SAŽETAK • *Proizvodnja namještaja oduvijek je bila važan segment gospodarstva Republike Hrvatske. Da bi se potencijali hrvatske industrije namještaja što bolje iskoristilite da bi se potrebne promjene mogle provesti na odgovarajući način, prethodno je važno utvrditi početno/trenutačno stanje tvrtki. Zbog navedenoga, cilj rada bio je analizirati opće, proizvodne, tehnološke, marketinške i tržišne segmente u hrvatskim tvrtkama za proizvodnju namještaja.Istraživanje je provedeno na području Republike Hrvatske, u tvrtkama kojima je proizvodnja namještaja glavna djelatnost poslovanja. Od 409 potencijalnih ispitanika u istraživanju je sudjelovalo njih 77. Analiza je pokazala kako je stanje u hrvatskim tvrtkama za proizvodnju namještaja na zadovoljavajućoj razini, iako je uvijek potrebno težiti što je moguće boljim općim i proizvodnim, tehnološkim, marketinškim i tržišnim aktivnostima.*

Ključne riječi: *proizvodnja namještaja, analiza stanja, proizvodne operacije i tehnologija, marketing, tržište*

ABSTRACT • *Furniture manufacturing has always been a very important segment of the Croatian economy. In order to achieve better results of Croatian furniture industry potentials and to make appropriate and adequate changes, it is necessary to determinate the initial/current state of the company. The aim of this study was to analyze the general, production, technological, marketing and market segments in Croatian furniture industry companies. The study was conducted in Croatia in companies where furniture manufacturing is the main business activity. The analysis involved 77 out of 409 potential respondents. The analysis showed that the situation in Croatian furniture manufacturing companies is at a satisfactory level, although it is always necessary to seek, as much as it is possible, better company activates.*

Key words: *furniture manufacturing, analysis, production operations and technology, marketing, market*

1. UVOD
1 INTRODUCTION

Proizvodnja namještaja oduvijek je bila važan segment gospodarstva Republike Hrvatske. Svoju proizvodnju uvelike temelji na iskorištavanju domaćih prirodnih resursa i na dugogodišnjoj tradiciji prerade drva. Da bi se navedeni potencijali iskoristili te se odgovorilo na ključne izazove kao što je konkurentnost, iznimno je važnan strateški razvoj drvne industrije, u užem smislu industrije namještaja, što znači i svake, pa i najmanje njezine tvrtke. Međutim, u trenutku globalizacije, kada se u svijetu pojavljuju nove mogućnosti tehnološkog razvoja te se pronalaze novi

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modeli, tehnike i organizacija upravljanja, drvna industrija, a time i industrija namještaja, jednim dijelom počinje bivati krajnje osiromašena, tehnološki zastarjela i programski i marketinški nedorečena djelatnost (Motik i dr., 2002.), što upućuje na potrebne promjene u smislu primjena novih tehnologija, novih proizvoda, novih načina poslovanja, boljeg obrazovanja i znanja ali i bolje međusobne povezanosti istraživačkih institucija i tvrtki (Berginc i dr., 2011.). No navedene potrebne aktivnosti vrlo je bitno pravilno i dobro usmjeriti. Prema istraživanjima (Pirc i dr., 2010; Motik i dr., 2012), iz godine se u godinu povećavavrijednost prihoda namještaja (uz iznimku 2009. godine, kad je vrijednost prihoda namještaja bila manja nego na prethodnoj, 2008.), što je pozitivan pokazatelj razvoja hrvatske industrije namještaja, ali ostvareni prihodi još nisu na razini kojom bi se zadovoljili svi tržišni zahtjevi (Kitek Kuzman i dr., 2012; Jelačić i dr., 2012.) kao niti investicijska aktivnost (Ojurović i dr., 2013). To potvrđuje i odnos vrijednosti proizvodnje i potrošnje. Jednako tako, istraživanja pokazuju i ovo: uvoz namještaja iz ostalih europskih i svjetskih zemalja u Republiku Hrvatsku prilično je velik te u području industrije namještaja u posljednjem desetljeću vrijednosti uvoza premašuju vrijednosti izvoza (uz iznimku 2010. i 2011. godine) (Pirc i dr., 2012).

Kako bi se potrebne promjene mogle i provesti na što je moguće bolji i primjereniji način, prethodno je potrebno utvrditi početno/trenutačno stanje tvrtki (Paluš i Šupin, 2004). Stoga je, cilj ovog rada bio analizirati opće, proizvodne, tehnološke, marketinške i tržišne segmente u hrvatskim tvrtkama za proizvodnju namještaja.

2. MATERIJALI I METODE
2 MATERIALS AND METHODS

Metoda prikupljanja podataka za ovaj rad bio je anketni upitnik. Anketni je upitnik odabran zato što su troškovi tog načina prikupljanja podataka financijski prihvatljivi (Dillman, 2000),a ta metoda omogućuje prikupljanje podataka sa šireg geografskog prostora (Zahs i Baker, 2007). Uzorak za prikupljanje podataka preuzet je iz Registra poslovnih subjekata Hrvatske gospodarske komore. Uzorak je činilo 409 poslovnih subjekata razvrstanih prema djelatnosti na temelju Nacionalne klasifikacije djelatnosti NKD 2007, NN 58/2007. Prema NKD-u 2007, istraživani poslovni subjekti pripadaju području C – *Prerađivačka industrija*, odjeljku 31 – *Proizvodnja namještaja*, s pripadajućim razredima 31.01 – *Proizvodnja namještaja za poslovne i prodajne prostore*, 31.02 – *Proizvodnja kuhinjskog namještaja* i 31.03 – *Proizvodnja madraca* i 31.09 – *Proizvodnja ostalog namještaj,* a ti poslovni subjekti svoju glavnu djelatnost poslovanja obavljaju na području C 31 – *Proizvodnja namještaja*. Nadalje, jedinice promatranja bila su trgovačka društva (društva s ograničenom odgovornošću i dionička društva).

Anketni upitnik razvijen je na temelju prethodno definiranih ciljeva istraživanja, s namjerom dobivanja informacija o hrvatskim tvrtkama za proizvodnju namještaja. Sadržavao je i pitanja o općim informacijama potencijalnih ispitanika/poslovnih subjekata, dok su pojedina pitanja definirana u obliku da/ne tvrdnji ili uz pomoć višestrukih tvrdnji, jer je ustanovljeno kako će se određena pitanja bolje opisati primjenom višestrukih tvrdnji, a ne samo jednom jedinom (Thorndike, 1967; Churchill, 1979; Lewis-Beck i dr., 2004). Nadalje, određene su tvrdnjeocjenjene su primjenom Likertove ljestvice od pet stupnjeva (*Five-point Likert scale*) tako da su uz pojedine tvrdnje bili navedeni rasponi od 1 do 5, pri čemu 1 označava 'nikako se ne slažem' ili 'nevažno', a 5 označava 'potpuno se slažem' ili 'vrlo važno', tj. ispitanici su određivali stupanj zadovoljstva ili značenja koji pridaju pojedinim tvrdnjama. Nacrt anketnog upitnika testiran je na pet slučajno odabranih poslovnih subjekata. U provođenju prikupljanja podataka, što je više bilo moguće, primjenjivana je Dillmanova (2000) metoda prikupljanja podataka poštom putem anketnog upitnika.

Od svih 409 anketnih upitnika poslanih na adrese potencijalnih ispitanika, 91 anketni upitnik izuzet je iz istraživanja zbog ovih razloga: upitnik nije bilo moguće dostaviti na definirane adrese, poslovni subjekt više ne obavlja djelatnost na području C 31 ili poslovni subjekti nisu bili zainteresirani za istraživanje. Ukupan broj vraćenih pravilno ispunjenih anketnih upitnika čiji su podaci korišteni u daljnjoj analizi iznosio je 77, odnosno konačni je odaziv ispitanika bio 24,2 %. Analiza podataka provedena je primjenom programa *MS Ecxel* za Windows platforme.

3. REZULTATI I RASPRAVA
3 RESULTS AND DISCUSSION

Najmlađi poslovni subjekt za proizvodnju namještaja osnovan je 2008., a najstariji davne 1927 godine. Prosječna starost poslovnog subjekta svih 77 ispitanika iznosila je 14,1 godinu. Od 77 ispitanika 82 % izjasnilo se kako je direktor osoba koja poslovni subjekt prema trećim osobama, u svim poslovima u zemlji i inozemstvu, zastupa pojedinačno i samostalno. Nadalje, 11,5 % ispitanika izjavilo je kako je to predsjednik uprave poslovnog subjekta, dok se njih 6,5 % izjasnilo kako je to jedan od članova uprave.

3.1. Obilježja tvrtki za proizvodnju namještaja
3.1 Features of furniture manufacturing companies

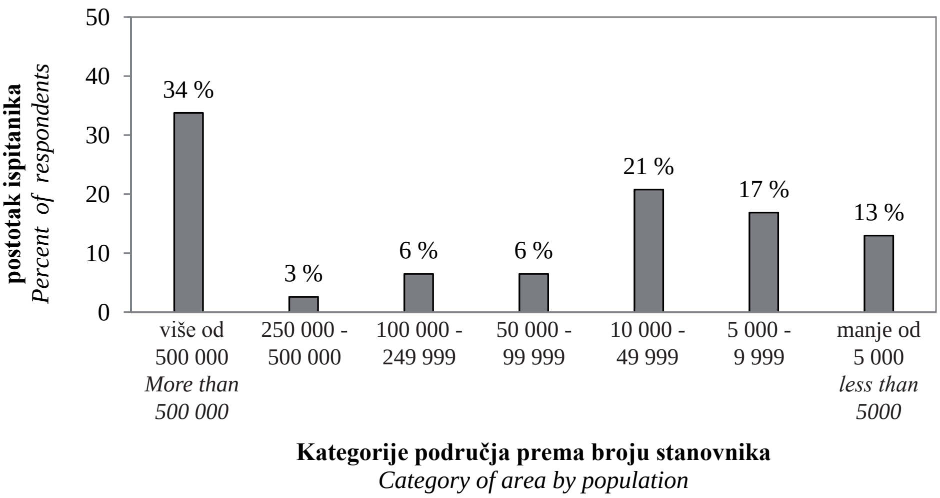
Prema Nacionalnoj klasifikaciji prostornih jedinica za statistiku (NKPJS) iz 2007. godine (NN 35/2007), županije Republike Hrvatske moguće je svrstati u tri regije: Središnja i Istočna Hrvatska, Sjeverozapadna Hrvatska i Jadranska Hrvatska. Stoga su sjedišta poslovnih subjekta za proizvodnju namještaja razvrstana prema trima prethodno navedenim regijama. Najviše poslovnih subjekata proizvođača namještaja, 57 % od 77 ispitanika, pripada regiji Sjeverozapadne Hrvatske, 27,4 % nalazi se na području Središnje i Istočne Hrvatske, dok je najmanje proizvođača namještaja ili 15,6 % njih smješteno na području Jadranske Hrvatske. Na pitanje o lokaciji sjedišta tvrtke, pri čemu se lokacija promatra na razini županije, 34 % ispitanika navodi grad Zagreb kao mjesto sjedišta tvrtke, 12 % ispitanika za sjedište svoje tvrtke naznačilo je Zagrebačku županiju, a 8 % ispitanika Međimursku županiju. Nadalje, po 6 % ispitanika kao sjedište svoje tvrtke navodi Osječko-baranjsku i Primorsko-goransku županiju, a 5 % ispitanika Splitsko-dalmatinsku županiju. U Brodsko-posavskoj, Karlovačkoj, Krapinsko-zagorskoj, Požeško-slavonskoj i Virovitičko-podravskoj županiji nalazi se sjedište 4 % ispitanika, u Bjelovarsko-bilogorskoj, Istarskoj i Varaždinskoj županiji sjedište ima 3 % ispitanika, dok 1 % ispitanika kao sjedište svoje tvrtke navodi Zadarsku županiju. Nijedan od 77 ispitanika kao sjedište svoje tvrtke ne navodi Dubrovačko-neretvansku, Koprivničko-križevačku, Ličko-senjsku, Sisačko-moslavačku ni Vukovarsko-srijemsku župa-niju. Osim po županijama, od ispitanika se tražilo da definiraju područje s obzirom na broj stanovnika mjesta u kojemu je sjedište njihove tvrtke. Kao što je vidljivo iz slike 1, najviše ispitanika, njih 34 %, izjasnilo se kako se sjedište njihove tvrtke nalazi na području s više od 500 000 stanovnika, dok se najmanje ispitanika, 3 %, izjasnilo kako se sjedište njihove tvrtke nalazi na području na kojemu živi između 250 000 i 500 000 stanovnika. S druge strane, više od 51 % ispitanika izjasnilo se kako su sjedišta njihovih tvrtki smještena na području gdje živi 49 999 stanovnika i manje. Dvanaest posto ispitanika ističe kao je njihovo sjedište smješteno na području na kojemu živi između 50 000 i 249 999 stanovnika.

Od 76 ispitanika 96 % izjasnilo se kako je njihov poslovni subjekt u potpunosti u hrvatskom vlasništvu, dok se samo 3 % ispitanika izjasnilo kako je njihov poslovni subjekt u potpunosti u stranom vlasništvu. Još manje, samo 1 % ispitanika navodi kako njihova tvrtka u većini pripada stranom vlasniku, tj. 51 % vlasništva tvrtke i više u stranom je vlasništvu, a 49 % i manje u hrvatskom vlasništvu. Nijedan od 76 ispitanika ne navodi da je njihov poslovni subjekt djelomično u hrvatskom vlasništvu (51 % vlasništva tvrtke i više u hrvatskom je vlasništvu, a 49 % i manje u stranom vlasništvu).

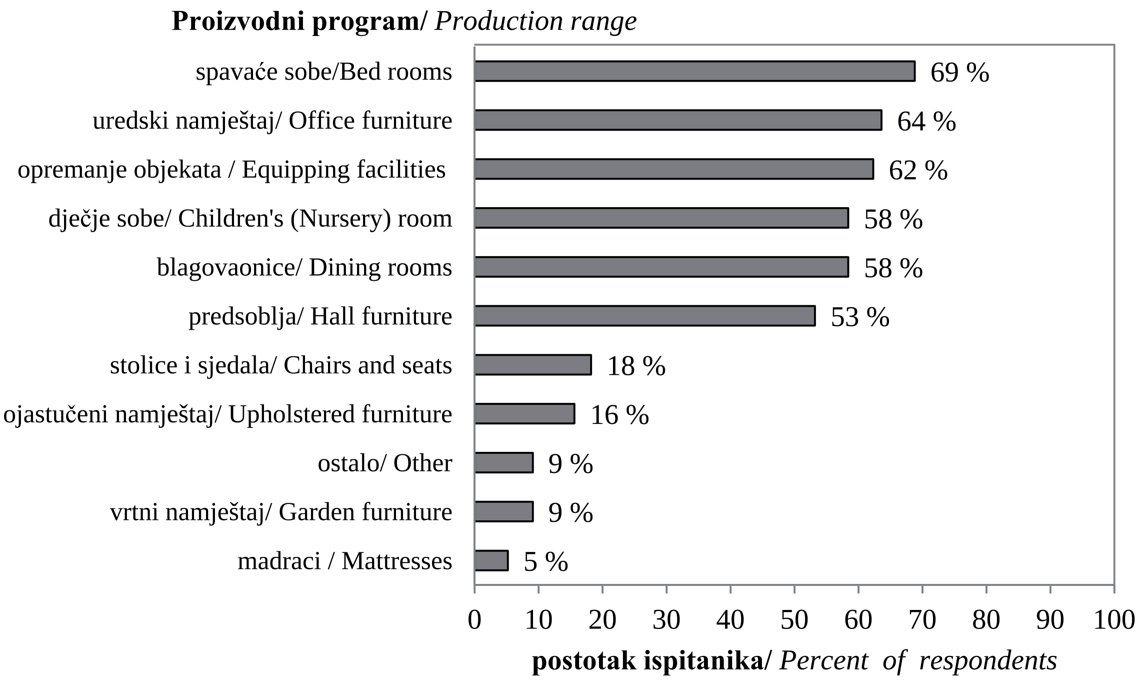
Na pitanje o proizvodnom programu (sl.2), više od 60 % ispitanika kao svoj proizvodni program navodi spavaće sobe, uredski namještaj te opremanje objekata namještajem. Proizvodnja dječjih soba, blagovaonica i predsoblja glavna je aktivnost više od 50 % ispitanika. Osamnaest posto ispitanika kao svoj proizvodni program navodi proizvodnju stolaca i sjedala, a 16 % proizvodi ojastučeni namještaj. Najmanje ispitanika proizvodi vrtni namještaj (9 %) i madrace (5 %). Jednako tako, 9 % ispitanika navodi kako ne pripada nijednoj od navedenih kategorija i odabire kategoriju ostalo, premda nijedan od ispitanika nije naveo što čini njihov ostali proizvodni program.

Odgovori na pitanje o broju i strukturi zaposlenika pokazali su kako više od polovine ispitanika, točnije 57 % od 77 ispitanika, u svojim tvrtkama za proizvodnju namještaja zapošljava do deset osoba, 16 % ispitanika zapošljava od 11 do 25 osoba, dok 4 % ispitanika zapošljava od 26 do 50 zaposlenika. Šest posto ispitanika zapošljava između 51 i 100 osoba, dok njih 10 % zapošljava između 101 i 250 osoba. Da zapošljava više od 250 osoba izjasnilo se 6 % ispitanika. Razmatrajući spolnu strukturu ukupnog broja zaposlenih osoba na temelju 77 upitnika, 80 % ukupno zaposlenih su muškarci, a samo 20 % žene.

Nadalje, ispitanike se tražilo da se izjasne o dobnoj i obrazovnoj strukturi svojih zaposlenika. Obje su te odrednice podijeljene na pet kategorija (tabl.1). Na pitanje o starosnoj strukturi zaposlenika odgovorilo je 75 ispitanika. Ispitanici navode kako ukupnu strukturu zaposlenika u njihovim tvrtkama u najvećoj mjeri, 65 %, čine osobe do 40 godina života. Od ukupnog broja zaposlenika u prosjeku 27 % čine osobe mlađe od 30



Slika 1. Sjedišta proizvođača namještaja prema područjima i broju stanovnika (n = 77)
Figure 1 Furniture manufacturer headquarters by regions according to population (n=77)



Slika 2. Proizvodni program proizvođača namještaja (*n*=77) (mogućnost višestrukog odgovora)
Figure 2 Furniture manufacturer production range (*n*=77) (multiple responses possible)

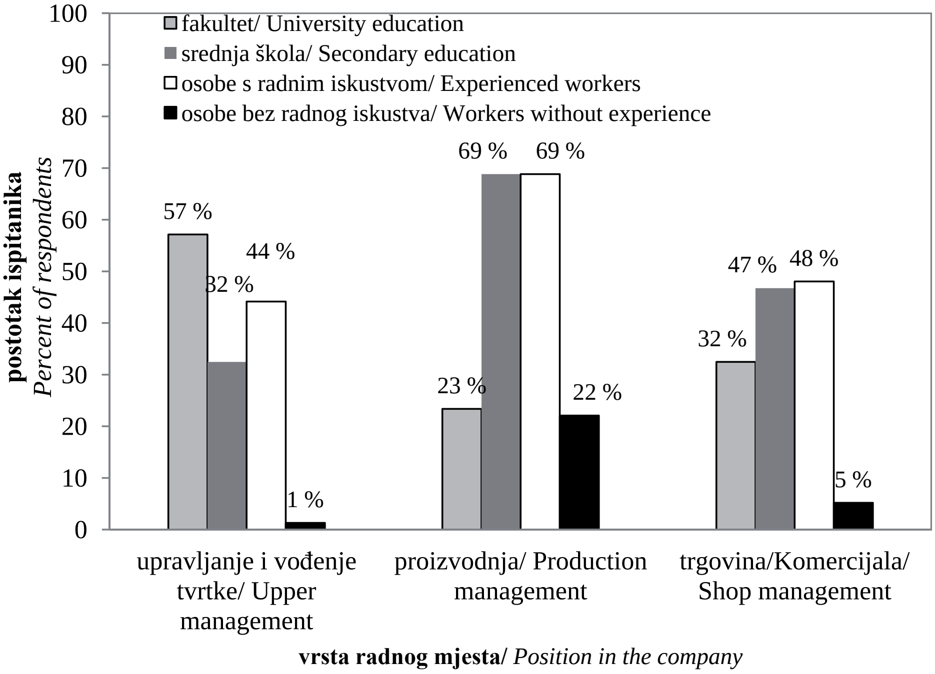
godina, prosječno 12 % čine osobe između 51 i 61 godine, dok samo 1 % ukupnog broja zaposlenika čine starije osobe, osobe gotovo na kraju svog radnog vijeka, tj. osobe starije od 61 godinu.

Na pitanje o obrazovnoj strukturi zaposlenika 76 ispitanika navodi kako u ukupnoj obrazovnoj strukturi osoba zaposlenih u njihovim tvrtkama u prosjeku najviše, odnosno 71 % čine osobe srednje stručne spreme. Dvanaest posto ispitanika u prosjeku zapošljava osobe visoke stručne spreme, dok 11 % njih zapošljava niskokvalificirane osobe. Nadalje, 6 % ukupno zaposlenog osoblja čine osobe koje prema kategoriji obrazovanja pripadaju onima s višom stručnom spremom, dok samo 1 % ukupnog broja zaposlenih osoba čine magistri i/ili doktori znanosti.

Kao što je vidljivo na slici,3,57 % ispitanika izjasnilo se da će na radno mjesto upravitelja i voditelja svoga poslovnog subjekta zaposliti osobu sa završenim fakultetskim obrazovanjem, 44 % ispitanika navodi kako će na to radno mjesto zaposliti osobu s prethodnim radnim iskustvom, 32 % ispitanika na navedeno će radno mjesto zaposliti osobu srednjoškolskog obrazovanja, a samo će 1 % ispitanika upravljanje i viđenje svoje tvrtke prepustiti osobi bez radnog iskustva. Isti postotak ispitanika, 69 % od njih 77, navodi kako će u proizvodnim odjelima svoje tvrtke zaposliti osobe

Tablica 1. Dobna i obrazovna struktura u tvrtkama za proizvodnju namještaja
Table 1 Age and education structure in furniture manufacturing companies

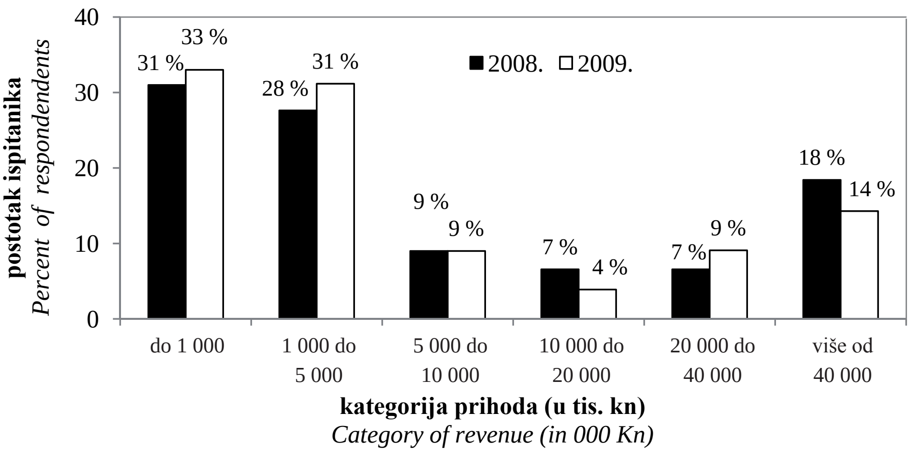
Kategorije starosne dobi (godina) *Age categories (years)*	**Srednja vrijednost postotka ispitanika (n=75)** *Mean of percent of respondents (n=75)*	**Kategorije obrazovanja** *Education categories*	**Srednja vrijednost postotka ispitanika (n=76)** *Mean of percent of respondents (n=76)*
20 do 30 *20 to 30*	27	niskokvalificirani radnik (NKV) *Low-skilled employee*	11
31 do 40 *31 to 40*	38	srednja stručna sprema (SSS) *Secondary education (medium expertise)*	70
41 do 50 *41 to 50*	22	viša stručna sprema (VŠS) *Higher education*	6
51 do 60 *51 to 60*	12	visoka sprema (VSS) *High education*	12
Više od 60 *More than 60*	1	Magisterij i doktorat *Master's and doctoral degree*	1



Slika 3. Izvori zaposlenika za određena radna mjesta u tvrtki (*n* = 77) (mogućnost višestrukog odgovora)
Figure 3 Source of employees for different categories of position in a company (*n*=77) (multiple responses possible)

srednjoškolskog obrazovanja i osobe s radnim iskustvom. Nadalje, gotovo jednak postotak ispitanika navodi kako će na to radno mjesto zaposliti osobe sa završenim fakultetskim obrazovanjem (23 %) te osobe bez radnog iskustva (22 %). Jednako su se tako i u trgovini i/ili komercijalnom odjelu ispitanici izjasnili kako će najradije zapošljavati osobe sa završenom srednjom školom (47 %) te osobe s radnim iskustvom (48 %). Iza navedenih kategorija zaposlenika, slijede odgovori ispitanika koji će na radno mjesto trgovaca i/ili komercijalista zapošljavati osobe sa završenim fakultetskim obrazovanjem (32 % ispitanika od 77) i, na kraju, vrlo mali broj osoba bez radnog iskustva (samo 5 % od 77 ispitanika).

Prema rezultatima sa slike, 4,59 % ispitanika navodi kako su u 2008. ukupni prihodi njihovih tvrtki za proizvodnju namještaja iznosili do 5 000 000 kn. Od 5 000 000 do 40 000 000 kn ukupnog prihoda ostvarilo je 23 % tvrtki, dok 18 % ispitanika navodi kako su njihove tvrtke u 2008. ostvarile više od 40 000 000 kn ukupnog prihoda. U odnosu prema 2008., 64 % ispitanika navodi kako su ukupni prihodi ostvareni u njihovim tvrtkama u 2009. iznosili do 5 000 000 kn. Isto kao i u prethodnoj godini, 9 % ispitanika izjasnilo se kako je njihov ukupni ostvareni prihod u 2009. iznosio između 5 000 000 i 10 000 000 kn. Četiri posto ispitanika ostvarilo je prihod između 10 000 000 i 20 000 000 kn, 9 % između 20 000 000 i 40 000 000 kn, a 14 % ispitanika navodi kako su u svojim tvrtkama

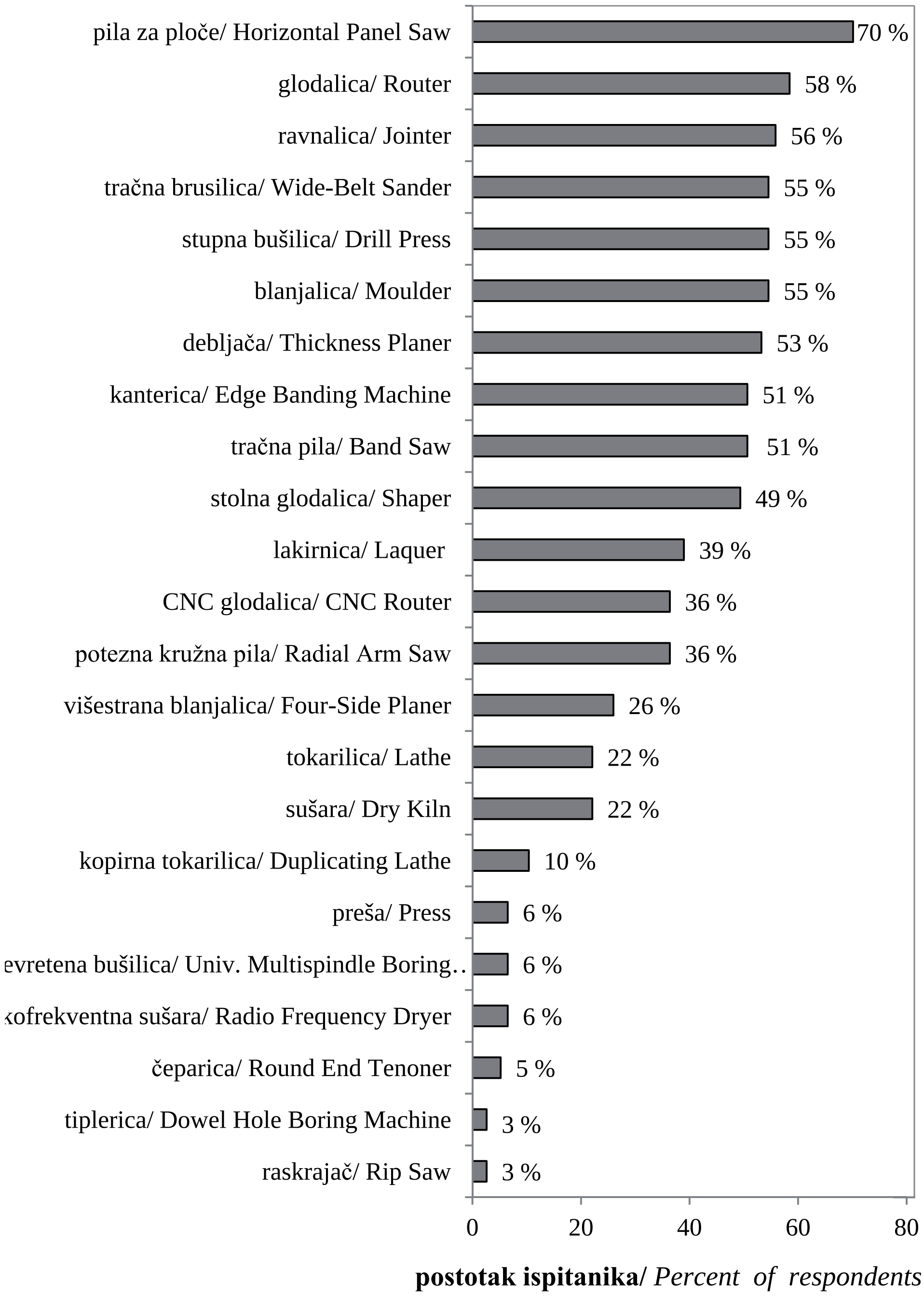


Slika 4. Ukupni prihodi tvrtki za proizvodnju namještaja u 2008. (*n* = 76) i 2009. godini (*n* = 77)
Figure 4 Total revenue of furniture manufacturing companies in 2008 (*n*=76) and 2009 (*n*=77)

u 2009. ostvarili ukupni godišnji prihod viši od 40 000 000 kn.

Razmatrajući udio prihoda ostvarenih prodajom namještaja u ukupnim prihodima 74 tvrtke, uočava se da je minimalni udio prihoda ostvarenih prodajom namještaja u ukupnim prihodima tvrtki iznosio 1 %, a najveći 100 %, tj. prihod ostvaren prodajom namještaja bio je jednak ukupnom prihodu tvrtke. Nadalje, u 2008. prosječan je udio prihoda ostvarenih prodajom namještaja u ukupnom prihodu tvrtke iznosio 67,8 %. U 2009. prosječan je udio prihoda ostvaren proizvodnjom namještaja u ukupnom prihodu tvrtki 75 ispitanika iznosio 68,9 %, s najnižim udjelom od 1 % i najvišim od 100 %. U 2008. Prosječan je postotak prihoda ostvarenih prodajom novih proizvoda u 66 istraživanih tvrtki u ukupnom ostvarenom prihodu iznosio 36,7 %, dok je navedeni postotak u idućoj godini, na temelju 67 ispitanika, iznosio 38,4 %.

Međutim, razmatrajući prihod koji tvrtke ostvaruju izvozom svojih proizvoda, proizlazi da više od 50 % ispitanika (54 % za 2008. i 60 % za 2009. g.) uopće ne izvoze proizvode na inozemno tržište, dok 13 % (u 2008.g.), odnosno 9 % (u 2009. g.) njih navodi kako manje od 5 % prihoda ostvaruje izvozom. Samo 7 % (u 2008.g.),



Slika 5. Strojevi korišteni u procesima proizvodnje u tvrtkama za proizvodnju namještaja (n = 77) (mogućnost višestrukog odgovora)
Figure 5 Equipment used in manufacturing processes (n=74) (multiple response possible)

odnosno 5 % (u 2009. g.) ispitanika 75 % do 100 % svojih ukupnih godišnjih prihoda ostvaruje izvozom.

3.2. Proizvodne operacije i tehnologija
3.2 Production operations and technology

Od ispitanika se tražilo da se izjasne o proizvodnim operacijama i tehnologijama kojima se koriste u procesima proizvodnje svojih proizvoda.

Na pitanje o tipovima proizvodnje u njihovim tvrtkama ispitanici su se izjasnili kako najvećibroj njih, čak 78 %, razvijaju pojedinačnu proizvodnju, 43 % ispitanika maloserijsku proizvodnju, a 21 % ispitanika navodi kako svoje poslovanje temelje na velikoserijskoj proizvodnji namještaja.

Najviše ispitanika, njih 42 % od 77, navode kako u svojim procesima proizvodnje koriste strojeve od 6 do 10 godina starosti. S druge strane, najmanje ispitanika (10 %) izjasnilo se kako u proizvodnji koriste strojeve proizvedene prije više od 15 godina,30 % ispitanika u procesima proizvodnje koriste se strojevima mlađim od pet godina, dok 18 % ispitanika ističe da imaju strojeve između 11 i 15 godina starosti. Osim o starosti, ispitanici su se trebali izjasniti i o broju strojeva koje posjeduju u svojim proizvodnim pogonima, a koji sudjeluju u procesima proizvodnje. Četrdeset posto ispitanika izjasnilo se kako se za proizvodnju koristi jednim do pet strojeva (što ne uključuje male priručne strojeve i alate). Nadalje, 27 % ispitanika navodi kako za proizvodnju raspolažu s više od 15 strojeva. Nešto manje, 21 % ispitanika, izjasnilo se kako se koriste sa šest do deset strojeva, dok njih 12 % za proizvodnju svojih proizvoda koristi od 11 do 15 strojeva.

Prema slici 5, pila za ploče najčešća je oprema u procesima proizvodnje namještaja među ispitanicima; 70 % ispitanika izjasnilo se kako pri izradi svojih proizvoda rabe pilu za ploče. Više od polovine ispitanika, od 51do 58 %, navodi kako su strojevi poput glodalice (58 %), ravnalice (56 %), tračne brusilice (55 %), stupne bušilice (55 %), blanjalice (55 %), debljače (53 %), kanterice (51 %) i tračne pile (51 %) najčešće korištena oprema u proizvodnji namještaja. Stolnu glodalicu u procesu proizvodnje upotrebljava gotovo polovina ispitanika, točnije njih 49 %. Trideset i devet posto ispitanika navodi kako im je i lakirnica, među ostalim, potrebna u procesu proizvodnje, dok po 36 % ispitanika navodi da je to CNC glodalica i potezna kružna pila. Od 20do 30 % ispitanika izjasnilo se kako u proizvodnji koristi ovu opremu: višestranu blanjalicu (26 %), tokarilicu (22 %), sušaru (22 %) te višelisnu pilu (21 %). Kopirna tokarilica stroj je koji u proizvodnji rabi 10 % ispitanika, dok preostale navedene strojeve u procesima proizvodnje upotrebljava manje od 10 % ispitanika; 6 % ispitanika izjasnilo se kako su preša, viševretena bušilica i visokofrekventna preša strojevi uključeni u njihove procese proizvodnje. Samo 5 % ispitanika navodi da se koriste čeparicom, dok samo 3 % ispitanika navodi kako su tiplerica i raskrajač strojevi korišteni u njihovim procesima proizvodnje.

Nadalje, na pitanje sudjeluju li u svim fazama i procesima proizvodnje svojih proizvoda, 70 % ispitanika (od 77) odgovorilo je potvrdno. Nasuprot njima, 30 % ispitanika ne sudjeluje u svim proizvodnim procesima, a njih 66 % navodi kako se za pojedine faze proizvodnje koriste uslugama kooperanata. Trideset i četiri posto ispitanika uopće se ne koristi uslugama kooperanata.

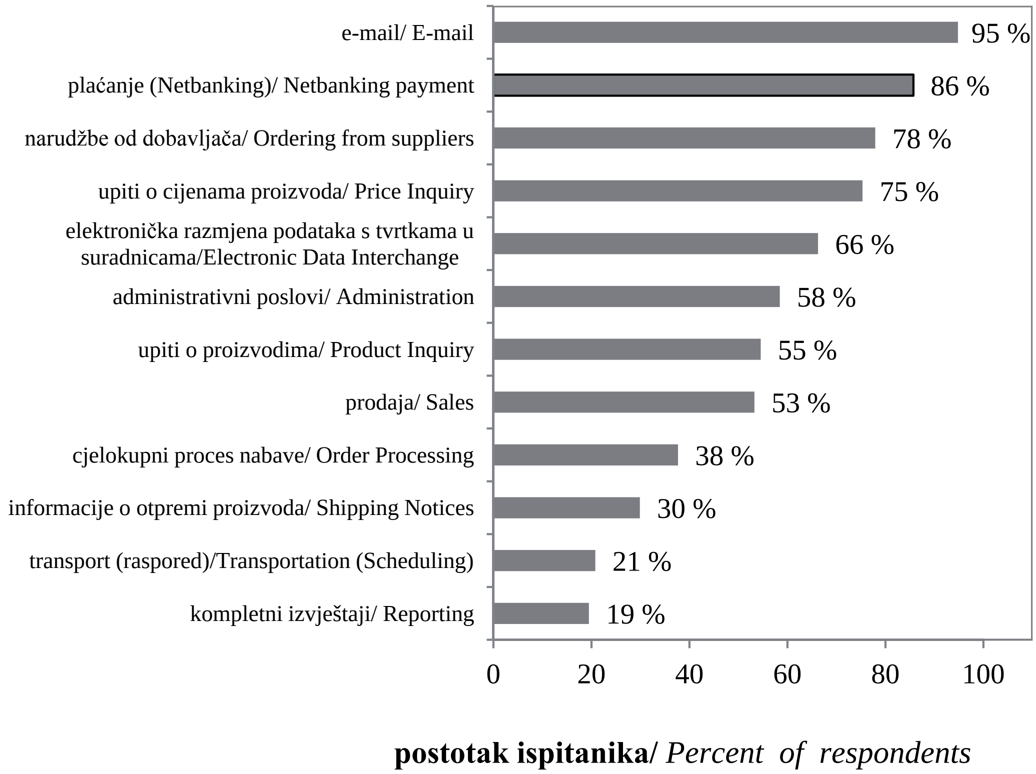
3.3 Marketing i tržište
3.3 Marketing and market

Od ispitanika se zahtijevalo da na Likertovoj ljestvici od pet stupnjeva izraze svoju razinu slaganja ili neslaganja s pojedinim tvrdnjama o aktivnostima njihove tvrtke koje se odnose na marketinške aktivnosti. Ispitanici su se gotovo u potpunosti složili s tvrdnjom da u svojim tvrtkama proizvode one proizvode koje zahtijevaju njihovi kupci (srednja cijena = 4,6; SD = ±0,65), ali se i prilično slažu s tvrdnjom da svojim kupcima prodaju one proizvode koje su osposobljeni proizvesti u svojim proizvodnim pogonima (srednja ocjena = 4,1; SD = ±1,09). Ispitanici su se također prilično složili da u oglašavanju svojih proizvoda ističu njihovu kvalitetu (srednja ocjena = 4,3; SD = ±0,93), njihove posebnosti (srednja ocjena = 4,0; SD = ±1,12) i korisnosti (srednja ocjena = 3,8; SD = ±1,13). Ispitanici se slažu, sa srednjom ocjenom 3,3 (SD = ±1,26), kako način i ambalaža pakiranja proizvoda utječu na njihovu prodaju te se slažu kako pakiranje istodobno služi i za zaštitu proizvoda (srednja ocjena = 3,1; SD = ±1,20).

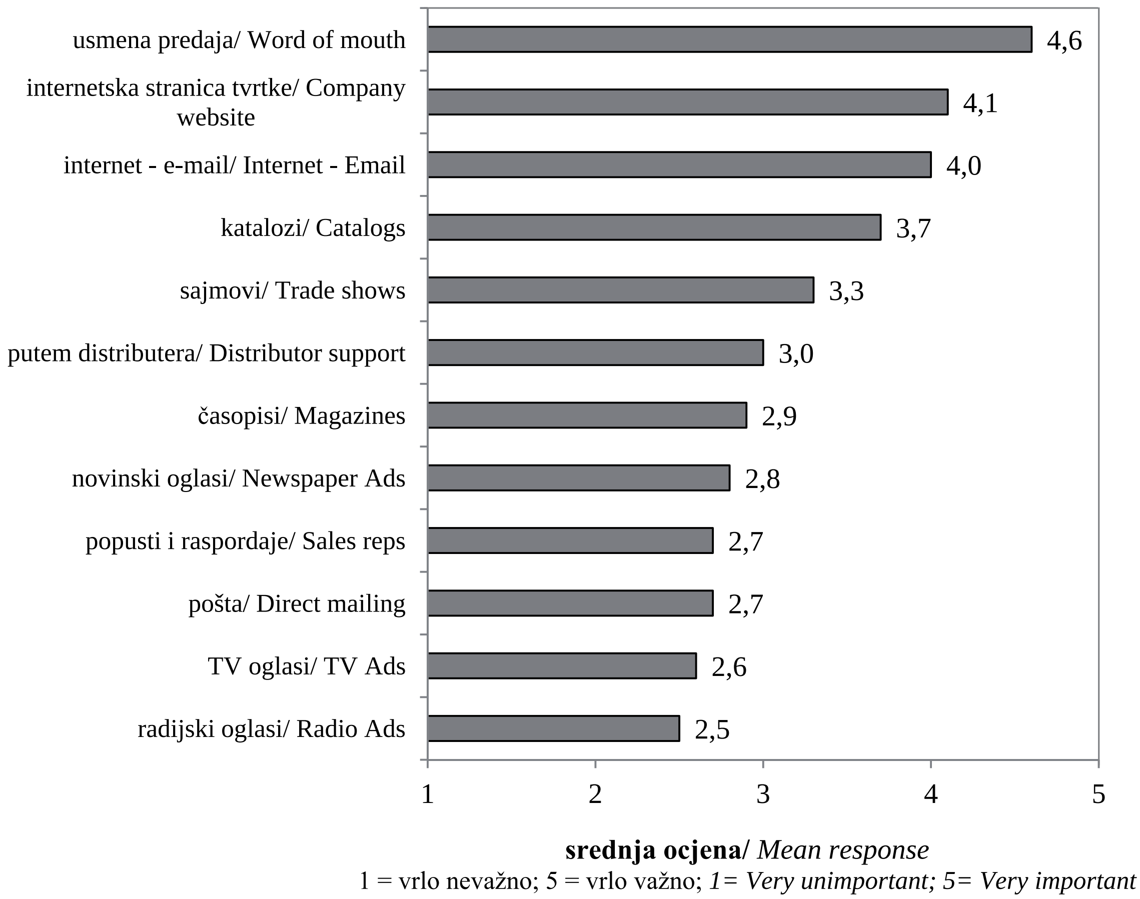
Na pitanje o provedbi marketinških istraživanja, od 77 ispitanika 43 %, odnosno 47 % navodi kako u svojim tvrtkama ne provode (ili vrlo rijetko provode) marketinška istraživanja kako bi definirali zadovoljstvo, odnosno potrebe svojih kupaca. Trideset posto ispitanika uglavnom provodi spomenuta istraživanja s ciljem postizanja zadovoljstva svojih kupaca, dok s ciljem zadovoljavanja potreba kupaca navedena istraživanja provodi samo 19 % ispitanika. Dvadeset i sedam posto ispitanika složilo se s tvrdnjom da u svojim tvrtkama provode marketinška istraživanja radi definiranja zadovoljstva kupaca, dok se 34 % složilo s tvrdnjom kako takva istraživanja provode da bi definirali potrebe svojih kupaca.

Na pitanje o zalihama proizvoda ispitanici su se izjasnili kako baš ne stvaraju zalihe proizvoda ni na temelju zahtjeva kupaca (srednja ocjena = 2,6, SD = ±1,43), ali ni na temelju zahtjeva proizvodnje (srednja ocjena = 2,4; SD = ±1,30).

Ispitanici su se trebali izjasniti o tome imaju li internetsku stranicu te zašto se, i u koju svrhu, koriste uslugama interneta. Od 76 ispitanika njih 78 % izjasnilo se kako imaju internetsku stranicu, dok se ostatak ispitanika (22 %) izjasnio suprotno – da nemaju internetsku stranicu svoje tvrtke. Na pitanje o svrsi korištenja internetom, gotovo su svi ispitanici (95 %) naveli *e-mail* kao glavni razlog služenja internetom. Osamdeset i šest posto ispitanika navodi kako putem interneta obavlja financijska plaćanja, 78 % ispitanika internet koristi za narudžbe od svojih dobavljača, a 66 % preko interneta obavlja razmjenu podataka s tvrtkama suradnicama. Upiti o cijenama proizvoda razlog su zbog kojega se 75 % ispitanika koristi uslugama inter-



Slika 6. Upotreba interneta (*n* = 77) (mogućnost višestrukog odgovora)
Figure 6 Internet usage (*n*=77) (multiple responses possible)



Slika 7. Metode promocije proizvoda (*n* = 76)
Figure 7 Methods for promoting products (*n*=76)

neta, upiti o proizvodima također su jedna od aktivnosti korištenja internetom među ispitanicima (55 %), ali i više od polovine ispitanika (53 %) preko interneta prodaju svoje proizvode. Jednako tako, više od 50 % ispitanika navodi kako administrativne poslove (58 %) obavlja putem interneta. Proces nabave materijala (38 %), informacije o opremi proizvoda (30 %) i transportu (21 %) manje su uobičajene aktivnosti zbog kojih se ispitanici u svojim tvrtkama koriste internetskim uslugama(sl.6).

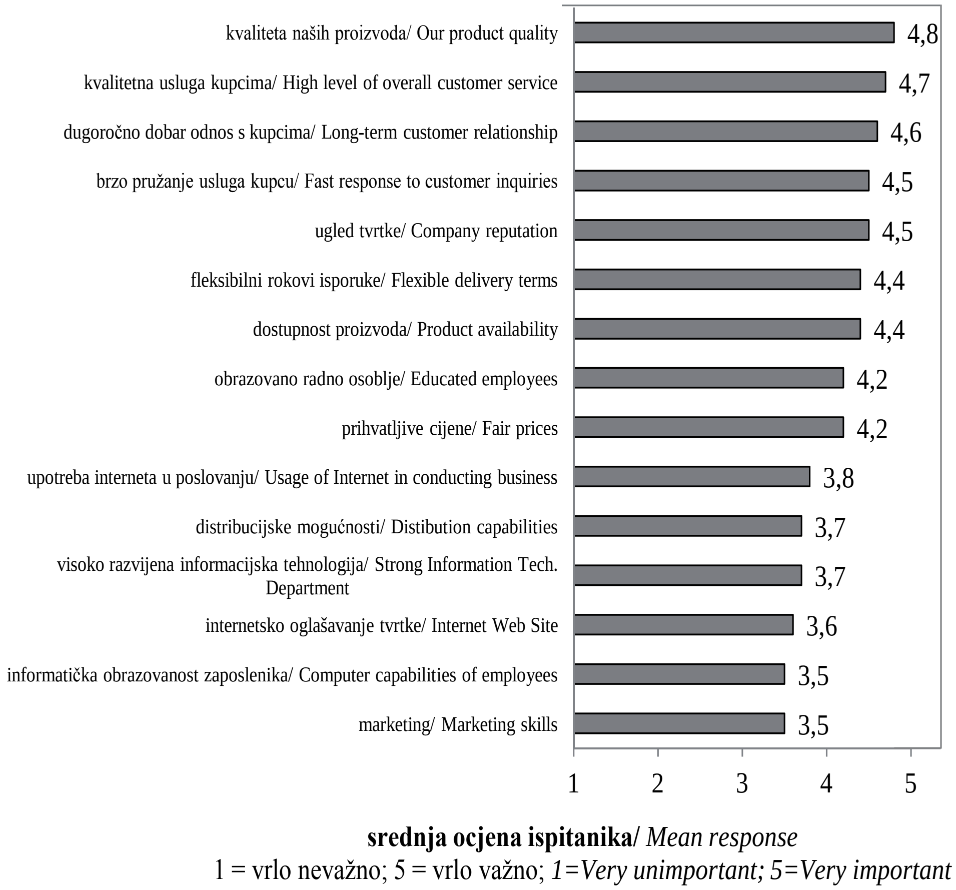
Želeći proširiti razine slaganja ili neslaganja s tvrdnjama o internetu, od ispitanika se tražilo da na Likertovoj ljestvici od pet stupnjeva izraze svoju razinu slaganja ili neslaganja s tvrdnjama vezanima za koristi interneta. Ispitanici su pokazali dosta visoku razinu slaganja s tvrdnjom da upotreba interneta njihovoj tvrtki štedi novac (srednja ocjena = 4,1; SD = ±1,10) te da im je internet važan alat u istraživanju tržišta (srednja ocjena = 4,0; SD = ±1,19). Ispitanici se nisu previše složili s tvrdnjom kako korist od interneta pronalaze u tome što im je on važan alat u donošenju odluka (srednja ocjena = 3,3; SD = ±1,03) te da im omogućuje posebnu koordinaciju među odjelima unutar tvrtke (srednja ocjena = 3,2; SD = ±1,39).Na pitanje o upotrebi interneta i koristima što ih internet donosi njihovim tvrtkama ispitanici se slažu da je primjena interneta ispunila njihova očekivanja (srednja ocjena = 3,6; SD = ±1,05), ali se baš previše ne slažu s tvrdnjom kako je upotreba interneta prihvaćena na inzistiranje menadžmenta tvrtke (srednja ocjena = 2,9; SD = ±1,37). Jednako tako, ispitanici se ne slažu ni s tvrdnjom kako je primjena i upotreba interneta smanjila broj njihovih konkurenata (srednja ocjena = 2,4; SD = ±1,00).

Od ispitanika se tražilo da na Likertovoj ljestvici od pet stupnjeva iznesu svoju razinu važnosti prema mogućim metodama promocije proizvoda. Ispitanici navode kako im je usmena predaja još uvijek najvažnija metoda u promociji proizvoda (srednja ocjena = 4,6; SD = ±0,8). Iza toga, internetska je stranica tvrtke ispitanicima također bitna za promociju proizvoda (srednja ocjena = 4,1; SD = ±1,20), a sljedeća je po važnosti metoda korištenja *e-mailom* tvrtke, sa srednjom ocjenom 4,0 (SD = ±1,22). Promocija proizvoda putem kataloga, prema navodima ispitanika,također je važna metoda (srednja ocjena = 3,7; SD = ±1,10), dok odlaske na domaće i međunarodne sajmove namještaja i prateće opreme ispitanici ne smatraju toliko važnom aktivnošću koja bi im pomogla u promociji proizvoda tvrtke (srednja ocjena = 3,3; SD = ±1,27). Nadalje, ni promoviranje putem distributera tvrtke (srednja ocjena = 3,0; SD = ±1,32), oglašavanjem u časopisima (srednja ocjena = 2,9; SD = ±1,20) i novinama (srednja ocjena = 2,8; SD = ±1,17) ispitanicima nisu posebno važne metode promocije. Najmanje važnim ispitanici smatraju davanje popusta na svoje proizvode i rasprodaja (srednja ocjena = 2,7; SD = ±1,43), slanje letaka i drugih promotivnih materijala poštom (srednje ocjena = 2,7; SD = ±1,13 te televizijske (srednja ocjena = 2,6; SD = ±1,33) i radijske oglase sa srednjom ocjenom 2,5 (SD = ±1,32) (slika 7).

Od 77 ispitanika 75 % navodi kako za svoje poslovanje i proizvodnju svojih proizvoda surađuju s do deset dobavljača drvnog materijala. Sedamnaest posto ispitanika izjasnilo se kako suradnju ostvaruje s 11 do 20 dobavljača drvnog materijala. Broj dobavljača drvnog materijala u 7 % ispitanika iznosi između 21 i 40. Samo 1 % ispitanika navodi kako surađuje s 41 do 50 dobavljača drvnog materijala, dok nitko od ispitanika ne ostvaruje suradnju s više od 50 dobavljača drvnog materijala. Na pitanje o važnosti pojedinih kriterija pri odabiru dobavljača drvnog materijala ispitanici najviše ističu važnost kvalitete materijala (srednja ocjena = 4,8; SD = ±0,45), dostupnosti materijala (srednja ocjena = 4,7; SD = ±0,56), brze rokove isporuke (srednja ocjena = 4,5; SD = ±0,79) te cijene drvnog materijala (srednja ocjena = 4,5; SD=±0,82). Fleksibilno vrijeme isporuke, visoka razina usluge i pogodnost također su, prema navodima ispitanika, jednako važni kriteriji za odabir dobavljača drvnog materijala (srednje ocjene = 4,2; SD = ±0,95, SD = ±0,90 i SD = ±0,89). Srednjom ocjenom 4,0 (SD = ±1,14), 3,9 (SD = ±1,15) i 3,9 (SD = ±1,01) i 3,7 (SD = ±1,16) ispitanici su ocijenili važnost ovih kriterija: uvjeta plaćanja, neovisnosti dobavljača, znanja i ugleda dobavljača, što znači da navedene kriterije ispitanici također smatraju važnima pri odabiru dobavljača drvnog materijala. Najmanju važnost ispitanici daju kreditnim uvjetima plaćanja (srednja ocjena = 3,3; SD = ±1,34) (sl.8).

Na pitanje o suradnji s kupcima, najviše ispitanika (40 %) odgovorilo je da u svom poslovanju ostvaruje suradnju s više od 50 kupaca/klijenata, dok 18 % njih surađuje s najviše deset kupaca. Gotovo jednak postotak ispitanika, njih 17 %, navodi kako u svom poslovanju suradnju ostvaruju s 21 do 30 kupaca. Jedanaest posto ispitanika surađuje s 11 do 20 kupaca, a 1 % manje ispitanika (9 %) u svom poslovanju surađuje s 41 do 50 klijenata. Najmanje ispitanika (5 %) navodi kako svoje poslovanje temelji na suradnji s 31 do 40 kupaca svojih proizvoda. Nadalje, od ispitanika se nastojalo saznati na koji način ostvaruju suradnju s kupcima kada u svojoj tvrtki razvijaju nove proizvodei rade na poboljšanju već postojećih. Devedeset posto ispitanika izjasnilo se kako pri razvoju i dizajniranju novih proizvoda surađuje sa svojim kupcima, dok samo njih 10 % u tim procesima ne ostvaruje suradnju. Nešto manje ispitanika (87 %) navodi kako i pri poboljšanju dizajna već postojećih proizvoda također surađuje sa svojim kupcima. Trinaest posto ispitanika ne ostvaruje suradnju sa svojim kupcima u provođenju procesa poboljšanja svojih proizvoda.

Prema slici 8, ispitanici navode kako su činitelji poput kvalitete proizvoda (srednja ocjena = 4,8; SD = ±0,61), pružanja kvalitetnih usluga kupcima (srednja ocjena = 4,7; SD = ±0,77), dugoročno dobrog odnosa s kupcima (srednja ocjena = 4,6; SD = ±0,79), brzog pružanja usluga kupcima (srednja ocjena = 4,5; SD = ±0,88) te ugleda tvrtke (srednja ocjena = 4,5; SD = ±0,72) najvažniji elementi u postizanju poslovnog uspjeha tvrtke. Fleksibilni rokovi isporuke te dostupnost proizvoda (srednje ocjene = 4,4, SD = ±0,80 i SD =



Slika 8.Činitelji uspjeha vezani za kupce (*n* = 77)
Figure 8 Company's success factors related to customers (*n*=77)

±0,89) također su važni činitelji uspjeha njihovih tvrtki.Iza toga slijede činitelji poput obrazovanoga radnog osoblja i prihvatljive cijene proizvoda (srednje ocjene = 4,2; SD = ±0,89 SD = ±1,01). Ispitanici navode kako su upotreba interneta u poslovanju (srednja ocjena = 3,8; SD = ±1,04), distribucijske mogućnosti (srednja ocjena = 3,7; SD = ±1,04), visokorazvijena informacijska tehnologija (srednja ocjena = 3,7; SD = ±1,19) te oglašavanje tvrtke putem interneta (srednja ocjena = 3,6; SD = ±1,14) donekle važni činitelji vezani za uspjeh tvrtke. Najmanju važnost ispitanici pridaju marketingu i informatičkoj obrazovanosti zaposlenika (srednje ocjene = 3,5; SD = ±1,06 i SD = ±1,03), odnosno navedeni su činitelji, prema njihovu mišljenju, u usporedbi s prethodnima manje važni za postizanje poslovnog uspjeha tvrtke.

4. ZAKLJUČAK
4 CONCLUSION

Tvrtke za proizvodnju namještaja u Republici Hrvatskoj većinom su smještene u većim gradskim sredinama Sjeverozapadne Hrvatske, većina ih je u 2008. i 2009. ostvarila do 5 000 000 kn prihoda, dok je prosječan udio prihoda ostvaren prodajom namještaja u ukupnom prihodu u 2008. u prosjeku iznosio 67,8 %, odnosno u 2009. iznosio je 68,9 %. Vrlo je važno naglasiti kako je i u 2008. i u 2009. više od trećine ukupnih godišnjih prihoda ostvareno prodajom novih/poboljšanih postojećih proizvoda.

Većina tvrtki zapošljava do deset djelatnika, po pravilu muškaraca starosne dobi do 40 godina i srednje stručne spreme.S obzirom na obrazovanje i radno iskustvo, više od 50 % ispitanika na mjesto menadžera/voditelja/direktora tvrtke zaposlit će osobu sa završenim fakultetom, dok će vodeće mjesto u proizvodnji (većina ispitanika, njih 69 %) dodijeliti osobama sa završenom srednjom školom i već stečenim radnim iskustvom.

Tvrtke imaju širok proizvodni program kojim dominira proizvodnja namještaja za sobe i uredski namještaj, a 78% njihove proizvodnje temelji se na maloserijskom tipu proizvodnje i najčešće se u procesima proizvodnje svojih proizvoda koriste jednim do pet strojeva do deset godina starosti.Promociju svojih proizvoda tvrtkejoš uvijek najčešće provode usmenom predajom, a primjena i korištenje internetombitan su im alat u gotovo svim aktivnostima poslovanja tvrtke.

Najviše njih surađuje s do deset dobavljača,čiju kvalitetu i dostupnost materijala smatraju najvažnijim obilježjima za odabir suradnika. Tvrtke također surađuju s više od 50 svojih kupaca, a suradnja se u najvećem opsegu ostvaruje aktivnostima poboljšanja svojstava već postojećih proizvoda ili pri dizajniranju novih proizvoda.

Hrvatske tvrtke za proizvodnju namještaja na dobrom su putu prema postizanju dobrih poslovnih rezultata jer se trećina njihovih ukupno ostvarenih godišnjih prihoda temelji na poboljšanim postojećim/novim proizvodima. Nadalje, tvrtke prepoznaju važnost zapošljavanja visokoobrazovanih zaposlenika, primjene novih alata/strojeva u proizvodnim procesima te raznolikost proizvodnog programa kako bi što uspješnije i u što kraćem vremenu zadovoljili svakodnevne, iz dana u dan sve zahtjevnije želje i potrebe kupaca. Jednako tako, tvrtke se koriste marketinškim alatima i provode marketinške aktivnosti. No možda bi uz bolju suradnju s istraživačkim centrima te obrazovnim i znanstvenim institucijama tvrtke mogle poboljšati svoj položaj na domaćemu, a posebice na međunarodnom tržištu (s obzirom na to da je postotak izvoza u ukupnim prihodima tvrtki na nezadovoljavajućoj razini).

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Nencho Deliiski[1]

3D Modeling and Visualization of Non-Stationary Temperature Distribution during Heating of Frozen Wood

3D modeliranje i vizualizacija nestacionarne distribucije temperature tijekom zagrijavanja smrznutog drva

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ABSTRACT • *A 3-dimensional mathematical model has been developed, solved, and verified for the transient non-linear heat conduction in frozen and non-frozen wood with prismatic shape at arbitrary initial and boundary conditions encountered in practice. The model takes into account for the first time the fiber saturation point of each wood species,* u_{fsp}*, and the impact of the temperature on* u_{fsp} *of frozen and non-frozen wood, which are then used to compute the current values of the thermal and physical characteristics in each separate volume point of the material subjected to defrosting.*
This paper presents solutions of the model with the explicit form of the finite-difference method. Results of simulation investigation of the impact of frozen bound water, as well as of bound and free water, on 3D temperature distribution in the volume of beech and oak prisms with dimensions 0.4 x 0.4 x 0.8 m during their defrosting at the temperature of the processing medium of 80 °C are presented, analyzed and visualized through color contour plots.

Keywords: *3D mathematical model, frozen wood, finite difference method, temperature distribution, contour plots*

SAŽETAK • *Kreiran je i riješen 3D matematički model te provjeren za nelinearno provođenje topline u smrznutome i nesmrznutom drvu prizmatičnog oblika pri proizvoljnim početnim i rubnim uvjetima koji se susreću u praksi. Prvi put model uzima u obzir točku zasićenosti vlakanaca za svaku vrstu drva (*u_{fsp}*) i utjecaj temperature na* u_{fsp} *smrznutoga i nesmrznutog drva, koji se primjenjuju pri izračunavanju trenutačne vrijednosti termo-fizikalnih svojstava u svakoj posebno definiranoj točki volumena materijala koji se odmrzava.*
Rad prikazuje rješenja modela s eksplicitnim oblikom metode konačnih razlika. Rezultati simulacijskih istraživanja o utjecaju zamrznute vezane vode te vezane i slobodne vode na 3D raspodjelu temperature u volumenu bukovih i hrastovih prizmi dimenzija 0,4 x 0,4 x 0,8 m tijekom odmrzavanja pri temperaturi procesnog medija od 80 °C prezentirani su i analizirani te vizualizirani crtežima u boji.

Ključne riječi *: 3D matematički model, smrznuto drvo, metoda konačnih razlika, raspodjela temperature , konturni crteži*

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1 INTRODUCTION
1. UVOD

For the optimization of the control of the heating process of wood in veneer and plywood mills, it is necessary to know the temperature distribution at every moment of the process (Shubin, 1990; Trebula and Klement, 2003; Pervan, 2009). Considerable contribution was made to the calculation of non-stationary distribution of temperature in frozen and non-frozen logs, and to the duration of their heating (Steinhagen, 1986, 1991). Later on, 1-dimensional and 2-dimensional models were developed and solved (Steinhagen *et al*., 1987; Steinhagen and Lee, 1988; Khattabi and Steinhagen, 1992, 1993, 1995), whose applications are limited only to wood with moisture content above fiber saturation point.

The heat energy, required for melting the ice, formed from bound water in the wood, has not been taken into account in these models. The models assume that the fiber saturation point is identical for all wood species (i.e. u_{fsp} = 0.3 kg·kg^{-1} = const) and that the melting of the ice, formed from free water in the wood, occurs at 0 ºC.

However, it is known that there are significant differences between the fiber saturation point of different wood species (Požgai *et. al*., 1997; Videlov, 2003) and that, depending on this point, the quantity of the ice formed from free water in the wood melts at a temperature in the range between -2 ºC and -1 ºC (Chudinov, 1968, 1984). The complications and deficiencies indicated in these models have been overcome by a 2-dimensional mathematical model of the transient non-linear heat conduction in frozen and non-frozen logs suggested by Deliiski (2004, 2011).

This paper presents the development, verification and solutions of an analog 3-dimensional mathematical model of the transient non-linear heat conduction in frozen and non-frozen wood with prismatic shape at arbitrary initial and boundary conditions encountered in practice. The model takes into account for the first time the fiber saturation point of each wood species, u_{fsp}, and the impact of the temperature on u_{fsp} of frozen and non-frozen wood, which are then used to compute the current values of the thermal and physical characteristics in each separate volume point of the material subjected to defrosting.

This paper also presents the results of simulation investigation of the impact of the frozen bound water and free water on 3D temperature distribution in the volume of beech and oak prisms with dimensions 0.4 x 0.4 x 0.8 m during their defrosting at the temperature of the processing medium of 80 °C.

2 MATHERIAL AND METHODS
2. MATERIJAL I METODE

2.1. 3D mathematical model of the defrosting process of prismatic wood materials
2.1. 3D matematički model procesa odmrzavanja prizmatičnoga drvnog materijala

The defrosting process of prismatic wood materials during their thermal treatment can be described by a non-linear differential equation of the thermal-conductivity, using the Cartesian coordinates (Deliiski, 2003a):

$$c_e(T,u)\rho(T,u)\frac{\partial T(x,y,z,\tau)}{\partial \tau}=\frac{\partial}{\partial x}\left[\lambda_r(T,u)\frac{\partial T(x,y,z,\tau)}{\partial x}\right]+\frac{\partial}{\partial y}\left[\lambda_t(T,u)\frac{\partial T(x,y,z,\tau)}{\partial y}\right]+\frac{\partial}{\partial z}\left[\lambda_p(T,u)\frac{\partial T(x,y,z,\tau)}{\partial z}\right] \quad (1)$$

After the differentiation of the right side of equation (1) on the spatial coordinates *x, y,* and *z*, excluding the arguments in the brackets for shortening of the record, the following mathematical model is obtained of the non-stationary defrosting of wood materials with prismatic shape subjected to heating:

$$c_e\rho\frac{\partial T}{\partial \tau}=\lambda_r\frac{\partial^2 T}{\partial x^2}+\frac{\partial \lambda_r}{\partial T}\left(\frac{\partial T}{\partial x}\right)^2+\lambda_t\frac{\partial^2 T}{\partial y^2}+\frac{\partial \lambda_t}{\partial T}\left(\frac{\partial T}{\partial y}\right)^2+\lambda_p\frac{\partial^2 T}{\partial z^2}+\frac{\partial \lambda_p}{\partial T}\left(\frac{\partial T}{\partial z}\right)^2 \quad (2)$$

with an initial condition

$$T(x,y,z,0)=T_0, \quad (3)$$

and a boundary condition

$$T(0,y,z,\tau)=T(x,0,z,\tau)=T(x,y,0,\tau)=T_m(\tau). \quad (4)$$

For the solution of the system of equations (2) to (4), it is necessary to make a mathematical description of thermal and physical characteristics of the wood, c_e, λ_r, λ_t, λ_p, and of its density, ρ. Equations in (Deliiski, 2003a, 2011) and (Deliiski and Dzurenda, 2010) present a mathematical description of the effective specific heat capacity coefficient, c_e, of the frozen wood as a sum of the capacities of the wood itself, *c*, and the ice produced by freezing of the free water, c_{fw}, and of the hygroscopically bound water, c_{bw}. Other equations quoted by the above authors present mathematical descriptions of wood density, *ρ*, and of its thermal conductivity, λ, in different anatomical directions.

The given mathematical descriptions of c_e, λ_r, λ_t, and λ_p (Deliiski, 2011), which are part of the model (2) to (4), have now been updated by taking into account, for the first time, the influence of the fiber saturation point of wood species on the values of thermal and physical characteristics during wood defrosting, and the influence of the temperature on fiber saturation point of frozen and non-frozen wood. This has been done using the method presented by Deliiski (2013) during the update of the mathematical description of λ.

2.2. Transformation of 3D model to a form suitable for programming
2.2. Transformacija 3D modela u odgovarajući oblik za programiranje

The following system of equations (Equation 5) has been derived by passing to final increases in equation (2) with the usage of the same, as well as by the explicit form of the finite-difference method described by Deliiski (2003a, 2011) and taking into account the mathematical description of the thermal conductivity, λ, in different anatomical directions.

Since in practice prismatic materials subjected to thermal treatment usually do not have a clear radial or clear tangential orientation, and are partially radially or partially tangentially oriented, then in equation (5) instead of the coefficients λ_0 in the observed two anatomical directions, their average arithmetic value can be used, as it determines the thermal conductivity at 0 °C perpendicular to the wood fibers (Equation 6).

$$T_{i,j,k}^{n+1} = T_{i,j,k}^{n} + \\ + \frac{\gamma\Delta\tau}{c_e\rho}\left\{\begin{array}{l} \frac{\lambda_{0r}}{\Delta x^2}\left[\begin{array}{l}\left[1+\beta\left(T_{i,j,k}^{n}-273{,}15\right)\right] \\ \left(T_{i+1,j,k}^{n}+T_{i-1,j,k}^{n}-2T_{i,j,k}^{n}\right)+\beta\left(T_{i,j,k}^{n}-T_{i-1,j,k}^{n}\right)^2\end{array}\right]+ \\ \frac{\lambda_{0t}}{\Delta y^2}\left[\begin{array}{l}\left[1+\beta\left(T_{i,j,k}^{n}-273{,}15\right)\right] \\ \left(T_{i,j+1,k}^{n}+T_{i,j-1,k}^{n}-2T_{i,j,k}^{n}\right)+\beta\left(T_{i,j,k}^{n}-T_{i,j-1,k}^{n}\right)^2\end{array}\right]+ \\ \frac{\lambda_{0p}}{\Delta z^2}\left[\left[1+\beta\left(T_{i,j,k}^{n}-273{,}15\right)\right]\left(T_{i,j,k+1}^{n}+T_{i,j,k-1}^{n}-2T_{i,j,k}^{n}\right)+\beta\left(T_{i,j,k}^{n}-T_{i,j,k-1}^{n}\right)^2\right] \end{array}\right\} \tag{5}$$

$$\lambda_{0cr} = \frac{\lambda_{0r}+\lambda_{0t}}{2} \tag{6}$$

Also, the thermal conductivity at 0 °C in the direction parallel to the fibers λ_{0p} can be expressed through λ_{0cr} using the equation

$$\lambda_{0p} = K_{p/cr}\lambda_{0cr}\,, \tag{7}$$

where the coefficient $K_{p/cr} = \frac{\lambda_{0p}}{\lambda_{0cr}}$ depends on the wood species (Deliiski, 2003a).

For uniformity of the calculations, it is reasonable to use one step of the calculation mesh along the spatial coordinates $\Delta x = \Delta y = \Delta z$ (see Fig. 1). Taking into consideration this condition and equations (6) and (7), the system of equations (5) becomes equation (8).

The initial condition (3) in the model is presented using the following finite differences equation (9).

$$T_{i,j,k}^{0} = T_0\,. \tag{9}$$

$$T_{i,j,k}^{n+1} = T_{i,j,k}^{n} + \\ + \frac{\lambda_{0cr}\gamma\Delta\tau}{c_e\rho\Delta x^2}\left\{\begin{array}{l} \left[1+\beta(T_{i,j,k}^{n}-273{,}15)\right] \\ \left[\begin{array}{l}T_{i+1,j,k}^{n}+T_{i-1,j,k}^{n}+T_{i,j+1,k}^{n}+T_{i,j-1,k}^{n}+ \\ K_{p/cr}(T_{i,j,k+1}^{n}+T_{i,j,k-1}^{n})-(4+2K_{p/cr})T_{i,j,k}^{n}\end{array}\right]+ \\ +\beta\left[\begin{array}{l}(T_{i,j,k}^{n}-T_{i-1,j,k}^{n})^2+(T_{i,j,k}^{n}-T_{i,j-1,k}^{n})^2+ \\ K_{p/cr}(T_{i,j,k}^{n}-T_{i,j,k-1}^{n})^2\end{array}\right] \end{array}\right\}. \tag{8}$$

The boundary conditions (4) acquire the following form suitatable for programming:

$$T_{1,j,k}^{n+1} = T_{i,1,k}^{n+1} = T_{i,j,1}^{n+1} = T_{m}^{n+1}\,. \tag{10}$$

The presentation of a non-linear differential equation (2) from the mathematical model through its discrete analogue (8) corresponds to the setting of the coordinate system and positioning of the nodes in the mesh shown in Fig. 1, in which a non-stationary 3D temperature distribution in prismatic wood materials during their defrosting is calculated. The calculation mesh for the solution of the model through the finite-difference method is built on a 1/8 part of the prism volume, because of its mirror symmetry with the remaining 7/8 parts of the prism volume.

The setting of the coordinate system, shown in Fig. 1 allows, with the help of only one system of equations (8), to calculate the change in the temperature in any mesh node of the volume of the prism subjected to defrosting at the moment $(n + 1)\Delta\tau$ using the already calculated values of T at the preceding moment $n\Delta\tau$.

Wide experimental studies have been performed for the determination of a 1-, 2- and 3-dimensional temperature distribution in the volume of frozen and non-frozen oak, beech, poplar and pine

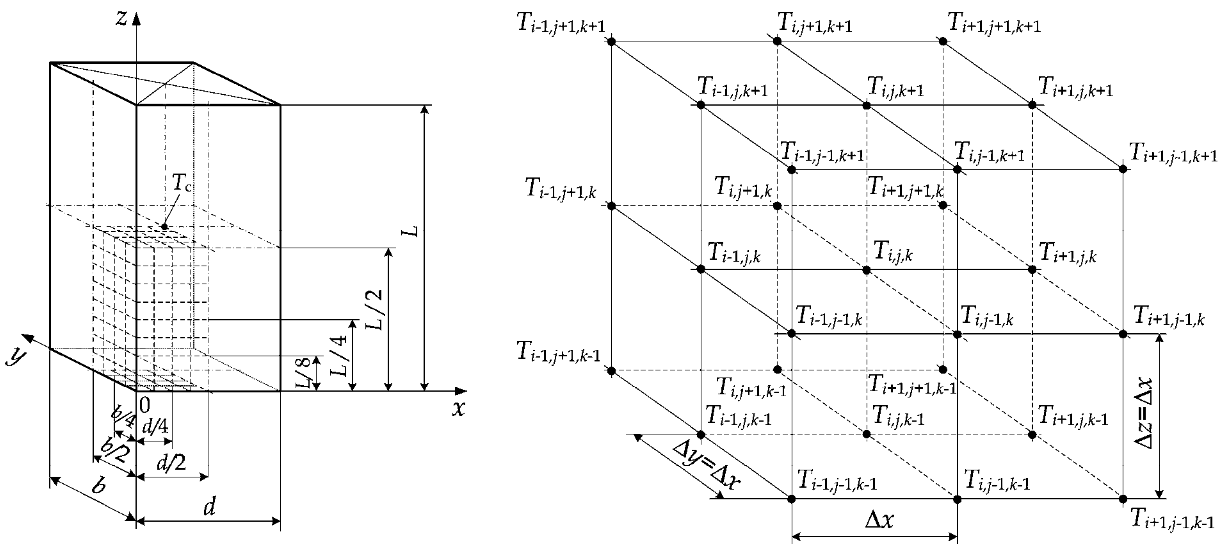

Figure 1 Positioning of nodes in a 3D calculation mesh of a discretized wooden prism
Slika 1. Pozicioniranje čvorova u 3D računskoj mreži u diskretiziranoj drvenoj prizmi

prismatic materials during their thermal treatment. The values of the coefficient $K_{p/cr} = \dfrac{\lambda_{0p}}{\lambda_{0cr}}$ in equation (8) have been determined through the solution of the model with the same initial and boundary conditions in order to achieve maximum conformity between the calculated and experimental results.

It has been determined that the coefficient $K_{p/cr}$ has the following values: for oak $K_{p/cr}$=1.76, for beech $K_{p/cr}$=1.88, for poplar $K_{p/cr}$=2.03, and for pine $K_{p/cr}$=2.26 (Deliiski, 2003a, 2011).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1. Computation of 3D temperature distribution in frozen wood during its defrosting
3.1. Izračun 3D raspodjele temperature u smrznutome drvnom materijalu tijekom njegova odmrzavanja

For the numerical solution of the above presented mathematical model, a software package has been developed in FORTRAN and integrated in the calculation environment of Visual Fortran Professional developed by Microsoft, as a part of the Windows Office software (Deliiski, 2011).

With the help of this software package, 3D temperature changes of beechwood (*Fagus Silvatica* L.) and oakwood (*Quercus petraea* Liebl.) prisms with dimensions d = 0.4 m, b = 0.4 m, L = 0.8 m, initial temperature of t_0 = -40 °C and two values of wood moisture content u = 0.3 kg·kg^{-1} and u = 0.6 kg·kg^{-1} have been studied during their 20 h heating with the intermediate stage of melting at the heating temperature of t_m = 80 °C. The prisms with u = 0.3 kg·kg^{-1} contain the maximum possible quantity of frozen bound water in beech and oak wood and contain no ice in the cell lumens (i.e. contain no ice from free water). The prisms with u = 0.6 kg·kg^{-1} not only contain frozen bound water but also contain a significant quantity of frozen free water.

The heating medium temperature, t_m, increases exponentially from $t_{m0} = t_0$ to t_m = 80 °C = const with the time constant of 1800 s. This increasing of t_m at the beginning of the heating process of prisms can be seen in Fig. 4 and 5. The values of d, b, L, t_m, and u have been selected so as to correspond to cases often encountered in practice.

The duration of 20 h of the prism heating at t_m = 80 °C has been proven suitable for complete melting of the ice in the studied prisms. The calculations have been done with average values of ρ_b = 560 kg·m^{-3} and u_{fsp}^{20} = 0.31 kg·kg^{-1} of the beech wood and of ρ_b = 670 kg·m^{-3} and u_{fsp}^{20} = 0.29 kg·kg^{-1} of the oak wood (Videlov, 2003; Deliiski and Dzurenda, 2010).

The computations have been carried out in a step on the spatial coordinates Δx = 0.001 m = 10 mm, i.e. with the nodes M = 1 + [d/(2 Δx)] = 21 and N = 1 + [b/(2 Δx)] = 21 along the x and y coordinates, respectively, and KD = 1 + [L/(2 Δx)] = 41 along the z coordinate. This means that the calculation meshes in the volume of the prisms consist of 21 x 21 x 41 = 18 081 nodes in total.

The step on time coordinate, $\Delta\tau$, which is determined by the software package that keeps the stability condition (Deliiski, 2011) of 3D solution of the explicit form of the finite-difference method and takes into account the maximum values of λ and c_e during wood defrosting process, is as follows:

▪ for beech wood: $\Delta\tau$ = 30 at u = 0.3 kg·kg^{-1} and $\Delta\tau$ = 25 at u = 0.6 kg·kg^{-1};
▪ for oak wood: $\Delta\tau$ = 40 at u = 0.3 kg·kg^{-1} and $\Delta\tau$ = 30 at u = 0.6 kg·kg^{-1}.

It takes 30 to 45 s to compute the temperature distribution in the volume of each of the studied prisms during a 20 h thermal treatment using the above values for $\Delta\tau$ with the help of Intel Pentium (4) CPU 3.0 GHz processor. Using the input data for solving the model, the value for the interval (INT) is given in seconds. After completing each INT from the beginning of the process, the calculated temperature distribution in the prism volume is recorded on computer hard-drive. The records can be consequently seen on a monitor, graphically processed, and/or printed. Besides taking into account the stability condition for solving the 3D model, the value of the step $\Delta\tau$ is calculated so as to be divisible by the input value of INT, using the software package.

Fig. 2 and 3 show the tables with the computed temperature distribution in 121 nodes of the calculation mesh in the central cross-section of the beech prisms at every 5 h of the defrosting process.

Fig. 4 and 5 shows the temperature change of the surface of beech and oak prisms subjected to defrosting, which is equal to t_m, as well as of t in 6 characteristic points of their volume.

The first three characteristic points with coordinates (d/4, b/8, L/8), (d/4, b/4, L/4), and (d/4, b/4, L/2) allow for the tracking of the influence on the defrosting process of the gap from the prisms base (see Fig. 1 –

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                         I N P U T   D A T A
                    3D DEFROSTING OF BEECH PRISM
Kq=11 M= 21 N= 21 KD= 41 ROb=560. Kwc=1.28 Kwpc=1.88 U=0.30 Ufsp=0.31 Da=2.4 La= 9.0
two= -40. to=-40. t1= 80.0 t2= 80.0 t3= 80.0 tes= 80.0  dtm=.010  tk=20.0 dTAU=   30
T1=1800. T2=  10. T3=  10. dT3=  0. dtm3= 0. T4=  10. T5= 600.  TAUk=     0 INT=18000
ds=.008  Si=.10  ROi=120. Ai=.00000022 dFa=0.05 Kk=.2  tcs= 47.0 dtwc= 0.0  Ts=     0
Pw=.30 Vw=14.39 Va=47.95 tbi= 0. Sim=0.200 Xp=1.00  Lw=0.80 bw=.40 dw=.40  dx=.01000
                              R E S U L T S
```

Time TAU, h / Coordinates z, mm y, mm	tm 0 oC	20 oC	40 oC	60 oC	80 oC	100 oC	120 oC	140 oC	160 oC	180 oC	200 oC
TAU = 0.0 h											
z=400 mm y= 0 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y= 20 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y= 40 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y= 60 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y= 80 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y=100 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y=120 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y=140 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y=160 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y=180 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y=200 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
TAU = 5.0 h											
z=400 mm y= 0 mm	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
z=400 mm y= 20 mm	80.0	75.3	70.8	66.9	63.7	61.2	59.4	58.3	57.7	57.4	57.3
z=400 mm y= 40 mm	80.0	70.8	62.1	54.2	47.7	42.6	39.1	36.8	35.5	34.9	34.7
z=400 mm y= 60 mm	80.0	66.9	54.2	42.7	33.0	25.4	20.0	16.7	14.8	13.9	13.6
z=400 mm y= 80 mm	80.0	63.7	47.7	33.0	20.4	10.4	3.3	-1.0	-3.7	-4.6	-4.9
z=400 mm y=100 mm	80.0	61.2	42.6	25.4	10.4	-1.7	-9.8	-13.9	-16.1	-17.2	-17.5
z=400 mm y=120 mm	80.0	59.4	39.1	20.0	3.3	-9.8	-17.3	-21.6	-23.9	-25.1	-25.5
z=400 mm y=140 mm	80.0	58.3	36.8	16.7	-1.0	-13.9	-21.6	-26.1	-28.7	-30.0	-30.4
z=400 mm y=160 mm	80.0	57.7	35.5	14.8	-3.7	-16.1	-23.9	-28.7	-31.5	-32.9	-33.4
z=400 mm y=180 mm	80.0	57.4	34.9	13.9	-4.6	-17.2	-25.1	-30.0	-32.9	-34.4	-34.9
z=400 mm y=200 mm	80.0	57.3	34.7	13.6	-4.9	-17.5	-25.5	-30.4	-33.4	-34.9	-35.4
TAU = 10.0 h											
z=400 mm y= 0 mm	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
z=400 mm y= 20 mm	80.0	77.8	75.7	73.7	71.9	70.3	68.9	67.8	67.1	66.6	66.5
z=400 mm y= 40 mm	80.0	75.7	71.5	67.5	63.8	60.6	57.8	55.7	54.1	53.1	52.8
z=400 mm y= 60 mm	80.0	73.7	67.5	61.6	56.1	51.2	47.1	43.8	41.4	39.9	39.4
z=400 mm y= 80 mm	80.0	71.9	63.8	56.1	48.9	42.5	36.9	32.5	29.3	27.3	26.6
z=400 mm y=100 mm	80.0	70.3	60.6	51.2	42.5	34.6	27.7	22.2	18.1	15.6	14.7
z=400 mm y=120 mm	80.0	68.9	57.8	47.1	36.9	27.7	19.7	13.1	8.1	5.0	4.0
z=400 mm y=140 mm	80.0	67.8	55.7	43.8	32.5	22.2	13.1	5.4	-0.6	-4.4	-5.5
z=400 mm y=160 mm	80.0	67.1	54.1	41.4	29.3	18.1	8.1	-0.6	-7.0	-10.3	-11.3
z=400 mm y=180 mm	80.0	66.6	53.1	39.9	27.3	15.6	5.0	-4.4	-10.3	-13.4	-14.3
z=400 mm y=200 mm	80.0	66.5	52.8	39.4	26.6	14.7	4.0	-5.5	-11.3	-14.3	-15.3
TAU = 15.0 h											
z=400 mm y= 0 mm	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
z=400 mm y= 20 mm	80.0	78.7	77.4	76.2	75.1	74.1	73.2	72.5	72.0	71.7	71.6
z=400 mm y= 40 mm	80.0	77.4	74.9	72.5	70.2	68.2	66.5	65.0	64.0	63.4	63.1
z=400 mm y= 60 mm	80.0	76.2	72.5	68.9	65.6	62.5	59.9	57.8	56.2	55.2	54.9
z=400 mm y= 80 mm	80.0	75.1	70.2	65.6	61.2	57.2	53.7	50.9	48.8	47.5	47.1
z=400 mm y=100 mm	80.0	74.1	68.2	62.5	57.2	52.3	48.1	44.6	42.0	40.4	39.9
z=400 mm y=120 mm	80.0	73.2	66.5	59.9	53.7	48.1	43.1	39.1	36.0	34.2	33.5
z=400 mm y=140 mm	80.0	72.5	65.0	57.8	50.9	44.6	39.1	34.5	31.1	29.0	28.3
z=400 mm y=160 mm	80.0	72.0	64.0	56.2	48.8	42.0	36.0	31.1	27.4	25.1	24.3
z=400 mm y=180 mm	80.0	71.7	63.4	55.2	47.5	40.4	34.2	29.0	25.1	22.7	21.9
z=400 mm y=200 mm	80.0	71.6	63.1	54.9	47.1	39.9	33.5	28.3	24.3	21.9	21.1
TAU = 20.0 h											
z=400 mm y= 0 mm	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
z=400 mm y= 20 mm	80.0	79.2	78.4	77.7	77.0	76.4	75.9	75.5	75.2	75.0	74.9
z=400 mm y= 40 mm	80.0	78.4	76.9	75.5	74.1	72.9	71.9	71.0	70.4	70.1	69.9
z=400 mm y= 60 mm	80.0	77.7	75.5	73.3	71.3	69.6	68.0	66.8	65.8	65.3	65.1
z=400 mm y= 80 mm	80.0	77.0	74.1	71.3	68.7	66.4	64.4	62.8	61.6	60.8	60.6
z=400 mm y=100 mm	80.0	76.4	72.9	69.6	66.4	63.6	61.1	59.1	57.7	56.8	56.5
z=400 mm y=120 mm	80.0	75.9	71.9	68.0	64.4	61.1	58.3	56.0	54.3	53.3	52.9
z=400 mm y=140 mm	80.0	75.5	71.0	66.8	62.8	59.1	56.0	53.5	51.6	50.4	50.0
z=400 mm y=160 mm	80.0	75.2	70.4	65.8	61.6	57.7	54.3	51.6	49.6	48.3	47.9
z=400 mm y=180 mm	80.0	75.0	70.1	65.3	60.8	56.8	53.3	50.4	48.3	47.0	46.6
z=400 mm y=200 mm	80.0	74.9	69.9	65.1	60.6	56.5	52.9	50.0	47.9	46.6	46.1

Figure 2 Change in t in the nodes of the calculation mesh, situated in the central cross section of a beech prism with dimensions 0.4 x 0.4 x 0.8 m and u = 0.3 kg·kg^{-1} during every 5 h of defrosting at t_m = 80°C
Slika 2. Promjene temperature u čvorovima računske mreže smještenima na središnjemu poprečnom presjeku bukove prizme dimenzija 0,4 x 0,4 x 0,8 m i u = 0,3 kg·kg^{-1} tijekom svakih 5 h odmrzavanja pri temperaturi t_m = 80°C

left side) to the points, which are equally distanced (at $d/4$ = 100 mm and $b/4$ = 100 mm) from both surfaces, shaping the cross sections of the prisms.

The first characteristic point is at $L/8$ = 100 mm from the prism base, the second one at $L/4$ = 200 mm, and the third one at $L/2$ = 400 mm. Fig. 4 and 5 shows that there is an almost identical non-linear character of the temperature change in these points, defined mainly by the heat transfer perpendicular to the wood fibers. The defrosting process in the wood slows down almost proportionally to the distance of the characteristic points from the prism base.

The fourth characteristic point with coordinates ($d/4$, $b/2$, $L/2$) is located at $d/4$ =100 mm and $b/2$ = 200 mm from the surfaces, forming the cross section of the prisms and at $L/2$ = 400 mm from the base and the top side of the prisms. The complex non-symmetrical heat transfer in both longitudinal and perpendicular directions to the wood fibers causes at that point an almost linear change in t during the defrosting process.

```
                          I N P U T   D A T A
                      3D DEFROSTING OF BEECH PRISM
Kq=11 M= 21 N= 21 KD= 41 ROb=560. Kwc=1.28 Kwpc=1.88 U=0.60 Ufsp=0.31 Da=2.4 La= 9.0
two= -40. to=-40. t1= 80.0 t2= 80.0 t3= 80.0 tes= 80.0  dtm=.010  tk=20.0 dTAU=   25
T1=1800. T2=  10. T3=  10. dT3=  0. dtm3= 0. T4=  10. T5= 600.  TAUk=    0 INT=18000
ds=.008  Si=.10  ROi=120. Ai=.00000022 dFa=0.05 Kk=.2  tcs= 32.0 dtwc= 0.0  Ts=    0
Pw=.30 Vw=14.39 Va=47.95 tbi= 0. Sim=0.200 Xp=1.00  Lw=0.80 bw=.40 dw=.40  dx=.01000
                              R E S U L T S
*************************************************************************************
```

Time TAU, h / Coordinates z, mm y, mm	tm 0 oC	20 oC	40 oC	60 oC	80 oC	100 oC	120 oC	140 oC	160 oC	180 oC	200 oC
						Coordinate x of the characteristic points, mm					
TAU = 0.0 h											
z=400 mm y= 0 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y= 20 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y= 40 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y= 60 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y= 80 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y=100 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y=120 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y=140 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y=160 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y=180 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
z=400 mm y=200 mm	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
TAU = 5.0 h											
z=400 mm y= 0 mm	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
z=400 mm y= 20 mm	80.0	74.7	69.7	65.3	61.8	59.2	57.5	56.6	56.1	55.9	55.8
z=400 mm y= 40 mm	80.0	69.7	59.8	51.0	43.7	38.4	35.0	33.2	32.4	32.0	31.9
z=400 mm y= 60 mm	80.0	65.3	51.0	37.8	26.9	18.7	13.5	10.3	9.7	9.4	9.3
z=400 mm y= 80 mm	80.0	61.8	43.7	26.9	12.2	-1.1	-3.2	-6.1	-6.9	-7.3	-7.4
z=400 mm y=100 mm	80.0	59.2	38.4	18.7	-1.1	-7.3	-11.8	-14.6	-16.1	-16.9	-17.2
z=400 mm y=120 mm	80.0	57.5	35.0	13.5	-3.2	-11.8	-17.2	-20.6	-22.7	-23.7	-24.1
z=400 mm y=140 mm	80.0	56.6	33.2	10.3	-6.1	-14.6	-20.6	-24.5	-27.0	-28.2	-28.6
z=400 mm y=160 mm	80.0	56.1	32.4	9.7	-6.9	-16.1	-22.7	-27.0	-29.6	-31.0	-31.5
z=400 mm y=180 mm	80.0	55.9	32.0	9.4	-7.3	-16.9	-23.7	-28.2	-31.0	-32.6	-33.0
z=400 mm y=200 mm	80.0	55.8	31.9	9.3	-7.4	-17.2	-24.1	-28.6	-31.5	-33.0	-33.5
TAU = 10.0 h											
z=400 mm y= 0 mm	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
z=400 mm y= 20 mm	80.0	77.5	75.1	72.8	70.8	69.0	67.5	66.3	65.5	65.0	64.9
z=400 mm y= 40 mm	80.0	75.1	70.3	65.7	61.6	57.9	54.8	52.5	50.8	49.8	49.5
z=400 mm y= 60 mm	80.0	72.8	65.7	59.0	52.7	47.1	42.4	38.8	36.3	34.8	34.3
z=400 mm y= 80 mm	80.0	70.8	61.6	52.7	44.4	36.9	30.6	25.7	22.2	20.2	19.7
z=400 mm y=100 mm	80.0	69.0	57.9	47.1	36.9	27.7	19.6	13.3	8.8	6.1	5.6
z=400 mm y=120 mm	80.0	67.5	54.8	42.4	30.6	19.6	9.8	2.2	-2.0	-3.7	-4.1
z=400 mm y=140 mm	80.0	66.3	52.5	38.8	25.7	13.3	2.2	-3.8	-6.6	-8.1	-8.6
z=400 mm y=160 mm	80.0	65.5	50.8	36.3	22.2	8.8	-2.0	-6.6	-9.5	-11.2	-11.7
z=400 mm y=180 mm	80.0	65.0	49.8	34.8	20.2	6.1	-3.7	-8.1	-11.2	-12.9	-13.5
z=400 mm y=200 mm	80.0	64.9	49.5	34.3	19.7	5.6	-4.1	-8.6	-11.7	-13.5	-14.1
TAU = 15.0 h											
z=400 mm y= 0 mm	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
z=400 mm y= 20 mm	80.0	78.5	76.9	75.5	74.1	72.9	71.9	71.0	70.4	70.0	69.8
z=400 mm y= 40 mm	80.0	76.9	73.9	71.0	68.3	65.8	63.7	61.9	60.6	59.8	59.5
z=400 mm y= 60 mm	80.0	75.5	71.0	66.7	62.6	58.9	55.6	52.9	50.9	49.6	49.2
z=400 mm y= 80 mm	80.0	74.1	68.3	62.6	57.2	52.3	47.8	44.2	41.4	39.6	39.0
z=400 mm y=100 mm	80.0	72.9	65.8	58.9	52.3	46.1	40.5	35.8	32.2	29.8	29.0
z=400 mm y=120 mm	80.0	71.9	63.7	55.6	47.8	40.5	33.8	28.0	23.4	20.4	19.4
z=400 mm y=140 mm	80.0	71.0	61.9	52.9	44.2	35.8	28.0	21.1	15.3	11.3	9.7
z=400 mm y=160 mm	80.0	70.4	60.6	50.9	41.4	32.2	23.4	15.3	8.1	2.6	-1.1
z=400 mm y=180 mm	80.0	70.0	59.8	49.6	39.6	29.8	20.4	11.3	2.6	-2.0	-2.1
z=400 mm y=200 mm	80.0	69.8	59.5	49.2	39.0	29.0	19.4	9.7	-1.1	-2.1	-2.3
TAU = 20.0 h											
z=400 mm y= 0 mm	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
z=400 mm y= 20 mm	80.0	79.0	78.0	77.0	76.2	75.3	74.6	74.1	73.6	73.4	73.3
z=400 mm y= 40 mm	80.0	78.0	76.0	74.1	72.3	70.7	69.3	68.2	67.3	66.8	66.6
z=400 mm y= 60 mm	80.0	77.0	74.1	71.3	68.7	66.2	64.1	62.4	61.1	60.3	60.0
z=400 mm y= 80 mm	80.0	76.2	72.3	68.7	65.2	62.0	59.2	56.8	55.1	54.0	53.6
z=400 mm y=100 mm	80.0	75.3	70.7	66.2	62.0	58.0	54.6	51.7	49.5	48.2	47.7
z=400 mm y=120 mm	80.0	74.6	69.3	64.1	59.2	54.6	50.5	47.1	44.6	43.0	42.4
z=400 mm y=140 mm	80.0	74.1	68.2	62.4	56.8	51.7	47.1	43.3	40.4	38.6	38.0
z=400 mm y=160 mm	80.0	73.6	67.3	61.1	55.1	49.5	44.6	40.4	37.3	35.3	34.6
z=400 mm y=180 mm	80.0	73.4	66.8	60.3	54.0	48.2	43.0	38.6	35.3	33.2	32.5
z=400 mm y=200 mm	80.0	73.3	66.6	60.0	53.6	47.7	42.4	38.0	34.6	32.5	31.8

Figure 3 Change in t in the nodes of the calculation mesh, situated in the central cross section of a beech prism with dimensions 0.4 x 0.4 x 0.8 m and u = 0.6 kg.kg^{-1} during every 5 h of defrosting at t_m = 80°C
Slika 3. Promjene temperature u čvorovima računske mreže smještenima na središnjemu poprečnom presjeku bukove prizme dimenzija 0,4 x 0,4 x 0,8 m i u = 0,6 kg·kg^{-1} tijekom svakih 5 h odmrzavanja pri temperaturi t_m = 80°C

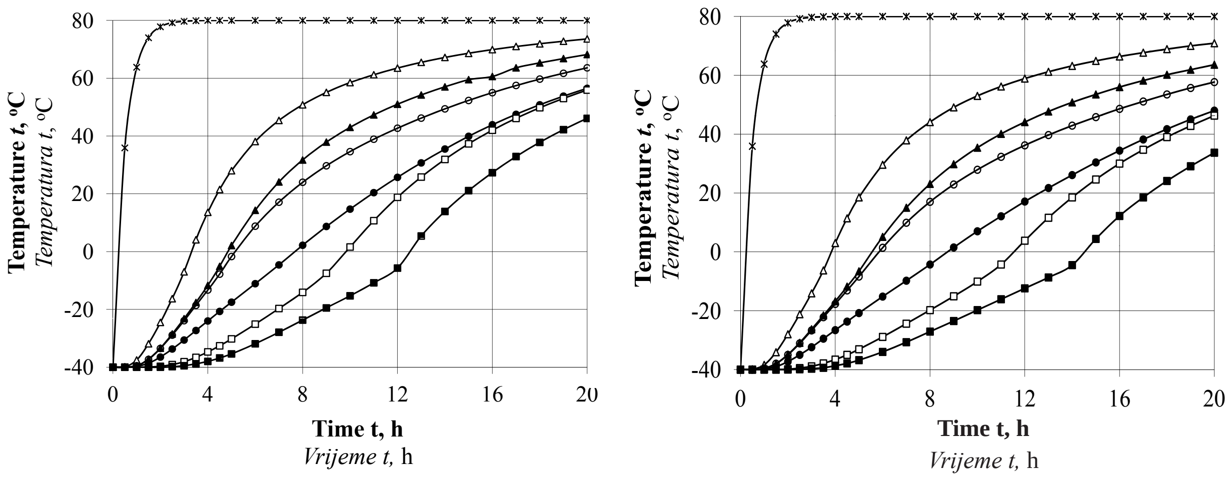

Figure 4 3D change in *t* of frozen beech (left) and oak (right) prism with dimensions 0.4 x 0.4 x 0.8 m, t_0 = -40°C, and $u = 0.3$ kg·kg^{-1} during their defrosting at t_m = 80°C, depending on τ
Slika 4. 3D promjene temperature smrznutih bukovih (lijevo) i hrastovih (desno) prizmi dimenzija 0,4 x 0,4 x 0,8 m, t_0 = -40°C, i $u = 0{,}3$ kg·kg^{-1} tijekom njihova odmrzavanja pri temperaturi t_m = 80°C, u ovisnosti o τ

The fifth and sixth characteristic points with coordinates (*d*/2, *b*/2, *L*/4) and (*d*/2, *b*/2, *L*/2) are located along the prism longitudinal axis. They are equally distanced (at *d*/2 = 200 mm and *b*/2 = 200 mm) from the surfaces forming the cross sections of the prisms. The sixth point with temperature T_C (see Fig. 1 – left side) is located in the centre of the prisms at a double distance (*L*/2 = 400 mm) from the prism base compared to the fifth point with *L*/4 = 200 mm.

The complex non-linear change in temperature in the fifth and sixth characteristic points is almost identical, but it differs from the change in the first three points. This is a result of not only the heat transfer perpendicular to the fibers, but is also caused, to a significant degree, by the heat transfer longitudinal to the fibers. Of course, the double distance of the sixth point from the base of the prism causes a significantly slower change in *t* compared to the temperature change in the fifth characteristic point.

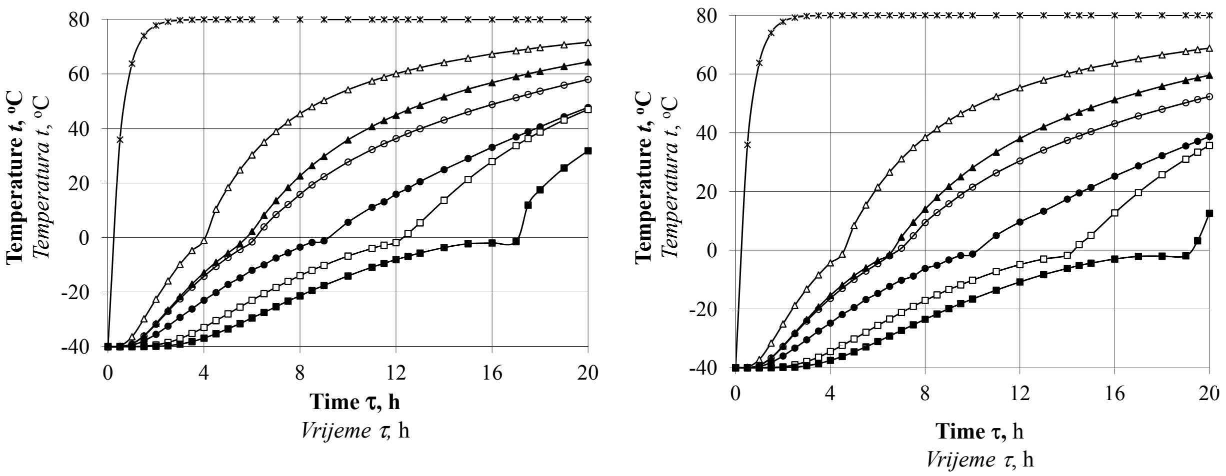

Figure 5 3D change in *t* of frozen beech (left) and oak (right) prism with dimensions 0.4 x 0.4 x 0.8 m, t_0 = -40°C, and $u = 0.6$ kg·kg^{-1} during defrosting at t_m = 80°C, depending on τ
Slika 5. 3D promjene temperature smrznutih bukovih (lijevo) i hrastovih (desno) prizmi dimenzija 0,4 x 0,4 x 0,8 m, t_0 = -40°C, i $u = 0{,}6$ kg·kg^{-1} tijekom njihova odmrzavanja pri temperaturi t_m = 80°C, u ovisnosti o τ

The computed values of temperature of the third, fourth, and sixth characteristic points during corresponding moments of the defrosting process are underlined in Fig. 2 and 3. Apart from them, the corresponding input data, which is used for the solution of the 3D model, is also underlined. The remaining input data, which is not underlined in the figures, is mainly related to the parameters of the equipment with which the thermal treatment of the wood materials (aimed at defrosting) is carried out. Using this input data, the energy parameters of the defrosting process and the efficiency of the equipment are calculated.

Fig. 4 and 5 shows that the change in temperature in the wood materials is significantly slower during ice melting then in the periods that follow when the materials are heated since there is no ice in the wood. This slowing down is increased in the presence of ice in the materials formed not only from bound water, but also from free water in the wood.

The curves in Fig. 5 show, through characteristic points located on the prism inner layers, the specific almost horizontal sections of long temperature retention in the range from –2 °C to –1 °C, while in these points a complete melting of the ice formed from free water in the wood occurs (Chudinov, 1968). However, the greater the distance of a given characteristic point from the prism surfaces, the higher are its temperature retention values.

For example, it takes about 0.5 h for melting of the ice formed from free water in the point with coordinates *d*/4, *b*/2, *L*/2; in the point with coordinates *d*/2, *b*/2, *L*/4 – about 1.2 h, and in the point with coordinates *d*/2, *b*/2, *L*/2 (central point of the prism volume) – about 2.5 h.

Such temperature retention in the range from –2 °C to –1 °C has been widely observed in experimental studies during the defrosting process of pine logs containing ice from free water (Steinhagen, 1986; Khattabi and Steinhagen, 1992, 1993).

It must be noted that there are no such almost horizontal sections in the change of wood temperature during defrosting of the ice formed only by bound water in the wood (Fig. 4). The reason lies in the fact that melting of the ice, formed by bound water, does not take place in a tight temperature range, but gradually throughout the whole range from the initial temperature of the frozen wood t_0 = -40°C to $t = -2\ ^{o}\mathrm{C}$. After the final melting of the ice formed from bound water, wood temperature increases more rapidly. This is evidenced by the increase in steepness of the curves in Fig. 4 after $t > -2\ ^{o}\mathrm{C}$, especially the curves in the inner layers of prisms subjected to defrosting.

A complete melting of the ice formed only from bound water in the center of the studied prisms with dimensions 0.4 x 0.4 x 0.8 m, t_0 = -40°C and u = 0.3 kg·kg^{-1} takes place approximately after 12.5 h of heating at t_m = 80°C for a beech prism and after 14.5 h for an oak prism (Fig. 4). I takes 4.5 h and 5.0 h, respectively, fFor melting the ice formed from free water in beech and oak prisms with u = 0.6 kg·kg^{-1}, under the same conditions, i.e. the final defrosting of the prisms takes place after 17.0 h of thermal treatment for a beech prism and after 19.5 h for an oak prism (Fig. 5). The longer duration of the defrosting process in oak wood is caused by the higher density of the oak wood compared to that of the beech wood.

3.2 Color visualization of 3D non-stationary temperature distribution in prisms during defrosting
3.2. Vizualizacija pomoću boja 3D nestacionarne raspodjele temperature u prizmi za vrijeme odmrzavanja

The results obtained by Visual Fortran for 3D temperature distribution in the volume of wooden prisms undergoing defrosting have been subjected to the following visualization with the help of the software Excel 2010. The color contour plots prepared by this software are exhibited in Fig. 6 and 7, showing the non-stationary temperature distribution in 12 cross sections equally distributed from each other in 1/8 of the volume of the prisms after 5 h and 10 h of heating.

The temperature distribution in oak prisms during their defrosting is analogical to the temperature distribution in beech prisms, as shown in Fig. 6 and 7. A certain slowing down of the defrosting process can be seen in oak prisms, which corresponds to the slowing down in the temperature change in denser oak wood compared to that in beech wood, as shown in Fig. 4 and 5.

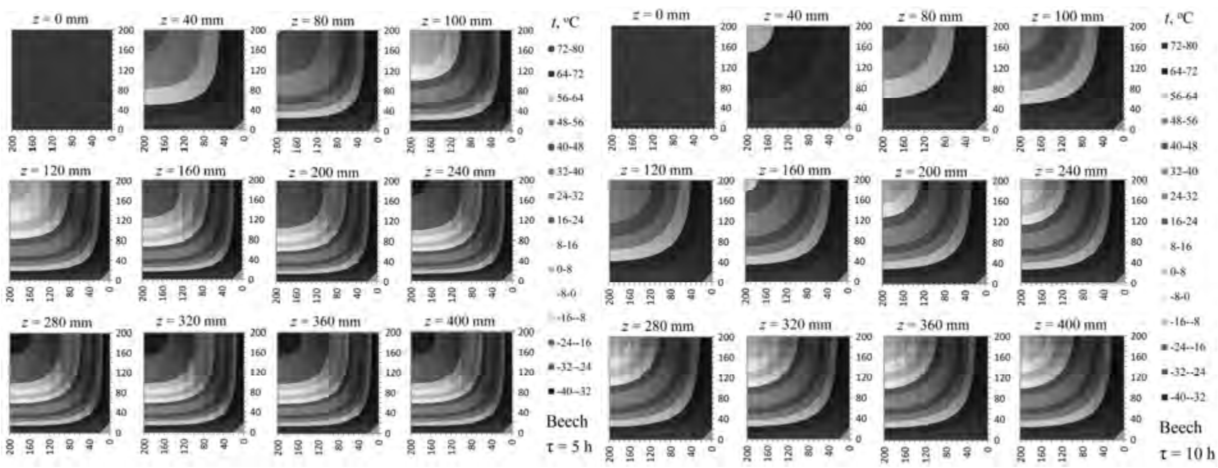

Figure 6 Contour plots of temperature distribution in 1/8 of the volume of the beech prism subjected to defrosting with t_0 = –40 °C and u = 0.3 kg.kg^{-1} after 5 h (left) and 10 h (right) heating at t_m = 80 °C
Slika 6. Konturni crteži raspodjele temperature u 1/8 volumena bukovih prizmi koje se odmrzavaju pri t_0 = –40 °C i uz u = 0,3 kg·kg^{-1} nakon 5 h (lijevo) i nakon 10 h (desno) zagrijavanja na temperaturi t_m = 80 °C

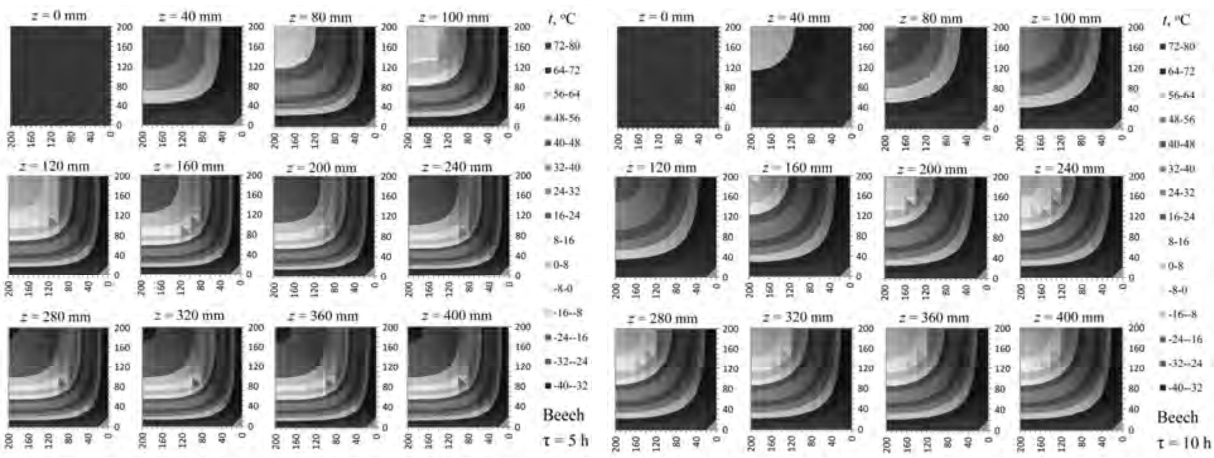

Figure 7 Contour plots of temperature distribution in 1/8 of the volume of the beech prism subjected to defrosting with t_0 = –40 °C and u = 0.6 kg.kg^{-1} after 5 h (left) and 10 h (right) heating at t_m = 80 °C
Slika 7. Konturni crteži raspodjele temperature u 1/8 volumena bukovih prizmi koje se odmrzavaju pri t_0 = –40 °C i uz u = 0,6 kg·kg^{-1} nakon 5 h (lijevo) i nakon 10 h (desno) zagrijavanja na temperaturi t_m = 80 °C

The analysis of the contour plots in Fig. 6 and 7 shows the following:

- When the prisms subjected to defrosting contain ice only formed from bound water in the wood, then all the borders between the adjacent temperature zones on the contour plots are represented by smooth, curved lines (Fig. 6);
- When the prisms contain ice formed from both bound and free water in the wood, then the smoothness of the curved lines of the borders between the adjacent temperature zones from -8 °C to 0 °C and from 0 °C to 8 °C (Fig. 7) is deformed. A reason for this is shown in the analysis presented in the above Fig. 5, when the temperature remains for a long period of time in the range from -2 °C to -1 °C in the points located in the inner layers of the prisms. The temperature ranges between -2 °C and -1 °C until the ice in these points, formed from free water in the wood, is completely melted (Chudinov, 1968). While the points with ice not completely melted are still located in the color zone from -8 °C to 0 °C, some of their adjacent points from the calculation mesh after complete melting of the ice go into the zone from 0 °C to 8 °C. This explains the deformation of the smoothness of the borders between these zones of the contour plots at τ = 5 h and τ = 10 h in prisms with u = 0.6 kg·kg^{-1} (Fig. 7).

A significantly faster temperature increase along the length of the prisms can be seen on the contour plots compared to the increase of the temperature in the cross sectional direction to the wood fibers. The reason for this is a much higher thermal conductivity in the direction longitudinal to the fibers than in the cross sectional direction: 1.76 times for oak and 1.88 times for beech wood (Deliiski, 2003a). For example, after 10 h of defrosting of the beech prism with u = 0.6 kg·kg^{-1} in the temperature zone from 0 °C to 8 °C moves inside the prism as follows (Fig. 7 – right side):

- to a distance equal to $x = y$ = 110 mm from the surfaces forming the central cross section with z = 400 mm, in which the heat transfer perpendicular to the fibers prevails;
- to a distance equal to $x = y$ = 180 mm from the surfaces forming the cross section with z = 160 mm, on which the heat transfer longitudinal to the fibers has a dominant impact.

4 CONCLUSIONS
4. ZAKLJUČCI

This paper describes the development and solution of a 3D non-linear mathematical model for the transient heat conduction in frozen wood with prismatic shape and with any $u \geq 0$ kg·kg^{-1} at arbitrary, initial and boundary conditions encountered in practice. The model takes into account for the first time the fiber saturation point of each wood species, u_{fsp}, and the impact of the temperature on u_{fsp} of frozen and non-frozen wood, which are then used to compute the current values of the thermal and physical characteristics in each separate volume point of the material subjected to defrosting (Deliiski, 2013).

Heat distribution in the entire volume of the prisms is described by the 3D partial differential equation of heat conduction. For the solution of the model, an explicit form of the finite-difference method is used, with the possibility of excluding any model simplifications.

For the numerical solution of the model a software package has been developed in FORTRAN and integrated in the calculation environment of Visual Fortran Professional developed by Microsoft.

Reliability and precision of the model, according to the results of our own experimental studies and studies by other authors, allow various calculations related to the non-stationary temperature distribution in frozen prismatic materials from various wood species during their defrosting.

The results presented in the figures of this paper show that the procedures for the calculation of non-stationary 3D temperature change, developed by the software, are efficient in cases of defrosting of frozen wooden prisms with ice formed of bound water in the wood as well as of both bound and free water in the wood.

The results obtained in the calculation environment of Visual Fortran for the 3D non-stationary temperature distribution in the wooden prism volume undergoing defrosting have been subjected to visualization with Excel 2010. Using this software, the prepared color contour plots show the change of the temperature in cross sections equally distant from each other in 1/8 of the volume of the prisms after the desired durations of their heating. The contour plots can be displayed not only individually at each time step of the defrosting process for detailed examination, but they can also be displayed together as an animation for the overall trend observation, which can be very helpful for the industry operators to easily foresee the overall changes of the process.

The visualization with color contour plots allows tracking and analyzing the movement of the border of ice melting in the volume of the prisms during their heating. Also the change in the temperature perpendicular and longitudinal to the fibers can be seen. With the help of the visualization of contour plots, it is easy to determine the moment of reaching the zone of optimal temperatures in the volume of different wood species, guaranteeing the necessary plasticizing of the wood and producing high-quality veneer.

The updated model is incorporated in the software for microprocessor programmable controllers used for model predictive automatic control (Hadjiyski, 2003) of the process of thermal treatment of prismatic wood with or without ice. The controllers ensure the improved science-based energy- and resource-saving control of plasticized veneer production, compared to that used in a previous version of the software (Deliiski, 2003b; Deliiski and Dzurenda, 2010).

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Symbols - Simboli

b – width, m
c – specific heat capacity, $J \cdot kg^{-1} \cdot K^{-1}$
d – thickness, m
L – length, m
T – temperature, K
t – temperature, C
u – moisture content, $kg \cdot kg^{-1}$ = %/100
x – coordinate along thickness: $0 \leq x \leq d/2$, m
y – coordinate along width: $0 \leq y \leq b/2$, m
z – longitudinal coordinate: $0 \leq z \leq L/2$, m
β, γ – coefficients in equations for determining of λ, given in Deliiski (2011, 2013)
λ – thermal conductivity, $W \cdot m^{-1} \cdot K^{-1}$
ρ – density, $kg \cdot m^{-3}$
τ – time, s
Δx – distance between mesh points in space coordinates, m
$\Delta \tau$ – interval between time levels, s

Subscripts:

b – basic (for density, based on dry mass divided to green volume)
bw – bound water
c – center (of prisms)
cr – cross sectional to wood fibers
e – effective (for specific heat capacity)
fsp – fiber saturation point
fw – free water
i – nodal point along prism thickness: i = 1, 2, 3,…, M=1+[d/(2Δx)]
j – nodal point along prism width: j = 1, 2, 3, …, N=1+[(b/(2Δx)]
k – nodal point in longitudinal direction of the prism: k = 1, 2, 3, …, KD=1+[L/(2Δx)]
m – medium (for heating substance)
r – radial to wood fibers
t – tangential to wood fibers
0 – initial (for t or at 0 ^oC for λ)
p – parallel to wood fibers
p/cr – parallel to cross sectional

Superscripts:

n – time level: n = 0, 1, 2, …
20 – 20 °C

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Evaluation of Material Characteristics of Xylite – Part 1. Influence of Moisture Content on Some Mechanical Properties

Procjena obilježja ksilita - Dio 1. Utjecaj sadržaja vode na mehanička svojstva

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ABSTRACT • *The structure of xylite as lithotype of lignite indicates that it predominately originates from tree stems, from the family Taxodiaceae or Cupressaceae. Despite drastic changes in the long term process of its transformation, it retains some relevant properties of wood, nowadays applicable for specific products. The research examined the influence of moisture content and temperature on modulus of elasticity (MOE) and modulus of rupture (MOR) as well as shear strength and hardness. With decreasing of moisture content, the bending strength and stiffness of xylite increased and was best fitted by power regression model. The increasing of testing temperature from 20 °C to 80 °C had negative effect on stiffness and bending strength of xylite. The hardness was positively correlated with density of xylite, whereas shear strength had the opposite tendency.*

Keywords*: xylite, moisture content, modulus of elasticity, modulus of rupture, shear strength, hardness*

SAŽETAK • *Građa ksilita, litotipa lignita, pokazuje da on većinom potječe iz stabala porodica Taxodiaceae i Cupressaceae. Usprkos drastičnim promjenama u dugotrajnim geološkim procesima transformacije, ksilit je zadržao neka važna svojstva drva. U istraživanju je ispitivan utjecaj sadržaja vode i temperature ksilita na njegov modul elastičnosti i modul loma pri savijanju, kao i na smicajnu čvrstoću te na tvrdoću. Sa smanjivanjem sadržaja vode u ksilitu posmična čvrstoća i modul elastičnosti poboljšavaju se. Ovisnost najbolje opisuje potencijski regresijski model. Podizanje temperature s 20 na 80 °C negativno je utjecalo na modul elastičnosti i čvrstoću savijanja ksilita. Tvrdoća ksilita bila je u pozitivnoj korelaciji s gustoćom, a modul lomsmicajna čvrstoća se s povećanjem gustoće smanjila.*

Ključne riječi: *ksilit, sadržaj vode, modul elastičnosti, modul loma pri savijanju, smicajna čvrstoća, tvrdoća*

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1 INTRODUCTION
1. UVOD

Xyilite is a lithotype of lignite, also known as xyloid lignite or fossil wood, mined in various parts of Europe, United States, India and Australia. In Slovenia lignite is found in the Velenje basin, which is tectonically controlled intermountain basin filled by a succession of Pliocene and Plio-Quarternary sediments more than 1000 m thick (Markič and Sachenhofer, 2010). The lower part of swamp should be covered with grass like vegetation, surrounded by bushes and than by higher woody plants and trees. Vegetation (plants) covered with water should be subject to gradual but strong diagenetic and epigenetic changes reflected by a strong petrological heterogeneity as well as highly variable geotechnical properties and behavior in different underground coal layers (Brezigar, 1985/86). The Velenje seam formed during the transition from the fluvial to lacustrine one. Petrographical investigations confirmed a zonation of lignite, changing from xylite rich layer characteristic for the outer and lower part of the lignite seam, to fine detrital layer predominating in the inner and upper part of the seam. Galafficational basis without distinctive structure (derit) prevails with approximately 60 %, the content of wood tissue with recognizable cellular xylem structure (tekstit) amounts to 40 % and there is a small amount of fizit (Drovenik, 1982; Justin and Markič, 2005).The form and structure of xylite indicate that it originates from tree stems. The investigation revealed that xylite mainly consists of traheids and contains uniseriate and homocellulare rays, taxodioid like cross-field pits, and abundant axial parenchyma with inclusion. Axial or radial resin channels were not observed (Gorišek *et al*., 2013). The observed features are typical of conifers of the family Taxodiaceae (e.g. genera *Taxodium*, *Sequoia*, *Sequoiadendron*) and Cupressaceae (e.g. genera *Juniperus*, *Chameacyparis*, *Cupressus*).

The structure of wood underwent considerable changes during the long term process of conversion from wood to xylite due to biochemical, geochemical and geological factors as well as carbonization (duration approx. 2 million years). The conversion of wood components is strongly influenced by environmental conditions. Submersion and underground embedding initiate very slow process of fossilization (Fengel, 1991) and solid state ^{13}C nuclear magnetic resonance and microscopic analysis showed good preservation of the cellulose structure so that fossil cellulose could not be degraded by cellulases and anaerobic microorganisms usually involved in the biodegradation of organic substances (Lechien *at al*., 2006). The most distinctive chemical changes are identified as gradual hydrolyzation or otherwise degradation of carbohydrates, while lignin structure remains more or less stable, and consequently its relative proportion increased (Hatcher *et al*., 1981; Hatcher *et al*., 1982; Drobnjak and Mastalerz, 2006). The polyoses are continuously degraded as acidic groups split off and cause an in-situ acid hydrolyses (Fengel, 1991). Changes of lignin molecules are held in interdependent reactions of oxidation, demetylation, loss of hydroxyl groups and condensation, which lead to more condensed structures (Fengel, 1991, Crook *et al*. 1965).

Chemical changes with interaction of mechanical stress resulted in deformity of individual cells, tissues or whole pieces of plants. High compressive forces acting in radial and tangential directions resulted in completely collapsed early wood cells. Latewood cells, which had thicker and more rigid cell walls, were less damaged. Due to collapse of cell walls into lumina, the density of xylite is high (the oven dry density of xylite was 1216 kg/m^3, whereas the basic density was only 873 kg/m^3, due to large volumetric shrinkage) but the capillary structure and hygroscopic characteristic of wood are preserved (Gorišek *et al*., 2012).

The appearance of xylite resembles that of precious wood species with dark heartwood and when it does not contain great amounts of mineral inclusions, it can be processed with wood working machines. Especially when polished, it often shows recognizable structure of wood and its color looks like wood species with dark colored heartwood, such as wenge (*Milletia-laurentii*) or ebony (*Dyospiros* sp.).

Xylite remains hygroscopic; therefore it should be dried to the appropriate moisture content, which can ensure dimensional stability during use (Gorišek *et al*. 2013). Consequently, with varying moisture, adequate changes of mechanical properties can be expected.

The present study is focused on determination of some basic and processing-relevant mechanical properties of xylite, and on possible use of xylite as a substitute for valuable, tropical wood species. Due to its high sorption capacity, the influence of temperature and moisture content on examined mechanical properties of xylite is studied.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

The xylite for the experiment originates from the Velenje basin in Slovenia. Individual pieces were selected from the regular production line of lignite mine. Since xylite is petrographic strongly heterogeneous with a large variation of geotechnical properties, our sampling was based on visual assessment of material by selecting the xylite with the best preserved wood structures. We cut out all mineral inclusions and kept the most conserved material with recognizable structure of wood, which allowed us to make quite well xylotomic oriented slices without visible growth features of injury incurred during xylite formation.

The mechanical properties were tested at two temperature levels (T_1 = 20 °C and T_2 = 80 °C); first in green state, immediately after cutting the specimens from the xylite blocks, and then after equilibrating at four different relative humidities (RH) achieved in thermostatically controlled chambers with the saturated salt solutions (RH_1 = 34 % ($MgCl_2$), RH_2 = 65 % ($NaNO_2$), RH_3 = 75 % (NaCl) and RH_4 = 87 % ($ZnSO_4$)).

To determine the modulus of elasticity (*MOE*), standard 3-point static bending test was used (EN 310). As the cross section of all samples was not identical, it varied namely between 6 by 15 mm to 10 by 25 mm (*h* by *b*), it was attempted to avoid the shear contribution at selected samples with the constant span to thickness ratio of 17. The bending modulus of elasticity was obtained as:

$$MOE = \frac{l^3}{4 \cdot b \cdot h^3} \cdot \frac{\Delta F}{\Delta y} \qquad (1)$$

where *l* is the distance between the supports, *b* and *h* are the width and thickness of the sample, ΔF is the load increment and Δy is deflection increment corresponding to the load increase ΔF.

With determination of the ultimate load (F_{max}) at failure, the bending strength, i.e. modulus of rupture (*MOR*) was evaluate as:

$$MOR = \frac{3 \cdot F_{max} \cdot l}{2 \cdot b \cdot h^2} \qquad (2)$$

Shear test parallel to the grain was carried out on a 20 mm cube using the Zwick-Roell Z100 universal testing machine. The cube was loaded at a rate of 2 mm/min. The tests were made on parallel specimens in the radial and tangential planes. The shear or rigidity modulus (*G*) was estimated within the elastic range on stress-strain diagram, whereas the shear strength (τ) was calculated at ultimate load of rupture.

Hardness (*HB*) of xylite was determinate by a standard test method according to EN 1534. The penetration depth (*h*) of iron sphere (*D* = 10 mm) was used in calculations at load *F* = 1000 N to determine the Brinell hardness of xylite by Eq. 3.

$$HB = \frac{2 \cdot F}{\pi \cdot D \cdot (D - \sqrt{D^2 - 4 \cdot h \cdot (D - h)}} \qquad (3)$$

3 RESUL TS AND DISCUSSION
3. REZULTATI I RASPRAVA

The long-term influence of various bio-geo-chemical factors of xylite development results in considerable changes not only of structure but also of mechanical properties of xylite. Despite the long process, the investigated mechanical properties of xylite remained close to the values of original wood species (the family *Taxodiceae* or *Cupressaceae*), but it cannot be related to the woods with similar density (c.f. ebony or wenge). Comparable values of mechanical properties of fossil conifers resulted in well preserved cell wall structure especially with still well organized cellulose. Due to its crystalline order, cellulose resists hydrolysis for a long time and slowly degradation is observed in samples with ages up to 1 million years (Fengel, 1991). It seems that continuous degradation of polyoses has minor effect on the strength of xylite. Visible changes of aging and fossilization are recognized in specific fracture, which is instantaneous and more brittle.

The mechanical properties of xylite varied with moisture content, as well as with the testing temperature. The influence of temperature on mechanical properties of xylite is more pronounced in determination of stiffness, and less in determination of strength properties (Tab. 1). The most distinctive reduction of stiffness and bending strength of xylite with increased testing temperature, with the ratio around 2.1 (between *MOE* at 20 °C and 80 °C) and 1.4 (for *MOR* at the same temperature interval), was perceived at about 14 % *MC*, which was the average equilibrium moisture content (*EMC*) of xylite at normal climate (20 °C / 65 %).

Based on data from the literature (Dinwoodie, 2000), linear dependence of strength from temperature changes was assumed within the investigated temperature range.

Similarly as wood, the marked increase in strength upon drying from the fiber saturation point to lower *MC* was determined for xylite, while the amount of free water filling the capillaries in elements did not

Table 1 Influence of moisture content (*MC*) and temperature (*T*) on modulus of elasticity (*MOE*) and modulus of rupture of xylite (*MOR*).
Tablica 1. Utjecaj sadržaja vode u drvu (*MC*) i temperature (*T*) na modul elastičnosti (*MOE*) i na modul loma pri savijanju ksilita (*MOR*)

Temperature / *Temperatura* *T* = 20 °C			**Temperature** / *Temperatura* *T* = 80 °C		
Moisture content *Sadržaj vode* *MC*, %	Modulus of elasticity *Modul elastičnosti* *MOE*, GPa	Modulus of rupture *Modul loma pri savijanju* *MOR*, MPa	Moisture content *Sadržaj vode* *MC*, %	Modulus of elasticity *Modul elastičnosti* *MOE*, GPa	Modulus of rupture *Modul loma pri savijanju* *MOR*, MPa
41.0	5070	35.5	40.5	4232	29.0
26.2	6604	57.5	26.5	4646	43.9
18.9	10148	76.6	19.1	5911	58.4
13.9	11868	96.8	14.2	5743	69.5
6.3	13758	148.7	6.0	13232	135.9

affect stiffness and strength above FSP, which was 36.0 % (Gorišek *et al*., 2012). As known, the increase is even more significant for wood. The MOE of dried xylite at room temperature was 2.7 times greater than in the fresh state. The difference is greater at higher temperature (80 °C), where the ratio is 3.1. An even more pronounced difference is observed when comparing the *MOR* of raw and dried samples. The phenomena can be ascribed to very high hygroscopic potential of xylite (Gorišek *et al*., 2012), where a large amount of water may reduce the cohesion and strength of the material with high *MC*. In fresh condition the *MOR* is 4- to 5-times lower than in the driest state. All dependencies of *MOR* and *MOE* on *MC* within the examined range can be successfully fitted into power regression model with high determination coefficient (Fig. 1 and Fig. 2).

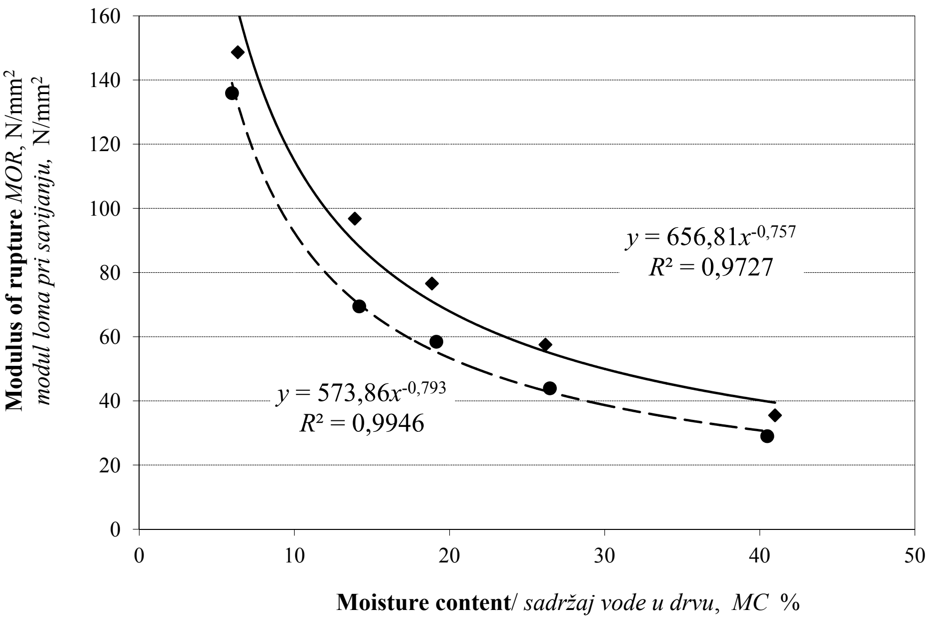

Figure 1 Influence of moisture content *(MC)* on modulus of rupture *(MOR)* at 20 °C (♦) and 80 °C (•).
Slika 1. Utjecaj sadržaja vode u drvu na modul loma pri savijanju pri temperaturi 20 °C (♦) i 80 °C (•)

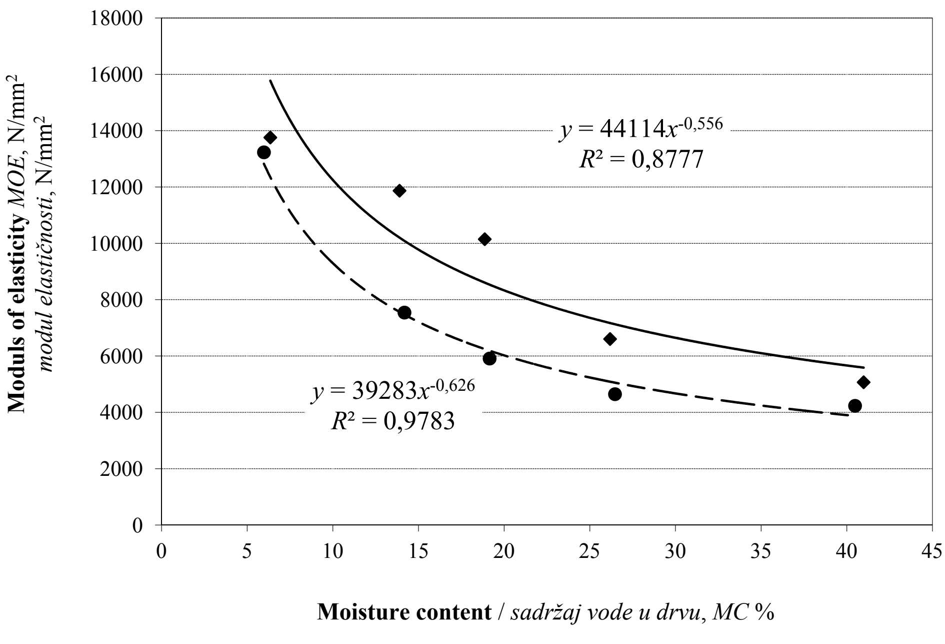

Figure 2 Influence of moisture content *(MC)* on modulus of elasticity *(MOE)* at 20 °C (♦) and 80 °C (•)
Slika 2. Utjecaj sadržaja vode u drvu na modul elastičnosti pri savijanju uz temperaturu 20 °C (♦) i 80 °C (•)

The high values of shear strength of xylite, compared to similarly dense and structurally alike current wood species were in some way unexpected (Tab. 2), so that great variability need to be considered (Dinwoodie, 2000). Relatively high average value of shear strength can be partly explained by interwoven tissue, while specimens with straight grain and tangential orientation reached tremendously low strength. Breaking of some samples immediately after loading had also to be taken into consideration and therefore a substantial number of samples had to be eliminated from further assessment. Much of fractures had been initiated during the drying process, which was confirmed by research on drying of this material (Gorišek and Straže, 2014). Some fractures were only observed at microscopic level, so that only 30.0 % to 56.9 % of dried xylite can be used for further manufacturing.

Table 2 Average values and basic statistics for shear modulus (*G*), shear strength (τ) and hardness (*HB*) of xylite
Tablica 2. Prosječna vrijednost i osnovna statistika modula smicanja (*G*), čvrstoće na smicanje (τ) i tvrdoće (*HB*) ksilita

	Shear modulus *Modul smicanja* *G*, GPa	**Shear strength** Čvrstoća na smicanje τ, MPa	**Hardness** *Tvrdoća* *HB*, MPa
Average	4.4	30.1	91.7
No.of samples	16	16	20
St.dev.	1.31	10.05	18.7
C.V:	29.6	33.4	20.4
Min.	2.3	12.5	57.9
Max.	6.2	40.7	118.3

It was interesting to observe the relation between density of xylite and its shear strength. Density had a negative impact on shear strength (Fig. 3), while the influence of density on hardness was positive with high prediction strength of fitted linear regression model (Fig. 4).

The latter result was expected due to the confirmed presence of highly collapsed cells in xylite, with positive impact on its density (Gorišek and Straže, 2013). On the other hand, densification is presumably not the only consequence of collapsing, but also rupturing of the structure with the resulting reduction in strength, determined by shear tests. Higher density was also observed when xylite contained more soil or mineral inclusions. Generally, they are arranged in series with relatively great influence on shear strength reduction.

4 CONCLUSIONS
4. ZAKLJUČAK

Long time influence of geological and biochemical factors on wood during its conversion into xylite is reflected not only on its structure but also on its mechanical properties.

The quality of mechanical properties of xylite was just slightly lower than the quality of mechanical properties of wood from which it originated. The high

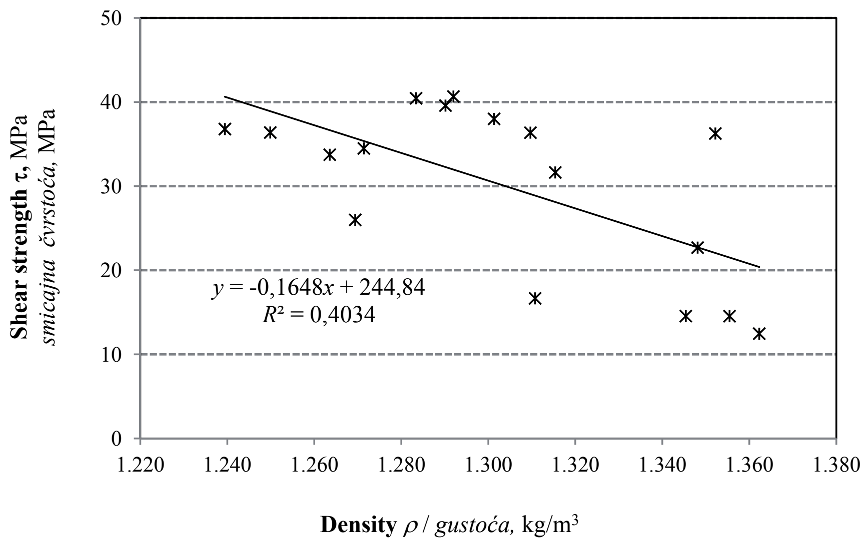

Figure 3 Influence of density on shear strength of xylite
Slika 3. Utjecaj gustoće na čvrstoću smicanja ksilita

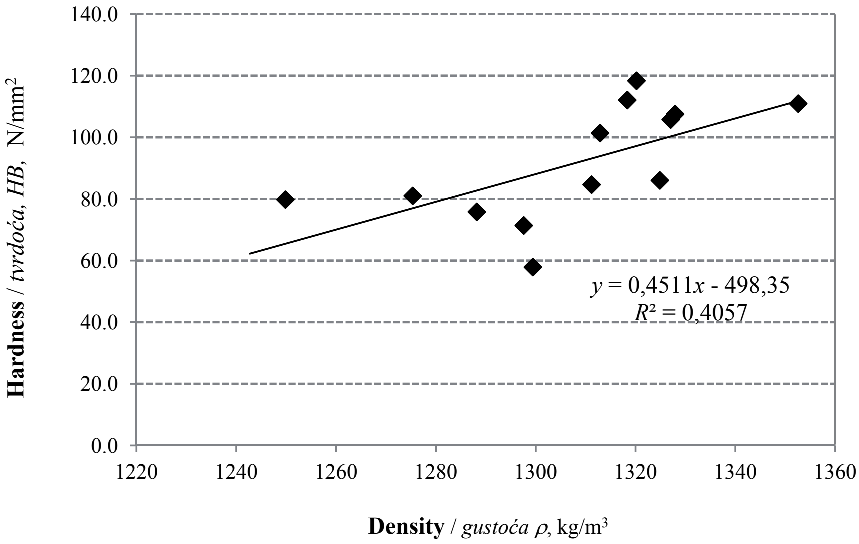

Figure 4 Influence of density on hardness of xylite.
Slika 4. Utjecaj gustoće na tvrdoću ksilita

density of xylite would presumably increase its mechanical properties. The results do not confirm this, since higher density of xylite is also caused by the presence of mostly bound water and frequently collapsed structure. *MOE* and *MOR* of xylite is likely to be reduced by temperature just as *MOE* and *MOR* of many current wood species of similar density.

Due to densification, xylite is characterized by high hardness. Great variability in shear strength is mainly attributed to structural and chemical changes. Namely, during the process of carbonization, polyoses are subject to major changes with significant influence on bonding between cellulose and matrix. The consequences are visualized as typical brittle fracture of xylite.

Additionally, the use of xylite is recommended in places not exposed to dynamic loading.

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LABORATORY FOR HYDROTHERMAL PROCESSING OF WOOD AND WOODEN MATERIALS

Testing of hydrothermal processes of wood and wooden materials

Thermography measurement in hydrothermal processes

Standard and nonstandard determination of moisture content in wood

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

Project and development of conventional and unconventional drying systems

Steaming chamber projects

Establishing and modification of kiln drying schedules

Consulting in selection of kiln drying technology

Introduction of drying quality standards

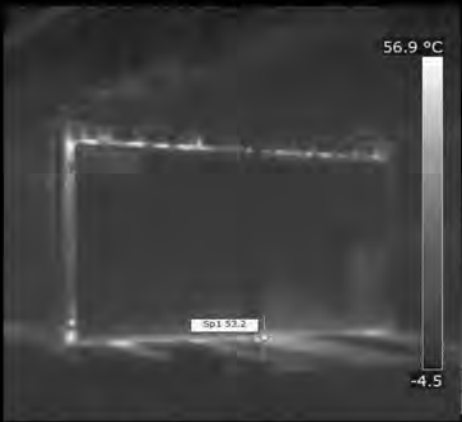
Determination of wood bending parameters

Detection and reducing of hydrothermal processes wood defects

Reducing of kiln drying time

Drying costs calculation

Kiln dryer capacity calculation



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Application of Risk Analysis in Business Investment Decision-Making

Primjena analize rizika u donošenju odluka o poslovnim investicijama

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ABSTRACT • *Investment decision-makings should be regarded in each business entity as the crucial factor for its long-term prosperity. An acquired decision affects the performance of the company as well as its competitiveness in long time. If a competent investor has an interest to make a qualified investment decision, it means that he must primarily determine the time and risk factor. In the capital-intensive investment projects, attention must be paid to the risks that the preparation, realization and use of investment bring. The aim of this paper is to identify critical factors that affect the expected profit and cash flow in the implementation of investment projects by applying the most advanced models used to quantify the risks of investing. Research was conducted in a wood processing and furniture manufacturing company. The results given by cash flow indicatiors show that the investment project is feasible and effective. By changing some parameters, sensitivity analysis shows that the main risk factors for the project in question are the selling price, volume of production, material costs and labor costs.*

Key words: *investment, enterprise investment, investment activity, risk of investment, sensibility analysis*

SAŽETAK • *Donošenje odluka o investicijama u svakom bi se poslovnom sustavu trebalo smatrati ključnim čimbenikom za njegovu dugoročnu uspješnost. Donesena odluka utječe na djelovanje kompanije, kao i na njezinu dugoročnu konkurentnost. Kako bi kompetentni investitor donosio kvalitetne investicijske odluke, potrebno je da prije svega donese odluku o vremenu i riziku investicije. U većim investicijskim projektima veću pozornost potrebno je pridati rizicima što ih donose priprema, realizacija i korištenje investicije. Cilj ovog rada jest identificirati kritične čimbenike koji utječu na očekivani profit i tijek novca pri primjeni investicijskih projekata korištenjem poboljšanih modela kojima se kvanitificiraju rizici u investiranju. Istraživanje je provedeno u jednom poduzeću za preradu drva i proizvodnju namještaja. Rezultati ispitivanja tijeka novca pokazuju da je investicijski projekt provediv i učinkovit. Analizom osjetljivosti promjenom pojedinih parametara vidljivo je da su osnovni rizici istraživanog projekta prodajna cijena, opseg proizvodnje, materijalni troškovi i troškovi rada.*

Ključne riječi: *investicije, investicije u poduzeće, aktivnost investicije, rizik investicije, analiza osjetljivosti*

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1 INTRODUCTION
1. UVOD

The issue of business risk - its principles, acceptance, evaluation and reflection of the impact, increasingly affects not only the permanent business activity, but also its role in planning and implementing new investments. This situation results from the still ongoing economic and financial crisis. Business risk cannot be understood without a comprehensive approach, because non-acceptance of its impact in all areas can significantly reduce business efficiency.

The allocation of available financial resources to fixed assets or investments in modernization of production technologies are possible ways when a company can ensure its prosperity. In order to ensure adequate use of these investments, it is necessary to evaluate their economic benefits and also to analyze the risk associated with the investment. It is not possible to develop business activity without taking into account an acceptable level of risk. It is difficult to find a suitable and acceptable balance between the current risk and a potential profit. It is not enough to identify business risks and apply the newest procedures of risk quantification to prevent bad decision-making and subsequent economic loss.

1.1 Decision-making under certainty, risk, uncertainty and undefined conditions
1.1. Donošenje odluka u sigurnim, rizičnim, nesigurnim i nedoređenim uvjetima

The terms “risked” and “uncertainty” were clearly defined and distinguished by Frank H. Knight (1921). Both terms refer to an indefinite future, but in a different way. Speaking of risk, the current situation can be described and on that basis the probability of certain future events can be determined. With uncertainty, due to the lack of information, it is not possible to describe the current state and quantify the possible outcomes of our future decisions (Baláž, 2009).

In decision theory, information about ambient positions and consequences of the decision alternatives is a fundamental classification aspect of decision-making processes. From this perspective, the following types of decisions can be distinguished: under certainty, risk, uncertainty and undefined conditions (Varcholová and Dubovická, 2008; Ojurović *et al*., 2013).

Decision-making in conditions of certainty: The company or investor has full information about the consequences of the decision alternatives considering different evaluation criteria (e.g. amount of profit, cash flow), i.e. he knows with certainty which ambient status (which situation) will occur and what consequences of the implemented variants can be expected (Varcholová and Dubovická, 2008). Environment of certainty assumes that the investor knows the sitation. Then it is much easier to make the decision and the investor chooses an alternative that can provide maximum profit. The problem of decision-making techniques is eliminated. Environment of certainty is extremely rare and does not exist in practice (Kolenka and Hajdúchová, 2008).

Decision-making in conditions of risk: If the investor has sufficient information to estimate the future status with some probability, he can assess the risk (Kolenka and Hajdúchová 2008). However, it is not easy to make this estimate and this is something expert teams and consulting firms deal with.

Decision making in conditions of uncertainty: An investor knows the possible future status of the environment (possible future situation) and the consequences of the decision alternatives in these conditions, but the probability of the status of individual variants is not known (Varcholová and Dubovická, 2008).

Decision-making under undefined conditions is described as the way in which the investor can identify future status, but is unable to determine the probability of occurrence (Kolenka and Hajdúchová, 2008).

1.2 Risk analysis of investment projects
1.2. Analiza rizika investicijskih projekata

Risk analysis of investment helps the companies to prepare investment projects in order to increase their probability of success. Through risk analysis, the company detects which risk factors are important in terms of the project and, on the other hand, which ways and measures can reduce the project risk and how much of the risk is still acceptable for the business.

The base of risk analysis is a systematic process of working with risk and uncertainty, which requires deeper knowledge of tools and methods of risk decision-making, all these resulting in a significant increase in the quality of preparation and evaluation of business projects (Fotr, 1992). The content of project risks analysis can be briefly divided as shown in Figure 1.

Appropriately selected risk categories, i.e. a clear definition of the content and boundaries between categories, are the basis for a well-structured systematic process of identifying business risks (Rybárová and Grisáková, 2010). The tools and resources that can be used to identify risk factors are the following: check lists, discussions and interviews, audits, results of financial controlling and financial analysis, as well as various analyzes of internal and external business environment, such as SWOT analysis, STEEP analysis, mind maps, brainstorming method, etc. It should be emphasized that the identification of project risk factors is the most important and time-consuming phase of the risk analysis. It requires experience, a systematic approach and ability to predict possible future situations.

For determining the significance of risks, it is possible to use sensitivity analysis by which risk factors can be quantified, or expert evaluation by which the assessed factors cannot be quantified and they are evaluated verbally.

The results of the identification and determination of the significance of the crucial factors are the basis for the next phase of risk analysis, namely the quantification or measurement of risk. In order to e.g. compare two investment options, it is necessary to express the risk (risk of failure or risk of another negative effect) in some way (Smejkal and Rais, 2009). The risk

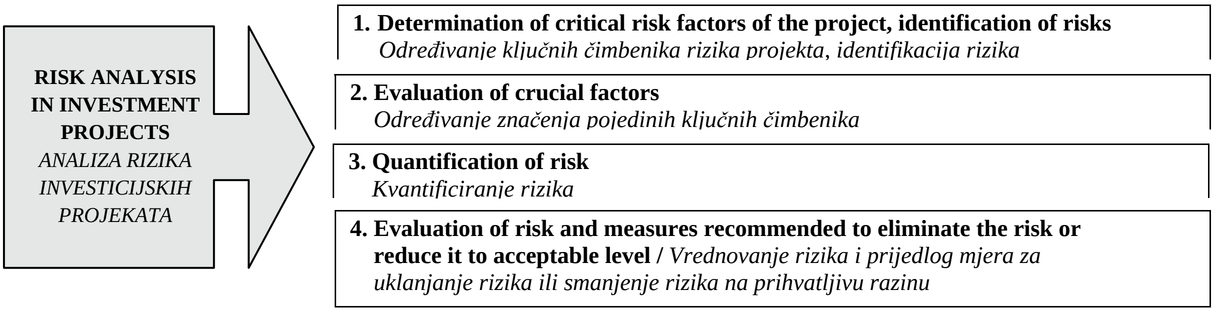

Figure 1 Risk analysis of investment projects (IP)
Slika 1. Analiza rizika investicijskih projekata (IP)

of the project can be determined numerically, where the starting point is to determine the probability distribution of one of the basic economic criteria (e.g. profit) for the evaluation. The risk can be determined directly, but this is, however, more difficult and requires the use of some tools of risk decision making (decision matrix, decision trees, probability trees, computer simulation, using models). The risk can also be determined indirectly, with certain characteristics, which together provide information about the greater or lesser degree of risk of the project (Polách *et al.*, 2012). The most common method of measuring risk is a statistical method of variance, standard deviation and coefficient of variation (Kráľovič *et al.*, 2008); a statistical method of variance and standard deviation of the cash flows (Hrdý, 2008) is a very common indicator of the project risk.

The objective of this paper is to make a qualified risk analysis of the suggested investment project in the company of wood production and to highlight the key risk factors of the investment. The aim is to identify the crucial factors that affect the expected profit, cash flow of investment projects and accomplishment of investment goals by using modern models for the quantification of investment risks.

On the basis of the economic analysis and investment risk analysis (sensitivity risk analysis and Monte Carlo simulation), final evaluations and conclusions are presented for the company and investment project.

The research was focused on achieving the following targets:

- Define theoretical background and methodology of used models for investment risk analysis and investment decision-making;
- Evaluate the investment project by dynamic methods (Net Present Value, Internal Rate of Return, Profitability Index and Discounted Payback Period);
- Apply the sensitivity analysis with the determination of significance of factors and Monte Carlo simulation;
- Evaluatie the achieved results of risk analysis and synthesis and their use as a support for investment decision-making of the company.

2 METHODOLOGY OF RESEARCH
2. METODOLOGIJA ISTRAŽIVANJA

Investment risk analysis and methodological process used in our research are defined and described below.

Sensitivity analysis of investment is an important part of decision-making on investment projects. Its function (Scholleová, 2009) is to:

- Stop in time the realization of the investment that seems to be profitable, if its risk does not meet the goals of the company. The expected deviation of its return may in fact be so large that the probability of the possible investment loss is not at an acceptable risk level of owners.
- Mark critical values, whose monitoring and control will be necessary during the investment, as they have a significant impact on the investment value and high probability of change.

The basic equation for sensitivity analysis (Polách *et al.*, 2012) is:

$$P = Q \cdot p - \left[\left(v_1 + v_2 + ... + v_n \right) \cdot Q + f_1 + f_2 ... + f_n + \frac{I}{T} \right] \quad (1)$$

Where:
P – profit from the investment project per year / *godišnji profit od investicije*
Q – quantity of production in natural units (pcs, kg, m, …) per year / *godišnja proizvodnja (kom, kg, m, …)*
p – price per unit / *jedinična cijena*
$v_1, v_2,..v_n$ – variable costs per unit / *varijabilni jedinični troškovi*
$f_1, f_2,..f_n$ – fixed costs per whole production / *fiksni troškovi cijele proizvodnje*
I – investment / *investicija*
T – time of the lifecycle (years) / *vrijeme životnog ciklusa (godine)*

The scope of sensitivity analysis in investment decision-making is to detect the sensitivity of the chosen criteria for possible changes in risk factor values that affect the criterion. The basic form of sensitivity analysis is the one-factor analysis, which determines the effects of selected changes in individual risk factors for the chosen criterion, while all other factors are stable at their projected (planned, most probable) values.

The sensitivity analysis, however, also has some limitations. These are mainly the effects of isolated changes in individual risk factors on the criterion, so that disregarding the possible dependence of several risk factors, the change of one factor can cause changes in another (for example a significant increase in the selling price leads to a decrease in demand and therefore sales). The solving point would be to apply a multifactor sensitivity analysis, which is more difficult (Hnilica and Fotr, 2009).

When performing a sensitivity analysis with the same relative changes in each factor (percentual changes from the most probable and planned values), a different level of uncertainty for risk factors, common in practice, is not respected when some deviations may be less than ±10 %, and others significantly larger. Given this fact, in setting the significance of risk factors, it is necessary to take into account not only the results of the sensitivity analysis, but also the assessment of different degrees of uncertainty, which also affect the significance of risk factors.

The purpose of Monte Carlo simulation is to generate a large number of scenarios (each scenario is a discrete arrangement) and the value calculation of financial criteria for each scenario. The result of Monte Carlo simulation is a graph of the probability distribution of the selected criteria. The Monte Carlo simulation allows a simple implementation of a large number of possible situations created as combinations of possible values of input variables, for example sales volume, price, cost, etc., to calculate the possible values of a profit (Varcholová and Dubovická, 2008; Fotr, 2011).

Generating the scenarios (many times repeated random experiments on the input data sample) is carried out until stable results are provided of the density of probability distribution. The results become more stable because the statistics data (that describe it) change less with the increasing number of simulated calculations. The number of trials will vary depending on the distribution functions.

The procedure of Monte Carlo simulation can be generally divided into several phases:

- Creating of mathematical model;
- Determination of the probability distribution of key risk factors;
- Determination of statistical dependence of risk factors;
- Selection of output variables and process of simulation.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Evaluation of economic efficiency of the investment project
3.1. Vrednovanje ekonomske učinkovitosti investicijskog projekta

Table 1 Operating costs (€)
Tablica 1. Operativni troškovi (€)

Cost item / Years *Trošak / Godina*	1	2	3	4	5	6
Material costs / *materijalni* troškovi	666 434	773 020	905 464	1 002 390	1 002 390	1 002 390
Personal costs / *osobni troškovi*	403 704	484 598	592 877	691 794	709 155	690 732
Lease / *unajmljivanje*	23 900	24 962	26 090	27 252	28 480	29 775
Administration, Services / *administracija, usluge*	54 106	56 562	59 085	61 774	64 529	67 450
Energy / *energija*	54 903	57 392	59 981	62 670	65 492	68 446
Repairs and maintenance / *popravci i održavanje*	49 127	51 318	53 641	56 065	58 587	61 210
Transport / *transport*	32 995	34 455	36 015	37 642	39 335	41 094
Insurance / *osiguranje*	5 045	5 278	5 510	5 743	6 008	6 274
Promotion / *promocija*	83 744	92 047	96 196	116 345	105 357	109 772
Other costs / *ostali troškovi*	40 862	42 687	44 613	46 604	48 729	50 919
Operating costs 1 / *operativni troškovi 1*	1 414 820	1 622 320	1 879 473	2 108 279	2 128 062	2 128 062
Amortization / *amortizacija*	188 774	187 612	185 919	184 326	143 730	142 435
Interests / *kamate*	63 750	52 125	40 500	28 875	17 250	8 625
Operating costs 2 / *operativni troškovi 2*	1 667 344	1 862 057	2 105 892	2 321 418	2 289 042	2 279 122

The company Pinus, Ltd., dealing with the production of construction and carpentry products, has to decide whether to accept the investment plan for increasing the production volume and expanding the range of offered products. In case of the investment, aimed at modernizing the production technology, another added value is a more efficient use of raw material. In addition, the implementation of the project will create new jobs to the region with high unemployment (Benková, 2012).

From the available input data, we calculated the net present value, internal rate of return, profitability index and discounted payback period. All calculated values of these criteria prove the suitability of the investment. The results are presented in Table 4.

Table 2 Financial sources for the investment project (€)
Tablica 2. Izvori financiranja investicijskog projekta (€)

Equity / *Vlastita sredstva*	**Debt** / *Dug*	**Total** / *Ukupno*
306 360 €	900 000 €	1 206 360 €

Table 3 Loan terms for the investment project
Tablica 3. Uvjeti kreditiranje investicijskog projekta

Outstanding debt *Iznos duga*	**Annual payment** *Godišnja otplata*	**Interest rate p.a.** *Godišnja kamatna stopa*	**Payback period** *Vrijeme povrata*
900 000 €	150 000 €	5.75 %	6 years / *godina*

Table 4 Evaluation of the investment project by Cash Flow (€)
Tablica 4. Vrednovanje investicijskog projekta tijekom novca (€)

	Indicator / Years *Pokazatelj / Godina*	1	2	3	4	5	6
	Total income *ukupni prihod*	1 676 700	1 957 460	2 258 200	2 558 940	2 678 000	2 678 000
-	Expenses *troškovi*	1 414 820	1 622 320	1 879 473	2 108 279	2 128 062	2 128 062
-	Amortization *amortizacija*	188 774	187 612	185 919	184 326	143 730	142 435
-	Interests *kamate*	63 750	52 125	40 500	28 875	17 250	8 625
=	**Profit before taxes** *dobit prije poreza*	9 356	95 403	152 308	237 460	388 958	398 878
-	Taxes 19 % *porez 19 %*	1 777.64	18 126.57	28 938.52	45 117.40	73 902.02	75 786.82
=	**Net profit** *neto dobit*	7 578.36	77 276.43	123 369.48	192 342.60	315 055.98	323 091.18
-	Funds 10 % *fondovi 10 %*	757.84	7 727.64	12 366.95	19 234.26	31 505.60	32 309.12
=	**Disposable profit** *raspoloživa dobit*	6 820.52	69 548.79	111 032.53	173 108.34	283 550.38	290 782.06
+	Amortization *amortizacija*	188 774	187 612	185 919	184 326	143 730	142 435
=	**Cash Flow** *tijek novca*	195 594.52	257 160.79	296 951.53	357 434.34	427 280.38	433 21706
-	Debt payment *otplata duga*	200 000	200 000	200 000	200 000	150 000	150 000
=	**Net Cash Flow** *neto tijek novca*	-4 405.48	57 160.79	96 951.53	157 434.34	277 280.38	283 217.06
	Discount 10 % *diskont 10 %*	0.90909	0.82645	0.75131	0.8301	0.62092	0.56447
	PVCF per year *TVTN godišnje*	177 813.20	212 529.58	223 104.08	244 132.46	265 307.50	244 539.74
	Present Value of Cash Flow - PVCF in total *trenutačna vrijednost tijeka novca – TVTN ukupno*	1 367 426.56 €					
	Net Present Value – NPV *trenutačna neto vrijednost - TNV*	161 066.56 €					
	Profitability index – PI *indeks profitabilnosti - IP*	1.13					
	Internal Rate of Return – IRR *interna stopa povrata - ISP*	13.87 %					
	Discounted Payback Period – DPP *diskontirano vrijeme povrata - DVP*	5.34 years					

As follows from the economic analysis of the project based on cash flow indicators, the project is feasible and effective, although some values (Discounted Payback Period) can be considered borderline. The project at the discount rate has the leeway to risk. Investment can be recommended to be implemented in practice, because the applied criteria meet the specified terms and hence ensure the required return of investment.

3.2 Sensitivity analysis of the investment project
3.2. Analiza osjetljivosti investicijskog projekta

The sensitivity analysis clearly identifies the factors that affect most the profit in the observed period. To evaluate the factors in a longer term, the focus is on the impact of the selling price, production volume, changes in cost price of inputs as well as changes in labor costs per unit of output. The results of the sensitivity analysis for the planned investment project are shown in Table 5.

Table 5 Project risk factor quantification (project sensitivity analysis)
Tablica 5. Kvantificiranje čimbenika rizika projekta (analiza osjetljivosti projekta)

Risk factor *Rizik*	**Item** *Naziv*	**Unit** *j.m.*	**Estimated value** *Procijenjena vrijednost* €	**Estimated value** *Procijenjena pojedinačna vrijednost* €/pcs	**Deviation** *Odstupanje* ± 10 %	**Profit after change** *Dobit nakon promjene* €	**Absolute change** *Apsolutni iznos promjene* €	**Relative change** *Relativni iznos promjene* %
Q	Production volume *Vrijednost proizvodnje*	Pcs *kom.*	885,00	885	797	323 378	75 500	18.93%
c	Price *cijena*	€/pcs *€/kom.*	3 025.99	3 025.99	2 723.39	131 078	267 800	67.14%
v_1	Material expenses *materijalni troškovi*	€/pcs *€/kom.*	1 002 390.00	1 132.64	1 245.91	298 639	100 239	25.13%
v_2	Personal expenses *osobni troškovi*	€/pcs *€/kom.*	690 732.00	780.49	858.54	329 805	69 073	17.32%
v_3	Promotion *promocija*	€/pcs *€/kom.*	109 772.00	124.04	136.44	387 901	10 977	2.75%
v_4	Administration, services *administracija, usluge*	€/pcs *€/kom.*	67 450.00	76.21	83.84	392 133	6 745	1.69%
v_5	Other variable expenses *ostali varijabilni troškovi* (35%)	€/pcs *€/kom.*	17 821.65	20.14	22.15	397 096	1 782	0.45%
v_6	Transport *transport* (30%)	€/pcs *€/kom.*	12 328.20	13.93	15.32	397 645	1 233	0.31%
v_7	Energy *energija* (15%)	€/pcs *€/kom.*	10 266.90	11.60	12.76	397 851	1 027	0.26%
v_8	Repairs and maintenance *popravci i održavanje* (20%)	€/pcs *€/kom.*	12 242.00	13.83	15.22	397 654	1 224	0.31%
f_1	Lease *unajmljivanje* (€)	€	29 775.00	29 775.00	32 753	395 900	2 978	0.75%
f_2	Insurance *osiguranje*	€	6 274.00	6 274.00	6 901	397 026	1 852	0.46%
f_3	Other fix expenses *ostali fiksni troškovi* (65%)	€	33 097.35	33 097.35	36 407	395 568	3 310	0.83%
f_4	Transport *transport* (70%)	€	28 765.80	28 765.80	31 642	396 001	2 877	0.72%
f_5	Energy *energija* (85%)	€	58 179.10	58 179.10	63 997	393 060	5 818	1.46%
f_6	Repairs and maintenance *Popravci i održavanje* (80%)	€	48 968.00	48 968.00	53 865	393 981	4 897	1.23%
f_7	Amortization *amortizacija*	€	142 435.00	142 435.00	156 679	384 634	14 244	3.57%
f_8	Interests *kamate*	€	8 625.00	8 625.00	9 488	398 015	863	0.22%
P	**Profit** *dobit*	**€**	**398 878**					

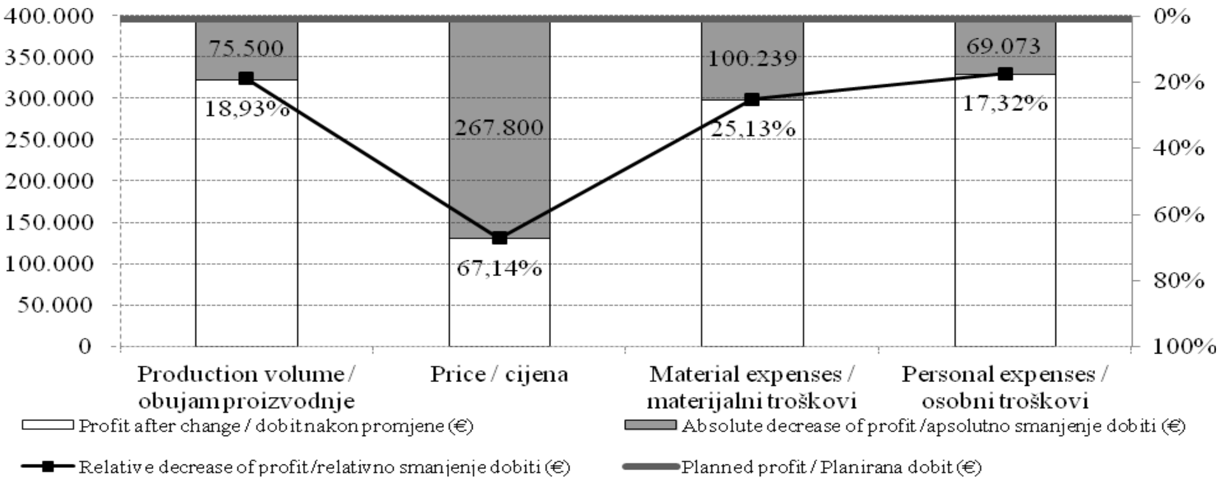

Figure 2 Impact of crucial factors in decreasing profit
Slika 2 Utjecaj ključnih čimbenika u smanjenju dobiti

The results of the project sensitivity analysis by changing the project values ± 10 % show that the risk factors that mostly cause the decrease of profit (Figure 2) are the selling price, production volume, material costs and labor costs. The effect of other factors such as amortization, advertising, services, energy, repairs and maintenance, other costs and transportation is not so significant. Costs for rent, insurance and interests have very little effect on profit.

3.3 Monte Carlo Simulation
3.3. Simulacija Monte Carlo

Determination of key risk factors: Key risk factors were selected by using the expert method with owners. Probability distribution was chosen for individual risk factors. The key risk factors that affect the profit of the company (or the investment project) are as follows:

1. Price – it is the average selling price for a unit of production (piece), triangular distribution, the most probability value, min., max.
2. Production volume – it is the number of sold units, BetaPERT distribution and the most probability value - 10%, 90%.
3. Material costs – raw material input costs, Beta distribution set to the most probability value.

Other risk factors have not a major impact on the planned profit of the enterprise. The statistical dependency between the selected key factors was considered.

Definitions of investment options: alternatives proposed for the project are presented in Figure 3.

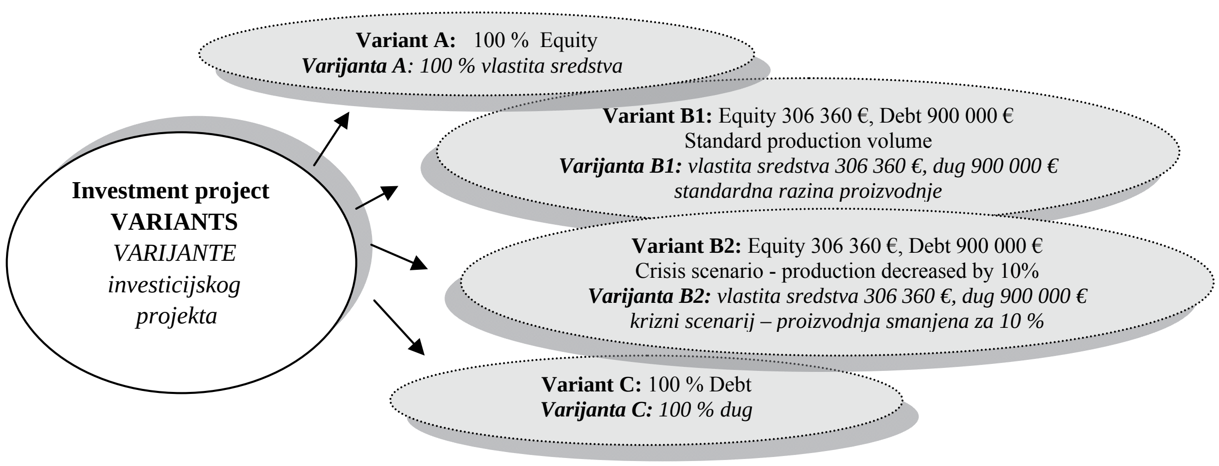

Figure 3 Investment alternatives and scenarios for the investment project
Slika 3 Alternative investiranja i scenariji za investicijski projekt

Determination of evaluation criteria and simulation parameters: Two types of variables were defined:

1. Variables that make the object of the simulation, known as Forecasts in the Crystal Ball system. These are the output variables based on which the simulation is carried out. In our case, the following indicators were defined: Net Present Value (NPV), Internal Rate of Return (IRR) and Profitability Index (PI) of the investment project. A total of 50 000 simulations were to be run.
2. Risk factors for the project are the input variables and their uncertainty is respected in the form of probability distribution. These variables are labeled as Assumptions in the Crystal Ball system. In case of two factors – production volume and price – these are not statistically dependent on each other and therefore may be generated independently during the simulation. The next pair of factors – price and material costs – shows a statistical dependence and it has been considered in the simulation.

The duration of the project is expected to be six years; with a total of 13 risk factors. A total of 50 000 simulations were to be run in order to obtain stable results.

Results of the simulation: The values confirm that the present investment project is significantly profitable in variants A, B1 and C. The criteria values for the investment project for the various alternatives are shown in Table 6.

The results of Monte Carlo simulation for option B1 are shown in the graph of the probability distribution of the output variables Profitability Index, Internal Rate of Return and Net Present Value (Figures 4-6). Statistical characteristics of output variables are presented in Table 7. A Weibull distribution was chosen as the type of probability distribution for NPV and PI, and Beta distribution for IRR.

Table 6 Criteria for different variants of the investment project
Tablica 6. Kriteriji za različite varijante investicijskog projekta

Variants / *Varijanta*	**NPV** / *TNV* (€)	**IRR** / *ISP* (%)	**PI** / *IP*	**DPP** / *DVP* (years / *godina*)
A	264 481.60	16.64	1.22	4.94
B1	161 066.56	13.87	1.13	5.34
B2	-550 503.00	-4.90	0.54	10.10
C	125 863.92	13.08	1.10	5.48

Table 7 Statistical characteristics of selected indicators – Variant B1
Tablica 7. Statističke značajke određenih pokazatelja – varijanta B1

Statistics / Indicators *Statistička značajka / Pokazatelji*	**Profitability Index** *Indeks profitabilnosti*		**Internal Rate of Return, %** *Interna stopa povrata*		**Net Present Value, €** *Neto trenutačna vrijednost*	
	Fit *Pokazatelj* Weibull	Forecast values *Procjenjena vrijednost*	Fit *Pokazatelj* Beta	Forecast values *Procjenjena vrijednost*	Fit *Pokazatelj* Weibull	Forecast values *Procjenjena vrijednost*
Mean / *srednja vrijednost*	1.040	1.042	13.73%	13.73%	154 822	154 839
Median / *medijan*	1.045	1.044	13.86%	13.87%	155 258	155 311
Mode / *mod*	1.050	-	13.82%	-	156 163	-
Standard Deviation / *standardna devijacija*	0.510	0.500	4.15%	4.15%	4 362.19	4 307.70
Variance / *varijanca*	0.2607	0.2509	17.22%	17.22%	19 028 713	18 556 319
Skewness / *simetričnost*	-0.9153	-0.5868	-0.1105	-0.1105	-0.5588	-0,5319
Kurtosis / *vršnost podataka*	4.44	3.76	2.96%	2.96%	3.38	3.57
Coeff. of Variability / *koef. varijabilnosti*	0.490	0.479	0.302%	0.302%	0.0281	0.0278
Minimum / *minimum*	0.160	0.570	-160.77%	2.03%	123 992	125 350
Maximum / *maksimum*	+ unlimited	1.215	107.76%	40.57%	+ unlimited	167 976
Mean Std. Error / *standardna pogreška*	-	0.000	-	0.08%	-	19

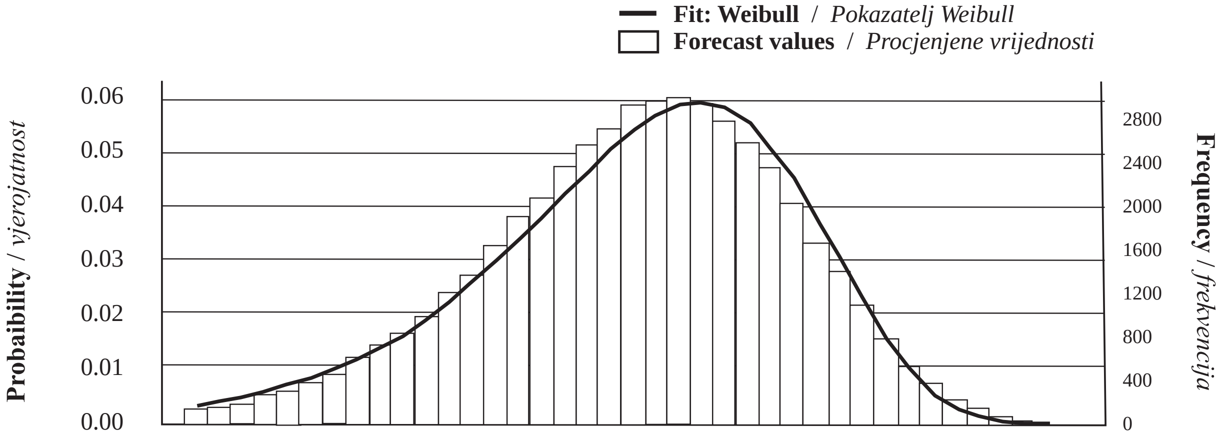

Figure 4 Probability distribution of the variable Profitability Index – Variant B1
Slika 4. Vjerojatnost distribucije varijable *indeks profitabilnosti* – varijanta B1

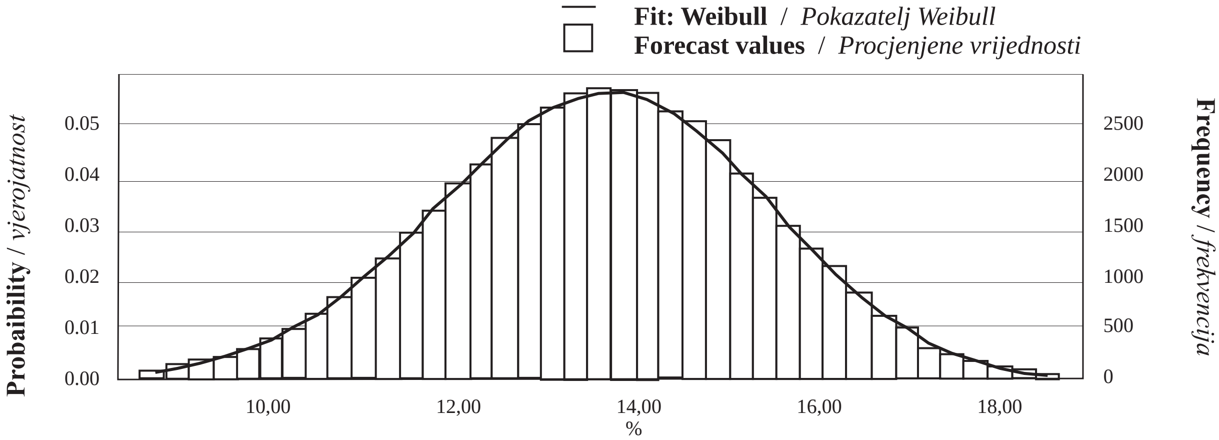

Figure 5 Probability distribution of the variable Internal Rate of Return – Variant B1
Slika 5. Vjerojatnost distribucije varijable *interna stopa povrata* – varijanta B1

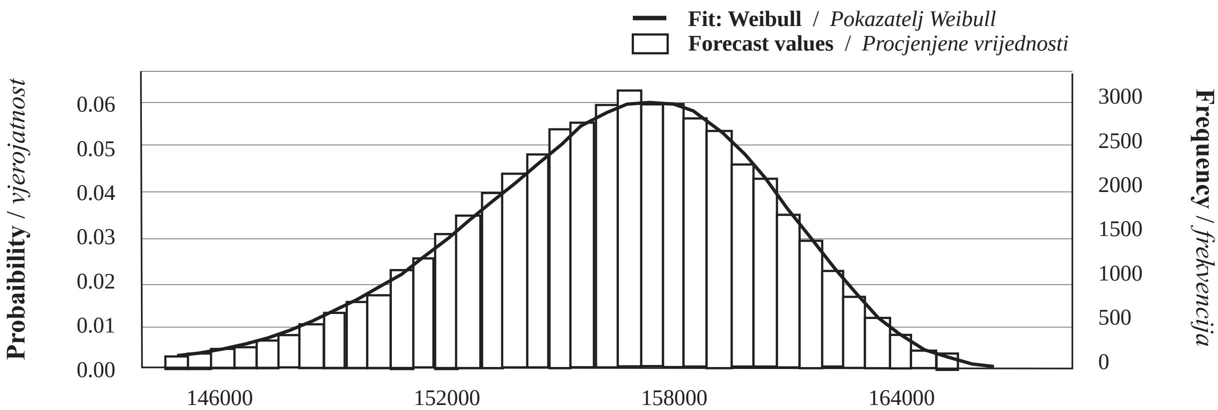

Figure 6 Probability distribution of the variable Net Present Value – Variant B1
Slika 6. Vjerojatnost distribucije varijable *neto sadašnja vrijednost* – varijanta B1

The statistical characteristics of the NPV of the project, variant B1, show that the indicator Mean of NPV is 154 839 €, which is about 6 227 less than the estimated value of 161 066.56 €, and the Median is 155 311 €. The risk characteristics of the project i.e. Standard Deviation is 24 910 €, Variance has a value of 18 556 319 € and the Coefficient of Variability, which represents the quotient of the standard deviation and the mean value, is 0.1953. Skewness is negative, meaning that the NPV probability distribution is not symmetrical (it is symmetrical when the skewness is zero); it is skewed to the left, i.e. towards lower values. The minimum simulated value of NPV is more distant from the Median than the maximum simulated NPV.

The world economic crisis has negatively affected the business efficiency of wood processing and furniture manufacturing in Slovakia since 2008. The crisis is reflected in an increase in prices of input raw materials and energy prices, and fall in demand for long-term products. The evaluation of variants suggests that the growth of production could not be associated with the growth of the project profitability because of the decline in selling prices and also the increase of costs of input materials and energy costs.

On the basis of the project risk analysis by Monte Carlo simulation, project implementation is recommended. Option B1 tested by Monte Carlo method has shown a 99.9 % probability of achieving positive results of net present value, internal rate of return and profitability index. The identified risk for the company Pinus, Ltd. is acceptable.

4 CONCLUSION
4. ZAKLJUČAK

Each investment activity in the company is accompanied by risk and uncertainty; therefore, in making everyday decisions, the enterprise must accept and consider their impact on future profits. After identifying the risks, their sources and impact on the project success, the measures can be taken to reduce the risk to an acceptable level.

Business risk is assessed in relation to specific criteria of efficiency evaluation of the project. By using risk analysis, i.e. the available methods and techniques applied in risk analysis, the company obtains information that will support its decision-making and help deciding whether to accept or reject the project.

The sensitivity analysis shows that, assuming the investment was made, the economic result (profit) of the project would be most strongly influenced by the selling price of the products and then by the change of the production volume, material costs and labor costs. The present risk should be reduced through diversification. Diversification gives the possibility of expanding the product range. The appropriate form of risk reduction is recommended to increase the production volume, provided that export of manufactured products to the EU markets or markets of Russia and Ukraine is increased. The implementation of the project would provide opportunities for further investments to the company Pinus, Ltd.

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Mechanical properties of sapwood versus heartwood, in three different oak species

Mehanička svojstva drva bjeljike u usporedbi s drvom srži tri vrste hrastovine

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ABSTRACT • *The aim of this study was to investigate the main mechanical properties of sapwood and heartwood in white and red oaks. Samples of wood were taken from 26 oak beams prepared to be used for railway sleepers, of which 62 % were from white oak (either Quercus petraea or Q. robur) and 38 % from red oak group, represented by Q. cerris. For both oak groups, the following parameters were determined: the density, bending strength, modulus of elasticity (MOE), compression strength and Brinell hardness of sapwood and heartwood. Multiple analyses were done to compare the properties of sapwood and heartwood, as well as the properties of white vs. red oaks. The results revealed no significant differences between sapwood and heartwood properties but statistically significant differences were found between the properties of white and red oaks. The research results contradict the common opinion of users that the mechanical properties of sapwood are inferior to those of heartwood. Investigations revealed that Q. cerris had even better mechanical properties than Q. robur or Q. petraea, which also contradicts the common opinion that its mechanical properties are inferior to those of white oaks. The results help to understand better wood variability for optimal selection of timber for constructions.*

Key words: *oak, Quercus, sapwood, heartwood, mechanical properties, density, bending strength, modulus of elasticity, Brinell hardness*

SAŽETAK • *Cilj ovog istraživanja bio je ispitati osnovna mehanička svojstva drva bjeljike i srži bijeloga i crvenog hrasta. Uzorci su uzeti od 26 hrastovih greda spremnih za izradu željezničkih pragova, od čega je 62 % greda od bijelog hrasta (Quercus petraea ili Q. robur), a 38 % od skupine crvenih hrastova, čiji je predstavnik Q. cerris. Za drvo bjeljike i drvo srži obiju skupina hrasta određena je gustoća, čvrstoća na savijanje, modul elastičnosti (MOE), tlačna čvrstoća i tvrdoća prema Brinellu. Napravljene su višestruke analize radi usporedbe svojstava bjeljike i srži, kao i usporedbe svojstava drva bijelih i crvenih hrastova. Rezultati su pokazali da nema značajne razlike između svojstava drva bjeljike i srži, ali statistički značajne razlike pokazale su se između svojstava drva bijeloga i crvenog hrasta. Rezultati istraživanja proturječe uvriježenome mišljenju korisnika da su mehanička svojstva bijeljike lošija od mehaničkih svojstava drva srži. Istraživanja su pokazala da drvo Q. cerris ima čak i bolja mehanička svojstva nego drvo Q. robur i Q. petraea, što je također suprotno ustaljenom mišljenju da su njegova svojstva lošija od svojstava drva bijelog hrasta. Rezultati će pridonijeti boljem razumijevanju varijabilnosti svojstava drva i optimalnom izboru drva za gradnju.*

Ključne riječi: *hrast, Quercus, bjeljika, srž, svojstva, gustoća, čvrstoća na savijanje, modul elastičnosti, tvrdoća prema Brinellu*

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1 INTRODUCTION
1. UVOD

Oak is one of the most important and widely used sources of structural timber in Europe. However, its properties have high variability for several reasons. Firstly, the genus oak *(Quercus)* contains numerous tree species (Mabberley, 1987) that cannot be easily differentiated based on wood structure. Trade timber can therefore contain more than one wood species under the same commercial name. Another source of variation is the cellular wood structure, with compact cell walls and void cell lumina, which directly affects wood density, as one of the most relevant wood properties. In ring porous oaks, the density is related to the earlywood/latewood proportion, whereby wood with narrower annual rings and a high proportion of earlywood usually has lower density than wood with wider rings and a lower proportion of earlywood (Kollmann and Cote, 1968).

Most European oaks are ring-porous species and can be assigned to white or red oak groups (Richter and Dallwitz, 2000). The main representatives of white oaks are the widely used sessile (*Quercus petraea*) and pedunculate oak (*Qercus robur*). Turkey oak (*Quercus cerris*), which belongs to red oaks, is less frequent. It grows and is mainly used in southern and south-eastern Europe (Richter and Dallwitz, 2000).

Oak wood, among other uses, is still largely used for the production of railway sleepers. The required wood properties for railway sleepers and similar products are defined by EN 13145 (2012). This standard recommends wood species, quality requirements, origin, manufacturing conditions, forms, dimensions and tolerances, as well as the durability and preservation of wood sleepers and bearers for use in railway tracks. According to EN 13145 (2012), wood for sleepers and bearers must have a natural or conferred durability allowing its use in hazard class 4 as defined in EN 335-1 (2006). According to EN 350-2 (1994), solid wood to be used in hazard class 4 must conform to natural durability class 1 or 2. Wood with natural durability of classes 3, 4 or 5 or containing non-durable sound sapwood must be treated to achieve a conferred durability, which allows its use in hazard class 4. The longevity of class 2 species may also be increased by treatment as recommended by EN 13145 (2012). Deviations from the procedures described above must be agreed between the customer and supplier.

Oaks are also among wood species recommended for railway sleepers. They are termed European oaks and include the following species: *Quercus robur* (pedunculate oak*), Q. petraea* (sessile oak) and *Q. pubescens* (pubescent oak). According to the standards, the presence of sapwood is permitted when sound (EN 13145, 2012).

In Slovenia, as a part of the railway sleepers market of the European Union, customers expect oak timber in trade to contain mainly heartwood of white oaks, *Quercus robur* and *Q. petraea*. They often claim that the mechanical properties of red oak, *Quercus cerris,* which also grows in the region, are inferior to those of both white oaks. They also avoid using sapwood, due to the belief that the mechanical properties of sapwood are inferior to those of heartwood. However, published information to support or reject such opinions is scarce or lacking. Standard literature that provides information on oak wood properties mainly reports on heartwood properties of *Quercus robur* and *Q. petraea* (Esau, 1965; Grosser and Teetz, 1987; Richter and Oelker, 2001; Wagenführ, 1996; Anonymus, 2012), while information on the properties of *Quercus cerris* and, particularly, oak sapwood is scarce (Ayobi *et al.*, 2011).

When lumber or other products are cut from the stem, the characteristics of these fibrous cells and their arrangement affect wood properties such as strength and shrinkage, as well as the grain pattern (Miller, 1989). The formation of heartwood is a natural aging process (Bosshard, 1968); development of sapwood into heartwood takes place in a relatively narrow transition zone, perhaps only the width of one or two growth increments (Wilson and White, 1986; Bamber and Fukazawa, 1985). Sapwood is involved in the transport of water and minerals from the roots and due to their function sapwood cells contain more water and lack the deposits of darkly staining chemical substances commonly found in heartwood. Many of these differences between sapwood and heartwood are chemical; in some cases heartwood substances impregnate cell walls, in others they can also be found in the cell lumina. The amount of starch in parenchyma cells declines in older sapwood and is completely metabolized when sapwood is transformed to heartwood (Hillis, 1987; Shigo and Hillis, 1973; Magel *et al.*, 1994; Taylor *et al.*, 2002). The death of parenchyma cells occurs as a consequence of the accumulation of toxic excretory products of metabolism (Zimmermann and Brown, 1971). Such excretions are trans-located through parenchyma cells towards the centre of the tree (pith), around which the cylinder of heartwood is formed and gradually expanded (Tsoumis, 1991).

Numerous studies have stressed that toxic heartwood compounds seem to function mostly in the exclusion of pathogens from the wood and may help wood to resist fungi, boring insects and bacteria and so increase its natural durability of wood (Hillis, 1987; Mabberley, 1987; Kollmann and Cote, 1968). In addition to differences in colour, sapwood and heartwood often differ considerably in regard to wood durability, whereas possible differences in other properties are rarely reported.

The aim of the present study was to identify oak wood (white oaks vs. red oak) in randomly collected material from a timber yard, and to determine the density and selected mechanical properties, separately for sapwood and heartwood and separately for white and red oaks. We tested the hypotheses that the mechanical properties of red oak *Quercus cerris* are inferior to those of white oaks (*Quercus robur* and *Q. petraea*) and that the mechanical properties of sapwood are inferior to those of heartwood.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Wood samples
2.1. Drvni uzorci

In a timber yard, we randomly selected 26 oak beams from freshly cut trees, originating from various sites in Slovenia. We then prepared clear, oriented samples of sapwood and heartwood. The heartwood samples were taken from the outer parts of the heartwood so that they contained only adult wood; innermost juvenile wood was not included.

After pre-cutting, the samples were seasoned to moisture content (*MC*) of approximately 15 % and then conditioned at relative air humidity (φ) 65 % and temperature (*T*) 20 °C.

Moisture equilibrated samples were cut to final dimensions as required by the standards used to determine mechanical properties (conditions of φ=65 % and *T*=20 °C).

2.2 Wood identification
2.2. Identifikacija drva

The cross-sections of all samples were polished. They were inspected under a microscope for the dimensions and appearance of latewood vessels. Large, solitary and thick-walled latewood vessels indicated the red oak group, which is mainly represented by Turkey oak (*Quercus cerris*). Very small, thin-walled latewood vessels occurring in multiples indicated white oaks, in the area mainly represented by pedunculate oak (*Quercus robur*) or sessile oak (*Quercus petraea*), on the assumption that these two oaks cannot be accurately differentiated in terms of their wood anatomy (Richter and Dallwitz, 2000).

2.3 Density
2.3. Gustoća

The oven-dry density was calculated according to ISO 3131 (1975a) and was based on the oven dry mass and volume:

$$\rho_0 = \frac{m_0}{V_0} \tag{1}$$

Where
ρ_0 is the oven-dry density, kg/ m^3
m_0 is the mass of the oven dried sample, kg
V_0 is the volume of the oven dried sample, m^3.

The samples were oven-dried at 103±2 °C and afterwards the volume was defined using a Breuil volume meter (Kollmann and Cote, 1968).

2.4 Bending strength and modulus of elasticity
2.4. Čvrstoća na savijanje i modul elastičnosti

The bending strength and modulus of elasticity were determined in agreement with ISO 3133 (1975c), using a Zwick-100 testing machine. The dimensions of the samples were 20 mm x 20 mm x 300 mm, with the longest dimension in the axial direction. The distance between the points of suspension was 280 mm. The velocity of force loading was set such that every test was finished within 90±30 seconds. Bending strengths (σ_B) in N/mm^2 were calculated for each sample as follows:

$$\sigma_B = \frac{3 \cdot P_{max} \cdot l}{2 \cdot b \cdot h^2} \tag{2}$$

Where:
P_{max} is the breaking load, N;
l is the distance between the centres of the supports, mm;
b is the width of the test piece, mm;
h is the height of the test piece, mm.

and modulus of elasticity in bending (*MOE*) in MPa:

$$MOE = \frac{l^3 \cdot m}{4 \cdot b \cdot h^3} \tag{3}$$

Where
m is the gradient (i.e., slope) of the initial straight-line portion of the load deflection curve:

$$m = \frac{P}{D}, \quad \text{N/mm} \tag{4}$$

where *D* is the deflection of the centre of the beam at load *P*.

2.5 Compression strength
2.5. Tlačna čvrstoća

Compression strength tests were done as specified by ISO 3132 (1975b). The dimensions of oriented samples were 20 x 20 mm in cross section and 40 mm in the axial direction. The velocity of loading was set so that every test was finished within 90±30 seconds, using a Zwick-100 testing machine. Finally, the compression strength was calculated (σ_c) for each of the sapwood and heartwood samples

$$\sigma_C = \frac{P}{a \cdot l} \tag{5}$$

Where
σ_c is the compression strength, MPa (N/mm^2)
P is the load, in N, corresponding to the proportional limit in compression perpendicular to the grain (conventional ultimate strength);
a is the thickness of the piece, mm;
l is the width of the piece, mm.

2.6 Brinell hardness
2.6. Tvrdoća prema Brinellu

Sapwood and heartwood hardness were measured according to EN 1534 (2000) on a Zwick-100 testing machine. The Brinell method was used, with a steel ball 10±0.01 mm in diameter and 1000 N of force loading. The tests were done so that 1000 N of force was reached in 15±3 s and this constant force was subsequently maintained for another 25±5 s. Brinell hardness was calculated from the depth of the ball impress and expressed in N/mm²: End-hardness and side-hardness were defined (Kollmann and Cote, 1968). For end-hardness, loading was performed in an axial direction (parallel to the grain) and the steel-ball was impressed on the cross-section of wood. In case of side-hardness, loading was performed in a tangential direction (perpendicular to the grain) with the ball impression on the radial surface of the wood. The tests were performed separately for sapwood and heartwood.

$$HB = \frac{2 \cdot F}{\pi \cdot D \cdot \left[D - \left(D^2 - d^2 \right)^{\frac{1}{2}} \right]} \quad (6)$$

Where

π is the ″pi″ factor (≈3,14);

F is the nominal force, N;

D is the diameter of the ball, mm;

d is the diameter of the residual indentation, mm.

2.7 Statistical analyses
2.7. Statističke analize

Statistical analyses of datasets were done with Microsoft Excel and Statgraphics Plus (version 5.1) computer software. Data were analyzed by ANOVA (analysis of variance). When the differences between analyzed groups were found to be significant, multiple range tests (95% LSD method) were used to determine the differences between means at a 95.0% confidence level.

3 RESULTS
3. REZULTATI

3.1 Wood identification
3.1. Identifikacija drva

Wood anatomical examination (Fig. 1) revealed that the samples originated from 16 white oak (*Q. robur* or *Q. petrea*) and 10 red oak (*Q. cerris*) beams. Differentiation of very small, thin walled latewood vessels grouped in multiples in white oaks and of large, solitary and thick-walled latewood vessels in red oaks is shown in Figure 1. In both white and red oaks, earlywood vessels in heartwood were filled with tyloses.

3.2 Density
3.2. Gustoća

Statistical values for the oven-dry density of 70 sapwood and 46 heartwood samples divided into white and red oak groups are presented in Figure 2. Oven-dry densities were in the range as reported in the literature

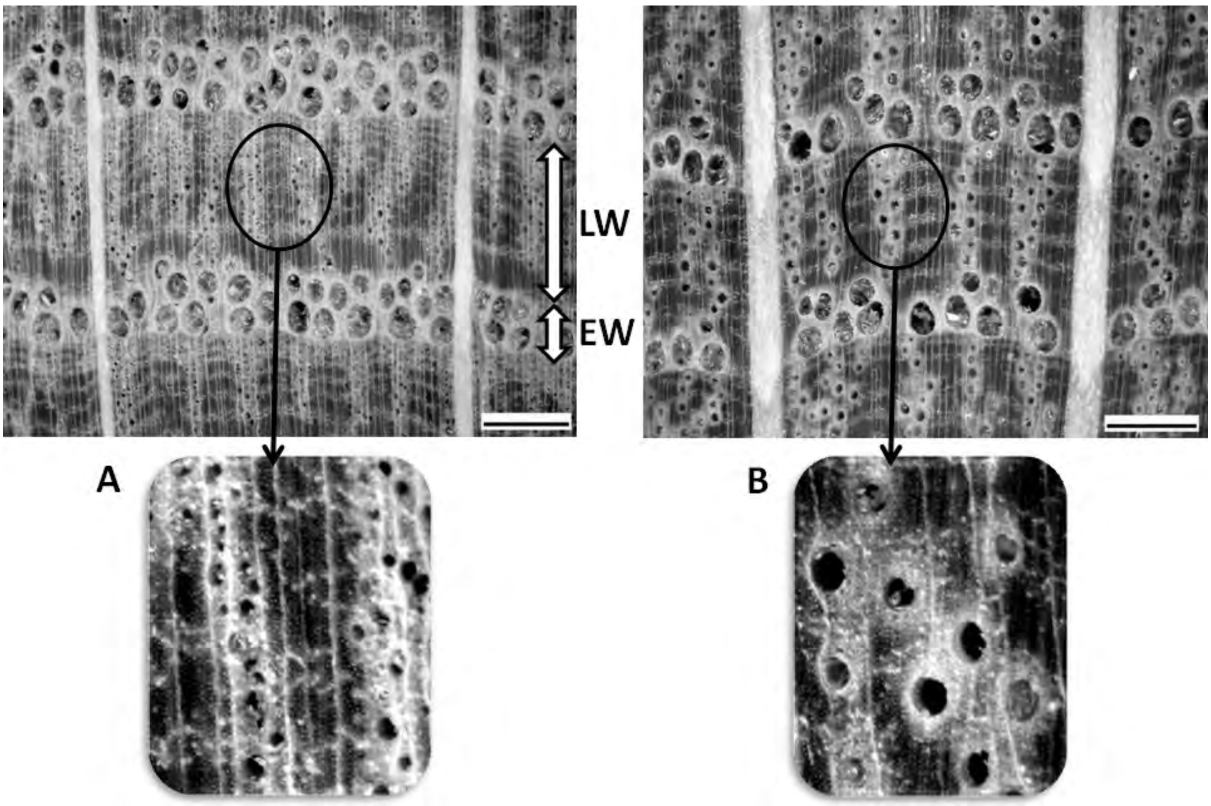

Figure 1 Cross-section of oak heartwood. A) White oak (*Qercus robur* or *Q. petrea*) and B) Red oak (*Quercus cerris*). Both are ring-porous, with clearly distinctive earlywood (EW) with large vessels (pores) and latewood (LW) with smaller radially oriented vessels. Red oaks have fewer, more solitary, and thicker walled latewood vessels (B) than white oaks (A). Scale bars: 1 mm

Slika 1. Poprečni presjek srži drva hrasta. A) bijeli hrast (*Qercus robur* ili *Q. petrea*), B) crveni hrast (*Quercus cerris*). Oba su prstenasto porozna, s jasno odvojenim ranim drvom (EW) velikih traheja (pora) i kasnim drvom (LW) manjih, radijalno orijentiranih traheja. Kasno drvo crvenih hrastova ima manje, više međusobno udaljene traheje debljih stijenki (B) nego drvo bijelog hrasta (A). Oznaka skale: 1mm

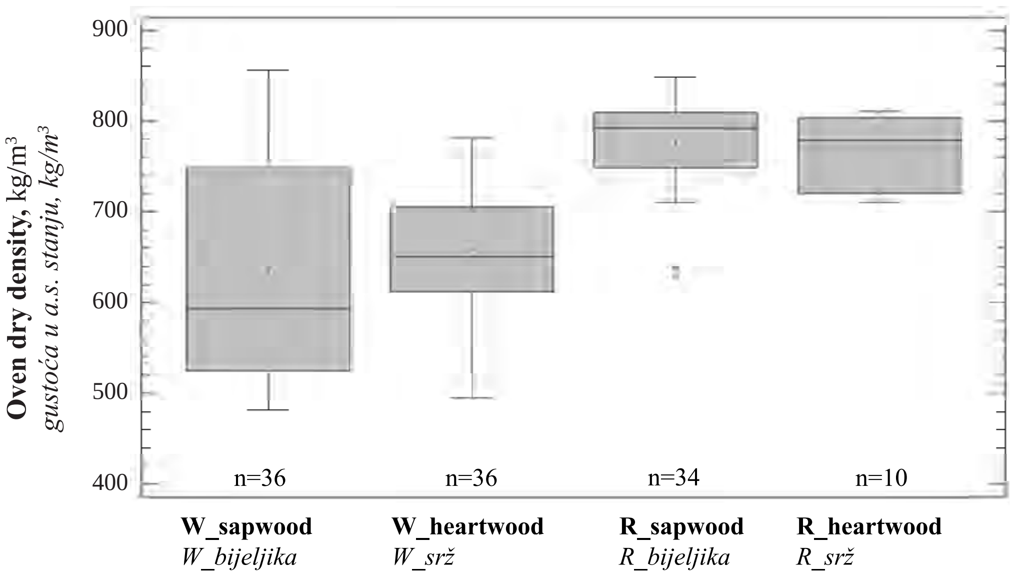

Figure 2 Oven-dry densities of white oak and red oak sapwood and heartwood. W_sapwood - white oak sapwood, W_heartwood - white oak heartwood, R_sapwood – red oak sapwood and R_heartwood - red oak heartwood; *n* – number of samples
Slika 2. Gustoća apsolutno suhog drva bjeljike i srži bijeloga i crvenog hrasta. W_sapwood – bjeljika bijelog hrasta, W_heartwood – srž bijelog hrasta, R_sapwood – bijeljika crvenog hrasta i R_heartwood – srž crvenog hrasta; *n* – broj uzoraka

(Table 11). On average, white oak sapwood has the lowest (634.1 kg/m^3) and red oak sapwood has the highest (767.3 kg/m^3) oven-dry density.

According to ANOVA (Table 1), differences between the densities of white and red oak groups were found to be significant (F = 20.88, P<0.05). The multiple range test (95 % LSD method) (Table 2) showed that the differences between sapwood and heartwood within white and red oak groups were not statistically significant.

The results confirm that the density of ring porous woods is mainly dependent on growth ring structure and its variability and less on structural and chemical changes as a result of heartwood formation processes (Tsoumis, 1991).

Table 1 ANOVA indicating the comparison of oven-dry densities of sapwood and heartwood at W_: white oak and R_: red oak
Tablica 1. ANOVA analiza za usporedbu gustoće u standardno suhom stanju drva bjeljike i srži bijeloga (W) i crvenog (R) hrasta

Source / *izvor*	***SS***	***DF***	***MS***	***F*-Ratio** *F-omjer*	***P*-Value*** *P-vrijednost**
Between groups *između skupina*	459573	3	153191	20.88	0.0000
Within groups *unutar skupina*	821563	112	7335.39		
Total (Corr.) *ukupno*	1.28114E6	115			

**P*<0.05; *SS* - sum of squares, *DF* - degrees of freedom, *MS* - mean square / *P<0.05; SS – zbroj kvadrata; DF – stupanj slobode; MS - srednja vrijednost kvadrata*

3.3 Bending strength and modulus of elasticity (MOE)
3.3. Čvrstoća na savijanje i modul elastičnosti (*MOE*)

The bending strength and *MOE* were defined for 70 sapwood samples (white oak: 36; red oak: 34) and 46 heartwood samples (white oak: 36; red oak: 10). The bending strength and MOE of sapwood and heartwood were compared separately for white and red oak groups (Figure 3 and 4).

Table 2 Multiple range tests (95% LSD method) of sapwood and heartwood oven-dry densities of W_: white oak and R_: red oak
Tablica 2. Višestruka (95% LSD metoda) usporedba gustoće u standardno suhom stanju drva bjeljike i srži bijeloga (W) i crvenog hrasta (R)

	Count *Broj*	**Mean** *Srednja vrijednost*	**Homog. Groups** *Homogene skupine*
W_sapwood *W_bjeljika*	36	634.1	X
W_heartwood *W_srž*	36	658.3	X
R_sapwood *R_bjeljika*	34	776.4	X
R_heartwood *R_srž*	10	767.3	X

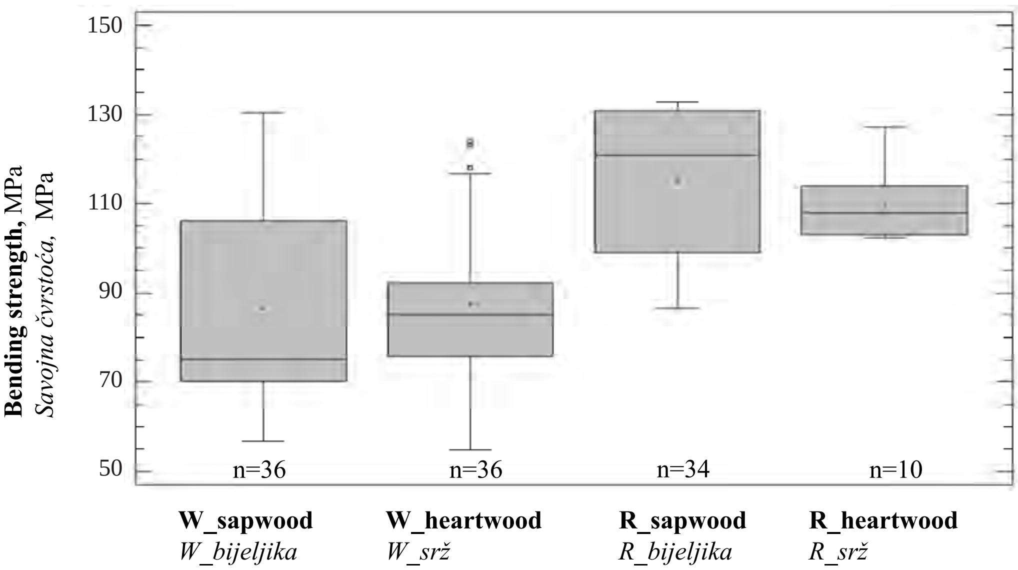

Figure 3 Bending strength of sapwood and heartwood samples. W_sapwood - white oak sapwood, W_heartwood - white oak heartwood, R_sapwood – red oak sapwood and R_heartwood - red oak heartwood; *n* – number of samples
Slika 3. Čvrstoća na savijanje drva bjeljike i srži bijeloga i crvenog hrasta. W_sapwood – bjeljika bijelog hrasta, W_heartwood – srž bijelog hrasta, R_sapwood – bjeljika crvenog hrasta i R_heartwood – srž crvenog hrasta; *n* – broj uzoraka

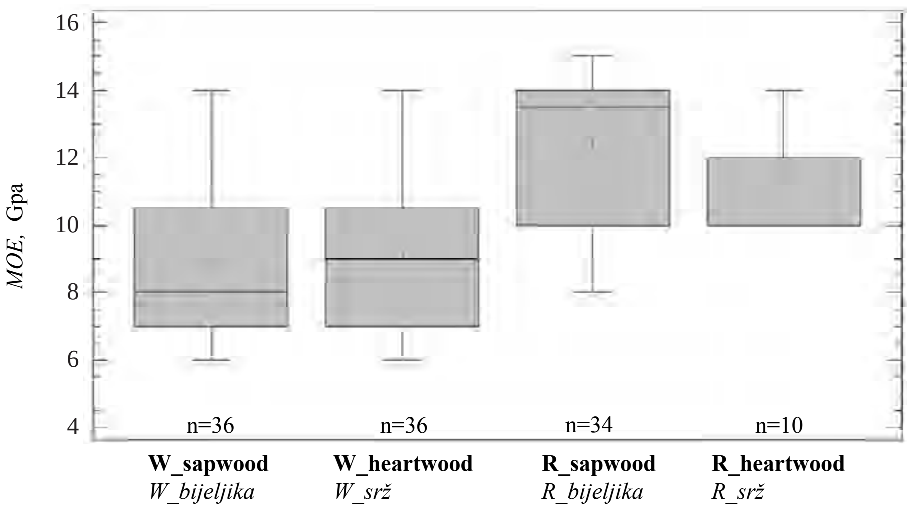

Figure 4 Modulus of elasticity (*MOE*) of sapwood and heartwood samples. W_sapwood - white oak sapwood, W_heartwood - white oak heartwood, R_sapwood – red oak sapwood and R_heartwood - red oak heartwood; *n* – number of samples
Slika 4. Modul elastičnosti (*MOE*) drva bjeljike i srži bijeloga i crvenog hrasta. W_sapwood – bjeljika bijelog hrasta, W_heartwood – srž bijelog hrasta, R_sapwood – bjeljika crvenog hrasta i R_heartwood – srž crvenog hrasta; *n* – broj uzoraka

Table 3 ANOVA for comparison of bending strength of sapwood and heartwood for W_: white oak and R_: red oak
Tablica 3. ANOVA analiza za usporedbu čvrstoće na savijanje drva bjeljike i srži bijeloga (W) i crvenog (R) hrasta

Source / *Izvor*	***SS***	***DF***	***MS***	***F*-Ratio** *F-omjer*	***P*-Value*** *P-vrijednost**
Between groups *između skupina*	20322.1	3	6774.04	19.40	0.0000
Within groups *unutar skupina*	39107.2	112	349.17		
Total (Corr.) *ukupno*	59429.3	115			

*P<0.05; *SS* - sum of squares, *DF* - degrees of freedom, *MS* - mean square / *P<0.05; SS – zbroj kvadrata; DF – stupanj slobode; MS - srednja vrijednost kvadrata*

Table 4 ANOVA for comparison of modulus of elasticity (*MOE*) of sapwood and heartwood for W_: white oak and R_: red oak
Tablica 4. ANOVA analiza za usporedbu modula elastičnosti (*MOE*) drva bjeljike i srži bijeloga (W) i crvenog (R) hrasta

Source / *Izvor*	***SS***	***DF***	***MS***	***F*-Ratio** *F-omjer*	***P*-Value*** *P-vrijednost**
Between groups *između skupina*	302.6	3	100.88	19.77	0.0000
Within groups *unutar skupina*	571.5	112	5.10		
Total (Corr.) *ukupno*	874.2	115			

*P<0.05; *SS* - sum of squares, *DF* - degrees of freedom, *MS* - mean square / *P<0.05; SS – zbroj kvadrata; DF – stupanj slobode; MS - srednja vrijednost kvadrata*

According to ANOVA (Tables 3 and 4), differences between groups (white vs. red oak) were found to be significant (F = 19.40, P<0.05 and F = 19.77, P<0.05). White oak sapwood had the lowest and red oak sapwood the highest bending strength. The LSD method (Tables 5 and 6) shows that there is no statistically significant difference between the means of the sapwood and heartwood bending strengths within either white or red oak group.

3.4 Compression strength
3.4. Tlačna čvrstoća

Values of compression strength (Figure 5) were within the range reported in the literature (Grosser and Teetz, 1987; Wagenführ, 1996; Anonymus, 2012; Giordano, 1976; Horvat, 1959) (Table 11).

Table 5 Multiple range tests (95% LSD method) of sapwood and heartwood bending strength for W_: white oak and R_: red oak
Tablica 5. Višestruka analiza (95% LSD metoda) za usporedbu čvrstoće na savijanje drva bjeljike i srži bijeloga (W) i crvenog (R) hrasta

	Count *Broj*	Mean *Srednja vrijednost*	Homog. Groups *Homogene skupine*
W_sapwood *W_bjeljika*	36	86.5	X
W_heartwood *W_srž*	36	87.4	X
R_sapwood *R_bjeljika*	34	115.3	X
R_heartwood *R_srž*	10	110.0	X

Table 6 Multiple range tests (95% LSD method) of sapwood and heartwood *MOE* for W_: white oak and R_: red oak
Tablica 6. Višestruka analiza (95% LSD metoda) s ciljem usporedbe modula elastičnosti (*MOE*) drva bjeljike i srži bijeloga (W) i crvenog (R) hrasta

	Count *Broj*	Mean *Srednja vrijednost*	Homog. Groups *Homogene skupine*
W_sapwood *W_bjeljika*	36	8.9	X
W_heartwood *W_srž*	36	9.1	X
R_sapwood *R_bjeljika*	34	12.4	X
R_heartwood *R_srž*	10	11.7	X

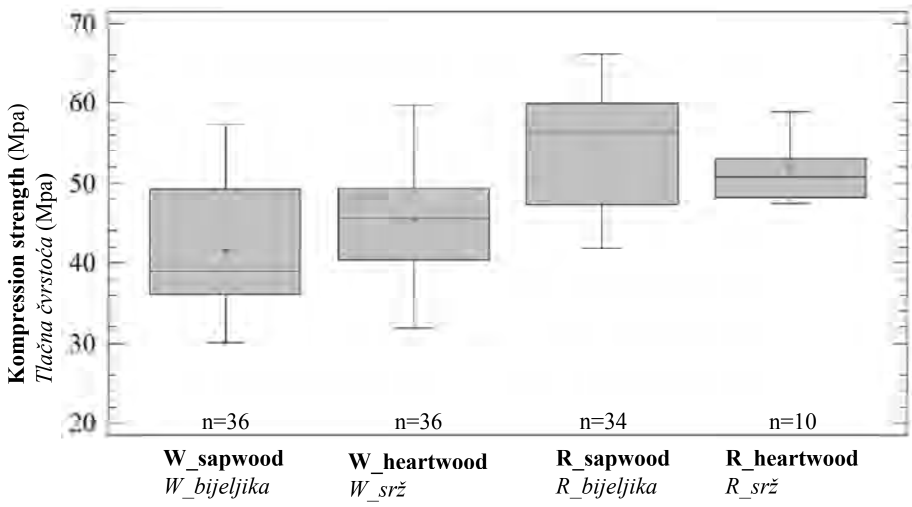

Figure 5 Compression strength of sapwood and heartwood samples. W_sapwood - white oak sapwood, W_heartwood - white oak heartwood, R_sapwood – red oak sapwood and R_heartwood - red oak heartwood; *n* – number of samples
Slika 5. Tlačna čvrstoća drva bjeljike i srži bijeloga i crvenog hrasta. W_sapwood – bjeljika bijelog hrasta, W_heartwood – srž bijelog hrasta, R_sapwood – bjeljika crvenog hrasta i R_heartwood – srž crvenog hrasta; *n* – broj uzoraka

Red oak group has higher bending strengths as well as higher *MOE*, which is in agreement with density variation. Strength also increased with increasing density, which is in agreement with reports in the literature (Tsoumis, 1991).

Table 7 ANOVA indicating the comparison of compression strength of sapwood and heartwood for W_: white oak and R_: red oak
Tablica 7. ANOVA analiza za usporedbu tlačne čvrstoće drva bjeljike i srži bijeloga (W) i crvenog (R) hrasta

Source / *Izvor*	***SS***	***DF***	***MS***	***F*-Ratio** *F-omjer*	***P*-Value*** *P-vrijednost**
Between groups *između skupina*	3382.6	3	1127.54	22.95	0.0000
Within groups *unutar skupina*	5502.0	112	49.13		
Total (Corr.) *ukupno*	8884.6	115			

**P*<0.05; *SS* - sum of squares, *DF* - degrees of freedom, *MS* - mean square / *P<0.05; SS – zbroj kvadrata; DF stupanj slobode; MS - srednja vrijednost kvadrata*

As seen from Table 7 (ANOVA), differences between the groups were found to be significant (*F* = 22.95, P<0.05). The LSD test showed that white oak sapwood had the lowest and red oak sapwood the highest compression strength (Table 8) and that there is a statistically significant difference between the means of sapwood and heartwood within the white oaks group.

3.5 Brinell hardness
3.5. Tvrdoća prema Brinellu

Brinell hardness (HB) was determined for white oak samples only (Figure 6).

According to ANOVA, the P-value of the F-test was greater than 0.05, indicating no statistically significant differences between the means for Brinell hardness in any of the two tested directions (Table 9).

As seen from multiple range tests (Table 10), there are no statistically significant differences between any pair of means at a 95.0% confidence level.

Table 8 Multiple range tests (95% LSD method) of sapwood and heartwood compression strength for W_: white oak and R_: red oak
Tablica 8. Višestruka analiza (95% LSD metoda) za usporedbu tlačne čvrstoće drva bjeljike i srži bijeloga (W) i crvenog (R) hrasta

	Count *Broj*	Mean *Srednja vrijednost*	Homog. Groups *Homogene skupine*
W_sapwood *W_bjeljika*	36	41.7	X
W_heartwood *W_srž*	36	45.4	X
R_sapwood *R_bjeljika*	34	54.8	X
R_heartwood *R_srž*	10	51.7	X

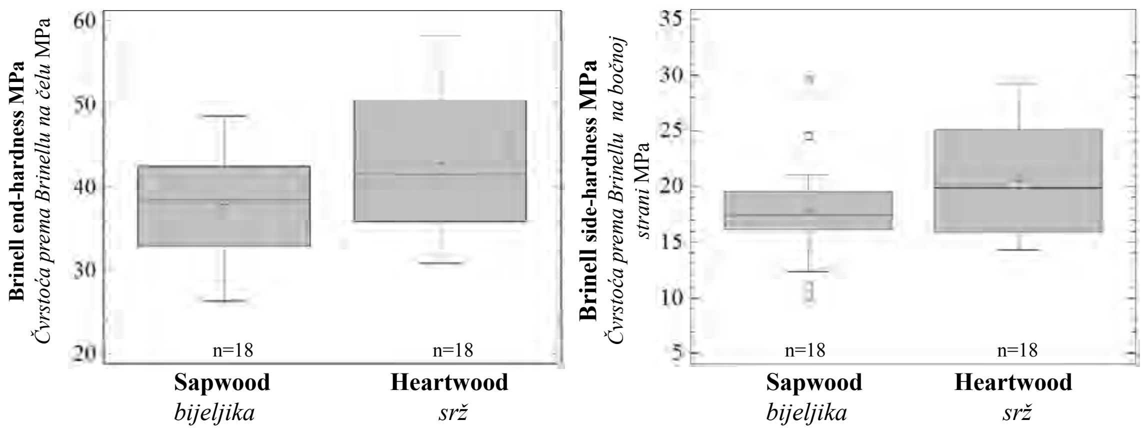

Figure 6 Brinell hardness of sapwood and heartwood samples of white oaks; left: end-hardness (impression on cross-section in an axial direction) and right: side-hardness (impression on radial surface in a tangential direction)
Slika 6. Tvrdoća prema Brinellu drva bjeljike i srži bijeloga hrasta; lijevo: tvrdoće na čelu (utiskivanje na poprečnom presjeku u aksijalnom smjeru) i desno: bočna tvrdoća (utiskivanje na radijalnom presjeku u tangencijalnom smjeru)

Table 9 ANOVA indicating the comparison of end and side Brinell hardness (HB) of sapwood and heartwood with white oak
Tablica 9. ANOVA analiza za usporedbu tvrdoće prema Brinellu na čelu i bočnoj strani uzorka od drva bjeljike i srži bijeloga hrasta

HB *Tvrdoća prema Brinellu*	Source / *Izvor*	***SS***	***DF***	***MS***	***F*-Ratio** *F-omjer*	***P*-Value*** *P-vrijed-nost**
End *Čelo*	Between groups *između skupina*	225.5	1	225.50	3.71	0.0623
	Within groups *unutar skupina*	2063.9	34	60.70		
Side *Bočna strana*	Between groups *između skupina*	69.4	1	69.44	3.08	0.0884
	Within groups *unutar skupina*	767.3	34	22.57		

*$P<0.05$; *SS* - sum of squares, *DF* - degrees of freedom, *MS* - mean square / *$P<0.05$; SS – zbroj kvadrata; DF – stupanj slobode; MS - srednja vrijednost kvadrata*

Table 10 Multiple range tests (95% LSD method) of end and side Brinell hardness (*HB*) for sapwood and heartwood in white oaks
Tablica 10. Višestruka analiza (95% LSD metoda) za usporedbu tvrdoće prema Brinellu (*HB*) na čelu i bočnoj strani uzorka od drva bjeljike i srži bijeloga hrasta

HB *Tvrdoća prema Brinellu*		Count *Broj*	Mean *Srednja vrijednost*	Homog. Groups *Homogene skupine*
End *Čelo*	sapwood *bjeljika*	18	38,0	X
	heartwood *srž*	18	42.9	X
Side *Bočna strana*	sapwood *bjeljika*	18	17.8	X
	heartwood *srž*	18	20.5	X

4 DISCUSSION AND CONCLUSIONS
4. RASPRAVA I ZAKLJUČCI

Our results showed that it is possible to differentiate between white and red oaks based on their wood anatomy as proposed by the literature (Richter and Dallwitz, 2000). Surprisingly, timber with the commercial name oak contained in addition to the expected white oaks *Quercus robur* and *Q. petraea,* also considerable amounts of red oak *Quercus cerris.*

Comparison of the obtained results with the data available in the literature (Table 11) shows that all obtained values varied within the ranges of the published data.

Based on our research, the hypothesis that the mechanical properties of sapwood are inferior to those of heartwood was generally rejected. In case of den-

Table 11 Comparison of the obtained results with density and mechanical properties of investigated white oaks *Quercus robur*, *Q. petrea* and red oak *Q. cerris* from the literature 1*- (Wagenführ, 1996); 2*- (Giordano, 1976); 3*- (Horvat, 1959); 4 *- (Anonymus, 2012); 5 *- (Grosser and Teetz, 1987); mark X in the table indicates missing data in the literature
Tablica 11. Usporedba dobivenih rezultata s podacima o gustoći i mehaničkim svojstvima drva bijelog hrasta *Quercus robur*, *Q. petrea* i drva crvenog hrasta *Q. cerris* iz literature 1*- (Wagenführ, 1996); 2*- (Giordano, 1976); 3*- (Horvat, 1959); 4 *- (Anonymus, 2012); 5 *- (Grosser and Teetz, 1987); oznaka X u tablici znači da u literaturi nema podataka

Oven-dry density / *Gustoća u standardno suhom stanju* kg/m3

	RESULTS		LITERATURE (heartwood)				
	sapwood	heartwood	1*	2*	3*	4*	5*
Q. robur	634	658	390 - 650 - 930	670	388 - 625 - 795	X	390 - 650 - 930
Q. petraea			390 - 650 - 930	670	465 - 662 - 837	X	390 - 650 - 930
Q. cerris	776	767	X	690	781	X	X

Bending strength / *Savojna čvrstoća* MPa

	RESULTS		LITERATURE (heartwood)				
	sapwood	heartwood	1*	2*	3*	4*	5*
Q. robur	86	87	74 - 88 - 105	53 - 108 - 153	58.8 - 92.1 - 98	60 - 110	88
Q. petraea			78 - 110 - 117	53 - 108 - 153	58.8 - 92.1 - 98	60 - 110	110
Q. cerris	115	110	X	65 - 110 - 152	X	75 - 120	X

Modulus of elasticity / *Modul elastičnosti* GPa

	RESULTS		LITERATURE (heartwood)				
	sapwood	heartwood	1*	2*	3*	4*	5*
Q. robur	8,9	9,0	10 - 11.7 - 13.2	10.6 - 12.5 - 14.6	11.5	10.5 - 14.5	11.7
Q. petraea			9.2 - 13 - 13.5	10.6 - 12.5 - 14.6	12.7	10.5 - 14.5	13
Q. cerris	12,4	11,7	X	X	X	10.2 - 15.7	X

Compression strength / *Tlačna čvrstoća* MPa

	RESULTS		LITERATURE (heartwood)				
	sapwood	heartwood	1*	2*	3*	4*	5*
Q. robur	41,6	45,4	54 - 61 - 67	29.4 - 60.8 - 84.3	51	42 - 64	61
Q. petraea			48 - 65 - 70	29.4 - 60.8 - 84.3	23.5 - 37.2 - 43.1	42 - 64	55 - 65
Q. cerris	54,8	51,6	X	36.3 - 57.4 - 83.3	57	42 - 60	X

Brinell end-hardness / *Tvrdoća prema Brinellu na čelu* MPa

	RESULTS		LITERATURE (heartwood)				
	sapwood	heartwood	1*	2*	3*	4*	5*
Q. robur	37,9	42,9	66	X	65,7	X	X
Q. petraea			66	X	41.1 - 67.7 - 97	X	X
Q. cerris	X	X	X	X	64.7 - 77.9 - 96.1	X	X

Brinell side-hardness / *Tvrdoća prema Brinellu na bočnoj strani* MPa

	RESULTS		LITERATURE (heartwood)				
	sapwood	heartwood	1*	2*	3*	4*	5*
Q. robur	17,7	20,5	34	X	X	23 - 42	X
Q. petraea			34	X	X	23 - 42	X
Q. cerris	X	X	X	X	X	22 - 35	X

sity, bending strength and MOE, compression strength and Brinell hardness, the differences between sapwood and heartwood were not significant. A significant difference was only found between the means of compression strength of sapwood and heartwood within the white oaks group. In all cases (density, bending strength, MOE, compression strength), red oak sapwood even had the highest values of all. This is, for example, in line with observations comparing the mechanical properties and extractive content in *Quercus castaneifolia* (Ayobi *et al.*, 2011) and partly in *Larix* sp. (Grabner *et al.*, 2005). The latter showed that extractive content directly affected transverse compression strength and MOE, whereas it was less pronounced in the case of axial compression strength, determined in our case. In Q. cerris mean density of sapwood found to be a little higher in sapwood than in heartwood, although the opposite was normally expected. It may happened due to relatively small size of logs used for specimens.

Our results indicate that the evaluated properties were mainly affected by wood structure. Chemical differences in terms of a higher content of heartwood extractives do not seem to affect these properties (Tsoumis, 1991).

We also rejected the hypothesis that the properties of red oak *Quercus cerris* are inferior to those of white oaks. In all cases, the properties of *Quercus cerris* had even higher values than those of white oaks.

Despite the present results, it cannot be excluded that some of the properties of *Quercus cerris* may be less favorable than those of white oaks. In Slovenia, Italy and Austria, *Quercus cerris* is often used for fuel. One of the problems is that it often has an irregular stem form. This problem may be less pronounced when using it for products such as railway sleepers. One of the differences between white oaks and *Quercus cerris* reported in the literature is natural durability. According to the EN 350-2 (1994) heartwood of *Q. robur* and *Q. petrea* has natural durability class 2 – durable, whereas heartwood of *Q. cerris* is reported to have natural durability class 3 – moderately durable. It should be noted here that natural durability, like other properties, is highly variable in oaks. Humar and co-authors (Humar *et al*., 2008) for instance, reported that the durability of heartwood in white oaks varies with wood structure; they showed that in extreme cases, white oak heartwood can even be as non-durable as beech wood (durability class 5 - not durable) (Humar *et al.*, 2008). In any case, heartwood class 2 must be treated in the case of railway sleepers to achieve a conferred durability that allows its use in hazard class 4 (EN 350-2, 1994). It should also be noted that the heartwood of all three investigated oak species is extremely difficult to be treated (treatability class 4).

Oak sapwood, as the sapwood of any wood species, is not durable (class 5) and must be treated. Fortunately, oak sapwood is easy to be treated (treatability class 1) (EN 350-2, 1994) and adequately treated sapwood can be used in hazard class 4. According to the standards for wooden railway sleeper production (EN 13145, 2012), therefore, sapwood is permitted with oak, provided that it is completely sound before the treatment is applied.

Our results showed that marketed oak timber, in addition to white oaks, also contains red oak *Q. cerris*. Despite the relatively small sample, the variability of wood properties proved to be larger within the groups (white oaks, red oaks, sapwood, and heartwood) than among the groups (white vs. red oaks, sapwood vs. heartwood). The variability of all properties is among the main disadvantages of wood as a raw material. Knowing this is the basis for optimal selection and use of timber for structural purposes.

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Usporedba momenta loma kutnog spoja izvedenoga upotrebom različitih ljepila

The Fracture Moment of Corner Joint Bonded by Different Glues

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SAŽETAK • *Cilj istraživanja bio je odabrati najpogodniju vrstu adheziva za novorazvijeni kutni spoj s drvenim prstenom. Primjena tog spoja najčešća je u proizvodnji prozorskih okvira. Kutni spoj s drvenim prstenom rezultat je slovenskog znanja i zaštićen je međunarodnim patentom. Rezultati sile loma u kutnih spojeva napravljenih uz pomoć različitih ljepila ispitivani su standardnom metodom na kidalici. Najbolji rezultati postignuti su upotrebom polivinilacetatnog ljepila grupe D3. Prednost primjene spoja s drvenim prstenom jest način proizvodnje koji omogućuje izradu okvira od prethodno površinski obrađenih elemenata koji se neposredno prije spajanja pile na željenu duljinu. Sastavljanjem dijelova proces izrade prozorskog krila završava. Zbog toga je izuzetno važno odabrati odgovarajuće ljepilo koje može potpuno ispuniti mjesto spoja i prekriti cijeli nezaštićen čelni dio elemenata u sastavu. Za tu su svrhu u eksperimentu upotrijebljena poliuretanska ljepila koja tijekom otvrdnjavanja djelomično ekspandiraju.*

Ključne riječi: *prozor, konstrukcije, spoj, drvo, ljepilo*

ABSTRACT • *The main goal of this research is to determine the most appropriate adhesive to fix angular joints with wooden ring for manufacturing window frames. The joint with wooden ring is the result of Slovenian experience and is protected by international patent. The destructive strength of angular joints adhered with different glues was tested by the tensile-testing machine. Polyvinyl acetate glue of the D3 group was found to be the most appropriate from the point of view of strength. The biggest advantage of using a joint with wooden ring lies in the possibility of manufacturing wooden frames from finished elements. In this way, the process of manufacturing a window ends after assembling its parts. It is, therefore, very important to choose the right glue that can completely fill the junction and cover the whole unprotected front part of the joint. For this purpose, polyurethane glues were used in the experiment, as they slightly expand during the hardening phase.*

Key words: *window, construction, joint, wood, glue*

1. UVOD
1 INTRODUCTION

Čvrstoća spojeva lijepljenih PVAc ljepilom ovisi o kvaliteti mehaničke obrade drvnih površina prije lijepljenja (Singh i sur., 2002), koje moraju biti ravne i određene hrapavosti, kao i o vremenu proteklome od obrade do nanošenja ljepila (Nussbaum i Sterley, 2002). Najkvalitetniji spoj može se postići lijepljenjem neposredno nakon obrade površine. Preporučljivi sadržaj vode u drvu jest 5 – 12 %, a za posebno pripremljena ljepila moguća su i manja odstupanja (Resnik,

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1997). Istraživanja su pokazala da povećanje sadržaja vode u drvu od 12 na 15 % oslabi čvrstoću lijepljenja za 15 %, dok je pri smanjenju sadržaja vode u drvu sa 12 na 8 % ona veća za 6 % (Tankut, 2007). Pri hladnom lijepljenju potrebno vrijeme prešanja spoja nakon priljubljivanja iznosi 10 - 20 minuta (Marra, 1992), dok je pri temperaturi 80 °C ono smanjeno na samo dvije minute. Potreban tlak je 2-15 MPa, što ovisi o vrsti drva i obilježjima sljubnica.

Logično je da površina sljuba određuje čvrstoću spoja. Dziegelewski i Zenkteler (1975) dokazuju tu tvrdnju uspoređujući čvrstoće ispitanih spojeva jednostrukim i dvostrukim utorom i perom te zaobljenim čepom, pri čemu je najveću čvrstoću imao spoj s dvostrukim utorom i perom, koji je ujedno imao i najveću površinu sljuba. Mnogi su autori istraživali čvrstoću kutnih spojeva s različitih stajališta. Hill i Eckelman (1973) odredili su utjecaj dimenzija čepa na krutost spojeva. Wilczynski i Warmbier (2000) dokazali su da krutost i čvrstoća spojeva raste s povećanjem dimenzija spoja, a utjecaj debljine čepa na koeficijent krutosti spoja linearan je. U radu Prekrat i sur. (2004) dokazano je da je inoviranim sastavom promijenjene geometrije i manjom površinom lijepljenja moguće postići jednake ili čak bolje rezultate koji se odnose na čvrstoću. Sparkes je (1974) proučavao utjecaj dubine natisnutosti i dimenzije moždanika te njihov međusobni razmak na čvrstoću spoja, dok su Kamenicky i Paulenkova (1984) kreirali formulu za procjenu ukupne čvrstoće lijepljenog spoja, u koju su uvrstili utjecaj dimenzije sljubnica. Osim navedenoga, ne treba zanemariti ni utjecaj oblika lijepljene površine na čvrstoću spoja, koju opisuju Prekrat i Smardzewski (2010).

Izbor ljepila ovisi o materijalu, zahtjevu čvrstoće i izdržljivosti zalijepljenog spoja, svrsi i uvjetima upotrebe proizvoda te o tehnologiji i načinu lijepljenja. Za lijepljenje spojeva u proizvodnji prozora uglavnom se rabe polivinilacetatna (PVAc) i poliuretanska (PUR) ljepila.

Polimerizacijska PVAc ljepila za drvo sastoje od polivinil-acetata i aditiva koji modificiraju ljepilo za određenu upotrebu. Osnovno je vezivo PVAc ljepila vodena disperzija polivinilacetata, koji se stvara pri polimerizaciji vinilacetata. Vinilacetat se može polimerizirati uz pomoć polimerizacije u masi, polimerizacijom otopine i emulzijskom polimerizacijom. U proizvodnji ljepila za drvo najčešće se upotrebljava emulzija sa sadržajem suhe tvari od 40 do 60 % (Šernek i Kutnar, 2008).

Poliuretanska (PUR) ljepila nastaju poliadicijom izocianatnih polimera i poliola (alkohola s više OH skupina). Poznata su jednokomponentna, dvokomponentna, termo stabilna te taljiva ljepila. U drvnoj se industriji najčešće upotrebljavaju jednokomponentna PUR ljepila, i to za zahtjevna montažna lijepljenja, lijepljenje konstrukcijskih kompozita kao što su npr. nosači. Služe i za spajanje međusobno različitih materijala kao što su metali, guma i keramika. Pri primjeni jednokomponentnih ljepila preporučuje se da sadržaj vode u drvu bude veći od 8 % (Resnik, 1997).

Tipični kutni spojevi koji se primjenjuju pri izradi prozora jesu spojevi s čepom, a rjeđe se rabe spojevi s moždanicima, s eliptičnim umecima i s klinastim zupcima. Među alternativna rješenja može se svrstati Hoffmannov spoj, u kojemu je presjek spojnog elementa u obliku dvostrukoga lastina repa (Hoffmann-Schwalbe, 2008).

Spoj s drvenim prstenom bio je patentiran u WIPO (World Intellectual Property Organisation) pod nazivom *angular juncture for wooden frame constructions* (PTC/SI2005/000030), dobio je zlatnu medalju na Međunarodnom sajmu inovacija (Salon International des Inventions) u Ženevi te na Međunarodnom sajmu inovacija u Nürnbergu (International Fachmesse »Ideen – Erfindungen – Neuheiten«). Navedeni se spoj sastoji od dviju okvirnica koje su međusobno sastavljene drvenim prstenom i vijkom, pri čemu vijak preuzima ulogu stezanja dviju okvirnica. Nakon otvrdnjavanja ljepila vijak se može ukloniti.

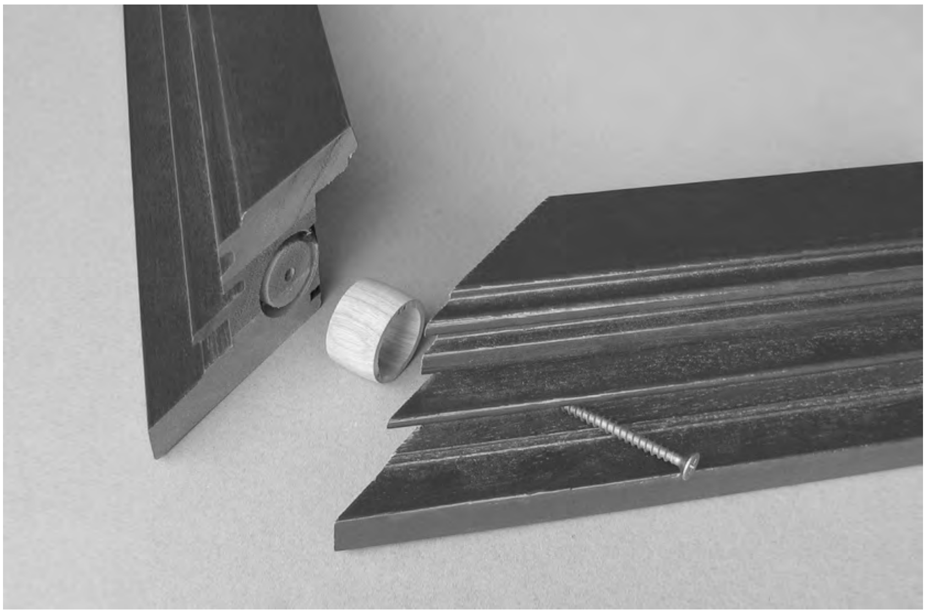
Cilj ovog istraživanja bio je utvrditi utjecaj vrste ljepila na silu loma kutnog spoja te odabrati najprikladnije ljepilo za proizvodnju prozorskih okvira i krila. Osim primjene različitih vrsta ljepila, ostali uvjeti ispitivanja u eksperimentu su bili jednaki za sve uzorke, a to se odnosi na površinu, krak djelovanja sile uvjetovane dimenzijama elemenata, postupak ispitivanja, obrada uzoraka te vlažnost drva. Usporedbom sila loma dobiven je pokazatelj izdržljivosti spojeva. Hipoteza istraživanja bila je da će se zbog bolje penetracije primijenjenog ljepila male viskoznosti postići veća čvrstoća spoja.

2. MATERIJALI I METODE
2 MATERIAL AND METHODS

Istraživanje se provodilo na novorazvijenom kutnom spoju s drvenim prstenom, uz upotrebu različitih ljepila (sl. 1). Elementi uzoraka bili su identičnoga poprečnog presjeka (sl. 2). Svi su elementi spojeni kosim sučeljem čelnih rubova pod kutom 45°. Za svaku skupinu ljepila izrađeno je šest uzoraka. Svi su uzorci izrađeni od radijalno ili radijalno-tangentne smrekovine homogene teksture, bez kvrga, smolnih vrećica i pukotina.

Za lijepljenje je upotrijebljeno PVAc ljepilo s otvrdnjivačem, dva dvakomponentna epoksi ljepila, dva PVAc ljepila u klasi D3, dva PUR ljepila i PUR ljepilo sa staklenim vlaknima. Uzorci su bili kondicionirani u laboratorijskom prostoru. Testiranje je provedeno sedam dana nakon lijepljenja. Temperatura u vrijeme testiranjem bila je 18 °C, a relativna vlaga 44 %. Sadržaj vode u elementima u procesu lijepljenja bio je 12 %. Ovisno o vrsti ljepila, grupe ispitnih uzoraka bile su označene slovima A, B, C, D, E, F, G i H.

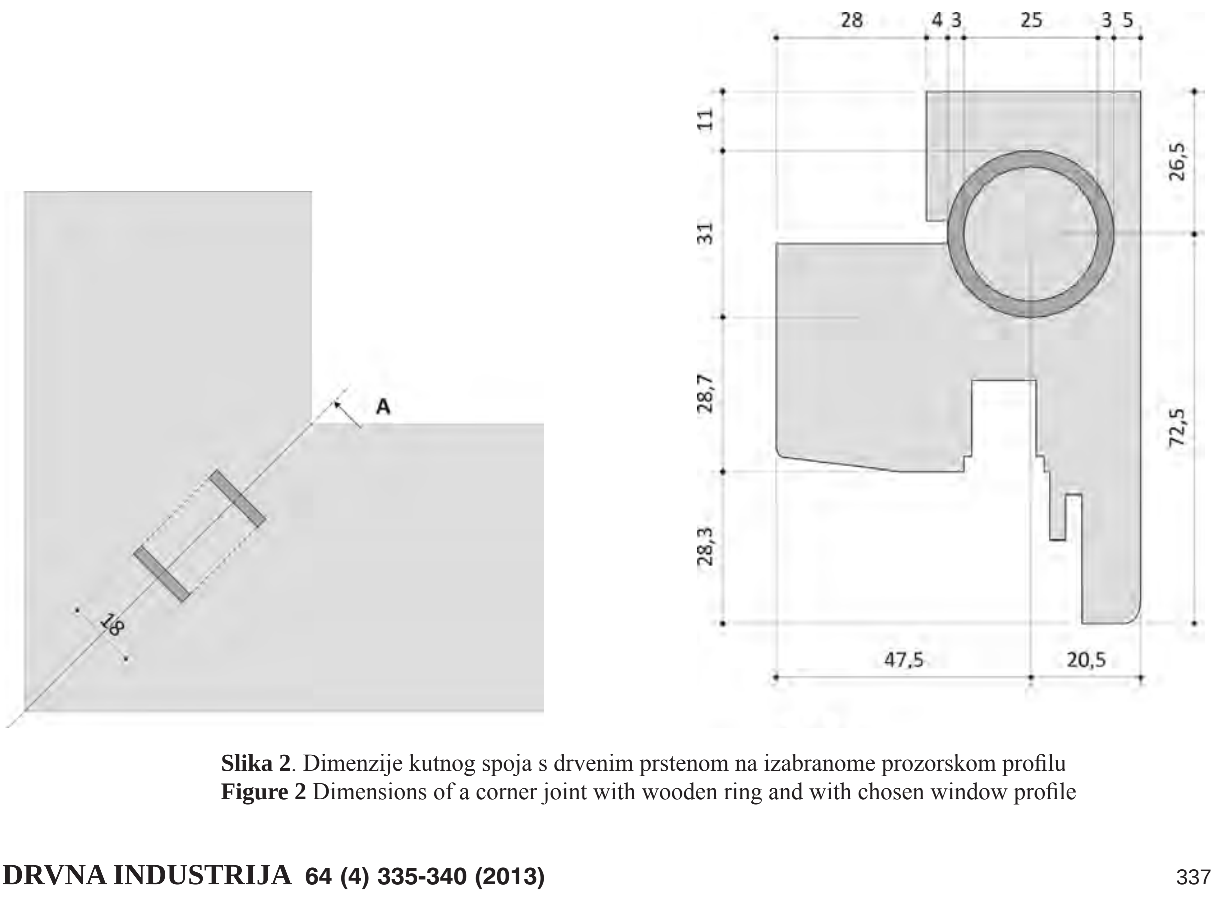
Sila loma kutnih prozorskih profila slijepljenih različitim ljepilima testirana je kidalici u laboratoriju tvrtke Jelovica d.d. (sl. 3). Za utvrđivanje čvrstoće i trajnosti slijepljenog drva primjenjuju se različite metode i postupci (Mihulja i Bogner, 2005). Standardna (JUS D.E8.008, 1987) metoda ispitivanja prilagođena



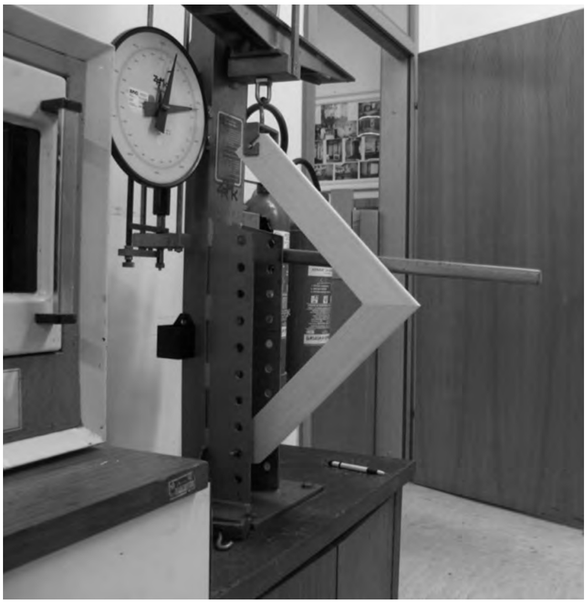
Slika 1. Kutni spoj s drvenim prstenom
Figure 1 Corner joint with a wooden ring

je prethodnim istraživanjem drugih autora – Korzeniowskog (1982), Warmbiera i Wilczynskog (2000). Uzorci su bili pripremljeni kao što je prikazano na slici 4. Dužina krakova uzoraka bila je 450 mm. Za učvršćenje uzoraka u kidalicu na krajevima krakova izbušene su rupe promjera 8,5 mm. Vlačna je sila u kidalici postupno povećavana do loma. Vrijednosti sile do trenutka loma mjerene su i kontinuirano bilježene u njutnima (N).

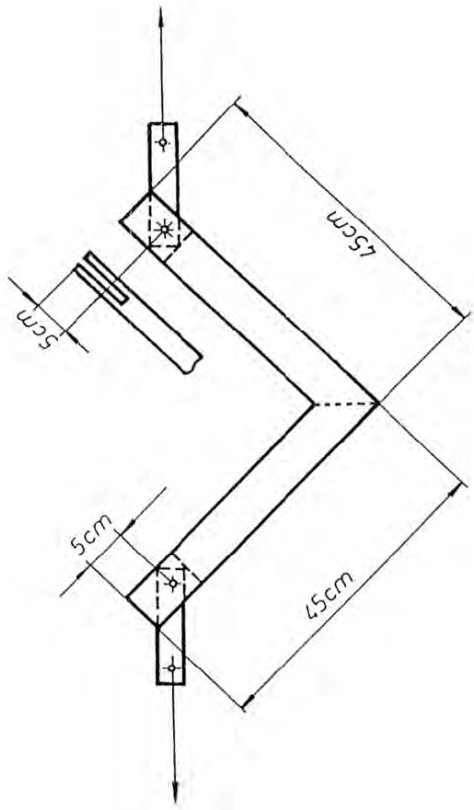
Sila loma kao kriterij definiranja kvalitete spoja odredio je proizvođač. Budući da su svi uzorci bili istovrsni, nije bilo potrebno izračunavati čvrstoću. U slučaju potrebe usporedbe rezultata s rezultatima drugih vrsta spojeva, uz pomoć opisa i dimenzija izrađenih elemenata spoja bilo je lako izračunati čvrstoću.



Slika 2. Dimenzije kutnog spoja s drvenim prstenom na izabranome prozorskom profilu
Figure 2 Dimensions of a corner joint with wooden ring and with chosen window profile



Slika 3. Uzorak u kidalici
Figure 3 Sample gripped into the tensile-testing machine



Slika 4. Skica s dimenzijama uzoraka
Figure 4 Sample dimensions

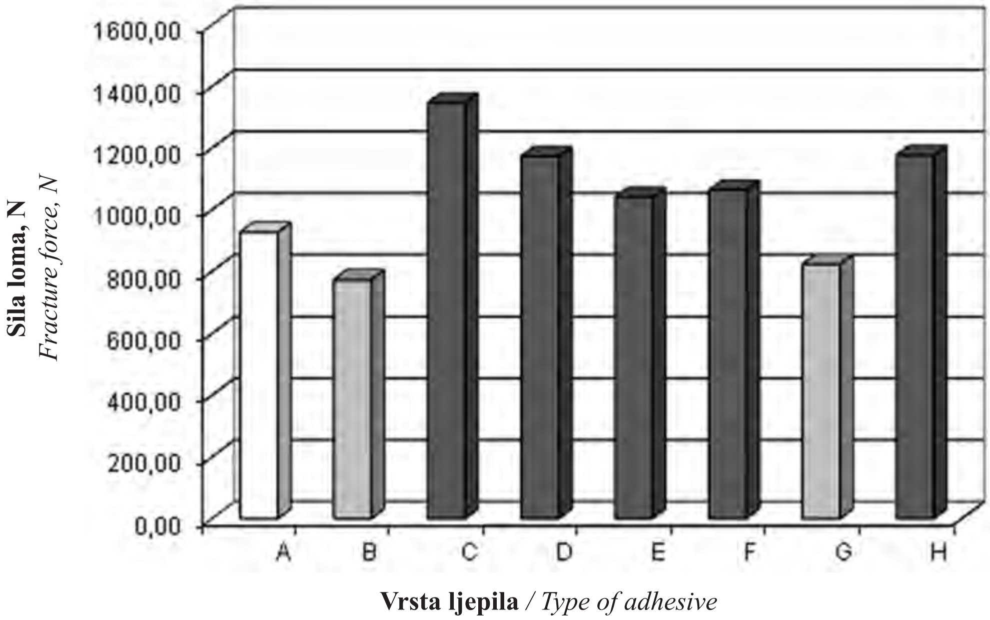
3. REZULTATI ISTRAŽIVANJA
3 RESULTS AND DISCUSSION

Tablica 1. prikazuje vrijednosti sile loma uzoraka ispitanih u kidalici za svih šest uzoraka iz svake skupine.

Tablica 1. Sile loma u njutnima (N) i izračunani momenti loma (Nm)
Table 1 Fracture forces in Newtons (N) and moment of fracture (Nm)

	Skupina - vrsta lijepila *Group - type of adhesive*	**Viskoznost - ISO 2555 (mPa.s)** *Viscosity - ISO 2555 (mPa.s)*	**Uzorci** *Test items* — Vrijednost: sile loma (N) momenta (Nm) *Value of: fracture force (N) moment (Nm)* **1**	**2**	**3**	**4**	**5**	**6**	**Prosječna vrijednost: sile loma (N) momenta (Nm)** *Average value fracture force (N) moment (Nm)*	**Odstupanje od prosječne vrijednosti (N) (Nm)** *Deviations from the average value (N) (Nm)*
A	PVA s otvrdnjivačem *PVA with hardener*	~ 12000	860 308	940 338	980 353	950 342	890 320	940 338	927 334	+53 -67 +19 -26
B	dvokomponentno epoksi lijepilo 1 *two-component epoxy adhesive 1*	~ 65000	760 274	760 274	800 288	790 284	750 270	780 281	773 278	+27 -23 +10 -8
C	PVA ljepilo 1, klase D3 *PVA 1, class D3*	~ 13000	1480 533	1160 418	1400 504	1390 500	1210 436	1440 518	1347 485	+133 -187 +48 -67
D	dvokomponentno epoksi lepilo 2 *two-component epoxy adhesive 2*		980 353	1110 400	1350 486	1190 428	1270 457	1140 410	1173 422	+177 -193 +64 - 69
E	PVA ljepilo 2, klase D3 *PVA 2, class D3*	~ 13500	1100 396	1120 403	900 324	990 356	1040 374	1090 392	1040 374	+80 -140 +29 -50
F	PUR ljepilo sa staklenim vlaknima *PUR + glass fiber*	~ 10500	1140 410	1060 382	990 356	1100 396	1080 389	1010 364	1063 383	+77 -73 +27 -27
G	PUR ljepilo 1 - jednokomponentno *PUR 1, one - component*	~ 8000	800 288	800 288	870 313	790 284	830 299	850 306	823 296	+74 -33 +17 -12
H	PUR ljepilo 2 - jednokomponentno *PUR 2, one - component*		1150 414	1200 432	1180 425	1170 421	1190 428	1170 421	1177 424	+23 -27 +8 -10

Na slici 5. prikazana je usporedba prosječnih vrijednosti sile loma po pojedinim skupinama. Bijelom bojom obilježena je prosječna vrijednost u skupini A, koja je izabrana kao referentna skupina. U predistraživanju je utvrđeno da je spoj s drvenim prstenom zalijepljen PVAc ljepilom s otvrdnjivačem dao zadovoljavajuću čvrstoću za prozorske okvire u masovnoj proizvodnji. Tamnosivom bojom označene su skupine koje su dale bolje rezultate u usporedbi s referentnom skupinom A. Svijetlosivom su bojom označene skupine čiji su rezultati lošiji od onih u skupini A.



Slika 5. Usporedba prosječne sile loma s obzirom na vrstu ljepila
Figure 5 Comparison of destructive forces depending on type of adhesive

Rezultati ispitivanja pokazali su da viskoznija ljepila daju lošije rezultate. Primjer je dvokomponentno epoksi ljepilo za opću uporabu, koje je upotrijebljeno u ispitivanju (skupina B). Manja sila loma od referentne uočena je i za poliuretansko ljepilo (skupina G), koje se pri otvrdnjavanju pjeni. Može se pretpostaviti da ljepilo skupine B zbog velike viskoznosti vjerojatno preslabo prodire u drvo. U kutnom spoju s drvenim prstenom postoji gotovo tupi sljub čelnog presjeka, pri čemu je odgovarajuća penetracija ljepila izuzetno važna za čvrstoću spoja. Pjenjenje ljepila pri otvrdnjavanju također smanjuje silu loma, pri čemu su važne veličina i količina mjehurića koji se pojavljuju u procesu otvrdnjavanja. Mjehurići su se pojavljivali i u uzorcima skupine F, no veće vrijednosti sile loma od referentne mogu se objasniti manjim brojem i manjim dimenzijama mjehurića. Najbolji su rezultati postignuti ljepilom skupine C (PVA ljepilo klase D3).

Spoj s drvenim prstenom omogućuje proizvodnju prozorskih okvira od potpuno mehanički i površinski obrađenih elemenata, što ga razlikuje od uobičajene proizvodnje prozora utorima i perima te čepovima.

Iako je proizvodnja od gotovo sasvim obrađenih elemenata navedena kao jedna od prednosti, taj način proizvodnje ima i potencijalne nedostatke. Pritom se osobito misli na to da možda ljepilo zbog nedostataka preciznosti nije naneseno preko cijele površine sljubnice. Zbog toga je u eksperiment uključeno i poliuretansko ljepilo koje tijekom otvrdnjavanja ekspandira. Treba naglasiti da poliuretanska ljepila, koja se pri otvrdnjavanju jako pjene, nisu prikladna, što dokazuju i rezultati ispitivanja.

Jedina alternativa spoju s drvenim prstenom koja je pronađena u literaturi jest Hoffmannov spoj sa spojnim elementom u obliku dvostrukoga lastina repa, koji se u praksi već potvrdio. No njegov je nedostatak vidljivosti spojnog elementa s jedne strane te se može koristiti samo na prozorima na kojima je dio s vidljivim spojnim elementom prekriven zaštitnim aluminijskim slojem. Hoffmannovim spojem moguće je također proizvesti i prozorski okvir s unaprijed obrađenim profiliranim i površinski obrađenim elementima. Problem zaštite spoja od prodora vlage jednak je, dakle, kao i pri spoju s drvenim prstenom. Ljepila u skupini C, D, E, F i H pokazala su se primjerenima s mehaničko-tehničkog gledišta, no ostaje problem trajnosti kad su okviri prozora izrađeni od prethodno obrađenih elemenata.

4. ZAKLJUČAK
4 CONCLUSION

Najbolje rezultate dao je spoj lijepljen PVAc ljepilom klase D3 (skupina C). Lošiji rezultati u referentnih dobiveni su pri upotrebi viskoznijih ljepila koja slabije prodiru u drvo.

Pri odabiru optimalnog ljepila za kutne spojeve prozorskih okvira nije važna samo sila loma spoja, koja ovisi o upotrijebljenom ljepilu, već i svojstvo zapunjavanja nezaštićenoga poprečnog presjeka elemenata od drva. To je osobito važno za proizvodnju prozorskih okvira iz unaprijed strojno i površinski obrađenih elemenata. Uporabljena ljepila manjeg viskoziteta i ona (uglavnom poliuretanska ljepila) koja se tijekom otvrdnjavanja pretjerano ne pjene, pogodnija su za izradu prozorskih okvira kutnim spojem s drvenim prstenom.

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Godišnja međunarodna znanstvena konferencija Ambienta 2013

U sklopu 40. međunarodnog sajma namještaja, unutarnjeg uređenja i prateće industrije (16. - 20. listopada 2013.) Ambienta ´13, na Zagrebačkom velesajmu, u dvorani Brijuni, dana 18. listopada uspješno je održano 24. međunarodno znanstveno savjetovanje pod nazivom *Drvo je prvo – materijal, tehnologija i projektiranje u funkciji korisnika*.

Organizatori savjetovanja bili su InnovaWood; Šumarski fakultet Zagreb; Oddelek za lesarstvo, Biotehniška fakulteta Univerze u Ljubljani, Zagrebački velesajam; Hrvatsko šumarsko društvo; Zveza lesarjev Slovenije; Znanstveno vijeće za poljoprivredu i šumarstvo – HAZU, Akademija tehničkih znanosti Hrvatske; Akademija šumarskih znanosti; Hrvatska komora inženjera šumarstva i drvne tehnologije.

Glavni pokrovitelj savjetovanja bilo je Ministarstvo poljoprivrede, a supokrovitelji su bili HAMAG, Hrvatski šumarski institut, Hrvatske šume d.o.o., Hrvatska komora inženjera šumarstva i drvne tehnologije, Hrvatska gospodarska komora, Hrvatska gospodarska komora – Zagreb, Virovitičko-podravska županija, Zagrebačka županija.

Savjetovanju su prisustvovali predstavnici drvnoindustrijskih tvrtki, predstavnici tvrtki koje se bave prodajom namještaja i ostalih proizvoda od drva, predstavnici Šumarskog fakulteta u Zagrebu, Zagrebačkog velesajma, Ministarstva poljoprivrede, Hrvatskih šuma d.o.o., kolege znanstvenici iz Poljske, Mađarske, Slovenije, Srbije, Bugarske, Grčke i Turske, brojni studenti drvne tehnologije te više zainteresiranih stručnjaka s različitih područja koji nisu izravno povezani s drvnom industrijom.

Ovogodišnje 24. međunarodno znanstveno savjetovanje ponovno je održano u suorganizaciji s vodećom europskom udrugom znanstvenih institucija - InnovaWood, koja obuhvaća osamdesetak najjačih institucija diljem Europe, Australije i Kanade koje se bave znanstvenim istraživanjima, transferom znanja, edukacijom i praksom u šumarstvu i drvnoj industriji. Međunarodno savjetovanje pod motom *Drvo je prvo - materijal, tehnologija i projektiranje u funkciji korisnika* već prema broju prijavljenih radova (25) i interesu uglednih domaćih i stranih stručnjaka pokazalo je da suradnja Šumarskog fakulteta i Zagrebačkog velesajma i u krizna vremena može rezultirati organiziranjem savjetovanja na visokoj međunarodnoj razini. To je rezultat ne samo kvalitete dosadašnjih znanstvenih savjetovanja već višegodišnje suradnje priznatih stručnjaka Šumarskog fakulteta kao punopravnog člana organizacije InnovaWood na međunarodnoj razini.

Evidentno je da je suradnja s organizacijom InnovaWood i dalje pridonosi još većoj afirmaciji Šumarskog fakulteta te učvršćivanju naše pozicije na razini vodećih međunarodnih znanstvenih institucija. Zbog velikog broja prijavljenih radova i ove je godine dio radova (13) bio prezentiran putem postera.

Ovo je savjetovanje bilo prilika za stjecanje novih spoznaja baziranih na znanstveno-istraživačkom timskom radu znanstvenika s više domaćih i stranih fakulteta i instituta.

Na savjetovanju su izloženi sljedeći radovi:

1. Barboutis Ioannis, Kamperidou Vasiliki:
   Klismos – the style and form of the ancient greek chair
2. Domljan Danijela, Vlaović Zoran, Župčić Ivica, Živković Vjekoslav, Jirouš-Rajković Vlatka, Grbac Ivica:
   Quality of the wooden products for design and equipping educational institutions
3. Esen Raşit, Yapici Fatih:

Slika 1. Sudionici konferencije

The effects of press time and press pressure on the screw strength properties of oriented strength board (OSB) manufactured from poplar wood

4. Fabisiak Beata, Kłos Robert, Maćkowiak Katarzyna:
Analysis of user preferences concerning e-trend in kitchen furniture design
5. Gornik Bučar Dominika, Merhar Miran, Gospodarič Bojan:
Influence of tool wear on the quality of the newly formed surface in the drilling of wood composites
6. Grladinović Tomislav, Perić Ivana, Stasiak-Betlejewska Renata, Škoda Petar:
Increasing the productivity of enterprises with the 20 keys method
7. Hrovatin Jasna, Vižintin Jože:
Kitchen furniture – accessibility of storage and working space
8. Jivkov Vassil, Simeonova Ralitsa, Marinova Assia, Gradesva Galina:
Study on the gluing abilities of solid surface composites with different wood based materials and foam PVC
9. Kamperidou Vasiliki, Barboutis Ioannis:
Lathe tool – it's development from the ancient times to nowadays
10. Kitek Kuzman Manja, Šernek Milan, Kariž Mirko:
Design and manufacturing of organic shape furniture
11. Klarić Miljenko, Pervan Stjepan:
Importance of botanical binominal nomenclature for hydrothermal wood processing
12. Kutnar Andreja, Kušar Tomaž, Kitek Kuzman Manja:
Environmental impact assessment as part of furniture design
13. Kyuchukov Georgi, Gruevski Georgi, Marinova Assia, Kyuchukov Borislav, Jivkov Vassil:
Comparative analysis of stiffness coefficients of end and t-shape corner joints of frame structural elements with two types of cross sections made of sweet chestnut wood
14. Miklečić Josip, Jirouš-Rajković Vlatka, Špoljar Marin:
Durability of waterborne coating systems for wooden windows
15. Nestorović Biserka, Grbac Ivica, Nestorović Predrag:
Numerical analysis of laminated wood structures – chairs by application of FEA
16. Palija Tanja, Vučković Aleksandar, Jevtić Petronije, Jaić Milan:
The impact of wood staining on the adhesion of certain types of coating
17. Perić Ivana, Grladinović Tomislav, Starčević Igor, Stasiak-Betlejewska Renata:
On enhancing of production planning in wood processing and furniture manufacturing
18. Smardzewski Jerzy, Majewski Adam, Prekrat Silvana:
Effect of cell-wall angle on the uniaxial crushing behaviour of paper hexagonal honeycombs
19. Stankevik Shumanska Mira, Meloska Živka, Efremovska Violeta:
Impact of the economic crisis on the wood industry production in Republic of Macedonia
20. Stasiak-Betlejewska Renata:
Constructions of the energy-saving wooden houses and its advantages on the example of polish construction
21. Svoboda Jaroslav, Tauber Jiří:
Microclimatic conditions for healthy sleep and rest – influenced by science, psychology and design
22. Šimek Milan, Kořený Adam, Dlauhý Zdeněk, Mihailović Stefan:
Possibilities of CNC manufacturing with regard to furniture design
23. Župčić Ivica, Grbac Ivica, Bogner Andrija, Žulj Ivan, Ljuljka Boris:
Influence of moisture content on the strength of welded joints
24. Yapici Fatih, Esen Raşit:
The effects of press time and press pressure on modulus of rupture and modulus of elasticity properties of oriented strength board (OSB) manufactured from poplar wood

Slika 2. Dio operativnoga organizacijskog tima savjetovanja

25. Yorur Huseyin, Yapici Fatih, Esen Rasit:
The effects of cast-polyamide on the modulus of rupture and modulus elasticity of oriented strength board (OSB) manufactured from scotch pine

Ovogodišnje savjetovanje ponovno pridonosi kampanji *Drvo je prvo,* čiji je cilj promicanje drva kao prirodnoga, ekološki prihvatljivog materijala. Iz programa je vidljivo da je okupljenim stručnjacima iz različitih zemalja i različitih disciplina zajednička ljubav prema drvu i drvnoj struci te želja za uspješnom promocijom drva. Zbornik radova s ovog savjetovanja donosi mnogo korisnih informacija za struku u cjelini, s mnogo novih spoznaja na području biotehničkih znanosti vezanih za valorizaciju i ocjenu stanja konkurentnosti na tržištu, oblikovanja namještaja, novih tehnologija i tehnoloških procesa obrade drva te primjene drva, drvnih i drugih materijala u proizvodnji namještaja i graditeljstvu kojima struka može povećati konkurentnost svoje tržišne ponude.

Zbornik radova u elektroničkoj verziji dostupan je s poveznice

http://www.sumfak.unizg.hr/Upload/Ambienta2013/doc/Proceedings%20AMBIENTA%202013.pdf

Fotografije su dostupne s poveznice

http://www.flickr.com/photos/ambienta2013/

prof. dr. sc. Ivica Grbac
prof. dr. sc. Stjepan Pervan
izv. prof. dr. sc. Silvana Prekrat
Miljenko Klarić, dipl. ing.

26. međunarodno savjetovanje – Istraživanja u industriji namještaja

The XXVIth International conference - Research for Furniture Industry

Po 26. put u Poznanu je od 19. do 20. rujna 2013. održano međunarodno savjetovanje na kojemu su svoje radove prezentirali stručnjaci koji se bave istraživanjima vezanima za namještaj. Savjetovanje je organizirala Katedra za dizajn namještaja Fakulteta drvne tehnologije u Poznanu. Uobičajeno jednodnevno savjetovanje ove je godine produljeno na dva dana. Razlog tomu bilo je sudjelovanje domaćina u pilot- projektu *StarDust of the Baltic Sea Region Programme 2007-2013*. To je strategijski višenacionalni projekt gospodarski orijentiranih aktivnosti znanosti i inovacija. Iako ne pripadaju baltičkoj regiji, tom su pilot-projektu pridružene Slovenija (sudjelovanjem Visoke šole za dizajn iz Ljubljane) i Hrvatske (sudjelovanjem Šumarskog fakulteta iz Zagreba)

U odabiru i recenzijama radova prezentiranih na savjetovanju sudjelovao je programski odbor u sastavu:
prof. Brigitte Borja de Mozota (Parsons Paris School of Art + Design, France),
prof. Csilla Csiha (University of West-Hungary, Hungary),
prof. Stanisław Dzięgielewski (Poznan University of Life Sciences, Poland),
prof. Eva Haviarova (Purdue University, USA),
prof. Peter Niemz (Institut für Baustoffe, ETH Zürich, Switzerland),
prof. Barbara Ożarska (University of Melbourne, Australia)
prof. Silvana Prekrat (University of Zagreb, Croatia),
prof. Nurgul Tankut (Bartin University, Turkey)
prof. Vasilios Vasiliou (Aristotle University of Thessaloniki, Greece)

Teme prvog dana savjetovanja bile su orijentirane na oblikovanje proizvoda s naglaskom na razvoj proizvoda za generaciju 65+ što je i središnja tema pilot-projekta *Comfort in Living*. Održane su sljedeće prezentacije:

1. *The presentation of the StarDust: Comfort in Living Pilot Project*
   Lotten Svensson, IDC West Sweden-project leader
2. *Aging of human body*
   Katarzyna Wieczorkowska-Tobis, Poznan University of Medical Sciences
3. *Analysis of users aged 65+ preferences concerning kitchen furniture and interior design*
   Beata Fabisiak, Robert Kłos, Poznan University of Life Sciences
4. *Important aspects of sitting for senior citizens*
   Milan Šimek, Mendel University in Brno
5. *Kitchen furniture for elderly people*
   Jasna Hrovatin, Academy of Design, Ljubljana
   Jože Vižintin, University of Ljubljana
6. *Aging Friendly Native House*
   Rihards Funts, Art Academy of Latvia
7. *Public procurement of innovation for elderly people*
   Max Rolfstam, Aalborg University
8. *Comfort in living for elderly people - The vision of future*
   Jerzy Smardzewski, Poznan University of Life Sciences

Program drugog dana savjetovanja obuhvatio je teme s područja dizajn-menadžmenta, dizajna, konstrukcija, antropotehnike i biomehanike namještaja.

Prezentirani su sljedeći radovi.

1. *Chair comfort analysis by body pressure measurement*
   Noémi Takács, Levente Dénes
2. *Performance properties of classical and modern upholstery techniques*
   Nihat Dongel, Baris Yilmaz
3. *Analysis of sitting furniture for elderly people*
   Milan Šimek
4. *Kitchen furniture for elderly people*
   Jasna Hrovatin
5. *Stasidia (church stalls) of the Greek Orthodox Church – a standing seat for elderly*
   Ioannis Barboutis, Vasileios Vasileiou
6. *Research on Evaluation Furniture Usability*
   Silvana Prekrat, Stjepan Pervan, Jerzy Smardzewski
7. *Design and equipping educational institutions – technical descriptions of the wooden products*
   Danijela Domljan, Ivica Grbac, Vlatka Jirouš Rajković, Zoran Vlaović, Vjekoslav Živković, Ivica Župčić
8. *Comparison of test methods for furniture corner connections*
   Ulrike Kröppelin, Michael Scheffler, Anne Weyrauch
9. *Combined stress analysis of mitered spline furniture joints under diagonal loading*

Slika 1. Sudionici savjetovanja u razgledavanju laboratorija za ispitivanje namještaja

Mosayeb Dalvand, Mohammad Derikvand, Sadegh Maleki, Ghanbar Ebrahimi

10. *Investigation on bleaching Beech wood using environment friendly agent*
    Csilla Csiha, Eva Annamaria Papp
11. *Strength properties of case type furniture produced with different construction techniques and panel thicknesses*
    Hasan Ozgur Imirzi, Hasan Efe
12. *Analysis of strength of corner joints in cabinet type furniture by using finite element method*
    Hasan Ozgur Imirzi, Hasan Efe
13. *Ancient Greek Furniture: Source of inspiration for the designers and manufacturers of modern times*
    Vasiliki Kamperidou, Vasileios Vasileiou, Ioannis Barboutis
14. *Modeling mechanical properties of paper honeycomb panels using the finite element method*
    Viktor Utassy, Levente Dénes
15. *Thin Purenit Honeycomb Panels*
    Adam Majewski, Jerzy Smardzewski

Radovi su objavljeni u zborniku i dostupni na web stranici http://furnituredesign.pl/publications.

izv. prof. dr. sc. Silvana Prekrat

Dizajn je tema koja gleda na duge tradicije – IMM Köln 2013

Od 14. do 20. siječnja 2013. godine više od 1 250 tvrtki iz 50 zemalja svijeta u Kölnu je predstavilo preko 100 000 uzoraka namještaja i drugih proizvoda za uređenje interijera, predočivši ujedno veliki inovacijski potencijal.

Zajedno s LivingKitchenom, IMM Köln se prostirao na više od 280 000 m² izložbenog prostora i nakon sedam intenzivnih dana zatvorio je svoja vrata s odličnim rezultatom. Sajam je posjetilo oko 142 000 posjetitelja iz raznih djelova svijeta.

Slika 1. Južni ulaz na sajam

Sajam je ponudio proizvode tvrtki koje prate novitete na tržištu, predstavljaju se kvalitetom i originalnim dizajnom te nas potiču u podizanju svijesti o kvaliteti stanovanja.

Ovogodišnji IMM Köln i LivingKitchen ponovno su ispuniti sva očekivanja kao međunarodna manifestacija. Dvije trećine izlagača došlo je iz raznih zemalja svijeta (Italije, Belgije, Austrije, Španjolske, Francuske, Poljske i Švedske). U tom mnoštvu vrhunskih natjecatelja, gdje se u širokom spektru ponude određuju budući trendovi, predstavilo se i dvanaest hrvatskih tvrtki – devet na zajedničkom štandu, dok su tri tvrtke nastupile samostalno. Nigdje drugdje posjetitelj ne može naći toliko međunarodnih usluga iz različitih segmenata.

Jedan megatrend koji i dalje dominira uređenjem unutarnjih prostora i koji se nametnuo kao ključna tema sajma jest priroda i prirodni materijali, koji se ne pojavljuju samo kao ukrasi već su i materijal prvog izbora, primjerice masivno drvo, koža i vuna. Namještaj od cjelovitog drva dobiva sve veće značenje, ponajviše zahvaljujući trendu zdravog življenja. Kada je u pitanju namještaj, dobra kvaliteta predstavljena je kao koncept triju elementa: dobrog dizajna, dobre završne obrade i, što je najvažnije, prirodnog materijala.

Slika 2. Prirodno je drvo na visokoj cijeni, pogotovo kad je stilski i dizajnerski dotjerano

U Kölnu je dizajn tema s dugom tradicijom. Fokus je bio na stvaranju umjetnih životnih situacija na samom sajmu. Paviljon 11. bio je srce dizajnerskih brendova i tradicionalno „dom brendova“ kao što su Ligne Roset, Tim 7, Walter Knoll, Rolf Benz, B&B Italia, koji su u stalnoj potrazi kako bi posjetiteljima prikazali savršeno postavljen svijet unutrašnjeg uređenja stambenog prostora.

Slika 3. Među lusterima prevladavaju nekovencionalni oblici i žarke boje (proizvođač: Mossapouri Hey-Light)

Slika 4. Dizajnerska rješenja slavina proizvođača Kartal

PURE VILLAGE

Za razliku od toga, Pure Village, u dvorani 3.1, karakteriziralo je dosljedno planiranje sajamske arhitekture s fokusom na fascinantnim konceptima interijera, osobito zbog zastupljenosti projekata poput Das Hausa, The Stagea i D³. Pure Village predstavio je platformu za promicanje proizvoda koji visokom kvalitetom i izrazito domišljatim dizajnom stvaraju spoj za koncept novoga životnog stila. Njemačka tvrtka Das Haus ugostila je u Pure Villageu talijanskog dizajnera Lucu Nichetta, koji je kreirao Das Hausovu pozornicu kao osobnu viziju spoja prirode i čovjeka.

Slika 5. Tvrtka Das Haus ugostila je u Pure Villageu talijanskog dizajnera Lucu Nichetta

Ovogodišnji IMM Köln imao je, kao i uvijek, dosta novih atrakcija. Sajamski postav u paviljonu 3.2. koncept je namijenjen izazivanju nemira i promjena uobičajenih načina gledanja na stvari. Raznolikim izložbama umjerenih dimenzija i uzbudljivim scenografijama namjena je bila da prikažu trenutačne trendove unutarnjeg uređenja stambenog prostora. Osim toga, paviljon 3.2. bio je novi dom dekorativnih tkanina koje su izložene u širokoj paleti boja i uzoraka.

Slika 6. Moderna tehnologija u retro stilu od proizvođača Soleil Bleu

Paralelno s IMM Cologne svoja je vrata ponovno otvorio međunarodni LivingKitchen sa gotovo 200 izlagača. Tržišni lideri na području dizajna, izrade kuhinja i kuhinjske opreme stali su licem u lice i efektnim prezentacijama predstavljali kuhinje u svim nji-

Slika 7. Vraćanje prugastih uzoraka i žarkih boja u svim segmentima ojastučenog namještaja

hovim aspektima. Predstavljeni su i kuhinjski aparati, sudoperi, sofisticirana oprema, rasvjeta i pribor.

Uz osnovna obilježja suvremene kuhinje, danas je bitna i njezina tehnička opremljenost i udobnost, ali i sigurnost. Najpopularnija je indukcijska ploča. Znatno je sigurnija od plinskih ploča i znatno štedi energiju. Zagrijava se samo površina ispod posude, a ploča je opremljena elektronikom, senzorima i termostatima pa se može precizno regulirati potrebna toplina. Ugradnjom novih indukcijskih kuhala, posuda za kuhanje može se prema potrebi pomicati po cijeloj površini ploče, bez opasnosti od opeklina. Modernu kuhinju obilježava i sofisticirana rasvjeta, u kojoj glavnu ulogu preuzima LED rasvjeta, koja je energetski iznimno učinkovita.

Slika 8. Indukcijske ploče za kuhanje opremljene su savršenom elektronikom, iznimno su sigurne i energetski učinkovite

Neki vrlo jaki brendovi iskoristili su ovogodišnji LivingKitchen kao prezentacijsku i poslovnu platformu za suradnju poslovnih posjetitelja i potrošača iz cijelog svijeta. Osim brendova kao što su Nobilia, Alno, Leicht, Hacker, Schuller i Nolte, svoje nove proizvode ugrađene u izložene kuhinje istaknuli su i AEG, Electrolux, Beko, Bosch, Gorenje, Miele te Siemens.

HRVATSKI IZLAGAČI

U organizaciji Hrvatske gospodarske komore i Sektora za trgovinu, u suradnji s Ministarstvom poljoprivrede, na Međunarodnom sajmu u Kölnu predstavilo se devet hrvatskih tvrtki koje se bave proizvodnjom namještaja.

Slika 9. Zajednički izložbeni prostor proizvođača iz Republike Hrvatske

Na zajedničkom štandu površine 200 m² predstavljene su tvrtke Modo interijer studio, Obrt Margalić, Malagić, Slikarstvo Potočnjak, Drvotokarija i Javor te Grupacija proizvođača namještaja HGK, dok su samostalno izlagale tvrtke Prima, Kvadra i Ancona grupa.

Slika 10. Kvadrin izložbeni prostor u Kölnu osmislio je dizajnerski studio Numen/ForUse

Hrvatski proizvođači oko 70 % proizvoda plasiraju na strano tržište, što je potvrda da im je, unatoč gospodarskoj krizi, mjesto na sajmovima poput IMM-a.

Ivan Žulj, dipl. ing.

Izložba Mojce Perše *I drveće ima lice*

Exhibition by Mojca Perše "The trees has a face too"

Arhitektica Mojca Perše bavi se oblikovanjem i unutarnjom opremom. Poučava na Visokoj školi za dizajn u Ljubljani, na smjeru Unutarnja oprema, u nastavi kolegija s područja stambenih i javnih prostora, materijala i konstrukcije te redizajna, a usto je voditeljica laboratorija za kreativne industrije.

Njezine strasti fotografiranja i slikanja mogle su se vidjeti na izložbi *I drveće ima lice*, postavljenoj 11. lipnja 2013. u Galeriji *Bernardo Bernardi,* smještenoj u prostoru Pučkoga otvorenog učilišta u Zagrebu.

"Spoznaja da posvuda oko sebe, u viđenome, otkrivam slike bila je uzrok da takve slike ovjekovječim i naslikam", izrekla je autorica izložbe Mojca Perše na postavljeno pitanje o inspiraciji za radove na izložbi. Svoje je radove izvela u tehnici crno-bijele fotografije snimajući kore stabala bora, nakon čega u ateljeu, inspirirana prirodom, uz pomoć akrilnih boja stvara šareni svijet slika.

Autorica u kori debla, koja je ključni element prepoznavanja različitih vrsta drveća, pronalazi čudesne oblike koji je podsjećaju na ljudska lica. Ona prepoznaje snagu prirode u razvoju koji oblikuje koru drveta u najrazličitije oblike, uzorke, ljuske, raspukline, teksture različitih boja. Brazde kore drveća iscrtavaju oblike očiju, usana, nosa, brkova. Kao posljedica rasta mogu se razviti i greške ili kvrge, koje su dio grane. Zajedno izražavaju mimiku lica i iskazuju izraze različitih osjećaja. Karikature djeluju kao stara naborana koža sa snažnim izrazima čovjekova lica. Svako drvo pripovijeda svoju priču. Kao i na čovjeku, i na drvetu se odražava sve što mu se zbivalo tijekom rasta: gdje i koliko dugo raste, kako postupaju s njim, što se s njim događa i što ga čeka. Drvo živi, pripovijeda, javlja se, kao i čovjek. Pripovijeda o misiji koju ima, o misiji života, rasta, govori kako je ovdje da nam uljepša svijet, da nam kao tvornica kisika omogućuje disanje, da nam služi kao ogrjev i sirovina za obradu, pruža nam hlad i plodove. Sve to mnogi ne primjećuju, a za autoricu Mojcu Perše to je posebno i drugačije, nešto što treba pokazati.

izv. prof. dr. sc. Silvana Prekrat

Slika 1. Fotografija kore drveta

Slika 2. Kora drveta izvedena u akrilu na platnu

KAORI

UDK: 674.032.473.3

NAZIVI I NALAZIŠTE

Drvo vrste *Agathis alba* Foxw. iz botaničke porodice *Araucariaceae* potječe iz jugoistočne Azije – iz Malaje, Indonezije, Filipina, te iz Australije i Oceanije.

Ostali su nazivi kaori (Francuska); istočnoindijski kauri (Australija, Njemačka, Velika Britanija); agathis (Njemačka); damar, ki damar, mangilan (Indonezija); damar minyak, sanum, sarawak kauri, tsanum (Malezija); adiangao, almaciga, bidiangao, busong, litao, salang, titau (Filipini).

STABLO

Drvo vrste *Agathis alba* Foxw. *četinjača* je srednje visine, između 45 i 60 m (70 m). Promjer debla kreće se između 100 i 300 cm, rjeđe i do 600 cm. Debla su cilindrična, obično čista od grana, vrlo visoka. Visina do prve grane iznosi od 30 do 40 m.

DRVO

Makroskopska obilježja

Srž je blijedo sivosmeđa do jako žutosmeđa. Bjeljika je svjetlosmeđa do svjetlobijela, široka od 8 do 11 cm. Kasno je drvo usko i samo malo tamnije od ranoga. Prijelaz iz ranoga u kasno drvo istoga goda postupan je. Drvni su traci dobro uočljivi. Drvo je mekano, fine i ujednačene svilenkaste teksture, a žica drva pravilna. Radijalna površina drva sjaji kao što se vidi na naslovnici.

Mikroskopska obilježja

Prijelaz iz ranoga u kasno drvo postupan je. Promjer lumena traheida iznosi 14,3...36,5...46,0 mikrometara, a debljina stijenki traheida 2,4...5,0...7,0 mikrometara. Dužina traheida je 4200...6200...7700 (9000) mikrometara, njihov udio iznosi oko 93 %. Drvni su traci homocelularni, rastresitog rasporeda. Visoki su 50...175...300 mikrometara (do 15 stanica), a široki 18...25...40 mikrometara. Gustoća drvnih trakova kreće se od 4 do 6 do 9 po mm poprečnog presjeka. Udio drvnih trakova iznosi oko 3 %. U polju ukrštanja jažice su kupresoidne i taksodioidne.

Fizikalna svojstva

Gustoća standardno suhog drva, ρ_0	360...460...630 kg/m^3
Gustoća prosušenog drva, $\rho_{12\text{-}15}$	400...500...670 kg/m^3
Gustoća sirovog drva, ρ_s	oko 800 kg/m^3
Poroznost	oko 70 %
Totalno radijalno utezanje	2,8...4,0...4,7 %
Totalno tangentno utezanje	8,3...9,3...11,4 %
Totalno volumno utezanje	11,4...13,6...16,4 %

Mehanička svojstva

Čvrstoća na tlak	34...51,5...66 MPa
Čvrstoća na savijanje	60...101...125 MPa
Čvrstoća na vlak paralelno s vlakancima	8,5...13,5...19,7 MPa
Čvrstoća na vlak okomito na vlakanca	oko 1,7 MPa
Tvrdoća prema Brinellu paralelno s vlakancima	29...38...57 MPa
Tvrdoća prema Brinellu okomito na vlakanca	7...15...30 MPa

Tehnološka svojstva

Obradivost

Drvo se lako obrađuje ručnim i strojnim alatima, uz sporo zatupljivanje oštrice alata. Dobro se blanja, buši, ljušti, dubi, lijepi, boji i politira. Čavle i vijke dobro drži.

Sušenje

Drvo se dobro suši, bez raspucavanja, vitlanja ili drugih deformacija. Stabilnost dimenzija mu je dobra, a jednom prosušeno drvo umjereno radi.

Trajnost i zaštita

Prema normi HRN 350-2, 2005, srž drva svrstana je u srednje do slabo trajna drva (klasa 3 – 4). Bjeljika je srednje permeabilna (klasa 2), slabo je trajna i nije otporna na napad termita, insekata i gljiva uzročnica truleži.

Uporaba

Drvo se upotrebljava za proizvodnju furnira, za obloge, unutarnje konstrukcije, za izradu namještaja i dijelova namještaja, za izradu kanua, čamaca za spašavanje, za izradu intarzija, bačava, drvenih kutija i drvene ambalaže.

Sirovina

Drvo na tržište dolazi u obliku trupaca i u obliku piljene građe. Trupci su obično većih dimenzija.

Napomena

Drvo sličnih svojstava daju i ostale vrste roda *Agathis*, kao i roda *Araucaria*. Kad im se zareže kora, mnoge vrste roda *Agathis* izlučuju obilnu količinu smole. Ta je smola poznata u trgovini kao damar ili kopal, a iskorištava se za proizvodnju lakova.

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Examples:
Krpan, J. 1970: Tehnologija furnira i ploča. Drugo izdanje. Zagreb: Tehnička knjiga.
Wilson, J.W.; Wellwood, R.W. 1965: Intra-increment chemical properties of certain western Canadian coniferous species. U: W. A. Cote, Jr. (Ed.): Cellular Ultrastructure of Woody Plants. Syracuse, N.Y., Syracuse Univ. Press, pp. 551-559.

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

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

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BERNARDA

medicinski madraci

ENERGY: zahvaljujući nitima srebra djeluje antistresno i regenerirajuće, obnavlja tjelesnu energiju i jača obrambenu snagu tijela uz antibakterijski učinak i zaštitu od štetnih elektromagnetskih zračenja

MAGIC TOUCH: vrhunski anatomski i antibakterijski madrac izuzetne dodirne mekoće. Zahvaljujući pozitivnim djelovanjima vlakna agave savršen za psiho-fizički odmor

WELLNES (ALOE VERA): antibakterijski madrac za vrhunski osjećaj ugode i lakoće s navlakom na bazi biljke ALOE VERA čija biološka hranjiva vlakna regeneriraju kožne stanice

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Uz navedeno medicinski madraci, proizvode se još npr. od materijala na bazi vitamina E (za samoobnavljanje stanica: "anti-aging"), u izvedbama otpornim na vatru, protiv neugodnih mirisa, te protiv insekata i komaraca...

Za siguran učinak ovih madraca izuzetno je bitna i podloga. Zato Bernarda kreveti kao npr. **Savoy** i **Palas** u kombinaciji s medicinskim madracima jamče
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