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Miha Humar[1]

Influence of Norway Spruce and European Larch Heartwood Ring-Width on Extractive Content and Durability

Utjecaj širine goda na sadržaj ekstraktivnih tvari i trajnost srži norveške jele i europskog ariša

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ABSTRACT • *Norway spruce and European larch wood are among the most important species for construction applications in central Europe. In order to assess the influence of the ring-widths and presence of the extractives on the performance of these wood species against wood decays fungi, Soxlet extracted and non-extracted spruce and larch wood specimens with different ring-widths were exposed to three brown rot fungi according to the EN 113 procedure. In parallel spruce and larch wood specimens were exposed in field test sites in use class 3 conditions according to the double layer procedure. The results showed that ring-widths do not influence the performance of the spruce and larch heartwood against brown rot fungi in laboratory conditions, but on the other hand have influence on the performance of spruce wood in field test setup. Additionally, extraction does not have an influence on the durability of spruce wood, but has an influence on the durability of larch wood.*

Key words: *Picea abies, Larix decidua, wood decay fungi, extraction, performance, laboratory tests, field testing*

SAŽETAK • *Norveška jela i europski ariš među najvažnijim su vrstama čije se drvo upotrebljava u graditeljstvu u središnjoj Europi. Kako bi se procijenio utjecaj širine goda i sadržaj ekstraktivnih tvari na otpornost tih vrsta drva na gljive truležnice, uzorci od ekstrahiranoga i neekstrahiranog drva jele i ariša izloženi su trima gljivama smeđe truleži prema postupku definiranom normom EN 113. Uzorci drva jele i ariša usporedno su bili izloženi na ispitnim mjestima uz primjenu uvjeta klase 3, u skladu s postupkom dvostrukog sloja. Rezultati su pokazali da širina goda ne utječe na otpornost drva srži jele i ariša na gljive smeđe truleži u laboratorijskim uvjetima, ali utječe na otpornost jelova drva u terenskim uvjetima. Osim toga, ekstrakcija nema utjecaja na trajnost drva jele, ali ima utjecaj na trajnost drva ariša.*

Ključne riječi: *Picea abies, Larix decidua, gljive truležnice, ekstrakcija, otpornost, laboratorijskitest, terenska ispitivanja*

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1 INTRODUCTION
1. UVOD

Norway spruce and Larch are among the most important central European wood species and they are frequently used for construction applications. The main part of all sawn timber is used in constructions that are not in immediate ground contact. One of the issues that limit outdoor use of spruce wood is insufficient durability (Brischke and Rapp, 2008). On the contrary, larch, especially European larch, has traditionally held a good reputation in the Alps as a source of building material. This reputation is based upon its excellent mechanical properties combined with its good natural durability out of soil contact (Collardet and Besset, 1988; Flæte *et al.,* 2011). Besides wood quality, it seems obvious that the longevity of these constructions also relies on a high ancestral level of building expertise. Furthermore, the apparent natural durability and longevity qualities of larch wood do not seem to be expressed in the same way outside its distribution within the Alps (Curnel *et al.*, 2008). Consequently, larch from the warmer, more fertile regions of the lowlandssometimes performs considerably worse than larch from the Alps. However, some of the authors reported, that durable larch wood can be found even in the lowland plantations in Eastern Europe (Curnel *et al*., 2008).

Natural durability, or alternatively decay resistance, is defined as the ability of wood to resist biological degradation (Eaton and Hale, 1993). Brown-rot decay is a common and very destructive type of decay of sawn softwoods in central Europe. Brown-rot fungi utilize the cellulose and hemicelluloses of the cell wall, leaving the lignin essentially undigested, albeit modified by demethylation and oxidation (Green and Highley, 1997). As a consequence the attacked wood darkens, shrinks, and breaks into brick-shaped pieces, leading to rapid structural failure (Solár *et al.,* 2007).

Larch and spruce wood are known as species with extreme variations of wood properties. Significant variability existed amongst the larch and spruce originating from non-autochthonous lowland locations (Brischke *et al*., in press). Local growth conditions, age and maturity of wood may be more relevant than genetic effects (Venäläinen *et al*., 2001). One of the factors that reflect the local growth conditions of coniferous wood species is ring-width. On a macroscopic level, it has been proven for several times that ring-width (and related density) is an important parameter predicting the mechanical properties of wood. According to Verkasalo (1992) MOE of conifer wood species increases with increasing density, number of growth rings per cross-sectional unit area, and increasing latewood percentage. On the contrary, there is less information on the performance of spruce wood against wood decay fungi regarding the ring-width, therefore this issue was elucidated in this paper.

Heartwood extractives play a key role for natural durability, besides lignification and growth characteristics. The significance of heartwood extractives for natural durability was demonstrated as early as 1924 (Hawley *et al*., 1924). Larch heartwood contains high amounts of extractives; the major part consists of arabinogalactan, a water-soluble and heavily branched polysaccharide comprising 5% to 30% of the total by weight (Cote *et al*., 1966). The high amounts of arabinogalactan are specific to larch; they are found primarily in the cell lumen and their role remains unclear (Cote *et al*., 1966). In brown-rot decay, it may even enhance fungal growth by being a nutrient source (Srinivasan *et al*., 1999). Besides arabinogalactan, up to 3.5% flavonoids are found in larch heartwood (Giwa and Swan, 1975), which may play a role in decay resistance. Among various extractives, phenolic extractives exhibited the highest biological activity (Gierlinger *et al*., 2004).Triglycerides, steryl esters, free sterols, resin acids, diterpene alcohols and free fatty acids are predominant extractives characterized in water based solvents (Örsa*et al.,* 1997). Triglycerides are the most important extractives in sapwood, while resin acids are reported as predominant extractives in Spruce heartwood (Hovelstad *et al*., 2006).

Several methods have been used to test the performance of wood species against wood decay fungi. In general, methods can be divided into laboratorial and field tests. Laboratory methods provide more comparable data and on the other hand reflect only the fungicidal or fungistatic properties of wood and do not reflect other important factors that influence the performance of the wood in real applications, like water repellence, sorption properties, etc. On the contrary, field test data reflect overall performance of the material, but it takes a considerably longertime to obtain the results.

The aim of this study was to elucidate the influence of the ring-width on the extractive content and performance of spruce and larch wood against wood decay fungi. These data are important both from the scientific and application point of view, as this is the key information for sorting and grading of sawn wood.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

For testing, various different Norway spruce (*Picea abies*) and European larch (*Larix decidua*)heartwood, semi-radial boards with different ring-widths were chosen. They were classified according to the ring-width into two groups for spruce and two groups for larch wood specimens (Table 1) and afterwardsdensity of the oven dry wood was determined. Samples originate from different boards. Spruce wood specimens were made of 6 different boards, and 4 boards were used for the preparation of larch specimens. Two types of specimens were obtained from the boards. The bigger ones (2.5 cm × 5.0 cm × 50 cm) were used for field testing according to the Horizontal double layer test (Rapp and Augusta, 2004; Augusta, 2007) and smaller ones (1.5 cm × 2.5 cm × 5.0 cm) for standard laboratory testing (EN 113, 2004). Laboratory tests were performed on larch and spruce wood specimens, while field tests were only performed on selected spruce and larch wood specimens.

Before exposure to fungi, half of the smaller specimens were extracted according to the Soxlet procedure usingthe following solvents: cyclohexane/ethanol (22 h), ethanol (22 h) and water (44 h) in automatic extraction system Büchi B-811. Extracted and non-extracted samples were oven-dried at 103+2 °C until a constant weight was achieved. Percentage of extractives was determined gravimetrically and expressed in percentages. Mass and dimensions of the oven dried specimens were determined and used for density calculations.

Thereafter, specimens were steam sterilized (121°C) and exposed to threebrown rot fungi (*Antrodia vaillantii, Serpula lacrymans* and *Gloeophyllum trabeum*) for 16 weeks according to the EN 113 procedure (2004). These wood decay fungi are predominant decomposers of spruce wood in commercial applications (Schmidt, 2007). Two specimens, one extracted and one non-extracted, were randomly exposed in the same experimental jar. After fungal exposure, specimens were isolated, oven-dried and weighed again. For comparison, Scots pine sapwood specimens (*Pinus sylvestris)*) were exposed to fungi as well. The experiment was performed with five replicate specimens per fungus / ring-width.

In parallel, FTIR analysis of the wood was performed. DRIFT spectra were collected between 4000 cm-1 and 450 cm-1 with the Perkin Elmer FTIR Spectrum One Spectrometer, using the Abrasive Pad 600 Grit-Coated, PK/100 (Perkin Elmer) paper.

In parallel, spruce wood specimens divided into two groups (Table 1) were exposed in use class 3 conditions according to the double layer test method (Rapp and Augusta, 2004; Augusta 2007). 10 specimens were grouped together in double layer test setup 500 mm above ground. Decay was visually evaluated and rated (0 – no attack; 1 – slight attack; 2 – moderate attack; 3 – severe attack; 4 – failure) every year as prescribed by EN 252 standard (1989).

Table 1 Properties of Norway spruce (*Picea abies*) and European larch wood (*Larix decidua*) obtained for small specimens, used for laboratory decay tests.
Tablica 1. Svojstva drva norveške jele (*Picea abies*) i europskog ariša (*Larix decidua*) dobivena za male uzorke korištene za laboratorijski test truljenja

Woodspecies *Vrsta drva*	**Ring-width** *Širina goda* mm	**Density** *Gustoća* kg/m^3	**Extractive content** / *Sadržaj ekstraktivnih tvari* %
Norway spruce *norveška jela*	< 2	431	2.98
	2 - 4	382	3.65
	4 - 6	327	3.98
Larch *ariš*	< 2	525	5.83
	2 - 4	532	6.69
Pine sapwood *bjeljika bora*	2 - 5	420	2.12

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The material used in this experiment was representative and originating from the northern Slovenia in order to limit the influence of the climate conditions on wood properties. As expected, correlation was determined between spruce wood density and ring-width. Density of the dry spruce wood varied between 327 kg/m^3 for specimens with the ring-width between 4 mm and 6 mm, and 431 kg/m^3 for spruce wood with the narrowest rings (up to 2 mm) (Table 1). Density of the larch heartwood was slightly higher, and varied between 525kg/m^3 and 532 kg/m^3. These results are in line with the values reported in the literature (Wagenführ, 1996).

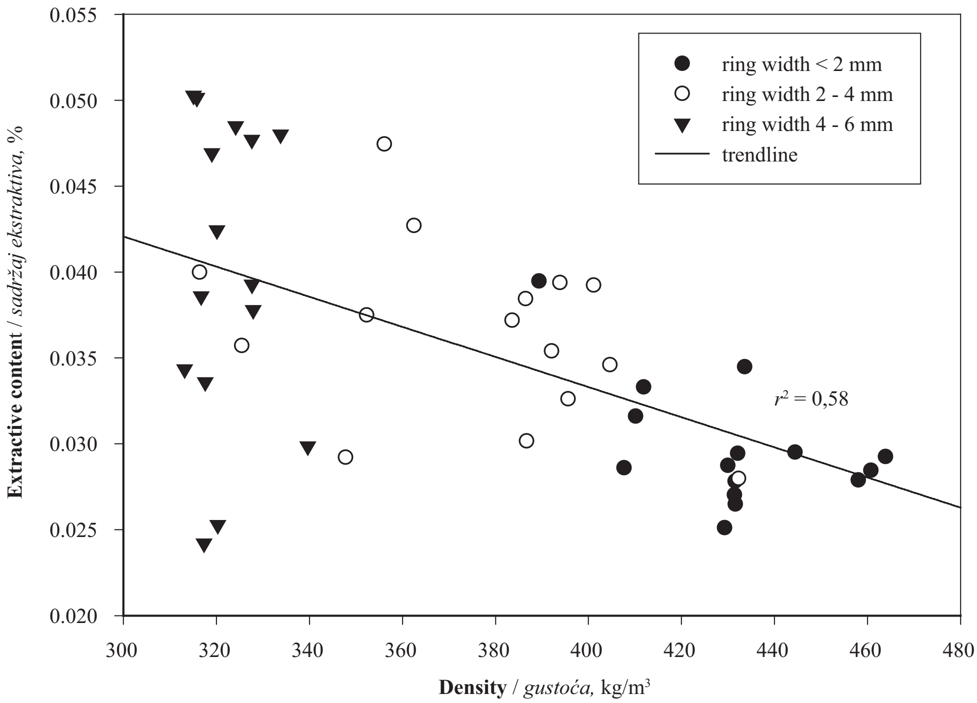

Figure 1 Relationship between density and extractive content ofNorway spruce wood specimens with different ring-widths
Slika 1. Odnos između gustoće i sadržaja ekstraktivnih tvari u uzorcima drva norveške jele različitih širina godova

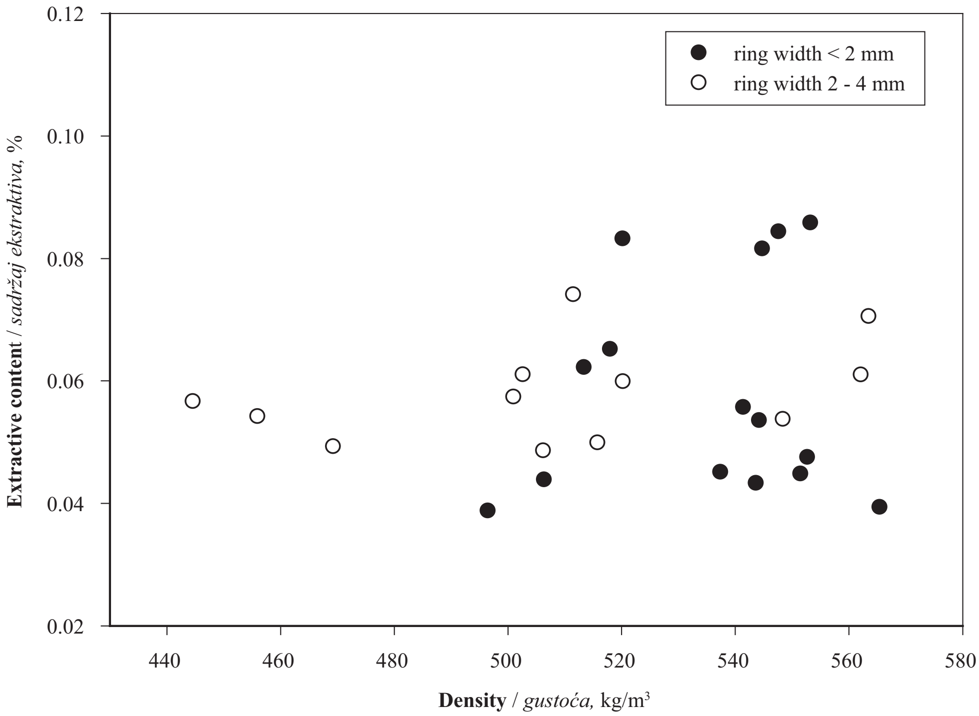

Figure 2 Relationship between density and extractive content of larch heartwood specimens with different ring-widths
Slika 2. Odnos između gustoće i sadržaja ekstraktivnih tvari u uzorcima od srži drva ariša različitih širina godova

Extractive content varied within the samples, as well. The data presented in Table 1 and 2 show that with the increasing density (narrow ring-width), the extractive content in spruce wood samples does not increase and, on the contrary, it even decreases. However, this correlation is not very tight, and there is huge scattering predominantly in the less dense spruce wood specimens (Figure 1). The equation expressingthe amount of extractives per volume of material (spruce), showed that there is a comparable amount of the extractives per given volume of the material. Similar relation is also observed with larch specimens. Specimens with the wider rings contain more extractives than parallel ones with narrower rings (Table 1). If at least a weak correlation was detected between density and extractive content with spruce specimens, no such correlation was observed between these two parameters with larch wood specimens (Figure 1 and 2). Another issue to be considered at this point is that larch wood specimens contain higher amountsof the extractives (6.3 %) than spruce ones (3.5 %). However,the performance of the respective wooden materials is not only defined by the concentration, composition or biological activity of the extractives. In parallel,wood FTIR spectra were determined. As shown inFigure 3, there was actually no difference in the FTIR spectra of spruce wood regarding the ring-width difference. No influence of the ring-width can be seenin FTIR spectra of larch wood either. The main reason for this is the fact that IR assignments of the extractives are similar or even the same as the assignments of lignin. Therefore, chemical changes of the extractives in wood cannot be determined with FTIR spectroscopy.

However, the most important question addressed in this paper was, how density or ring-width and extractive content define the performance of wood against brown rot fungi. Brown rot fungi were chosen, as softwood species are predominately degraded by brown rot fungi (Green and Highley, 1997). Mass loss of the pine sapwood specimens that was used as a virulence control clearly indicates that the fungi were active. After 16 weeks of exposure, those specimens lost between 48.6 % (*G. trabeum*) and 27.6 % (*A. vaillantii*). If these data are compared with mass losses of spruce wood, it can be seen that the mass losses of spruce wood are lower compared to pine sapwood, whichis in line with better natural durability of spruce wood (EN 350-1, 1994). Similarly as pine sapwood, *G. trabeum* was

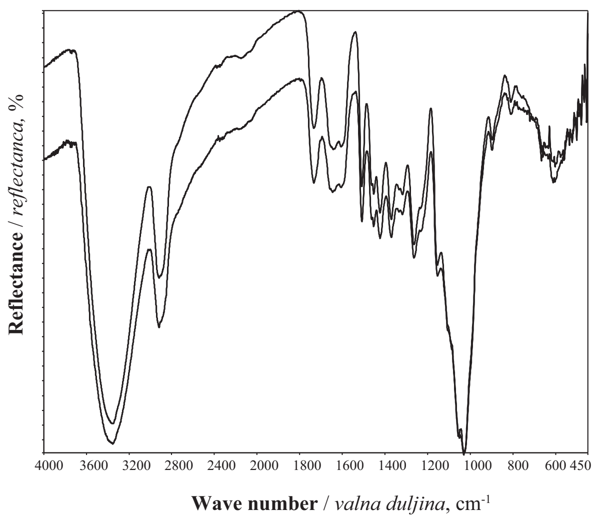

Figure 3 FTIR spectra of non-extracted spruce wood with narrow ring widths (dotted line) and the widest ring widths (solid line)
Slika 3. FTIR spektar za neekstrahirano drvo jele uskih godova (točkasta linija) i najširih godova (puna linija)

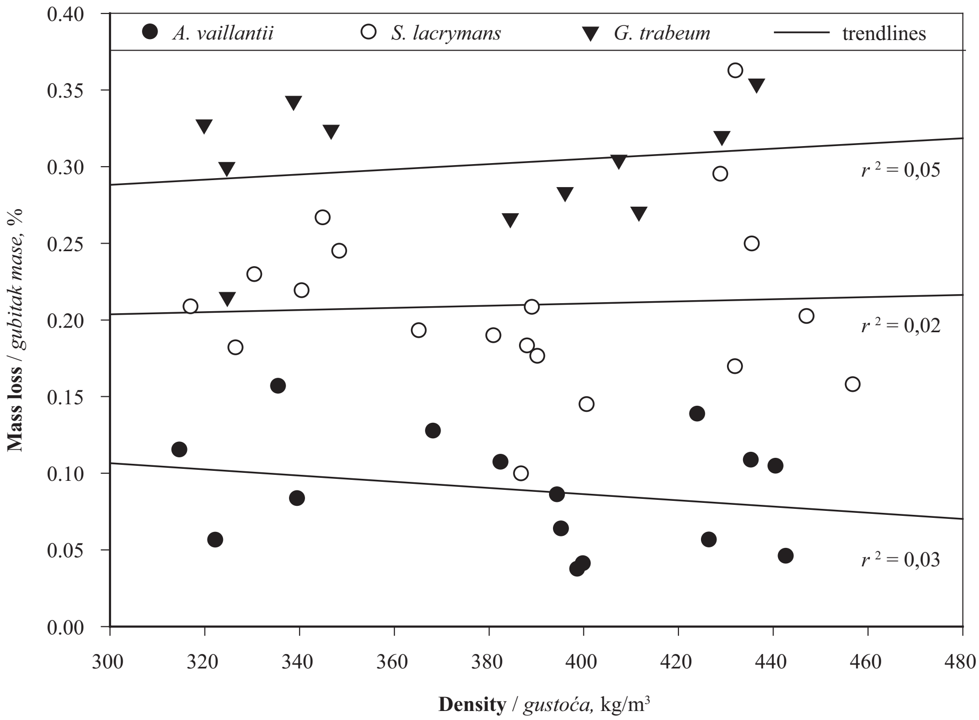

Figure 4 Relationship between density of Norway spruce wood and mass loss after 16 weeks of exposure to the respective brown rot fungi
Slika 4. Odnos između gustoće drva norveške jele i gubitka mase nakon 16 tjedana izlaganja odgovarajućim gljivama smeđe truleži

found the most aggressive, followedby *S. lacrymans* and *A. vaillantii* (Table 2). However, if comparison is made between the ring-width (Table 2) or density (Figure 4) of the specimens and the mass loss of the specimens, it can be seen that there is no correlation between the ring-width or density and mass loss after exposure to the fungi.Comparison of the extracted and non-extracted specimens showed that there is no statistically significant difference between mass loss of the extracted and non-extracted spruce wood specimens. This indicates that the extractives in spruce wood do not have very prominent effect on the natural durability of this wood species.

In contrasts to spruce and pine sapwood specimens, larch heartwood exhibited better performance against brown rot fungi. Mass losses of larch wood specimens were lower by approximately 50% compared to pine wood controls (Table 2). This confirms better durability of larch heartwood (durability class 3-4) compared to spruce (durability class 4) and pine sapwood (durability class 5) (EN 350-1, 1994).In contrast to spruce wood specimens, extracted larch wood was more susceptible to brown rot decay than non extracted larch wood. This was evident in all groups of the specimens with exception of larch wood with narrow ring-width exposed to *A. vaillantii* (Table 2), indicating that larch extractives play an important role byenabling durability. Similarly as the presence of extractives, ring width (or heartwood density) does not have significant influence on the durability of larch wood, ascan be seen in Figure 5. On the other hand, the extracted larch heartwood was still much more durable

Table 2 Influence of spruce and larch ring-width on the performance of respective heartwood against brown rot fungi; Scots pine sapwood was used as virulence control
Tablica 2. Utjecaj širine goda jele i ariša na otpornost drva srži na gljive smeđe truleži; bjeljika bora služila je kao kontrolni uzorak

Wood species *Vrsta drva*	**Ring-width** *Širina goda* mm	**Wood decay fungi** / *Gljive truležnice*					
		G. trabeum		*S. lacrymans*		*A. vaillantii*	
		extracted before exposure / *ekstrahirano prije izlaganja*					
		yes / *da*	no / *ne*	yes / *da*	no / *ne*	yes / *da*	no / *ne*
		Mass loss, % / *gubitak mase, %*					
Norway spruce / *norveška jela*	< 2	30.7	31.2	16.6	23.3	14.4	9.1
	2 - 4	27.1	29.8	18.9	16.8	7.3	6.7
	4 - 6	25.2	29.2	24.2	22.5	11.9	10.8
Larch / *ariš*	< 2	17.5	15.5	11.4	13.9	6.3	4.4
	2 - 4	20.6	16.1	14.4	8.9	6.8	3.7
Pine sapwood / *bjeljika bora*	2 - 5		48.6		42.1		27.6

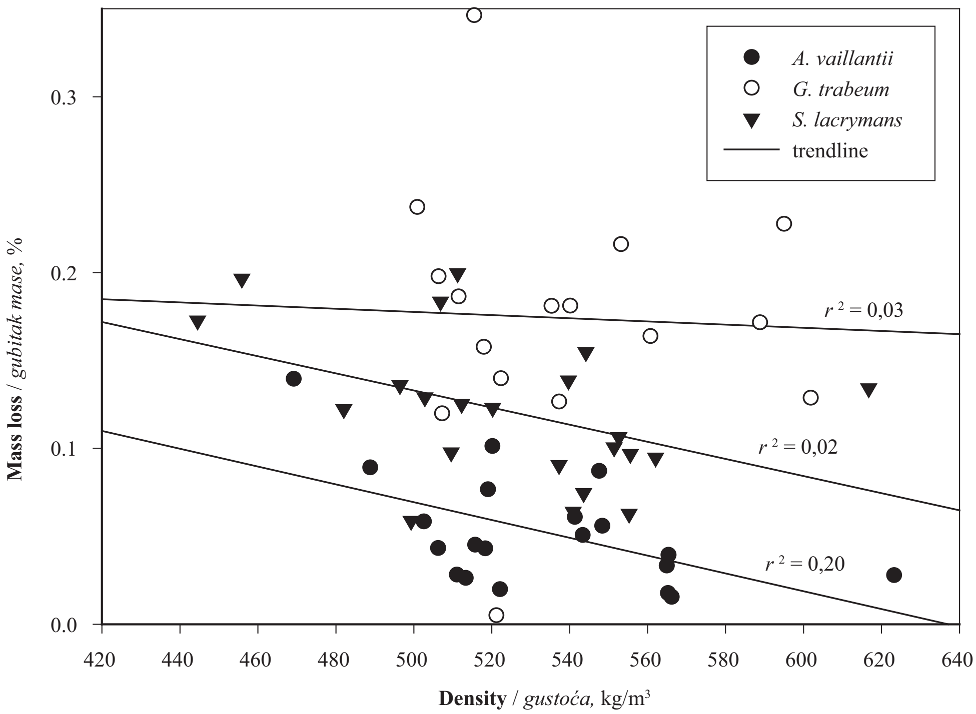

Figure 5 Relationship between density of larch heartwood and mass loss after 16 weeks of exposure to the respective brown rot fungi
Slika 5. Odnos između gustoće drva srži ariša i gubitka mase nakon 16 tjedana izlaganja odgovarajućim gljivama smeđe truleži

than spruce wood or pine wood. Thus, it is believed that this is another proof that natural durability of the wood cannot be explained by the presence or absence of the extractives, and that there must be some other mode of action that influences durability. One of the mechanisms that might affect the durability is the efficacy of water exclusion (Welzbacher *et al.,* 2009).

In order to overcome limitations of the laboratory tests, parallel specimens were exposed to the field test sites in above ground conditions. As it is considerably more difficult to obtain bigger specimens with homogeneous ring-widths, only two types of spruce wood specimens, and one type of larch wood specimens were exposed. As clearly shown in Table 3, the first signs of fungal decay appeared on spruce wood after the first year of exposure, while there was no decay on larch wood even after four years of exposure. Additionally, comparison of spruce wood samples with different ring-widths revealed that the specimens with wider ring-widths were completely decayed after four years of exposure, while the specimens with narrow ring-width were still not completely degraded after 6 years of exposure (Table 3). With both specimens, *Gloeophyllum sp.* was the prevalent reason for the degradation, as indicated by the fruiting bodies present. This field test proves better natural durability of spruce wood with narrow ring-widths compared to the ones with wide ring-widths. Furthermore, comparison of the field test data and laboratory data showed that the laboratory tests sometimes underestimate the performance of durable materials against wood decay fungi. Therefore, field tests are recommended in order to assess the actual performance of the material.

4 CONCLUSIONS
4. ZAKLJUČCI

Performance of spruce and larch heartwood with different ring-widths in standard fungal laboratory test does not show a significant influence of the durability against brown rot fungi. In contrast, field test data proved the influence of the ring-widths on the performance of spruce wood against fungi. Furthermore, extraction of spruce wood specimens,before fungal exposure,has no influence on the performance against wood decay fungi either. On the contrary, extraction of larch heartwood specimens hasa much more prominent influence on the fungal resistance.

Table 3 Performance of Norway spruce wood in outdoor test (use class 3 condition), according to double layer protocol
Tablica 3. Otpornost drva norveške jele u testu na otvorenome (u uvjetima klase 3), prema protokolu dvostrukog sloja

Wood species *Vrsta drva*	**Ring-width** *Širina goda* mm	**Beginning of exposure** *Početak izlaganja*	**Year of rating** / *Godina ocjenjivanja*					
			2007	2008	2009	2010	2011	2012
			Rating / *Ocjenjivanje*					
Norway spruce / *norveška jela*	2 - 4	7. 4. 2006	0.2	0.8	1.8	2.8	3.2	3.6
Norway spruce / *norveška jela*	4 - 8	28. 5. 2007	/	1.4	2.5	3.7	4.0	/
Larch / *ariš*	2 - 4	15. 5. 2008	/	/	0.0	0.0	0.0	0.0

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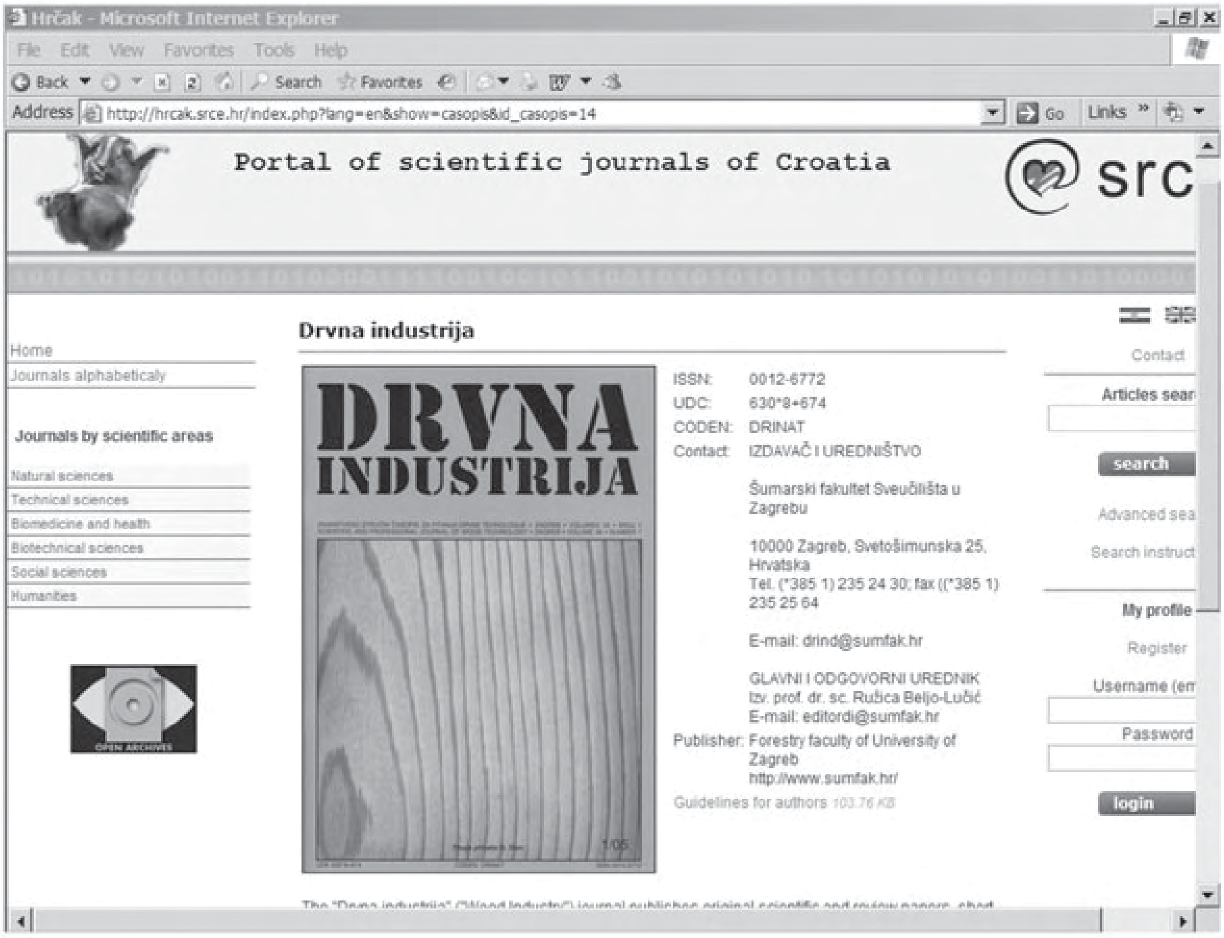

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Evaluation of Mechanical Properties and Formaldehyde Emission of Plywood Manufactured for Construction Applications

Ocjena mehaničkih svojstava i emisije formaldehida furnirske ploče proizvedene za primjenu u graditeljstvu

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ABSTRACT • *This study was aimed to evaluate some mechanical properties and formaldehyde emission of beech plywood panels manufactured from rotary cut veneers using phenol–formaldehyde (PF) resin. Six plywood panels of 5 plies with 15 mm thickness were manufactured. Modulus of rupture (MOR), modulus of elasticity (MOE) and formaldehyde emission values were determined. The values of MOR and MOE were higher than the EN requirements. Furthermore, the formaldehyde emission values measured by the European small-scale chamber (EN 717-1) and gas analysis (EN 717-2) methods were lower than the E1-emmison class. The results showed significant variations (P<0.001) among beech plywood panels, most of them caused by sample heterogeneity, and inconsistency of the values was related to the inter-panel variation. Moreover, a strongly positive correlation between the formaldehyde emission values measured by EN 717-1 and 717-2 methods was found (R^2 value of 0.87).*

Keywords: *mechanical properties, formaldehyde emission, beech plywood, European small-scale chamber, gas analysis.*

SAŽETAK • *Cilj istraživanja bio je procijeniti neka mehanička svojstva i emisiju formaldehida bukovih furnirskih ploča proizvedenih od ljuštenog furnira i fenol-formaldehidne (PF) smole. Proizvedeno je šest furnirskih ploča od pet slojeva furnira debljine 15 mm. Utvrđene su vrijednosti modula loma (MOR), modula elastičnosti (MOE) i emisija formaldehida. Vrijednosti MOR i MOE veće su od zahtjeva europskih normi. Nadalje, vrijednosti emisije formaldehida izmjerene metodom europske male komore (EN 717-1) i metodom plinske analize (EN 717-2) bile su niže od klase emisije E1. Rezultati su pokazali značajne razlike (P <0,001) među bukovim furnirskim pločama, a one su posljedica heterogenosti uzoraka. Nedosljednost izmjerenih vrijednosti povezana je i s varijacijama unutar*

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iste ploče. Također, utvrđena je jaka pozitivna korelacija između vrijednosti emisije formaldehida mjerene metodom EN 717-1 i metodom EN 717-2 (R^2 vrijednost iznosi 0,87).

***Ključne riječi:** mehanička svojstva, emisija formaldehida, bukove furnirske ploče, europska mala komora, plinska analiza*

1 INTRODUCTION
1. UVOD

Formaldehyde is a potential human carcinogen and, due to its high risk level, it is classified differently than most other pollutants. Many building materials including plywood emit formaldehyde, which has the potential to affect health and comfort. In the previous studies, the emissions of formaldehyde from wood-based panels were determined using differing standard test methods (Que and Furuno, 2007; Salem *et al*., 2011a; Salem *et al*., 2011b; Salem *et al*., 2012a, Böhm *et al*., 2012; Park *et al.,* 2010; Roffael *et al*., 2010; Risholm-Sundman and Wallin, 1999).

The formaldehyde emission from wood-based panels, including plywood and flooring materials, has received great attention from the general public as well as wood industries, ever since formaldehyde became known as a toxic air contaminant. In fact, the International Agency for Research on Cancer (IARC), a part of the World Health Organization (WHO), reclassified formaldehyde from 'probably carcinogenic to humans (Group 2A)' to 'carcinogenic to humans (Group 1)' in June 2004 (IARC, 2004). Nowadays, health and the environment constitute two key concerns of the 21st century (Lee *et al*., 2002).

Plywood is one of the main products that can be used as structural material and has traditionally played an important role in light frame construction. Plywood and other wood-based products are widely used in the manufacture of furniture, engineered flooring, housing and other industrial products (Böhm *et al*., 2012). The plywood panels are manufactured by gluing several wooden plies together in layers, which have perpendicular grain directions. The thickness of plies is generally from 2 to 3mm (Arriaga-Martitegui *et al*., 2008). Where there are no requirements with respect to the appearance of the material, lower-grade veneers for plywood may be suitable for structural purposes without compromising the function of structural members.

Plywood is a complex product and the bending properties as a strength class system are defined in EN 636 (2003) for quality control procedures (EN 636-1; EN 636-2; EN 636-3). Furthermore, the determination of all the mechanical properties of plywood requires a large amount of time-consuming testing for each different board composition. Additionally, the factors affecting physico-mechanical properties and formaldehyde emission from plywood panels and its products and have been studied (Sensogut *et al*., 2009; Aydin *et al*., 2006; Aydin and Colakoglu, 2007; Colak and Colakoglu, 2004; Martínez and Belanche, 2000).

Urea formaldehyde (UF) and phenol- formaldehyde (PF) resins are widely used as a major component in the production of building and furniture materials. PF resin is used to manufacture plywood for exterior applications because of its excellent water resistance. Plywood products used as an exterior product are suitable for moist and wet use, carrying and non-carrying construction elements. Phenolic-based compounds also tend to be more chemically stable and less susceptible to hydrolysis than UF. Both of these characteristics are beneficial to PF resin. Moreover, PF tends to be more chemically stable and less susceptible to hydrolysis than UF and is considered waterproof, while UF is not (Salem *et al*., 2011b; Dunky, 2005). PF resin has generally been the resin chosen by manufacturers of exterior grade structural panels. In addition, the C-C bonding in the PF resins was very stable against hydrolytic attack. The objectives of this study were to evaluate the mechanical properties of beech plywood manufactured for structural application and to check the formaldehyde emission according to the European standards.

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

2.1 Production of plywood panels and samples
2.1. Proizvodnja furnirskih ploča i uzoraka

Wood logs of 60 cm in diameter from European beech (*Fagus sylvatica* L.) were steamed for 48 h before the production of veneer. Sheets of veneer with dimensions of 50 cm × 50 cm × 3.2 mm were produced with rotary cuts and randomly chosen from the main veneer sheet, and then dried at 110 °C. Subsequently, the veneers were conditioned in a climate chamber to 4-6 % moisture content. Plywood (5-ply) with a nominal thickness of 15 mm was produced from beech veneers using PF resin (46 % solid content). The manufactured plywood was classified as external structural component (EN 636-3, 2003). The properties and composition of PF resin used are presented in Table 1. For manufacturing plywood panels, the following parameters were used: hot press time, pressure and temperature (Table 2). Six replicate panels (p1, p2, p3, p4, p5 and p6) were manufactured, wrapped with polyethylene film and delivered to the laboratory of Timber Research and Development Institute in Prague, Czech Republic.

2.2 Measuring of mechanical properties and formaldehyde emission
2.2. Mjerenje mehaničkih svojstava i emisije formaldehida

Since, as previously discussed, the determination of all the mechanical properties of plywood requires considerable time and effort, and the number of possible variables that define a type of plywood are large for the same thickness, it is possible to use different lay-ups, even different species, giving different mechanical

Table 1 Properties and composition of phenol-formaldehyde adhesive resin used for plywood
Tablica 1. Svojstva i sastav fenol-formaldehidnog ljepila upotrijebljenog za proizvodnju ploča

Parameter / *Parametar*	**phenol-formaldehyde adhesive resin** *fenol-formaldehidno ljepilo*
Solid resin content, % *Sadržaj krute tvari, %*	46
Viscosity (mPa·s at 20 °C) *Viskozitet, (mPa·s at 20 °C)*	250–1050
pH at 20 °C	min. 11.5
Density / *Gustoća*	1210–1250 kg/m³
Foaming agent[a] *Sredstvo za pjenjenje*	Oxyethylene castor oil and mixture of non-ionic tensides *oksietilen ricinusovo ulje i mješavina neionskih tenzida*
Free formaldehyde *Slobodni formaldehid*	max 0.1 % najviše 0,1 %

[a] PF resin + foaming agent (PF resin / foaming agent - 100:1) with density (PF resin + foaming agent): 750-850 kg/m³ / *PF smola + sredstvo za pjenjenje (PF smola / sredstvo za pjenjenje – 100:1) gustoće (PF smola + sredstvo za pjenjenje): 750-850 kg/m³.*

Table 2 Pressing conditions of plywood bonded with phenol-formaldehyde adhesive resin
Tablica 2. Uvjeti prešanja furnirskih ploča izrađenih fenol-formaldehidnim ljepilom

Parameter / *Parametar*	**Value** *Vrijednost*
Specific pressure / *specifični tlak*	1.5 MPa
Pressing temperature / *temperature prešanja*	118-124 °C
Pressing time / *vrijeme prešanja*	60 s / 1mm[a]
Veneer moisture / *sadržaj vode u furniru*	5±2 %
Veneer thickness / *debljina furnira*	≤ 3.2 mm
Adhesive spread / *nanos ljepila*	150 g/m² [b]

[a] Basic curing time for PF adhesive is 3 minutes and for the heating of 1 mm veneer thickness 1 minute. / *Osnovno je vrijeme stvrdnjavanja za PF ljepila 3 minute, a za zagrijavanje furnira debljine 1 mm iznosi 1 minutu.*
[b] Approximately 150 g/m² adhesive mixture was spread on single surfaces of veneers using a gluing machine. / *Na jednu površinu furnira prosječno je naneseno 150 g/m² smjese ljepila nanijeto je primjenom uređaja za nanos ljepila.*

properties (Arriaga-Martitegui *et al*., 2008). Therefore, in the present study the bending properties; modulus of rupture (MOR) and modulus of elasticity (MOE) were determined in accordance with EN 636-3 (2003) and EN 13986 (2004) standards.

Six samples from each panel of beech plywood, 15 mm thick, were prepared in accordance with the standards EN 636-3 and EN 13986 to measure the mechanical properties (MOR and MOE). These standards were designed for testing the requirements of plywood as well as wood-based panels. Additionally, six samples, representing randomly distributed portions of an entire panel, were edge–sealed with aluminum tape and conditioned at 23 °C ± 0.5 °C and relative humidity of 50% ± 5% (RH) for 10 days before the analysis of formaldehyde emission with gas analysis method (EN 717-2, 1994). Furthermore, formaldehyde emission was measured from another six samples by the European small-scale chamber method (EN 717-1, 2004), where the measuring was done after removing the polyethylene film.

In the referenced method (EN 717-1), two test pieces with the dimensions of 0.2 m × 0.28 m × 15 mm and a total area of 0.225 m² were used for the measuring of formaldehyde emission. The loading factor was 1 m²/m³ (1.5 m open edge/m²). The temperature and RH were 23 ± 0.5 °C and 45 ± 3 %, respectively. The values after 2 to 4 weeks of testing are given as the steady-state emission values. The E1-emission class is ≤ 0.1 ppm (0.124 mg/m³).

In the factory quality control method (EN 717-2), an edge-sealed test piece with self-adhesive aluminum tap of 400 mm × 50 mm × 15 mm was placed in a 4 L chamber with controlled temperature (60 ± 0.5 °C), relative humidity (RH ≤ 3%), airflow (60 ± 3 L/h) and pressure. The measuring of formaldehyde was repeated (six samples from each panel) for better homogeneity of the results. The E1-emission class was ≤ 3.5 mg/m² h. The emitted formaldehyde from both methods was absorbed in water and determined photometrically by the acetylacetone method (Nash, 1953).

2.3 Statistical analysis
2.3. Statistička analiza

The results of mechanical properties (MOR and MOE) and formaldehyde emission values were statistically analyzed using the SAS version 8.2 (2001) in a completely randomized design to test the differences among the panels. The comparison between means was done employing a Duncan's multiple-range test at 0.05 level of probability. Moreover, the correlation was done between the values of formaldehyde emission resulted from the two methods.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Table 3 presents the statistical analysis results of both mechanical tests and formaldehyde emission. Average value of MOR ranged from 41 to 51.9 N/mm² (bending parallel to grain) and from 27 to 31.9 N/mm² (bending perpendicular to grain). All the manufactured panels had higher MOR than the requirement level for 15 mm thick panels in accordance with EN 636 (the lower limit value of MOR 23 N/mm²). The range of result of MOE was from 5032 to 5722 N/mm² (bending parallel to grain) and from 2025 to 2536 N/mm² (bending perpendicular to grain). The recommended value of MOE is 1500 N/mm² as described by EN 636. All of the plywood panels had MOE higher than the requirement for EN 636.

Additionally, we monitored changes in the content of formaldehyde for each panel of beech plywood. The values of formaldehyde emission ranged from 0.01 to 0.027 mg/m³ as measured by EN 717-1 method with an average value of 0.016 mg/m³. The results showed that the panel p6 had the highest amount (0.027 mg/m³) while the panel p1 had the lowest amount (0.01 mg/m³) of formaldehyde emission. Similarly to EN 717-1

Table 3 Mechanical properties and formaldehyde emission from beech plywood (15 mm thick) bonded with phenol-formaldehyde resin
Tablica 3. Mehanička svojstva i emisija formaldehida iz bukovih furnirskih ploča debljine 15 mm zalijepljenih fenol-formaldehidnom smolom

Board No.	MOR, N/mm²		MOE, N/mm²		Formaldehyde emission *Emisija formaldehida*	
	A	B	A	B	mg/m³	mg/m²·h
1	47.2±11.4[c] (24)	31.3±9.18[a] (29.3)	5639±993[b] (18)	2536±539[a] (21)	0.01±0.001[e]	0.13±0.008[f]
2	41±6.03[e] (14.7)	31.8±8.08[a] (25.4)	5636±462[b] (8)	2451±462[c] (19)	0.013±0.0008[d]	0.17±0.015[e]
3	41.1±9.82[e] (23.9)	31.9±7.57[a] (23.8)	5032±612[e] (12)	2471±417[b] (17)	0.014±0.0005[cd]	0.21±0.018[d]
4	44.2±5.03[d] (11.4)	30.4±1.75[a] (5.8)	5379±548[d] (10)	2025±65.4[f] (3)	0.015±0.0009[c]	0.25±0.007[c]
5	51.9±5.49[a] (10.6)	25.4±4.17[b] (16.4)	5722±685[a] (12)	2071±2[e] (10)	0.019±0.0017[b]	0.29±0.02[b]
6	49.3±2.8[b] (5.7)	27±7.62[b] (28.2)	5426±385[c] (7)	2360±355[d] (15)	0.027±0.0018[a]	0.33±0.01[a]
mean	45.78	29.63	5472.33	2319	0.016 (0.013 ppm)*	0.23
R^2	0.89	0.70	0.99	0.99	0.96	0.95
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

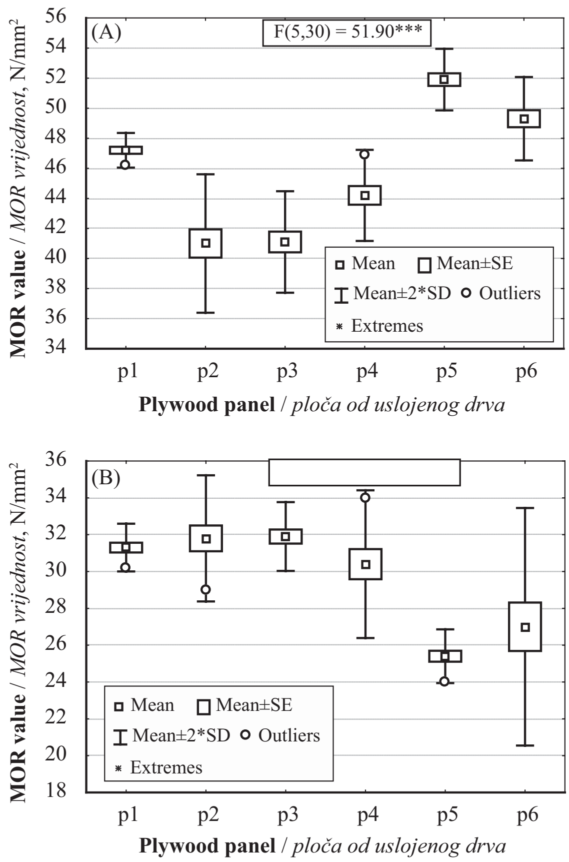
(A): Bending parallel to grain / *savijanje paralelno s vlakancima*; (B): Bending perpendicular to grain / *savijanje okomito na vlakanca*

* At 23 ºC and 1013 hPa, the following relationship exists for formaldehyde measured by EN 717-1: 1 ppm = 1.24 mg/m³ or 1 mg/m³ = 0.81 ppm / *Pri 23 ºC i 1013 hPa za emisiju formaldehida mjerenu metodom EN 717-1 vrijedi odnos: 1 ppm = 1,24 mg/m³ ili 1 mg/m³ = 0,81 ppm.*
Values are mean ± standard deviation (coefficient of variance). / *U tablici su dane srednja vrijednost + standardna devijacija (koeficijent varijacije)*
Means with the same letter within the same column are not significantly different at 0.05 level of probability, according to $LSD_{0.05}$.
Srednje vrijednosti označene istim slovom unutar istog stupca ne razlikuju se signifikantno pri razini vjerojatnosti 0,05.

method, the formaldehyde emission values measured by EN 717-2 had the same trend and ranged between 0.13-0.33 mg/m²·h; however, its values were much higher. This phenomenon could be explained by different conditions used by the two methods.

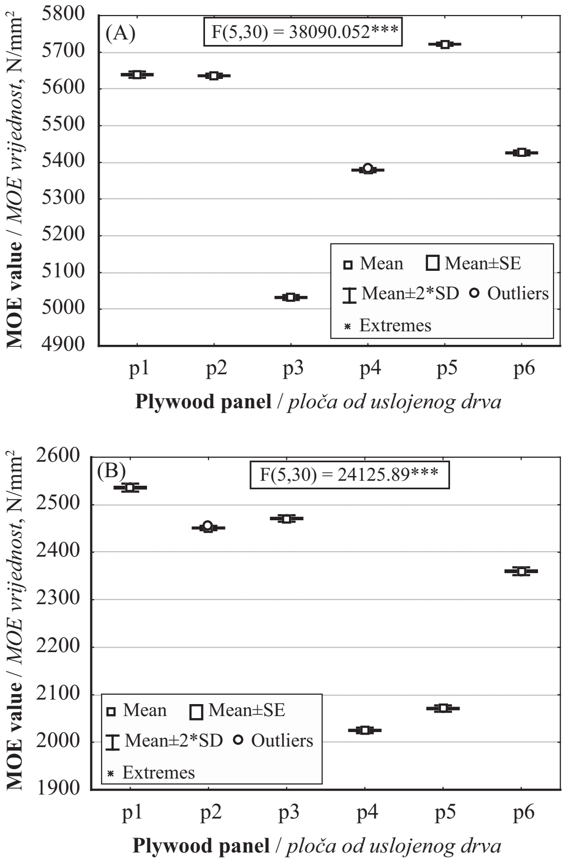
Analysis of variance was used to evaluate the differences between the boards. Statistically it was proven that there was a significant difference (P <0.001) between the means of the boards. The evaluation of the differences among the values of MOR, MOE and formaldehyde emission observed from the six panels of beech plywood is shown in Figs. 1-3. The summary of statistics and comparisons among the means are presented in Table 3 to evaluate the level of significance. The variations among the average of six measurements of MOR for each panel are shown in Fig. 1. The data showed that each of p1 and p2 and p1, p2, p4 and p5 (bending perpendicular to grain) had one value distance (outliers) from the rest of the data. Furthermore, Fig. 2 presents the variations among MOE values. The panel p4 (bending parallel to grain) and p2 (bending perpendicular to grain) had one value as an outlier. The results of formaldehyde emission presented in Fig. 3 show that the panel p6 as measured by EN 717-1 (mg/m³) and the panel p2 as measured by EN 717-2 had only one value outside the rest of the data.

On the other hand, the data presented in Table 3 showed a variety in the relative coefficient of variation (CV %) for the six measurements of each panel for MOR, MOE and formaldehyde emission. For instance, there were variations in the values of CV % for the values of MOR parallel to grain and ranged between 5.7 % (p6) and 24 % (p1) and from 5.8 % (p4) to 29.3 % (p1) for MOR perpendicular to grain. Furthermore, the outliers of the measured MOR, MOE and formaldehyde values for beech plywood showed that there



(A): Bending parallel to grain / *Savijanje paralelno s vlakancima.*
(B): Bending perpendicular to grain / *Savijanje okomito na vlakanca.*

Figure 1 Box-Whiskers plot of MOR value variation among plywood panels (15 mm)
Slika 1. Box-Whiskers dijagram varijacije vrijednosti MOR za furnirske ploče debljine 15 mm



(A): Bending parallel to grain / *Savijanje paralelno s vlakancima.*
(B): Bending perpendicular to grain / *Savijanje okomito na vlakanca.*

Figure 2 Box-Whiskers plot of MOE value variation among plywood panels (15 mm)
Slika 2. Box-Whiskers dijagram varijacije vrijednosti MOE za furnirske ploče debljine 15 mm

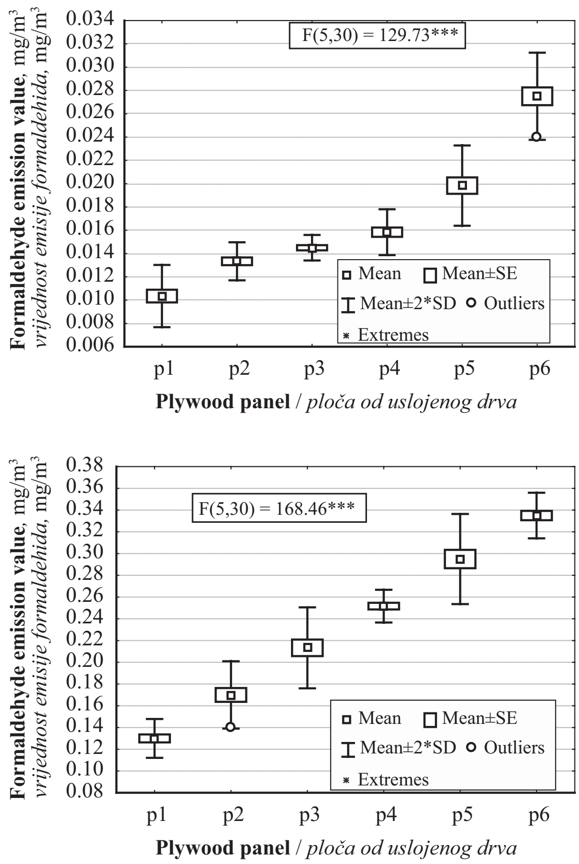


Figure 3 Box-Whiskers plot of formaldehyde concentration variation among plywood panels (15 mm)
Slika 3. Box-Whiskers dijagram varijacije vrijednosti koncentracije formaldehida za furnirske ploče debljine 15 mm

were differences between the values from the six panels for the same kind of wood product, which indicated that some panels had a number of values numerically more distant from the rest of the data than the others.

The data presented measurement points at a distance from the sample mean, i.e. some observations were far from the center of the data. Outlier points can therefore indicate faulty data, erroneous procedures, or areas where a certain theory might not be valid. The inter-panel comparison method used for such analysis depends critically on the quality of the measurements. Under the same standard conditions with the same type of board, significantly higher or lower emission of formaldehyde, MOR and MOE was found in one or more panels than in other boards. Statistical replicability across boards thus becomes an objective yardstick for both the relevance of a behavioral measure and for the estimation of the quality of its measurement.

Even considering that the samples were randomly distributed throughout the plywood panel, which makes it unlikely that the observed variations were due to inter–panel variability, there were some variations in the measured parameters through the tested panel. Consequently, the variations among the values of MOR, MOE and formaldehyde emission were due to sample heterogeneity. For example, the formaldehyde emission values were 0.13, 0.17, 0.21, 0.25, 0.29 and 0.33 mg/m2 h for p1, p2, p3, p4, p5 and p6, respectively. Thus, these results suggested that the most important source of variation is due to heterogeneity of board samples. The obvious results of high, intermediate or low values found among the panels and inter-panel for the same kind of plywood, were in agreements with the previous investigations (Wiglusz *et al.*, 2000; Risholm-Sundman *et al.*, 2007; Salem *et al.*, 2012b; Roffael *et al.*, 1979; Bulian *et al.*, 2003; Salem *et al.*, 2013).

Despite these differences between formaldehyde emission values among the panels, a strongly positive correlation between the formaldehyde emission values measured by EN 717-1 and 717-2 methods was found. The measured values of free formaldehyde from plywood panels with 15 mm thickness had an R^2 value of 0.87 (Fig. 4).

The plywood panels were manufactured with PF resin and formaldehyde emission was close to that of solid wood, because the C-C bonding in the PF resin was very stable against hydrolytic attack (Salem *et al.*, 2011b; Böhm *et al.*, 2012, Dunky, 2005). Moreover, this low susceptibility to hydrolysis is one of the reasons why PF resins are considered waterproof. At such low levels of free formaldehyde emission, the boards

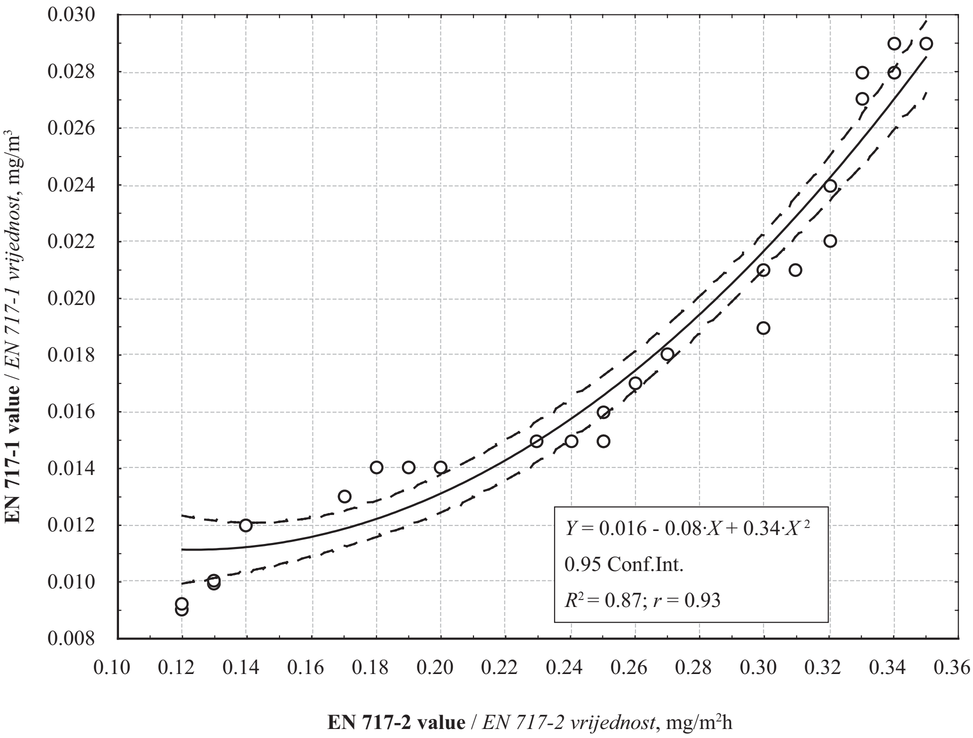


Figure 4 Correlation between the values of formaldehyde emission measured by EN 717-1 and 717-2 methods for beech plywood with 15 mm thickness
Slika 4. Korelacija između vrijednosti emisije formaldehida mjerene metodom EN 717-1 i metodom EN 717-2 za furnirske ploče debljine 15 mm

are considered to be formaldehyde free. It is important to point out here that such low free formaldehyde values may be emitted from the wood itself and the boards are considered formaldehyde free. On the other hand, it was found in the previous studies that the highest amount of formaldehyde released during hot pressing was related to the wood structure (beech wood consists of bigger vessel surfaces) and could be related to the higher density of the beech wood (Salem *et al*., 2012a; Böhm *et al*., 2012).

Simultaneously, the mean values of formaldehyde emission from all the beech plywood panels measured by EN 717-1 were 0.016 mg/m^3 (0.013 ppm) and these values are much lower than the requirements of the California Air Resources Board (CARB, 2007) regulations for Phase 1 ($\leq$ 0.08 ppm) and for Phase 2 with the limit value $\leq$ 0.05 ppm.

Recently, governments of many countries have already imposed or are about to impose regulations limiting the formaldehyde emission from building materials as well as from materials used for the manufacture of furniture, engineered flooring, housing and other industrial products. The emission of formaldehyde in wood products can be minimized during the manufacturing process, or by post treatment and surface treatment of the boards.

4 CONCLUSION
4. ZAKLJUČAK

The results showed significant variations (P<0.001) among the beech plywood panels with 15 mm thickness bonded with PF resin, most of them being caused by sample heterogeneity and inconsistency of the values related to inter-panel variation. The values of MOR and MOE were higher than the EN requirements. The concentrations of formaldehyde in these products were below the prescribed limits in the Czech Republic and EU. Moreover, a strongly positive correlation between the formaldehyde emission values measured by EN 717-1 and 717-2 methods was found (R^2 value of 0.87).

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Influence of Temperature on Cambial Activity and Cell Differentiation in *Quercus Sessiliflora* and *Acer Pseudoplatanus* of Different Ages

Utjecaj promjena temperature na djelovanje kambija i diferencijaciju stanica drva hrasta kitnjaka i gorskog javora različite dobi

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ABSTRACT • *We evaluated the response of active cambium of sessile oak (Quercus sessiliflora) and sycamore maple (Acer pseudoplatanus) to experimentally increased (20–22 °C) and decreased (9–11 °C) temperatures. Heating and cooling experiments on 150-year old Q. sessiliflora were performed during the growth season of 2007 and on 30-year old A. pseudoplatanus in 2008. In 2009, heating experiment was carried out on 30-year old Q. sessiliflora. For each treatment, two trees were selected of each species and sampled at 21-day intervals during the vegetation period and investigated by means of light microscopy. Continuously elevated temperatures slightly promoted the development of xylem cells in old Q. sessiliflora trees in the first month of cambial activity. However, no effect of elevated or decreased temperature was detected in the timing and dynamics of wood and phloem formation. The applied treatments, therefore, had no visible impact on the structure or width of the xylem or phloem increments in 2007. On the other hand, heating young A. pseudoplatanus trees provoked the development of epicormic shoots two months after the onset of the experiment and finally the death of trees. The cambium of those trees did not reactivate in 2008; xylem and phloem increments were consequently not formed. Low temperature treatments slowed down cell production at the very beginning of the growing season, but no alterations in wood or phloem formation dynamics or structure were observed later. The heating of young Q. sessiliflora trees caused the development of epicormic shoots and the death of trees four months after the experiment. The pattern of their dying was similar as in A. pseudoplatanus but with a two month delay. The observations indicate that tree age, thickness of dead bark and duration of the applied treatments influence the response of cambium. The development of dead bark is species specific and it occurs earlier in Q. sessiliflora than in A. pseudoplatanus. Thick dead bark acts as a very good insulation layer for the sensitive internal, living tissues of bark and cambium and therefore protects them against external abiotic and biotic factors.*

Key words: *sessile oak, sycamore maple, heating, cooling, cambium, cell differentiation, xylem, phloem, dead bark, light microscopy*

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SAŽETAK • *U radu je istraživan utjecaj grijanja (20–22 °C) i hlađenja (9–11 °C) na djelovanje kambija i stvaranje drva i floema u dijelu debla 150 i 30 godina starog hrasta kitnjaka (Quercus sessiliflora) i 30 godina staroga gorskog javora (Acer pseudoplatanus). U svakom tretmanu odabrali smo dva stabla svake od tih vrsta i skupili uzorke u 21-dnevnim intervalima tijekom vegetacije, koje smo analizirali svjetlosnom mikroskopijom. Stalno povišena temperatura potaknula je nešto raniji početak stvaranja stanica drva u starim stablima Q. sessiliflora u prvome mjesecu kambijske aktivnosti u 2007. Međutim, učinak povišene ili smanjene temperature na vrijeme ili dinamiku stvaranja drva i lika nismo potvrdili. Stoga, tretmani nisu utjecali na strukturu i širinu goda drva i lika u 2007. Nasuprot tome, grijanje mladih stabala A. pseudoplatanus potaknulo je razvoj adventivnih izdanaka dva mjeseca nakon pokusa i na kraju prouzročila njihovu smrt. Kambij se u tim uzorcima u 2008. nije reaktivirao, stoga se nije formirao ni god drva i lika. Niske temperature usporile su proizvodnju stanica u kambiju na samom početku vegetacije, ali nisu utjecale na dinamiku stvaranja ili strukturu drva i lika. Grijanje mladih stabala Q. sessiliflora rezultiralo je nastankom adventivnih izdanaka i umiranjem stabala četiri mjeseca nakon eksperimenta. Proces umiranja bio je sličan umiranju stabala A. pseudoplatanus, samo uz dva mjeseca zakašnjenja. Promatranja pokazuju da starost stabala (debljina mrtve kore) i trajanje primijenjenih tretmana također mogu utjecati na djelovanje kambija. Početak stvaranja mrtve kore specifičan je za pojedine vrste drveća i ranije se pojavljuje u vrste Q. sessiliflora nego u A. pseudoplatanus. Debela mrtva kora djeluje kao vrlo dobar izolacijski sloj za unutarnja, živa i osjetljiva tkiva (floem i kambij) i stoga ih štiti od vanjskih abiotičkih i biotičkih čimbenika.*

Ključne riječi: *hrast kitnjak, gorski javor, grijanje, hlađenje, kambij, stanična diferencijacija, drvo, liko, mrtva kora, svjetlosna mikroskopija*

1 INTRODUCTION
1. UVOD

Wood is a natural product of the growth of trees. As a material, it is still essential to mankind, but has evolved over the ages from a simple, natural material into a modern industrial and engineering material. It is produced by the vascular cambium, which in temperate and boreal climatic zones expresses annual periodicity. Seasonal alternations of active and dormant (resting) periods are generally associated with exchanges of hot and cold or dry and rainy seasons (Larcher, 2003). This periodicity plays an important role in the formation of wood and reflects the environmental adaptivity of trees to the growing conditions (Begum *et al*, 2012).

Cambial activity usually starts in spring with cell division and ends in late summer with the completed development of the latest formed cells. At the beginning of cambial activity, the number of cambial cells increases and they start to divide, which is followed by differentiation of derivatives into the adult elements of xylem or phloem (Plomion *et al*, 2001). Xylo- and phloemogenesis, which lead to specialization of cells, are periodic processes driven by a variety of internal and external factors, whose influence changes during the growing season. These complex processes are not pre-determined, but are plastic end-products of interactions between the genotype and the environment (Savidge, 2001). Environmental signals affect the beginning, cessation and rate of individual developmental processes, which determine the morphology of cells (Sundberg *et al,* 2000; Wodzicki, 2001). Despite numerous studies, the mechanism of wood and phloem formation is still not fully explained (Chaffey, 2002); however, a detailed knowledge of all these processes will improve our understanding of the relationship among wood structure, properties and end-use of wood.

The effect of specific climatic factors on the mechanism of xylem and phloem growth ring formation can be studied on trees growing in their natural environment or under experimentally controlled conditions (e.g., Oribe *et al,* 2001; Gričar *et al,* 2006; Begum *et al,* 2008, 2010). Additionally, many controlled experiments have been performed on growing seedlings or saplings, allowing simulation of different growing conditions on the growth and adaptivity of young trees (e.g. Rossi *et al*, 2009; De Luis *et al*, 2011). However, to predict the response of different (adult) tree species and forests to possibly changed climate conditions, long-term adaptive responses and highly flexible resource allocation patterns in these long-lived plants must be taken into account. This makes simple extrapolation from laboratory seedling or sapling studies to mature forests difficult if not impossible (Meier and Leuschner, 2008).

Experiments on adult trees are more complicated and are usually restricted to a part of a tree (e.g., stem, branch). It has been demonstrated that the application of temperature in the period of either cambial activity or dormancy can cause alterations in its regular rhythm of periodicity and cell differentiation (e.g., Denne and Dodd, 1981; Mellerowicz *et al,* 1992; Barnett and Miller, 1994; Oribe and Kubo, 1997; Oribe *et al,* 2001; Gričar *et al,* 2006, 2007; Begum *et al,* 2007, 2008). The application of heat has revealed differences in the response of dormant cambium to treatments among different species of evergreen and deciduous habit (e.g., Oribe *et al*, 2003; Gričar *et al*, 2006; Begum *et al*, 2010); however, in all cases, temperature has been proven to be crucial for the onset of cell division and cell development at the beginning of the growing season, while other factors prevail in the second part (Gričar *et al,* 2007).

The majority of such experiments have been carried out on conifers and, recently, on the deciduous diffuse-porous hardwood *Populus sieboldii x Populus grandidentata* (Begum *et al*, 2007) but information on ring-porous species is still lacking. In addition, the effect of elevated temperature on cambial activity has been mostly investigated during dormancy over short periods of time, while only a few studies have been performed during the vegetation period or with decreased temperature. Moreover, the age of the tree has only rarely been taken into consideration as one of the factors that could affect the response of trees to applied treatments (Begum *et al*, 2010). We, therefore, evaluated the response of active cambium of deciduous ring-porous sessile oak (*Quercus sessiliflora* Salisb.) and diffuse-porous sycamore maple (*Acer pseudoplatanus* L.) to experimentally increased (20–22 °C) and decreased (9–11 °C) temperatures. Experiments on 150-year old *Q. sessiliflora* were performed during the growth season of 2007, on 30-year old *A. pseudoplatanus* in 2008 and on 30-year old *Q. sessiliflora* in 2009. Samples of bark, cambium and xylem were taken at 21-day intervals and investigated by means of light microscopy.

2 MATERIAL AND METHODS
2. MATERIJALI I METODE

The experiments were performed in the forest site Rožnik in Ljubljana (46°03'N, 14°28'E, 323 m a.s.l.), which belongs to the *Blechno fagetum* forest association. The predominant tree species at the site are *Fagus sylvatica* and *Quercus sessiliflora*. The climate on the location is humid continental. Average, maximum and minimum daily air temperatures during the experiments were recorded by a weather station located 50 m from the test trees. For the study, we selected six dominant, healthy sessile oaks (*Quercus sessiliflora* Salisb.) at the beginning of the vegetation period of 2007. The trees were about 150 years old, with a DBH of 55-80 cm (considered to be old oaks). In winter 2008, we chose six dominant, healthy sycamore maples (*Acer pseudoplatanus* L.). The trees were about 30 years old, with a DBH of about 15 cm. Two trees of each species were used for the heating experiment and two for the cooling treatment. Two trees were not treated and served as controls. In winter 2009, we selected four dominant, healthy *Q. sessiliflora* trees. The trees were assessed to be approximately 30 years old, with a DBH of about 15 cm (considered to be young oaks). Two trees were used for the heating experiment and two for control. The crowns of all selected trees appeared to be normally developed and the trunks to be without any visible mechanical injuries. The distance between the test trees was about 10 m.

Localized heating and cooling of the stem portion of the old *Q. sessiliflora* was performed in the period between 30 March and 12 September 2007, and cooling between 26 April and 12 September 2007. In the case of *A. pseudoplatanus*, heating was carried out in the period 29 February – 15 September 2008 and cooling between 10 April and 15 September 2008. In 2009, only heating experiments were carried out in young *Q. sessiliflora* in the period 10 March – 17 September. The stem portion of the two trees of each species were heated with a 15 m long electric heat cable (FSM-17, 17W/+5°C, 11W/25°C, 230V) wrapped around 1 meter of the stem length. The lower part of the heating system was 70 cm above the ground. Insulation material was wrapped around the electric heat cable to prevent energy loss. The temperature between the bark and the insulation was adjusted to 20-22 °C, and monitored daily with a thermometer sensor. For cooling of the stem portion of the selected trees, we used a circulating pump that pushed cooled water through copper tubes, which were wrapped around 1 meter of the stem length. The system was carefully insulated. The temperature between the stem and the insulation was set to 9-11 °C, monitored and regulated daily with a capillary thermostat.

We took blocks of intact tissue (10 x 10 x 30 mm) containing bark, cambium and outer xylem from living trees 1.3 m above ground at 21-day intervals. At the beginning of the heating experiment, we took the first three samples at 3-day intervals. The distance between neighbouring samples was at least 10 cm in a horizontal direction to avoid the influence of wounds on tissues of the next sampling locations. The insulation was replaced in the original position after each sampling. After sampling, blocks of tissue were immediately fixed in FEA (formaldehyde-ethanol-acetic acid solution), dehydrated after one week in a graded series of ethanol and reduced to a size of 2 x 2 x 5 mm for embedding in paraffin (for details see Rossi *et al,* 2006). Permanent cross-sections of 13 μm thickness for light microscopy were prepared on a rotary microtome Leica RM 2245, using disposable Leica blades. Sections were stained with safranin and astra blue and finally mounted in Euparal. An Olympus BX51 light microscope and the Nikon NIS-Elements Basis Research v.2.3 analysis system were used for anatomical observations and evaluation of the developing tissue.

We followed the cambial activity and the development of the xylem and phloem elements on the cross-sections. We distinguished among radially flattened cambial cells with blue stained, thin primary cell walls and xylem and phloem cells at various stages of development (i.e., post-cambial growth, secondary cell wall synthesis and lignification) and mature cells. An increase in the number of cells in the cambium indicated its divisional activity. Expanding cells with thin primary walls between the cambium and a zone of xylem cells with secondary walls were considered to be xylem cells in the stage of post-cambial growth. The initiation of secondary wall thickening was determined by birefringence of the cell walls under polarized light. Blue-stained inner parts of cell walls and the protoplasmic content in the cell lumina indicated incompletely developed xylem cells. Fully matured xylem cells had red-stained cell walls and empty lumina. On the phloem side, we observed the timing and formation of early and late phloem sieve tubes and fibres.

At the end of each experiment, we took additional blocks of intact tissue of bark (10 x 10 x 30 mm) from living trees 1.3 m above ground and measured the thickness of dead bark. Moreover, in 2009 we sampled 70 years old Norway spruce trees, with a DBH of about 35 cm, which we used for heating experiments carried out in 2004 and 2005 for our previous studies (Gričar *et al*, 2006, 2007) in order to examine the possible relationship between heating effect on cambial activity and cell differentiation with tree age and thickness of dead bark in various tree species.

3 RESULTS
3. REZULTATI

3.1 Temperature profiles
3.1. Temperaturni profili

Climate data for the period between 20 March and 20 September 2007 are shown in Fig. 1a. At the beginning of the experiment, at the end of March, minimum air temperatures were above freezing and maximum about 10°C. April and May were dry, with the sum of precipitation less than 40 mm in both months together. In the middle and at the end of May, two short, colder periods were recorded, when maximum temperatures fell below 20 °C and minimum below 10 °C. June and July were relatively wet (116 and 141 mm, respectively) with maximum temperatures frequently above 30 °C, especially in mid-July. At the end of August, average temperatures slowly started to decrease to about 15 °C and remained unchanged until the treatments ended.

The daily average, maximum and minimum air temperatures and amount of precipitation recorded in the area from 1 February to 30 September 2008 are shown in Fig. 1b. At the beginning of the experiment, at the end of February, minimum air temperatures were above freezing and maximum about 10 °C. Average temperatures in March varied within the usual limits; from 0 to 10 °C. The amount of precipitation in March and April was above the long-term average – 163 and 138 mm, respectively. In April, temperatures gradually increased, with minimum temperatures around 5 °C and maximum often about 20 °C. Maximum temperatures reached 30 °C at the end of May. In mid- June, a short, colder period was recorded, when maximum temperatures fell below 20 °C. Frequent interruptions of warm periods by heavy storms in combination with cold fronts were typical of July and August 2008. Those two months were above average wet, with more than 170 mm/per month of precipitation recorded. The first third of September was warm and sunny, but the rest of the month was cooler and drier than usual.

The climate diagram spanning 1 February to 30 September 2009 is shown in Fig. 1c. We started with the heating experiment in mid-March, when minimum air temperatures were around freezing and maximum about 10-15 °C. March was warm and above-average wet, but precipitation was concentrated mainly in the first and the last weeks of the month. April and May were considerably warmer and sunnier than average. In addition, May was dry, with only 52 mm (48 % of the average amount) of precipitation recorded. June and July were relatively wet months, with 170 mm of precipitation in each month, mainly expressed as showers or storms. In Ljubljana, average temperatures were 3.3 °C in August and 1.9 °C in September higher than long-term average. In addition, only half the amount of precipitation was recorded in the mentioned months (77 mm in August and 64 mm in September).

3.2 Experiments on old *Q. sessiliflora* trees in 2007
3.2. Eksperimenti na starim stablima *Q. sessiliflora* u 2007.

When we started the heating experiment, on 30 March 2007, cell divisions in the cambium of old *Q. sessiliflora* trees had already started. The walls of the cambial cells were very thin and their number had increased up to 10 cell layers. Newly formed xylem cells (early wood vessels and fibres) adjacent to the cambium slowly began to expand. The development of the first early wood vessels progressed very rapidly. We observed some differences between heated and control samples in mid-April. The formation of early

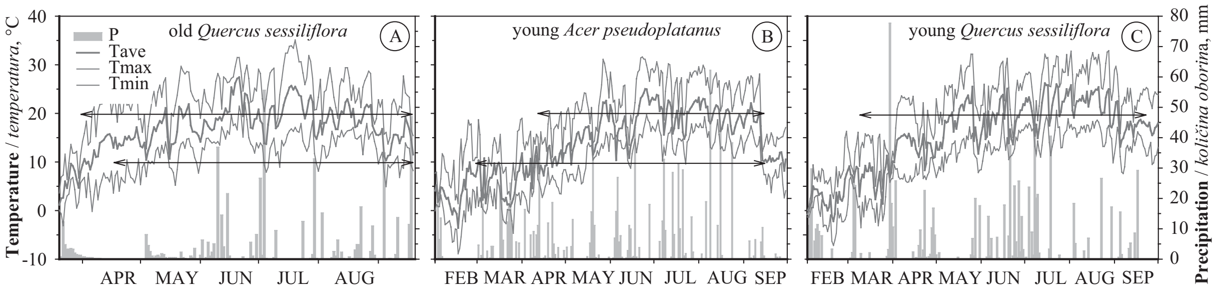

Figure 1 Average, maximum and minimum daily air temperatures and amount of precipitation in Ljubljana (46°03'N, 14°28'E, 323 m a.s.l.) in 2007, 2008 and 2009; during the experiments; the duration of the heating (to 20-22 °C) and cooling (to 9-11 °C) experiments is indicated by horizontal arrows

Slika 1. Prosječne, maksimalne i minimalne dnevne temperature te količina oborina u Ljubljani (46°03'N, 14°28'E, 323 m a.s.l.) u 2007, 2008. i 2009; za vrijeme pokusa; trajanje pokusa grijanja (do 20–22 °C) /hlađenja (do 9–11 °C) naznačeno je strelicama

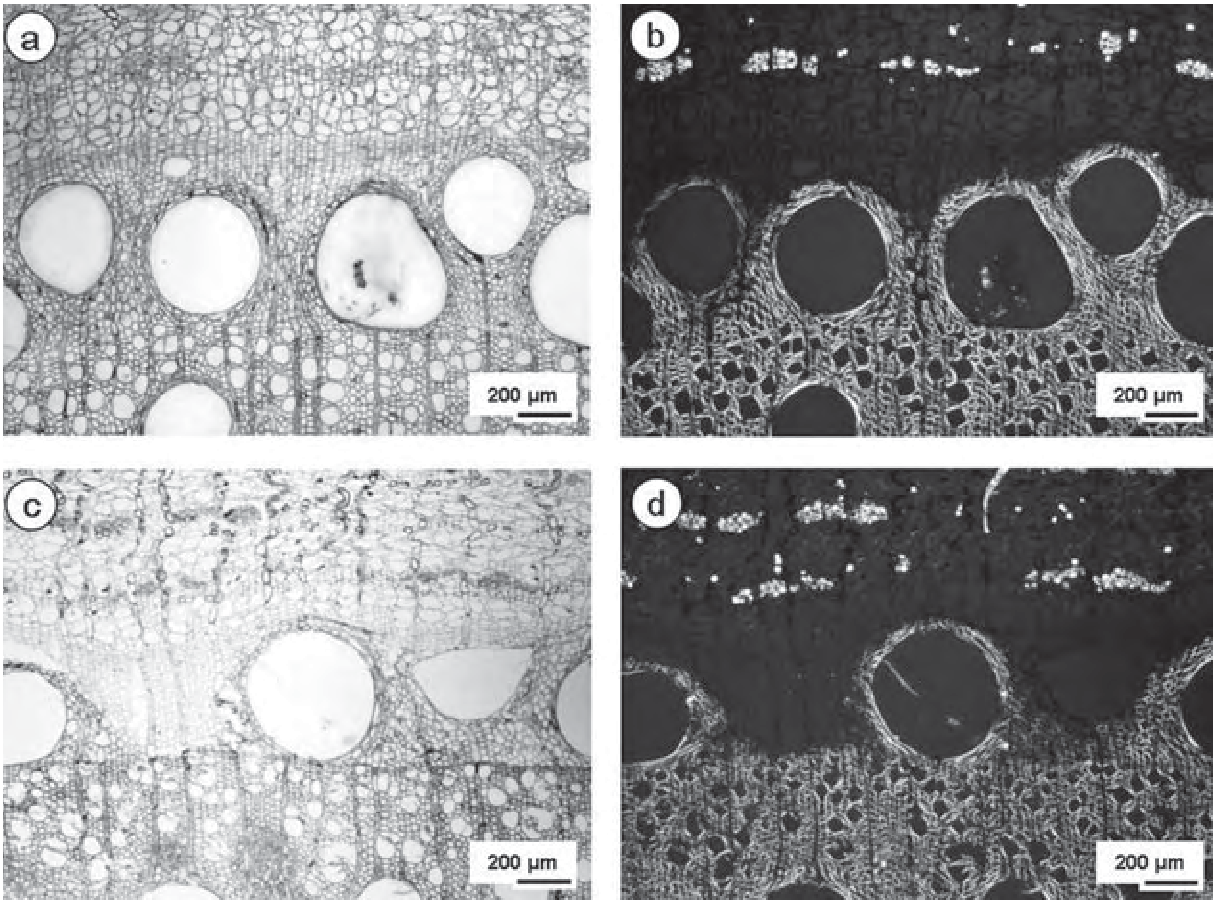

Figure 2 Development of the xylem growth ring in old *Quercus sessiliflora* in the second part of April 2007; more progressive development in the heated sample (a - bright-field and b – polarized light) than in the control sample (c – bright field and d – polarized light)

Slika 2. Razvoj ksilema u starim stablima *Q. sessiliflora* u drugoj polovici travnja 2007; brži razvoj u grijanom uzorku (a – obična svjetlost i b – polarizirana svjetlost) u usporedbi s kontrolom (c –obična svjetlost i d – polarizirana svjetlost)

wood vessels occurred faster in the heated samples, resulting in complete formation of the first ring of vessels at that time. The vessels and neighbouring tissue were almost completely lignified, whereas the walls of the remaining tissue were still being created. This temporal delay between the development of the vessel together with neighbouring tissue and the remaining tissue was detected during the entire growth ring formation period and is consistent with earlier observations of other authors in various hardwood species (e.g. Mellerowicz *et al*, 2001; Grünwald *et al,* 2002; Gričar, 2010). On the other hand, secondary cell walls of early wood vessels and neighbouring tissue in control samples were noticeably less developed, as clearly demonstrated under polarized light (Fig. 2). Moreover, the remaining tissue began to thicken (but not to lignify) only at the growth ring boundary. However, in the further development and dynamics of xylem growth ring formation of 2007, we could not detect any difference between heated and control samples.

We started the cooling experiment in the first week of May, but found no differences in the wood formation pattern among cooled, heated and control samples. The transition from early- to latewood occurred in mid-May and was identified by a decreasing diameter of the vessels, which were no longer arranged in characteristic rings. The rate of radial growth in this period slowed down. Divisions in the cambium ended in mid-August in all of the investigated samples. The number of cambial cells was reduced to 5-6 cell layers wide and the latest formed xylem cells were still developing. The formation of the xylem growth ring of 2007 was finished by the end of September.

On the phloem side, at the beginning of our experiment at the end of March we observed the first layer of expanding sieve tube elements, accompanied by companion cells and axial parenchyma. The effect of elevated and decreased temperature on phloem formation was negligible. Typical phloem fibres that are found in tangentially orientated groups began to form the secondary cell wall in the second part of May in the heated samples, while wall thickening of the fibres in the control and cooled samples was detected a little later; at the beginning of June (Fig. 3). Late phloem formation occurred in the second part of the growing season and ceased in mid-August. With the exception of the delayed development of the phloem fibres, no differences in formation of the phloem growth ring of 2007 were observed among the groups (Fig. 4).

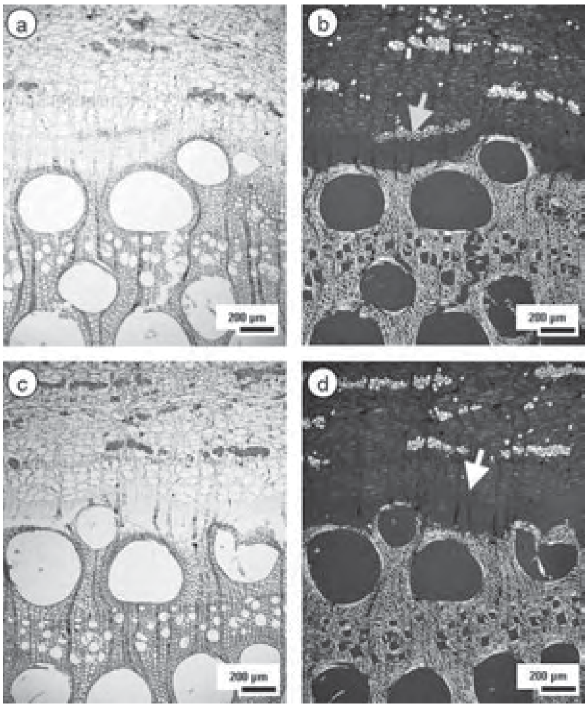

Figure 3 Development of the phloem in old *Quercus sessiliflora* in mid-May 2007; phloem fibres (orange arrow) in the heated trees (a – bright field and b – polarized light), but no fibres (white arrow) in the control trees (c – bright field and d – polarized light)
Slika 3. Razvoj floema u starim stablima (*Quercus sessiliflora*) sredinom svibnja 2007.g.; floemska vlakna (narančaste strelice) u grijanim stablima (a – obična svjetlost i b – polarizirana svjetlost) i nedostatak vlakana (bijele strelice) u kontrolnim i hlađenim stablima (c – obična svjetlost i d – polarizirana svjetlost)

In order to establish possible differences among heated, cooled and control samples, we measured the widths of the xylem and phloem growth rings of 2007 and calculated the ratio between xylem and phloem increments for each tree group (Table 1). Xylem and phloem ring widths differed among sampled trees due to high variability within a single tree and also among trees. The presence of variability in xylem and phloem ring widths is a common characteristic of tree species and was not a result of our experiment (Fig. 4). The trees with wider growth rings in 2007 also had wider xylem increments in 2006 and *vice versa* (heated trees = 1028.5 μm, cooled trees = 1665.25 μm and control trees = 1494.5 μm). The variability in the increment widths was less expressed on the phloem side (Table 1), as already reported in previous studies on sessile oak (Gričar, 2010). Xylem and phloem increments were widest in the cooled samples (on average 1789.15 and 333.05 μm, respectively) and narrowest in the heated samples (1190.10 and 274.74 μm). The anatomical structure of the xylem growth rings in 2007 remained unchanged in the temperature treated stem portions.

Table 1 Widths of xylem and phloem growth rings of 150 years old *Quercus sessiliflora*, and the ratio between phloem and xylem increments in 2007 for each tree group
Tablica 1. Širina ksilema i floema goda 150 godina starog hrasta (*Quercus sessiliflora*) formiranoga u 2007. g. te njihov omjer u svakoj testiranoj skupini drveća

Tree group *Skupina stabla*	**Xylem, μm** *Ksilem, μm*	**Phloem, μm** *Floem, μm*	**Ratio P/X** *Omjer F/K*
Heating *Grijanje*	1109.10	247.75	0.24
Cooling *Hlađenje*	1789.15	333.02	0.22
Control *Kontrola*	1569.54	289.42	0.21

3.3 Experiments on young *A. pseudoplatanus* trees in 2008
3.3. Eksperimenti na mladim stablima *A. pseudoplatanus* u 2008.

At the beginning of the experiment, on 29 February 2008, the dormant cambium was 5-7 cell layers wide in all sycamore maples. Three weeks later (mid-March), the cambium of the control and heated trees was still not active; however, expansion of the initial sieve tubes of early phloem from the overwintered cambial cells had already started (without previous cell

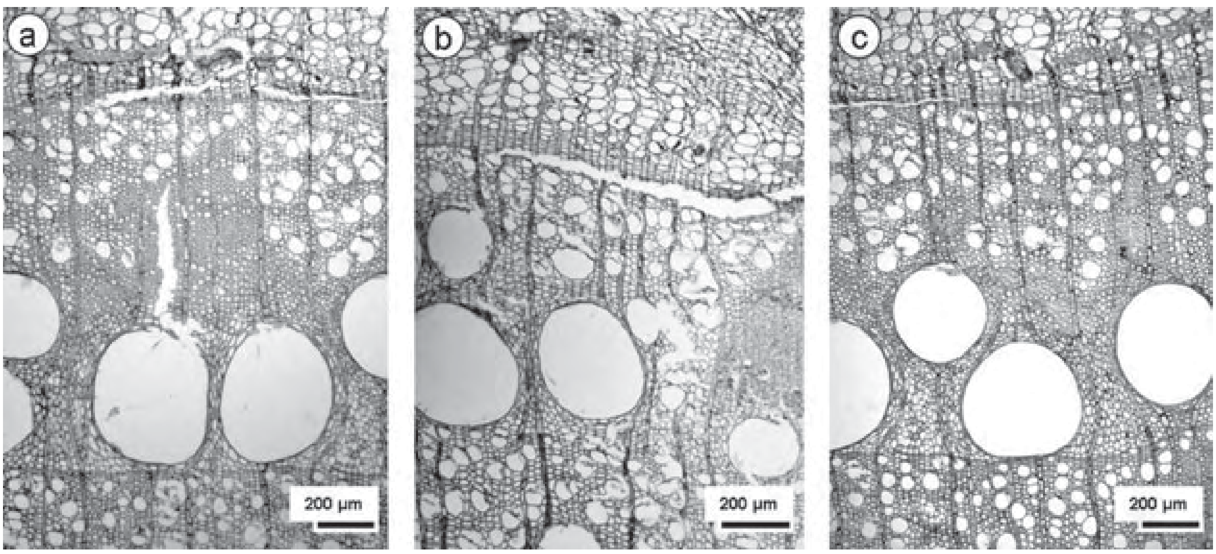

Figure 4 Xylem and phloem growth rings in the heated (a), cooled (b) and control (c) trees in 2007
Slika 4. Godovi ksilema i floema u grijanome (a), hlađenome (b) i kontrolnom (c) stablu u 2007.

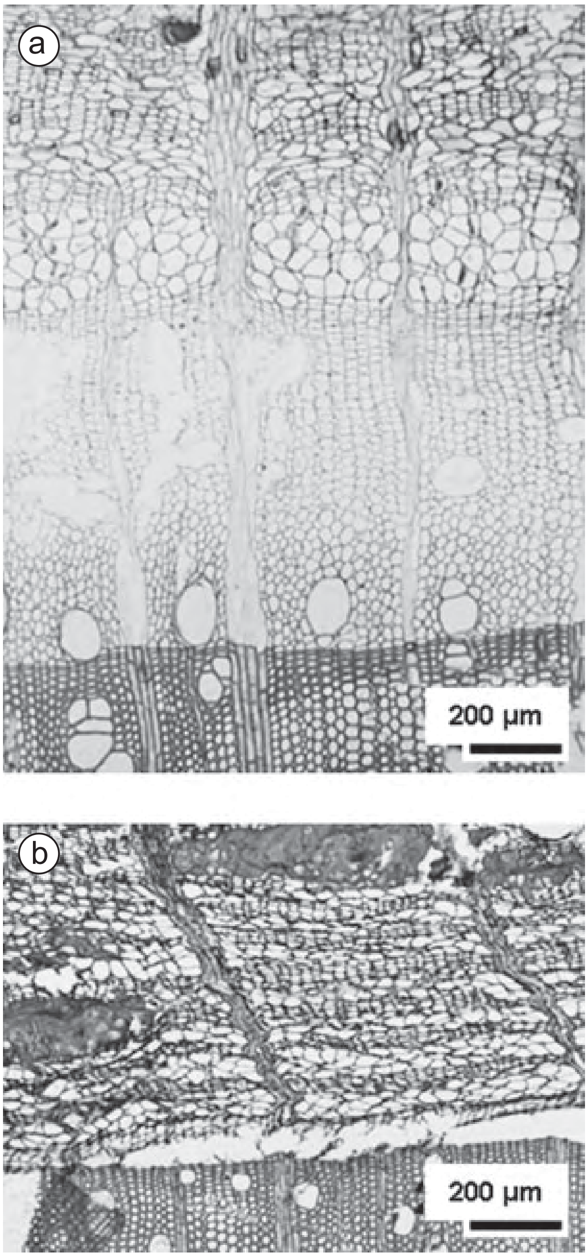

Figure 5 Developing xylem and phloem growth rings of 2008 in control sycamore maples in mid-June (a); dead cambial and living bark tissues in the heated trees (b)
Slika 5. Nastajući godovi ksilema i floema u 2008. u kontrolnom stablu gorskog javora sredinom lipnja (a); mrtvo staničje kambija i žive kore u grijanim stablima (b)

division) in the latter trees. On 10 April, the cambium and living phloem of the heated trees showed the first signs of decaying, as indicated by disintegrated and collapsed living content of cambial cells and phloem ray and axial parenchyma cells. During a 3-week period (i.e., from 19 March to 10 April) the cambium reactivated, since the number of cambial cells increased up to 7-9 layers, but it died before producing new xylem or phloem cells. Cambium of the controls was still inactive at that time. At the end of April, cambial cell division also started in the control samples and we could subsequently follow the development of xylem and phloem growth rings of 2008 (Fig. 5a). In contrast, no new xylem or phloem cells were created in the heated stem portions (Fig. 5b). Inner, living bark of the insulated stem portion started to dry and turn brown, whereas it was still light-green and wet above the insulated stem portion, similarly as in the control trees (Fig. 6b, d). At the end of May, we detected a deterioration of the crown (i.e., leaves were drying and falling off) and the development of epicormic shoots at the base of the heated tree, above and below the insulated stem portion (Fig. 6a, c). In June, July and August, progressive decaying of the crown and formation of epicormic shoots occurred in the heated trees. Desiccation and dying of living tissues spread from the isolated stem portion towards the crown, which was clearly seen at the cellular level in the form of gradual destruction of cambial and phloem tissues in samples taken above the heated regions. The living bark and cambium dried up, so the bark separated from the wood (Fig. 5b). Repeatedly taken samples over the growing season of 2008 showed that the cambium of the heated stem portion did not produce any xylem or phloem cells. Its vitality started to decline rapidly after the applied heat treatment. At the end of our experiment, in mid-September, the crowns of the heated trees were dead and epicormic shoots also started to die. In the spring 2009, these trees were dead and the bark began to fall off, indicating beyond doubt that our treatment terminally damaged the young sycamore maples.

We began the cooling experiments in mid-April and continued until the end of the 2008 growing season. Samples taken at the beginning of May indicated that applied low temperatures slowed down the reacti-

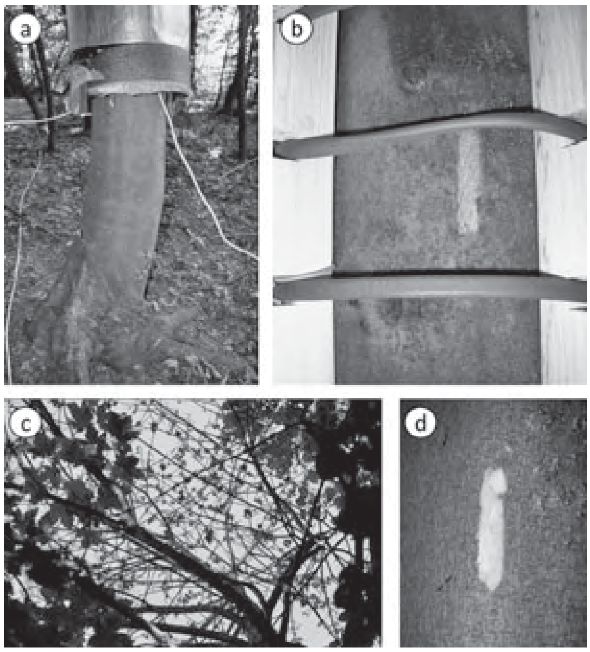

Figure 6 Formation of the first epicormic shoots at the base of the heated sycamore maples at the end of May (a); dark coloured dead living bark two months after the beginning of the heating (b); damaged crown of heated sycamore maples (c); light coloured living bark of the control trees (d)
Slika 6. Stvaranje prvih adventivnih izdanaka u žilištu grijanih stabala gorskog javora potkraj svibnja (a); smeđe obojena umrla živa kora dva mjeseca nakon početka grijanja (b); oštećena krošnja grijanih stabala gorskog javora (c); svjetlozelena živa kora kontrolnih stabala (d)

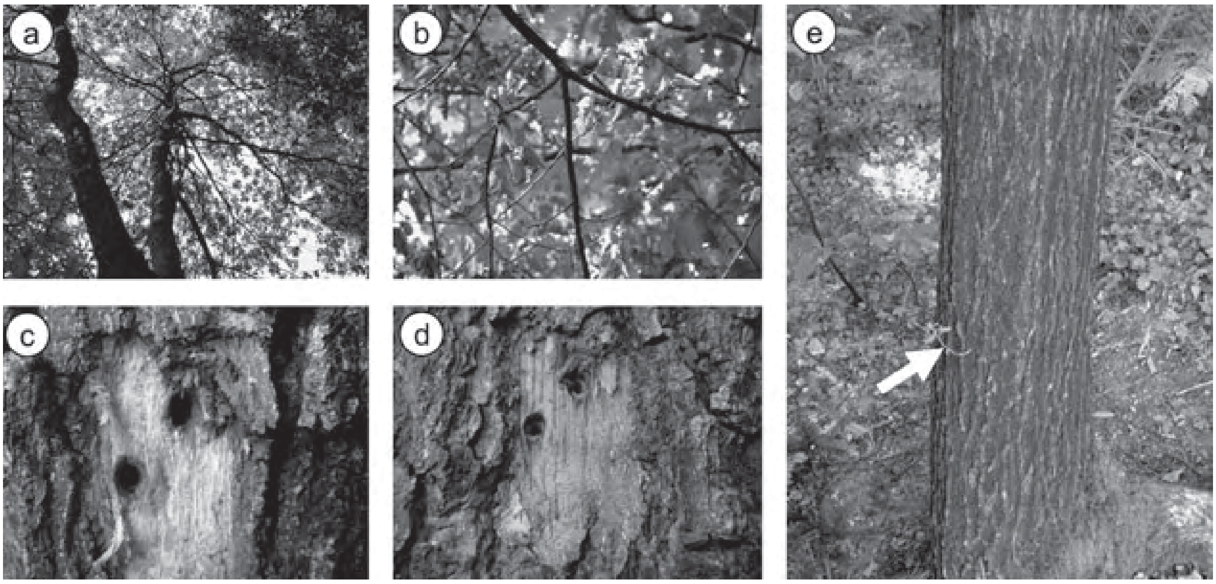

Figure 7 Damaged crown of heated sessile oak at the end of July (a, b); light coloured living bark of the control trees (c) and dark coloured dead living bark of the heated tree (d); formation of the first epicormic shoot (arrow) at the base of the tree (e)
Slika 7. Oštećena krošnja grijanih stabala hrasta kitnjaka potkraj srpnja (a, b); svijetlo obojena živa kora kontrolnih stabala (c) i smeđa umrla živa kora grijanog stabla (d); stvaranje prvih adventivnih izdanaka u žilištu stabla

vation of cambium compared with the controls but no effect of cool treatments was detected in the following months in these samples in terms of a changed dynamics of phloem or xylem development. Differences were noticed in the widths of xylem and phloem increments among the trees and samples taken, and they were attributed to normal variability within and among trees and were not a result of the applied treatment. Cessation of cambial activity occurred at the end of August in the cooled and control samples.

3.4 Experiments on young *Q. sessiliflora* in 2009
3.4. Eksperimenti na mladim stablima *Q. sessiliflora* u 2009.

In view of the different reactions of old sessile oaks and young sycamore maples to the applied treatments, we started to assume that the age of a tree might be one of the reasons for a different response of the cambium to elevated or decreased temperatures. More specifically, the increasing thickness of dead bark with the aging of trees may have contributed to their different response. The onset of dead bark formation (i.e., additional layers of peridermis) is species specific and had not yet started to form in the sycamore maples involved in our study. It is commonly known that the dead part of the bark functions as a very good isolation layer for the sensitive inner, living bark and cambial tissues, thus protecting them from external abiotic and biotic factors (e.g., Nicolai, 1989). In order to confirm our assumptions, we selected young sessile oak trees of similar age as sycamore maples and exposed them to elevated temperatures during the growing season of 2009.

In contrast to the young sycamore maples, the sessile oaks of the same age already had dead bark, but it was relatively thin (up to 0.5 cm). The first signs of decay of the young sessile oaks were visible around 4 months after the applied heat treatment. Apart from a time lag, the process of degradation was similar as in sycamore maples; i.e., the formation of epicormic shoots at the base of the trees, desiccation of the bark in the heated stem portions with its slow spread along the stem and deterioration of the crown (Fig. 7). It is plausible that this relatively thin layer of dead bark was able to provide temporary protection of the living phloem and meristem tissues from steadily elevated temperatures, but only for a short period of time.

3.5 Effect of applied heat treatments on trees of different age
3.5. Utjecaj promjena temperature na stabla različite dobi

The heating experiments that we performed on different tree species revealed that the impact of bark thickness (linked with tree age) on cambium response cannot be neglected (Table 2). Summarizing the results of such experiments, it was shown that the heating effect was most distinctive in young trees (30-year old sessile oak and sycamore maple) without or with a very thin layer of dead bark. In this case, the short-term effect of heating was positive, since it stimulated cambial cell division; however, in the long-term its influence was negative because it caused the death of the trees. In a 70-year old Norway spruce with about 0.5 cm thick dead bark, the cambium response to heat treatment was positive, especially in the first part of the growing season, since elevated temperatures promoted cell division, resulting in wider phloem and xylem increments. Finally, 150-year old sessile oaks with more than 1 cm thick bark showed no response in the phloem or xylem anatomy/width to continuously elevated temperatures.

4 DISCUSSION
4. DISKUSIJA

Our results suggest that the response of cambium to elevated/decreased temperatures in stem portions of

Table 2 Comparison of the heating effect on cambial activity and cell differentiation in stem portions of different tree species of different age and dead bark thickness
Tablica 2. Usporedba učinka grijanja na aktivnost kambija i diferencijaciju stanica u dijelovima debala drveća različite vrste i starosti te s različito debelom mrtvom korom

Tree species *Vrsta drveta*	**Age of the tree, years** *Starost drveća, godine*	**DBH, cm** *Promjer na prsnoj visini, cm*	**Thickness of dead bark, cm** *Debljina mrtve kore, cm*	**Effect of heating** *Učinak grijanja*
Sessile oak *hrast kitnjak*	150	70	> 1	No *nema ga*
Norway spruce *obična smreka*	70	35	0.5	In xylem and phloem *u drvu i liku*
Sessile oak *hrast kitnjak*	30	15	< 0.5	Death after 4 months *smrt nakon 4 mjeseca*
Sycamore maple *gorski javor*	30	15	0	Death after 2 months *smrt nakon 2 mjeseca*

different tree species depends not only on the age of the tree (in terms of dead bark thickness) but also on the duration of the applied treatments. The short-term effect (1-2 months) of heating juvenile trees with thin or no dead bark stimulated cell division in the cambium and cell differentiation, while long-term treatments led to the death of the tree. On the other hand, old trees with thick dead bark responded to the heat treatments only at the beginning of the growing season, as seen by a slightly faster cell wall formation and lignification of the initial xylem cells in old sessile oaks; no (devastating) effects were detected in the long-term. Cessation of cambial activity was not prolonged and also the structure and widths of xylem and phloem increments remained unchanged.

Our observations are in contrast with previous findings of similar experiments with elevated temperature carried out by other scientists on different tree species (*Abies sachalinensis*, *Larix leptolepis, Cryptomeria japonica*, *Populus sieboldii* x *P. grandidentata*) (e.g., Oribe and Kubo, 1997; Oribe *et al*, 2001, 2003; Begum *et al,* 2007, 2010). However, in their cases the selected trees were either relatively young (12-40 years old) or they were exposed to elevated temperatures only for a short period of time (i.e., one month). In addition, experiments were mainly performed during the dormant period. In the listed tree species, the application of heat stimulated cell division in the cambium and cell differentiation. Cambial cells of evergreen conifers (*Abies sachalinensis*, *Cryptomeria japonica*, *Picea abies* and *Picea sitchensis*) at the quiescent stage of cambial dormancy, which is imposed by external factors, can re-initiate cell division independently of the growth of new shoots and the development of buds in spring (Oribe and Kubo, 1997; Oribe *et al,* 2001, 2003; Gričar *et al,* 2006). On the other hand, heating did not stimulate cell division in cambium before regular cambial activity in the deciduous *Larix leptolepis*, which appeared only after the activation of buds (Oribe *et al,* 2001). Cambial reactivation in *Populus sieboldii* x *P. grandidentata* occurred before bud burst, indicating their independence of each other (Begum *et al,* 2007). Begum *et al* (2010) reported that cambial sensitivity from late winter to early spring under natural conditions and in locally heated stems of *Cryptomeria japonica* might depend both on cambial age and the stage of cambial dormancy. Cambial reactivation was induced earlier and xylem differentiation started sooner in 55-year old cambium at breast height than 80-year old cambium at the same height under natural conditions (Begum *et al*, 2010).

The first long-term experiments with elevated and decreased temperature were carried out on Norway spruces, aged around 70 years and with a dead bark thickness of about 0.5 cm (Gričar *et al*, 2007). The response of the cambium to heat treatment was positive, especially in the first part of the growing season, since elevated temperatures promoted cell division and differentiation, resulting in wider phloem and xylem increments. Cooling treatments, on the other hand, slowed down and shortened cell production and differentiation periods, so xylem and phloem rings were reduced by about one third. The experiment indicated that temperatures have greater impact on cambial cell production at the very beginning of the growing season, whereas other factors prevail in the period of late wood formation (Gričar *et al*, 2007).

Based on the latest results, we presume that the dead part of the bark might function as a very good isolation layer for sensitive inner, living bark and cambial tissues, thus protecting them from external abiotic and biotic factors. Bark thickness varies greatly not only with age, but also in different species; with oaks, periderms are formed quickly, one after another, forming dead bark together with dead, older and collapsed secondary phloem. We suspect that experimentally elevated temperatures did not influence cambial activity in old sessile oaks merely due to the fact that they had very thick bark, which prevented the temperatures from reaching the cambium. That would also explain the absence of changes in the dynamics of cambial activity and cell differentiation. With young sessile oaks and sycamore maples, the effect was the reverse, since the experimental trees were young with very thin or no dead bark, so the heating of the living part of the bark and cambium tissues was very intense. It seems that long-term heating was fatal for these trees, since they started to die a few months after exposure to elevated temperatures.

Deterioration of the crown resulted in the formation of epicormic shoots at the base of the sycamore maples and sessile oaks. Epicormic shoots arise from latent buds on the stem of a tree that are stimulated in the case of stress, such as sudden environmental change, crown dieback, thinning, heavy pruning, root death, cold and change in the water table (e.g., Fontaine *et al,* 1998). In addition to genetic determinism in some tree species, their appearance is also linked to abrupt changes in a tree environment (Nicolini *et al,* 2001). Supressed or moribund trees with low cambial activity often produce numerous epicormic branches on the base of the stem in order to form a new crown to replace the old, ineffective and dying one. However, secondary growth does not resume until epicormic branch formation slows down or stops, several years after the first epicormic branches are formed, suggesting that other conditions have to be fulfilled before cambial growth can resume. Assimilates produced by the first epicormic branches may initially be used to ensure their perenniality and enable the formation of new branches, but probably also to resume growth of the root system, which may also show reduced development (Nicolini *et al,* 2001).

When cambium necrosis occurs around the entire stem circumference (girdling), the stem will be unable to regenerate phloem and xylem in that area. When a tree is girdled by fire, cambium necrosis is always accompanied by phloem necrosis because phloem is external to the cambium. The crown of a girdled tree will continue to fix carbon and grow, but with a phloem girdle photosynthates will not be transported to the roots. The root system must rely on carbohydrate reserves; these reserves will eventually be depleted, fine-root production will cease and the tree will die from water stress. Reductions in leaf area and fine-root area will also affect tree carbon and water budgets (Michaletz and Johnson, 2007).

Research results support the theory of older trees with a thicker bark being more resistant to fires (e.g., Michaletz and Johnson, 2007). Tree bark structure also has an important ecological function; trees growing in open canopy in arid ecosystems often have richly structured, thick bark because of a higher risk of sun burn due to solar radiation reaching the trunks (Nicolai, 1989).

The timing of cambial reactivation plays an important role in determination of the amount and quality of wood and environmental adaptivity of trees. The response of cambium and wood formation processes to experimental heating or cooling depends on the tree species (e.g., Oribe *et al*, 2003; Begum *et al*, 2007). Temperature treatments have shown a different effect on cambial activity and cell differentiation in evergreen and deciduous conifers and angiosperms, although tree age in combination with bark thickness appears to influence the extent of this effect. In addition, the duration of the applied treatments also has an impact on long-term cambial response. Our findings show that factors affecting cambial activity are numerous and interact in a complex way, which needs to be taken into consideration in order to understand cambial response to applied heat/cool treatments. However, further investigations on the same species with trees of different age need to be carried out in order to confirm our speculations. Finally, our findings are also important in the context of a potential response of trees to a changing climate; especially to the rise in summer temperatures.

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Thermally Compressed Poplar Wood (TCW): Physical and Mechanical Properties

Toplinski prešano drvo topole (TCW): fizikalna i mehanička svojstva

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ABSTRACT • *Various thermal modification techniques are used to improve some properties of wood materials. Thermally compressed wood (TCW) is obtained by using a hot-press. This study investigates the effect of thermal compression on the density, vertical density profile (VDP), moisture content (MC), thickness swelling (TS), Janka hardness, and drying characteristics of the poplar wood boards. The experimental boards were cut from poplar wood (Populus spp). The boards with dimensions of 100 mm by 500 mm by 25 mm were thermally compressed at press temperature of either 150 °C or 170 °C, press pressure of either 1 or 2 MPa for 45 minutes in a hot-press. A total of 10 experimental boards were prepared - two boards for each group plus two for control. The results obtained in this study indicated that the density and Janka hardness values increased with the increase of the press pressure. The thermal compression process decreased the thickness of the boards. The thickness reduction increased with the increase of the press pressure. An improvement was not seen in the TS values of the samples when compared to those of the untreated samples. This study revealed that the thermal compression technique should be used to improve some properties of poplar wood. In this way better use could be made of low-cost poplar wood.*

Keywords: *Thermally compressed wood (TCW), hardness, vertical density profile, density, poplar wood (Populus spp)*

SAŽETAK • *Kako bi se poboljšala neka svojstva drva, primjenjuju se različite tehnike toplinske modifikacije. Toplinski prešano drvo (TCW) dobije se uz pomoć vruće preše. U radu se prikazuje istraživanje učinka toplinske kompresije na gustoću drva, vertikalni profil gustoće (VDP), sadržaj vode (MC), bubrenje (TS) i tvrdoću prema Janki, kao i obilježja sušenja topolova drva. Uzorci za istraživanja izrađeni su od drva topole (Populus spp.). Ploče dimenzija 100 mm x 500 mm x 25 mm toplinski su prešane pri temperaturi 150 i 170 °C te pri tlaku 1 i 2 MPa tijekom 45 minuta u vrućoj preši. Uz jednake uvjete prešane su po dvije ploče, što s dvije kontrolne ploče ukupno iznosi deset uzoraka. Rezultati istraživanja pokazali su da se gustoća i tvrdoća prema Janki povećavaju s povećanjem tlaka prešanja. Toplinskim se prešanjem smanjuje debljina ploča. Smanjenje debljine povećava se s povećanjem tlaka prešanja. Nije ustanovljeno smanjenje bubrenja toplinski prešanih ploča u odnosu prema kontrolnim uzorcima. Istraživanja su pokazala da se toplinskim prešanjem mogu poboljšati samo neka svojstva topolova drva. Na taj bi se način moglo bolje iskoristiti relativno jeftino drvo topolovih šuma.*

Ključne riječi: *toplinski prešano drvo (TCW), tvrdoća, vertikalni profil gustoća, gustoća, topolovo drvo (Populus spp.)*

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1 INTRODUCTION
1. UVOD

Poplar wood (*Populus* spp) is one of the fast growing tree species in Turkey. It has some advantages such as wide availability, fast growing rate, and low cost. However, it also has some undesired properties such as low surface hardness because of its low density, low dimensional stability, and some drying problems.

It is known that thermal modification could improve dimensional stability, equilibrium moisture content, permeability, surface quality, and durability of wood materials (Burmester, 1973; Giebeler, 1983; Korkut and Kocaefe, 2009). There are various thermal treatment methods in Europe. This technology is registered in many European countries: France (Perdure, New Option wood, retifraction), Finland (Thermowood), Netherlands (Plato, Lignius, Lambowood), Danmark (Wood Treatment Technology - WTT)), Austria (Huber Holz), Germany (Menz Holz), Russia (Barkett), and Netherlands (Plato, Lignius, Lambowood) (Tjeerdsma, 2006). The main differences between the processes are to be seen in the process conditions, process steps, oxygen or nitrogen, steaming, wet or dry process, use of oils, steering schedules, etc. (Militz, 2002).

Thermally modified wood materials could be considered as an ecological alternative to impregnated wood material. It could also be used in the landscape architectural application, production of kitchen and outdoor furniture, sauna elements, building elements, flooring materials, ceilings, inner and outer bricks, door-window joinery, sun blinds, and noise barriers (Sevim Korkut *et al*., 2008; Korkut and Kocaefe, 2009).

The purpose of combining compression and temperature application on wood is to improve its physical and mechanical properties. Compressed wood is known as Staypak (Seborg *et al*., 1945; Stamm *et al*., 1964) while compressed wood with phenol formaldehyde (PF) resin pretreatment is called Compreg (Stamm, 1964; Stamm and Haris, 1953). Further studies were done by Tarkow and Seborg (1968) who investigated the surface densification of wood.

Compression in wood is generally considered to be analogous to hot pressing of wood composites, except that it takes longer to obtain solid wood compression without the bonding effect of resins. Wang and Cooper (2004) studied the effects of grain orientation and surface plasticizing methods on the VDPs of compressed balsam fir and spruce. In another study, Wand and Cooper (2005) studied the effects of hot press closing rate, wood initial moisture content, and sample size on the VDPs of thermally compressed fir wood. Density distribution through the thickness of wood composites, such as fiberboard and oriented strandboard, traditionally exhibits higher surface density and lower core density. Density gradient is affected by the combined influence of pressure, MC, temperature, resin curing, and other factors during pressing and it affects physical and mechanical properties of wood composites (Strickler, 1959; Kamke and Casey, 1988; Wang and Winistorfer, 2000; Candan, 2007). Due to differences in material properties and hot pressing parameters compared to wood composite production, densified wood boards could show a different density profile. Thermal compression process might affect drying characteristics, dimensional stability, density, Janka hardness, and surface quality.

Physical, mechanical, anatomical, durability, and surface properties of TCW have been studied in previous works by Wang *et al*. (2000), Wang and Cooper (2004), Wang and Cooper (2005), Unsal and Candan (2007), Unsal *et al*. (2008), Unsal and Candan (2008), Unsal *et al*. (2009), Candan *et al*. (2010), Dogu *et al*. (2010), Abraham *et al*. (2010), Unsal *et al*. (2011a), Unsal *et al*. (2011b), Candan *et al*. (2013).

The influence of press pressure and temperature on the vertical density profile, Janka hardness, and MC of pine wood was studied by Unsal and Candan (2008). It was stated that the final MC reduced while the density and Janka hardness increased. Unsal *et al*. (2009) performed thermal compression of pine wood boards. It was reported that the thickness swelling values of the boards improved except for the boards pressed at 7 MPa and 150 °C.

This study investigated Janka hardness, final MC, density, VDP, and thickness swelling properties of the poplar wood boards affected by thermal modification.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Poplar (*Populus* spp) wood was used in this study. Experimental wood boards with dimensions of 100 mm by 500 mm by 25 mm were cut from the logs.

The boards were compressed at a press temperature of either 150 °C or 170 °C, and press pressure of either 1 or 2 MPa for 45 minutes by using a laboratory type hot press. A total of ten experimental boards were prepared - two boards for each group plus two boards for the untreated group. The boards (A) were compressed at a press temperature of 150 °C, and press pressure of 1 MPa for 45 minutes. The boards (B) were compressed at a press temperature of 150 °C, and press pressure of 2 MPa for 45 minutes. The boards (C) were compressed at a press temperature of 170 °C, and press pressure of 1 MPa for 45 minutes. The boards (D) were compressed at a press temperature of 170 °C, and press pressure of 2 MPa for 45 minutes.

2.2 Method
2.2. Metoda

Larger specimens (100 mm″tangential by 500 mm longitudinal by final board thickness) were cut into 50 mm by 50 mm to perform tests. In this study, density and thickness swelling was performed according to international standards. VDPs were measured with an X–ray density profiler (GreCon Measurement Systems, Germany) at Kastamonu Integrated Inc. Test Laboratory located in Kocaeli, Turkey. Peak density (PD) and core density (CD) values were generated

Table 1 Thickness swelling and water absorption values of TCW boards
Tablica 1. Rezultati mjerenja debljinskog bubrenja i upijanja vode uzoraka toplinski prešanog drva

Panel groups *Skupina uzoraka*	**Thickness swelling (TS), %** *Debljinsko bubrenje, %*	**Duncan's grouping** *Grupiranje prema Duncanu*	**Water absorption (WA), %** *Upijanje vode (WA), %*	**Duncan's grouping** *Grupiranje prema Duncanu*
Control / *kontrolna*	1.750 (0.664)	e	35.162 (3.366)	e
A (150 °C + 1 MPa)	2.334 (0.867)	de	42.182 (7.333)	acde
B (150 °C + 2 MPa)	5.991 (1.207)	acde	38.247 (2.293)	c
C (170 °C + 1 MPa)	2.380 (0.395)	ce	40.362 (2.806)	be
D (170 °C + 2 MPa)	5.632 (1.228)	bcde	37.235 (6.462)	d

* Values in parentheses are standard deviation / *vrijednosti u zagradama standardne su devijacije*.

from the VDP graphs. PD indicates the mean value of the highest densities measured within each half of the density profile, while core density indicates the average density of the central region of the panel (Candan, 2007). Janka hardness test was performed according to ASTM D1037 (1999) standard using a universal test machine and its results were expressed in newtons. Before the thermal modification process, the initial MC values of the samples were measured to determine the drying behavior of the poplar boards. For this aim, TS 2471 (1976) was used. After the thermal modification, the average final MC values were also determined. To evaluate the results of the boards modified with hot-press, all multiple comparisons were first tested using an analysis of variance (one-way ANOVA) at $p < 0.05$. Significant differences between the mean values of thermally modified groups and the control group were determined using Duncan's multiple range test.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Thickness swelling and water absorption
3.1. Bubrenje i upijanje vode

Among the modification groups, the poplar boards pressed at 1 MPa had the lowest thickness swelling values after being soaked in water for 24 hours. The boards pressed at 2 MPa and at the temperature of 150 °C showed the highest thickness swelling values (Table 1).

All thermally compressed poplar boards showed higher thickness swelling values than the control boards. This result might be explained by springback behavior of wood due to the densification during hot-pressing. The thickness swelling values of the treated boards increased with the increase of press pressure. According to Abraham *et al*. (2010) the higher densification ratio resulted in higher springback, due to the memory effect of wood. The springback phenomenon is greatly controlled by the press pressure level. Higher press pressure level may cause greater springback. On the other hand, higher temperature resulted in higher permanent deformation. Improvement in TS with the increase of press temperature could be explained by changes in chemical composition of wood. Unsal *et al*. (2009) obtained similar results for pine wood to the results of this study. It was also stated that the thickness swelling values of the TCW significantly increased with the increase of press pressure.

The water absorption (WA) values of the unmodified poplar wood boards, after being soaked in water for 24 hours, were lower than those of the modified poplar wood boards. Among the modified groups, it was determined that the boards modified with press pressure of 1 MPa at 150 °C had the highest WA values, while the boards modified with press pressure of 2 MPa at 170 °C had the lowest values. The findings obtained from the WA tests show that the thermal compression procedure had a negative effect on WA properties. On the other hand, the WA values decreased as the press pressure or temperature increased.

3.2 Moisture reduction during thermal compression
3.2. Smanjenje sadržaja vode tijekom vrućeg prešanja

The initial MC values of the samples were around 15%. All TCW groups had lower MC values than those of the untreated group. The TCW modified with 2 MPa at 170 °C had the lowest MC values (Table 2).

According to the present study, it could be stated that the drying effect of thermal modification is remarkable. The results obtained in this study were in accordance with a previous study by Unsal and Candan (2008). They applied thermal compression technique on pine wood boards. It was reported that the thermal compression process had a significant effect on drying properties of wood boards. Esteves *et al*. (2007) used a steam heating process on eucalyptus wood and found that the equilibrium MC decreased by 61 % while the dimensional stability increased.

Table 2 MC values of Poplar TCW
Tablica 2. Sadržaj vode toplinski prešanoga topolova drva

Panel groups *Skupine uzoraka*	**MC values** *Sadržaj vode, %*	**Duncan's grouping** *Grupiranje prema Duncanu*
Control/ *kontrola*	14.93 (0.505)	abcde
A	10.67 (0.244	bcde
B	10.10 (0.079)	d
C	10.27 (0.166)	ce
D	9.97 (0.120)	e

* Values in parentheses are standard deviation / *vrijednosti u zagradama standardne su devijacije*.

Table 3 Mean density values of Poplar TCW
Tablica 3. Prosječna gustoća toplinski prešanoga topolova drva

Panel groups *Skupine uzoraka*	**Density values** *Gustoća* g/cm^3	**Duncan's grouping** *Grupiranje prema Duncanu*
Control / *kontrolna*	0.387 (0.027)	c
A	0.366 (0.034)	e
B	0.417 (0.013)	bcde
C	0.368 (0.032)	d
D	0.455 (0.054)	abcde

* Values in parentheses are standard deviation / *vrijednosti u zagradama standardne su devijacije*.

Table 4 Janka Hardness of Poplar TCW
Tablica 4. Tvrdoća prema Janki toplinski prešanoga topolova drva

Panel groups *Skupine uzoraka*	**Janka hardness, N** *Tvrdoća prema Janki,* N	**Duncan's grouping** *Grupiranje prema Duncanu*
Control *kontrolna*	1563.86 (181.71)	e
A	1814.72 (316.36)	c
B	2063.02 (359.02)	ae
C	1804.52 (347.84)	d
D	2041.45 (375.59)	be

* Values in parentheses are standard deviation/ *vrijednosti u zagradama standardne su devijacije*.

3.3. Vertical density profile (VDP) and mean density
3.3. Vertikalni profil gustoće (VDP) i prosječna gustoća

The results obtained in this study showed that the mean density values were affected by the thermal compression. No significant difference was observed between the density values of the TCWs modified with 1 MPa and the untreated wood boards. When the press pressure was increased from 1 MPa to 2 MPa, the density values increased from 0.37 to 0.45 g/cm^3. The TCW modified with 2 MPa at 170 °C had the highest density values (Table 3).

Peak density (PD) and core density (CD) values as vertical density profile (VDP) characteristics of the TCWs were affected by the modification. The control group had a PD value of 403 kg/m^3 and a CD value of 368 kg/m^3. The TCW modified with 2 MPa had the highest PD and CD values. It was concluded that the modification increased the PD and CD values of poplar wood. Similar results were determined by Unsal and Candan (2008). It was reported that the PD values of the pine wood boards increased with the increase of press pressure. Unsal *et al*. (2011b) examined the effect of the thermal modification on overall density or VDP properties of the Eucalyptus wood boards. They established that the control group had the lowest PD value, while the boards modified at 150 °C and pressure of 60 bar had the highest value. It was also reported that the mean density and PD values of the boards increased as the hot-press pressure increased.

3.4 Janka hardness
3.4. Tvrdoće prema Janki

The Janka hardness values evaluated for the control and the modified poplar boards are shown in Table 4.

The unmodified group had the lowest Janka hardness value (1563.86 N), while the group B had the highest value (2063.02 N). When the press pressure was increased from 1 MPa to 2 MPa at 150 °C, the hardness value increased from 1814.72 to 2063.02 N. Similarly, when the pressure was increased from 1 MPa to 2 MPa, the hardness value of the boards pressed at 170 °C increased from 1804.52 to 2041.45 N. By using maximum pressure, hardness increased by approximately 32 % as compared to the unmodified board. The improvement in the Janka hardness values could be attributed to an increase in density values. The hardness values of the TCW groups were higher than those of the untreated group. The results obtained in this study revealed that the hardness of the poplar boards was improved by the thermal compression. The hot-press temperature had no significant impact on the hardness values of the boards in the applied range. According to the study of Abraham et al. (2010), an elevated temperature (200 °C) resulted in significantly higher Brinell-Mörath hardness values. The results of a previous study by Unsal and Candan (2008) were similar to the results of the present study. It was reported that the hardness values improved as the press pressure increased.

4 CONCLUSIONS
4. ZAKLJUČCI

The thermal modification process could not generate an improvement in the thickness swelling property of the boards. The density values of the boards increased as the press pressure increased. It was concluded that the VDP of the poplar boards was closely related with the press pressure. Increasing of the press pressure resulted in an enhanced peak density and mean density values, which are the defining factors of VDP.

The results obtained in this study revealed that the Janka hardness values of the poplar wood boards were improved with the increase of the press pressure. The surface hardness values were positively affected by the densification that occurred on the surface layers of the poplar wood boards. The boards pressed at press pressure of 2 MPa and press temperature of 150 °C had the highest hardness values.

It could also be concluded that surface hardness of wood materials from fast growing and low-value species could be improved by the thermal compression process. Thus, value added wood products could be produced with a wider range of use.

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Natural Durability of Timber Exposed Above Ground – a Survey

Prirodna trajnost drva izloženoga iznad zemlje – pregled istraživanja

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ABSTRACT • *Besides its inherent resistance against degrading organisms, the durability of timber is influenced by design details and climatic conditions, making it difficult to treat wood durability as an absolute value. Durability classification is, therefore, based on comparing performance indicators between the timber in question and a reference timber. These relative values are grouped and related to durability classes, which can refer to a high range of service-lives. The insufficient comparability of such durability records has turned out to be a key challenge for service-life prediction.*

This paper reviewed literature data, based on service-life measures, not masked by a durability classification. It focused on natural durability of timber tested in the field above-ground. Additionally, results from ongoing above-ground durability studies in Europe and Australia are presented and have been used for further analysis. In total, 163 durability recordings from 31 different test sites worldwide based on ten different test methods have been considered for calculation of resistance factors. The datasets were heterogeneous in quality and quantity; the resulting resistance factors suffered from high variation. In conclusion, an open platform for scientific exchange is needed to increase the amount of available service-life related data.

Keywords: *durability classes, field tests, resistance factor, service life prediction, test methodology, use class 3*

SAŽETAK • *Osim otpornosti drva prema štetnim organizmima, na prirodnu trajnost drva utječe i dizajn detalja na proizvodima od drva te klimatski uvjeti, pa je teško razmatrati svojstvo trajnosti drva kao apsolutnu vrijednost. Stoga je klasifikacija trajnosti drva utemeljena na usporedbi pokazatelja izgleda drva, čija se trajnost određuje prema izgledu referentne drvne građe. Te su relativne vrijednosti grupirane i povezane s klasama trajnosti, što se može odnositi na veliki raspon životnog vijeka drvnih proizvoda. Nedovoljna usporedivost takvih zapisa trajnosti pokazala se kao ključni izazov za predviđanje životnog vijeka drvnih proizvoda.*

U radu se daje pregled literaturnih podataka utemeljenih na životnom vijeku drvnih proizvoda koji nisu maskirani klasifikacijom trajnosti. Naglasak je na prirodnoj trajnosti drva ispitanoj pri izloženosti drva iznad zemlje. Osim toga, prezentirani su rezultati aktualnih istraživanja prirodne trajnosti drva iznad zemlje u Europi i Australiji te su

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iskorišteni za daljnju analizu. U obzir za izračun faktora otpornosti uzeta su ukupno 163 podatka o trajnosti drva dobivena s 31 različitoga ispitnog mjesta u svijetu na temelju deset različitih metoda ispitivanja uzeti . Skupovi podataka su heterogeni s obzirom na kvalitetu i količinu, što je rezultiralo velikom varijacijom čimbenika otpornosti. Zaključno, potrebna je otvorena platforma za znanstvene razmjene kako bi se povećala količina dostupnih podataka o životnom vijeku proizvoda.

Ključne riječi: *klase trajnosti, terenska ispitivanja, faktor otpornosti, predviđanje životnog vijeka, metodologija ispitivanja, uporabna klasa 3*

1 INTRODUCTION
1. UVOD

The natural durability of timber products is influenced by the interaction of wood properties, environmental conditions and structural design. Wood anatomy and the presence of natural protective chemicals (extractives) provide resistance against biodeterioration by microorganisms and insects. Communities of wood-destroying organisms vary between different locations, and their activity is influenced by climatic factors. Fungal decay and termite attack, for example, are generally more severe in warm and humid environs (Scheffer, 1971; Brischke, 2007; MacKenzie *et al.,* 2007; Thelandersson *et al.,* 2011). The extent to which timber components are affected by biodeterioration and weathering is also mediated by the design and maintenance of timber structures; for instance, the position of different structural elements and use of surface coatings alter their rates of wetting and drying, while untreated joinery and cracks in poorly maintained timber coatings may trap water and thus support decay (Norton and Francis, 2008).

Worldwide building codes and standards have traditionally provided natural durability information in a prescriptive context. Timber species are generally categorized into heartwood durability classes and the allowable uses of timbers belonging to those durability classes are prescribed (Stirling, 2009). Criteria for natural durability classification differ between countries and include combinations of field test data, laboratory test data, history of performance and expert experience (CEN, 1994; CEN, 2006; Standards Australia, 2008).

Many different field and laboratory tests are used to measure natural durability. These include standardized and non-standardized methods, among which test environments, configurations and evaluation methods vary widely (Gobakken and Viitanen, 2004; Råberg *et al.;* 2005; Stirling, 2009; Fredriksson, 2010). Tests that present a high biodeterioration hazard often involve soil contact or inoculation with microorganisms or insects. Above ground field tests generally pose a lower biodeterioration hazard, but most test configurations are designed to accelerate decay by various moisture trapping elements. Durability evaluation procedures for field tests commonly involve objective or subjective measures of strength loss, while mass loss is commonly measured for laboratory tests. Traditionally, field test results are reported in a variety of ways, including mean or median measures of specimen service life or arbitrary scores that represent levels of biodeterioration. The performance of test species is commonly compared with the ones of non-durable reference species such as the sapwood of Scots pine (*Pinus sylvestris* L.) or southern yellow pine (*Pinus* spp.) for softwoods and common beech (*Fagus sylvatica* L.) wood for hardwoods. Beyond the relative performance of specimens in the circumstances of each test, however, the practical implications of durability test data are only beginning to be explored. Willeitner and Peek (1997) highlighted that comparing different durability tests is difficult, as in addition to the heterogeneity of test methodology, one may face results that are mostly codified - sometimes in a cryptic way - or even incompletely published.

A major challenge remains to extract information from durability tests to help quantify the key factors that affect natural durability and integrate this information so that it is useful for predicting the service life of timber building products. Modern performance-based construction criteria require building products to be characterized in terms of the reliability that they will perform as expected over time. For timber, the current level of understanding of durability is far less developed than for other properties such as structural and fire safety performance, and continued research is required to develop robust service life models (Foliente, 2000). Reliable service life data are also of crucial importance for Life Cycle Assessment (LCA) studies that are used to compare the environmental impacts of wood competing building materials.

Timber performance models have been developed that incorporate climate, durability classification and design factors (Wang *et al.,* 2008b; Viitanen *et al.,* 2010; Brischke and Frühwald Hansson, 2011; Thelandersson *et al.,* 2011), however more data are sought for calibration and fine tuning. As an alternative to using durability class categories to represent wood properties in design guides (MacKenzie *et al.,* 2007), the use of a resistance index and resistance classes has been proposed (Thelandersson *et al.,* 2011). Incorporation of ‘durability factors’ into a factor method has also been suggested (Dickinson, 2005; ISO 15 686-1, 2000).

Despite the importance of above ground structures in timber engineering, reports of natural durability studies involving above-ground exposures are relatively rare. Numerous laboratory decay tests have been reported, but their relationship with timber performance in service appears limited (Da Costa, 1979; Van Acker *et al.,* 1999). Publications containing in ground ‘graveyard’ test data are more readily available, but their usefulness for service life modeling of above ground structures is unclear. The need for above ground durability to support performance modeling was more recently recognized, but due to their long duration, many above ground tests are incomplete and yet to be published. Above ground test results are likely to be most heterogeneous as they take a long time to complete and a wider range of standardized and non standardized methods may be used.

The aims of this review paper were to: (1) survey above-ground natural durability test data from published and ongoing field studies; (2) examine the usefulness of data obtained for service life prediction; and (3) compute resistance factors and consider their implications for understanding the effects of differences between field test sites and methods.

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

2.1 Literature survey on above ground durability test data
2.1. Pregled literature o ispitivanjima trajnosti drva iznad zemlje

Relevant literature was reviewed concerning the natural durability of timber species determined in field tests above ground. Modified and preservative treated timber was not considered as this would be unmanageable, due to increased amount of data and different testing approaches compared to non-treated timbers. Two a priori criteria for articles or data inclusion were set: (1) published in a peer reviewed journal, printed conference proceedings, international standard, project report or PhD thesis; (2) a focus on natural durability, field testing or service life.

The reference lists in the articles found and publication lists from durability researchers worldwide were checked for additional articles. The studies which met the a priori criteria used only four different test methods: the horizontal lap-joint test (CEN, 2003; Palanti *et al.,* 2011); the horizontal double layer test (Augusta, 2007; Brischke *et al.,* 2009); the cross brace test (Eslyn *et al.,* 1985; Highley, 1995); and the accelerated L-joint test (Van Acker and Stevens, 2003). The principal configurations of these methods are illustrated in Figure 1. In most cases, there were minor variations in the basic set up for each test method between different studies, for instance in terms of shading, distance to ground, test rig size and material. Untreated control specimens included in tests of treated timber were included if necessary and appropriate.

2.2 Above ground field tests
2.2. Testovi trajnosti drva iznad zemlje

In addition to published information, data from ongoing tests, which had not been published to date but were accessible to the authors, were included (Tab. 1).

Table 1 Above ground field trials and corresponding literature sources considered for service life related data (Test ID and abbreviations refer to data in Tab. 7 and 8)
Tablica 1. Ispitivanja trajnosti drva iznad zemlje i odgovarajući literaturni izvor za podatke o njegovu životnom vijeku (ID testa i kratice odnose se na podatke u tablicama 7 i 8)

ID	**Test method** *Metoda ispitivanja*	**Abbr.** *Kratica*	**Durability measure** *Mjera trajnosti*	**Reference species** *Referentna vrsta*	**Reference** *Referenca*
1	Lap-joint test	LpJ	SL_{mean}	Scots pine sapwood	Original data
2	Lap-joint test	LpJ	v_{5years}	Scots pine sapwood	Palanti *et al.* 2011
3	L-joint coated	LJc	$v_{21years}$	Radiata pine sapwood	Original data
4	L-joint uncoated	LJu	$v_{21years}$	Radiata pine sapwood	Original data
5	Accelerated L-joint test	ALJ	$v_{ML, 4 years}$	Scots pine sapwood	Van Acker & Stevens 2003
6	Cross brace test	CB	SL_{median}	SYP sapwood[1]	Highley 1995
7	Cross brace test	CB	SL_{median}	SYP sapwood[1]	Highley 1995, Eslyn *et al.* 1985
8	Double layer	DL	v_{6years}	Scots pine sapwood	Original data
9	Double layer	DL	v_{8years}	Scots pine sapwood	Original data
10	Double layer	DL	v_{9years}	Scots pine sapwood	Original data
11	Double layer	DL	v_{7years}	Scots pine sapwood	Brischke *et al.* 2009
12	Double layer	DL	SL_{mean}	Scots pine sapwood	Original data
13	Double layer	DL	SL_{median}	Scots pine sapwood	Original data
14	Double layer	DL	v_{6years}	Scots pine sapwood	Original data
15	Double layer	DL	v_{7years}	Scots pine sapwood	Original data
16	Double layer	DL	v_{8years}	Scots pine sapwood	Original data
17	Double layer	DL	$SL_{5th\ percentile}$	Scots pine sapwood	Rapp *et al.* 2010
18	Double layer	DL	$SL_{25th\ percentile}$	Scots pine sapwood	Rapp *et al.* 2010
19	Double layer	DL	v_{7years}	Scots pine sapwood	Rapp *et al.* 2010
20	Multi layer, bottom	MLb	$v_{10years}$	Scots pine sapwood	Original data
21	Multi layer, upper	MLu	$v_{10years}$	Scots pine sapwood	Original data
22	Bundle test A	BuA	v_{4years}	Scots pine sapwood	Original data
23	Bundle test B	BuB	v_{4years}	Scots pine sapwood	Original data
24	Bundle test C	BuC	v_{4years}	Scots pine sapwood	Original data
25	Bundle test D	BuD	v_{4years}	Scots pine sapwood	Original data

[1]SYP = Southern Yellow Pine

L-joint tests in Australia
Testovi L-spoja u Australiji

Above-ground durability L-joint tests were established in 1987 at different exposure sites in Australia (Francis and Norton 2005, Francis *et al.* 2007, Wang *et al.* 2008a). Eight untreated wood species were exposed at 10 field test sites throughout eastern Australia, while an additional 19 untreated wood species were set out at the Beerburrum test site, 65 km north of Brisbane (Tab. 2 and 3).

L-joint test units were constructed according to Fig. 1d using timber 35 x 35 mm² in cross section. Half of the specimens for each species were painted. Each joint was pulled apart after painting to completely break the paint film along the frame of the joint and therefore create a uniformly high decay hazard by allowing moisture to enter and remain in the joint and under the broken paint. The 35 x 35 mm² faces at the distal ends of the joint components were sealed with bituminous tape.

At each site L-joints were placed on exposure racks that were constructed using CCA treated plywood and durable framing timbers that are resistant to insect attack. Plastic strips and brackets were fixed to the racks to support L-joints and prevent them from coming into direct contact with each other or the plywood. At all locations the racks were faced north, and they were constructed the way that L-joints placed on them were oriented 10° backward from vertical to channel moisture toward the joint.

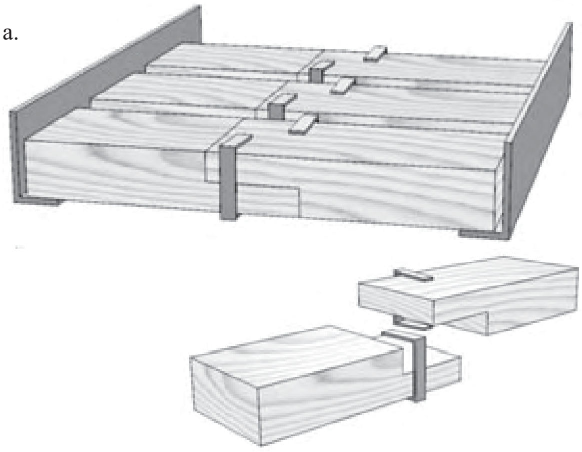
Assessment of the specimens was undertaken after 3, 5, 7, 9, 11, 16, 19 and 21 years of exposure. Only the 35 x 35 x 11 mm³ face of the tenon part of each joint - the component most susceptible to decay - was assessed. The depth and distribution of decay was detected using the pick test, which involves firm probing using a small knife. Decay scores were assigned between 0 (sound, resistant to probing and no apparent loss of structural integrity) and 4 (failure, severe decay through the 11 x 35 mm² tenon part of an L-joint) according to Carey *et al.* (1981).

Table 2 Mean decay rating according to EN 252 (CEN 1989) of specimens exposed in horizontal L-joint tests after 21 years of exposure in Beerburrum, Australia.
Tablica 2. Prosječna ocjena trulosti uzoraka izloženih testu horizontalnog L-spoja prema EN 252 (CEN 1989) nakon 21 godine izlaganja u Beerburrumu, Australija

Wood species *Vrsta drva*	**Botanical name** *Botanički naziv*	**Mean decay rating [0-4]** *Prosječna ocjena trulosti [0-4]*	
		unpainted / *neobojen*	painted / *obojen*
Johnstone River hardwood	*Backhousia bancroftii*	1.2	3.7
Rose alder	*Caldcluvia australiensis*	3.7	4.0
Northern silky oak	*Cardwellia sublimis*	4.0	3.8
Spotted gum	*Corymbia citriodora*[1]	2.5	3.5
Kapur	*Dryobalanops* spp.	1.6	3.1
Kamamere	*Eucalyptus deglupta*	3.3	3.7
Alpine ash	*Eucalyptus delegatensis*	3.8	3.8
Grey ironbark	*Eucalyptus drepanophylla*	0.8	2.9
Rose gum	*Eucalyptus grandis*	2.2	3.0
Messmate	*Eucalyptus obliqua*	3.7	3.6
Black butt	*Eucalyptus pilularis*	2.3	2.9
Mountain ash	*Eucalyptus regnans*	4.0	3.8
Red mahogany	*Eucalyptus resinifera*	1.1	2.7
Sydney blue gum	*Eucalyptus saligna*	2.3	2.8
Forest red gum	*Eucalyptus teretticorni*	1.2	2.6
Queensland maple	*Flindersia brayleyana*	3.7	4.0
Brush box	*Lophostemon confertus*	2.3	3.0
Fishtail silky oak	*Neorites kevedianus*	1.5	3.3
Light red meranti	*Shorea* spp.	3.9	4.0
Red balau	*Shorea* spp.	0.7	2.9
White Eungella satinash	*Syzygium wesas*	1.9	3.1
Hoop pine	*Araucaria cunninghammii*	4.0	3.4
Black cypress	*Callitris endlichrei*	4.0	4.0
White cypress	*Callitris glaucophylla*	1.8	2.2
White cypress sapwood	*Callitris glaucophylla*	4.0	4.0
Carribean pine	*Pinus caribaea*	3.6	3.8
Slash pine	*Pinus elliottii*	3.9	3.9
Radiata pine	*Pinus radiata*	4.0	3.9
Douglas fir	*Pseudotsuga menziesii*	3.9	3.9
Western Red Cedar	*Thuja plicata*	4.0	3.3

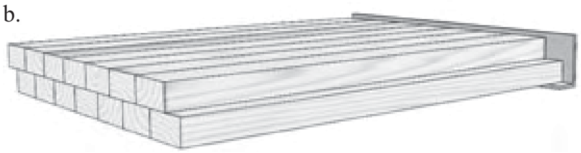
[1] *Corymbia citriodora* subsp. *variegata*

a.



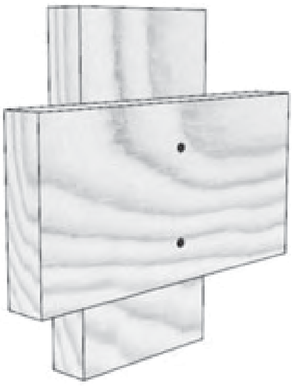
Horizontal lap-joint test
(CEN, 2003)
Horizontalni test lap-spoja
Specimens (38 x 85 x 300 mm³) are exposed horizontally on test rigs with supports 1 m above ground. The two lap-joint segments are fixed through stainless steel clamps or plastic cable strips. The end-grain of each lap-joint is sealed with polyurethane or silicone.

b.



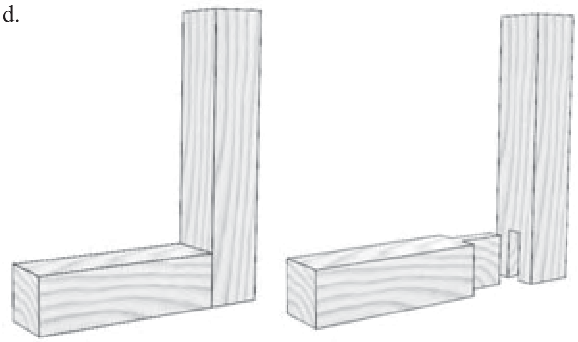
Horizontal double layer test
Horizontalni test dvostrukog sloja
Specimens (500 x 50 x 25 mm³) are exposed horizontally in double layers according to Augusta (2007) with the upper layer displaced laterally by 25 mm to the lower layer. Supports are 25 cm above ground and made from aluminum L-profiles or Norway spruce beams with or without a bituminous foil.

c.



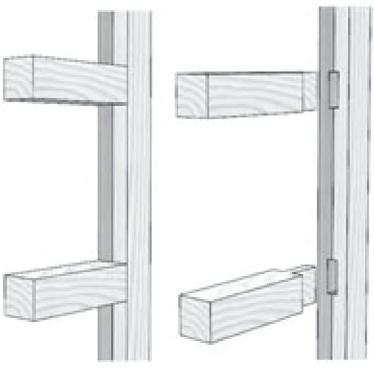
***Cross brace test** – Križni test*
Test units are constructed of 19 x 76.2 x 152.4 mm³ boards, that are nailed together at their centers to form a cross (e.g. Highley, 1995) and installed on test fences.

d.



L-joint test (CEN, 1993)
Test L-spoja
Specimens with dimension of 38 x 38 mm² in the cross section with a machined mortise and tenon joint are used. The members measure 203 mm in length. The whole L-joint assembly is either coated and afterwards disassembled or stays uncoated. Different modifications of the standard procedure are also considered.

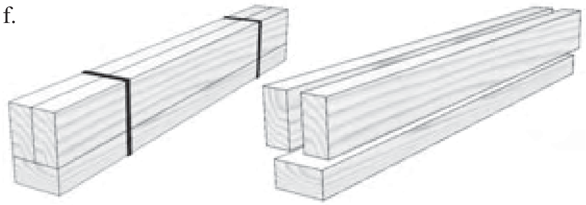
e.



Accelerated L-joint test
Ubrzani test L-spoja
A modified version of the L-joint test (CEN, 1993) is applied, e.g. according to Van Acker and Stevens (2003). L-joint tenon members are made from the test species. In contrast, the mortise member is half made of beech, and half made of Scots pine sapwood acting as feeder specimen.

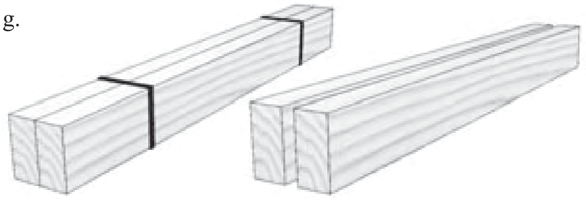
Figure 1 Above ground test set ups considered for durability records
Slika 1. Testovi trajnosti drva iznad zemlje

f.



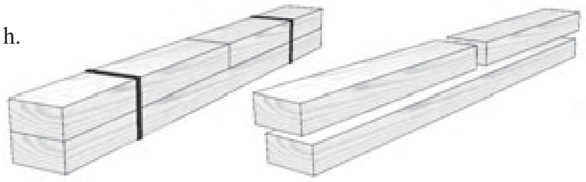
***Bundle test Type* A**
Test svežnja tipa A
Each specimen consists of three segments, which are stakes of 25 x 50 x 500 mm^3 and are ex-posed as a bundle.

g.



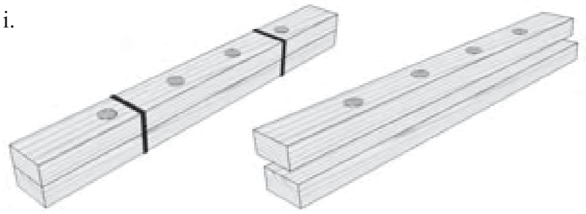
Bundle test Type B
Test svežnja tipa B
Each specimen consists of two segments, which are stakes of 25 x 50 x 500 mm^3 and are exposed as a bundle.

h.



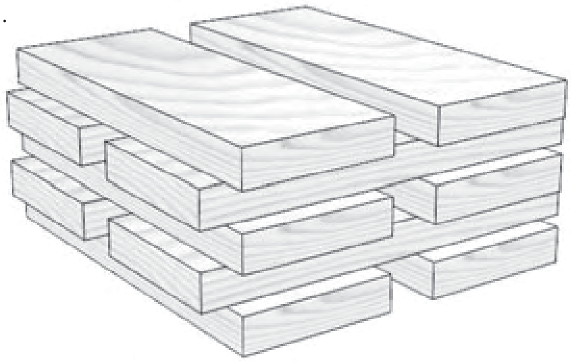
Bundle test Type C
Test svežnja tipa C
Each specimen consists of three segments, one bottom stake of 25 x 50 x 500 mm^3 and two top stakes of 25 x 50 x 250 mm^3, which are exposed as a bundle.

i.



Bundle test Type D
Test svežnja tipa D
Each specimen consists of two segments, which are stakes of 25 x 50 x 500 mm^3 and are exposed as a bundle. The upper specimen has four circular drill holes with a diameter of 20 mm to allow water trapping.

j.



Ground-proximity multiple layer test
Višeslojni test u blizini zemlje
Each test unit consists of ten specimens of 22 x 95 x 250 mm^3, stacked two by two in five crossed layers, bottom layer on the ground, e.g. according to Edlund (2004). To avoid weed growth the ground is covered with a geotextile. Either the two upper boards or the two bottom boards are assessed (indicated as 'upper' and 'bottom').

Figure 1. cont'd: Above ground test set ups considered for durability records.
Slika 1. (nastavak). Testovi trajnosti drva iznad zemlje

Horizontal double layer tests in Europe
Horizontalni dvoslojni testovi u Europi

Double layer tests have been performed at 23 different European test sites to establish dose-response functions for above ground wood decay with wood moisture content (MC) and temperature. A detailed description of the study and a corresponding dose-response performance model is given by Brischke and Rapp (2008a, 2008b, 2010).

Specimens made from Scots pine sapwood (*Pinus sylvestris* L.) and Douglas fir heartwood (*Pseudotsuga menziesii* (Mirb.) Franco) were monitored in terms of MC, wood temperature and the progress of fungal decay up to a period of eight years. The specimens (500 x 50 x 25 mm^3), according to EN 252 (CEN 1989), were exposed horizontally in double layer test rigs (see Fig. 1b) producing a decay risk corresponding to European Use Class 3 (CEN 2006). The upper layer was displaced laterally by 25 mm with respect to the lower layer. The lower layer consisted of seven pine sapwood specimens and six Douglas fir specimens; the upper layer consisted of six pine sapwood specimens and five Douglas fir specimens. The whole test set-up formed a closed deck (73 x 65 x 21 cm^3). The specimens were evaluated yearly through a pick-test using a small knife and rating the extent and distribution of decay according to EN 252 (CEN 1989) as: 0 (sound), 1 (slight attack), 2 (moderate attack), 3 (severe attack) or 4 (failure).

Horizontal double layer tests in Norway
Horizontalni dvoslojni testovi u Norveškoj

Horizontal double layer tests (Fig. 1b) were conducted with 29 different wood species (Tab. 6) as described by Evans *et al.* (2011) and Flæte *et al.* (2008, 2011). Specimens were exposed at three different locations in Norway: Oslo (exposed in 2002), Bergen and

Table 3 Mean decay rating according to EN 252 (CEN 1989) of specimens exposed in horizontal painted and unpainted L-joint tests after 21 years of exposure at ten different test sites in Australia.
Tablica 3. Prosječna ocjena trulosti obojenih i neobojenih uzoraka izloženih testu horizontalnog L-spoja prema EN 252 (CEN 1989) nakon 21 godine izlaganja na deset različitih mjesta u Australiji

	Mean decay rating [0-4] / *Prosječna ocjena trulosti [0-4]*									
	Beer-burrum	Dalby	Frank-ston	Pennant Hills	Rock-hampton	South Johnstone	Toow-oomba	Yarra-lumba	Mount Isa	Towns-ville
Painted / *Obojeno*										
Northern silky oak	3.8	3.7	3.8	3.7	3.7	3.9	3.9	3.6	2.2	3.5
Spotted gum	3.5	3.1	2.9	3.8	3.1	3.4	3.1	3.0	0.1	2.7
Grey ironbark	2.9	3.1	2.6	3.8	2.9	3.5	2.7	2.6	0.6	2.8
Brush box	3.0	3.0	3.2	3.8	3.4	4.0	2.9	3.1	1.6	2.9
White cypress	2.2	3.2	3.4	3.7	3.2	4.0	3.1	3.0	2.0	3.3
White cypress sapwood	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	2.4	4.0
Radiata pine	3.9	4.0	4.0	4.0	4.0	4.0	4.0	3.8	2.9	4.0
Douglas fir	3.9	3.9	4.0	3.9	4.0	4.0	3.9	3.7	2.7	3.9
Western red cedar	3.3	2.7	3.8	3.9	3.6	4.0	2.2	2.4	1.4	2.4
Unpainted / *Neobojeno*										
Northern silky oak	4.0	3.8	3.9	3.8	3.6	4.0	4.0	3.5	2.7	2.1
Spotted gum	2.5	1.5	1.7	2.4	0.8	3.7	0.7	0.3	0.0	0.6
Grey ironbark	0.8	1.5	1.2	2.2	1.0	3.5	0.4	1.0	0.6	1.3
Brush box	2.3	2.0	1.8	2.6	1.7	3.8	1.6	2.0	1.8	2.2
White cypress	1.8	2.9	2.4	3.3	3.6	4.0	3.3	3.0	1.8	3.7
White cypress sapwood	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	2.8	4.0
Radiata pine	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	2.6	3.9
Douglas fir	3.9	3.9	3.9	4.0	3.9	4.0	4.0	3.8	2.9	3.6
Western red cedar	4.0	2.9	3.4	3.8	3.8	4.0	3.9	3.6	1.7	3.4

Ås (exposed in 2004). In Oslo the test site is on the roof of the Norwegian Institute of Wood Technology, an 8 floor building, while the two test sites in Bergen and Ås are on ground level. Test set up and assessment of the specimens were identical with the above described procedure apart from the test rack size, which was larger due to a higher number of tested wood species. Samples were evaluated every year.

Lap-joint and ground-proximity multi layer tests in Sweden
Lap-spoj i prizemni višeslojni testovi u Švedskoj

Horizontal lap-joint tests (Fig. 1a) according to CEN TS 12 037 (CEN 2003) and ground-proximity multi layer tests (Fig. 1j) according to Edlund and Jermer (2007) were conducted in Borås, Sweden. Besides different treated timbers, the following untreated control wood species were tested: European larch (*Larix decidua* Mill.), Siberian larch (*Larix sibirica* Ledeb.), Norway spruce (*Picea abies* (L.) H. Karst.), Scots pine (*Pinus sylvestris* L.), European beech (*Fagus sylvatica* L.), Aspen (*Populus tremula* L.), and English oak (*Quercus robur* L.).

The lap-joint tests were started in 1996 and the specimens were assessed after 5, 8, 10, 12, 13, and 15 years of exposure. The ground-proximity trials were started in 2001 and assessed after 1, 2, 3, 5, and 10 years. Each ground-proximity multi layer test unit consisted of ten specimens, 22 x 95 x 250 mm³, that were stacked two by two in five crossed layers, with the bottom layer on the ground. The assessment of the specimens in the stacks was carried out separately for the bottom and the upper part (Tab. 1) using the pick-test. To avoid weed growth around the stacks, the ground had been covered with a geotextile, permeable for micro-organisms.

Bundle tests in Germany
Testovi svežnja u Njemačkoj

Bundle tests of four different types (A-D) after Brischke *et al.* (2011) were conducted in Northern Germany. The specimens were made from Norway spruce as illustrated in Fig. 1f-i and exposed in 2007. Afterwards they were evaluated annually by using the pick-test and rating the extent and distribution of decay according to EN 252 (CEN 1989).

2.3 Durability measures
2.3. Mjere trajnosti

Numerous evaluation and assessment procedures were analyzed with respect to their significance and informative value for the prediction of service life. The following ranking of preference was applied to the different durability assessment measures:

1. Mean service life of specimens SL_{mean} (1)
2. Median service life of specimens SL_{median} (50th percentile, 2)
3. 25th percentile of service life of specimens $SL_{25th\ percentile}$ (3)
4. Decay rate (after x years) v_{mean} (4)
5. 5th percentile of service life of specimens $SL_{5th\ percentile}$ (5).

$$SL_{mean} = \frac{\sum_{i}^{n} SL_i}{n} \tag{1}$$

$$SL_{\text{median}} \begin{cases} SL_{\frac{n+1}{2}} & \text{; if } n \text{ is uneven} \\ \frac{1}{2}\left(SL_{\frac{n}{2}} + SL_{\frac{n}{2}+1}\right) & \text{; if } n \text{ is even} \end{cases} \quad (2)$$

$$SL_{\text{median}} \begin{cases} SL_{\frac{n+1}{4}} & \text{; if } n \text{ is uneven} \\ \frac{1}{2}\left(SL_{\frac{n}{4}} + SL_{\frac{n}{4}+1}\right) & \text{; if } n \text{ is even} \end{cases} \quad (3)$$

$$v_{\text{mean}} = \frac{\sum_i^n v_i}{n} = \frac{\sum_i^n \frac{R}{t}}{n} \quad (4)$$

$$SL_{\text{median}} \begin{cases} SL_{\frac{n+1}{20}} & \text{; if } n \text{ is uneven} \\ \frac{1}{2}\left(SL_{\frac{n}{20}} + SL_{\frac{n}{20}+1}\right) & \text{; if } n \text{ is even} \end{cases} \quad (5)$$

Where SL_i is the service life of a single specimen (the year when a specimen was recorded to have failed) [y], v_i is the decay rate of single specimen [y^{-1}], R is the decay rating (score), t is the exposure time [y], and n is the number of replicate specimens.

Decay rate, as represented by the rate of change in decay rating over time, was considered as less desirable quantity with which to determine resistance factors. Whilst decay does not necessarily proceed at a linear rate, it was necessary to consider it as such for the purposes of this study. Different decay rating schemes had been applied, e.g. the five step scales according to EN 252 (CEN, 1989) and EN 330 (CEN, 1993). Alternatively, the decay rate was expressed as 'mass loss rate v_{ML}', when only mass loss, but not decay ratings were available (e.g. Van Acker and Stevens, 2003).

2.4 Resistance factors
2.4. Čimbenici otpornosti

To make the different durability measures comparable, they were related to the respective reference species and resistance factors *f* were calculated according to 6 and 7.

$$f_{SL} = \frac{SL_{\text{tested species}}}{SL_{\text{reference species}}} \quad (6)$$

$$f_v = \frac{v_{\text{reference species}}}{v_{\text{tested species}}} \quad (7)$$

Where f_{SL} and f_v are resistance factors based on service life and decay rate (after x years), respectively, SL is the service life [y], and v is the decay rate [y^{-1}]. The equation used depended on the durability measure applied for each test: Equation 6 if service life measures were reported or equation 7 if decay ratings were recorded. Resistance factors were calculated for the six species with most available data: spotted gum (*Corymbia* spp.), oak (*Quercus robur/petraea*), Norway spruce (*Picea abies* (L.) H. Karst.), Scots pine (*Pinus sylvestris* L.), Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), and western red cedar (*Thuja plicata* Donn ex D. Don).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Ongoing durability studies
3.1. Aktualna istraživanja trajnosti

In total, results from six published and five different ongoing durability studies were considered for this survey. To illustrate the latest state of the ongoing studies, which took place at different locations around the world and made use of seven different tests methods, the mean decay ratings are presented for all timber species tested (Fig. 2 and Tab. 2 to 6).

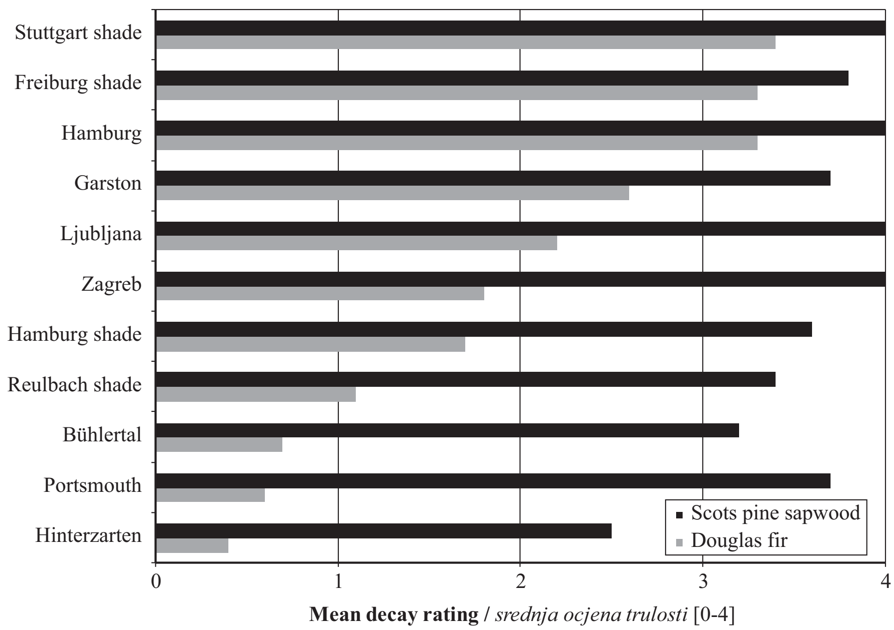


Figure 2 Mean decay rating according to EN 252 (CEN, 1989) of Douglas fir and Scots pine sapwood specimens after 6.5 years exposure in horizontal double layer tests at different locations in Europe.
Slika 2. Prosječna ocjena trulosti uzoraka od bjeljike duglazije i bora izloženih horizontalnome dvoslojnom testu prema EN 252 (CEN 1989) nakon 6,5 godina izlaganja na različitim lokacijama u Europi

Table 4 Mean decay rating according to EN 252 (CEN 1989) of specimens exposed in horizontal lap-joint tests after 12 years of exposure in Borås, Sweden.
Tablica 4. Prosječna ocjena trulosti uzoraka izloženih testu horizontalnog lap-spoja prema EN 252 (CEN 1989) nakon 21 godine izlaganja u Boråsu, Švedska

	Mean decay rating [0-4] / *Prosječna ocjena trulosti [0-4]*			
	Scots pine sapwood *(Pinus sylvestris)*	Scots pine heartwood *(Pinus sylvestris)*	Norway spruce *(Picea abies)*	European larch *(Larix decidua)*
after 5 years	0.4	0.1	0.8	0.3
after 8 years	2.7	0.5	3.4	1.5
after 10 years	3.7	2.1	3.9	2.3
after 12 years	4.0	2.2	4.0	2.5
after 13 years	-	2.6	-	2.8
after 15 years	-	2.9	-	3.0

Table 5 Mean decay rating according to EN 252 (CEN 1989) of specimens exposed in ground-proximity multi layer tests after 10 years of exposure in Borås, Sweden.
Tablica 5. Prosječna ocjena trulosti uzoraka izloženih prizemnom višeslojnom testu prema EN 252 (CEN 1989) nakon deset godina izlaganja u Boråsu, Švedska

Wood species *Vrsta drva*	**Botanical name** *Botanički naziv*	**Mean decay rating [0-4]** / *Prosječna ocjena trulosti [0-4]*	
		Bottom part / *Donji dio*	Upper part / *Gornji dio*
Scots pine sapwood	*Pinus sylvestris*	4.0	4.0
Scots pine heartwood	*Pinus sylvestris*	4.0	1.0
European larch	*Larix decidua*	3.0	0.5
Norway spruce	*Picea abies*	4.0	4.0
Beech	*Fagus sylvatica*	2.8	4.0
English oak	*Quercus robur*	2.5	0.5
Aspen	*Populus tremula*	4.0	3.3

Table 6 Mean decay rating according to EN 252 (CEN 1989) of specimens exposed in horizontal double layer tests after 6 years of exposure at three test locations in Norway.
Tablica 6. Prosječna ocjena trulosti uzoraka izloženih horizontalnome dvoslojnom testu prema EN 252 (CEN 1989) nakon šest godina izlaganja na tri različite lokacije u Norveškoj

Wood species *Vrsta drva*	**Botanical name** *Botanički naziv*	**Mean decay rating [0-4]** / *Prosječna ocjena trulosti [0-4]*		
		Oslo	Ås	Bergen
Norway maple	*Acer platanoides*	-	1.5	3.0
Lime	*Tilia cordata*	-	1.5	3.2
Aspen	*Populus tremula*	2.1	1.1	2.2
Silver birch / Downy birch	*Betula pendula / B. pubescens*	2.1	1.5	2.0
Alder / Grey alder	*Alnus glutinosa*	2.4	1.5	3.5
Rowan	*Sorbus aucuparia*	-	1.2	2.0
Goat willow	*Salix caprea*	-	0.5	2.1
European oak	*Quercus spp.*	0.5	0.5	1.4
Ash	*Fraxinus excelsior*	-	0.9	1.7
Wych elm	*Ulmus glabra*	-	0.5	2.0
Beech	*Fagus sylvatica*	-	2.0	3.1
Cedrela	*Cedrela spp.*	0.0	-	-
Sitka spruce	*Picea sitchensis*	0.4	1.7	3.0
Norway spruce 6 mm rings	*Picea abies*	-	2.4	2.1
Norway spruce 3 mm rings		2.2	2.1	1.9
Norway spruce 1 mm rings		-	0.9	1.9
Norway spruce standing rings		-	1.9	2.4
Silver fir	*Abies alba*	-	2.9	2.9
Scots pine 3 mm rings	*Pinus sylvestris*	0.2	1.2	1.5
Scots pine 1 mm rings		0.0	1.0	1.9
Scots pine sapwood		2.4	1.2	2.3
Scots pine sapwood + heartwood		-	0.6	2.1
Western red cedar (N-America)	*Thuja plicata*	-	0.2	1.2
Western red cedar (Norway)		-	1.3	1.4
Juniper	*Juniperus communis*	-	0.3	0.9
Larch (Russia)	*Larix sibirica*	0.4	0.9	1.4
Larch (Norway)	*Larix decidua*	-	0.3	1.2
Douglas fir (N-America)	*Pseudotsuga menziesii*	-	0.2	1.2

Site characteristics were found to affect the performance of particular wood species differently. The mean decay ratings for Douglas fir heartwood after 6.5 years of exposure in horizontal double layer tests at 11 different locations in Europe is shown in Fig. 2 in order descending severity of decay. The respective 'non-durable' reference Scots pine sapwood did not show the same trend for decay severity amongst the 11 test sites. The differing ratio between mean decay rating for Douglas fir and the reference species was presumably caused by a combination of their respective wood properties and climatic differences between sites. The particular properties of each species, such as moisture permeability and potential for leaching of protective extractives, may cause differences in the effects of climatic conditions, such as rainfall and temperature. Similar observations were made for the horizontal double layer samples exposed at three Norwegian test sites (Tab. 6). For instance, the mean decay ratings of grey alder (*Alnus glutinosa* L.) and Scots pine sapwood were almost the same after 6 years of exposure in Oslo and Ås, whilst the mean decay rating was significantly higher for grey alder in Bergen compared to the Scots pine sapwood reference (Tab. 6). For other species, such as aspen (*P. tremula*), the ratios between tested timber and reference were nearly the same at all three test locations.

In addition to differences in decay progress between species at climatically different locations, the impact of test methods and test design became apparent. As shown in Tab. 5, the ratio of the mean decay ratings for seven wood species differed significantly between the upper and bottom parts of ground-proximity multi layer tests in Borås, Sweden. The higher moisture load and limited potential for re-drying in the bottom parts of the stack diminished the differences between different timbers, which coincides with the reports by Augusta (2007) and Rapp *et al.* (2010), who compared the decay development of different European wood species under different exposure conditions above ground. For instance, the good moisture performance of the heartwood of European larch (*L. decidua*), Douglas fir (*P. menziesii*) or Scots pine (*P. sylvestris*) is abolished when permanent wetting is provoked. For further comparative analyses of the different above ground trials considered for this survey, resistance factors were considered.

3.2 Resistance factors
3.2. Čimbenici otpornosti

The computation of resistance factors allowed the wide range of previous and ongoing tests to be compared, irrespective of test configurations and assessment methods. We found, however, that the number of durability recordings that were freely accessible from publications and relevant for service life prediction was generally sparse. Apart from the fact that above ground durability studies are rare, many of the reported studies contained insufficiently detailed results. The condensed format of presenting test results that is often used for publication inhibited the calculation of resistance factors with sufficiently high statistical reliability. The significance of this problem can be illustrated by considering the Australian L-joint test, which includes 29 different wood species represented by painted and unpainted specimens installed at various locations, and the test has been assessed eight times to date. If the results were reported together, there would be 1808 mean scores alone. It is obviously beyond the scope of one publication to deal with this volume of data, so selected results have been published over time. If only mean scores at a particular time are reported in a single publication, they are not very useful to timber engineers researching service life prediction, as they attempt to find and compile a complete set of data for analysis (Tab. 2 and 3). Furthermore, representative measures of durability may need to be transformed for analysis, for example from ratings (scores) to service life values, so raw data are required. While it is possible to seek data directly from researchers managing durability tests, they may be difficult to find. Individual publications may not reveal the full extent of an entire durability test when only specific elements of data are reported.

Tab. 1 gives an overview of the data regarded for this survey. In total, 163 durability measures from 31 different test sites have been considered for the calculation of resistance factors: 37 for hardwoods and 126 for softwoods. Only three reference species were used to compare the different durability tests: Scots pine sapwood (*P. sylvestris*), Radiata pine sapwood (*Pinus radiata* D.Don) and southern yellow pine sapwood (*Pinus* spp.). The resistance factors for six selected wood species, for which most durability records were found, are presented in Tab. 7 and 8. Several of these timbers are commonly used untreated for above ground structures that are exposed to the weather, including oak (*Quercus* spp.), spotted gum (*Corymbia* spp.) and western red cedar (*T. plicata*).

Most of the durability recordings were based on preliminary test results, and consequently, decay ratings after 4 to 21 years were used for calculating resistance factors. For most species the range of resistance factors was quite high, for example between 0.90 and 4.54 for Douglas fir (*P. menziesii*), and in extreme - between 15.88 and 43.03 - for spotted gum (*Corymbia* spp.). In the case of Douglas fir this can be translated to durability classes (DC, according to EN 350-1, CEN 1994) between DC 5 (non durable) and DC 2 (durable). This variation and how it can be related to at least three, in some cases even to four or five durability classes, is shown for six selected wood species in Fig. 3. The importance of this variation becomes even more obvious when calculating the expected service life: Based on a mean service life of 6.5 years of the Scots pine sapwood reference (Tab. 8), the service life to be expected for Douglas fir ranges from 7.4 to 29.5 years. Even more drastic is the range for spotted gum (*Corymbia* spp.), which is from 18.7 years and 473.3 years. These findings highlight the potential value of service life modeling to greatly increase the accuracy and relevance of information available regarding the expected durability of timber used at different locations.

Table 7 Service life related data from above-ground field tests according to Tab. 1 Hardwoods.
Tablica 7. Podaci o životnom vijeku povezani s testovima izloženosti drva iznad zemlje prema tablici 1. za tvrde vrste drva

Wood species *Vrsta drva*	**Botanical name** *Botanički naziv*	**Site** / *Mjesto*	**Country code** *Kod zemlje*	**Test method** *Metoda*	**Test ID**	**Resistance factor** *Faktor otpora*	$SL_{Reference}$ [1]
Spotted gum	*Corymbia citriodora*	Beerburrum	AUS	LJu	4	**12.40**	5.1
					4	**4.62**	8.5
				LJc	3	**7.23**	3.7
					3	**3.68**	5.0
		Dalby	AUS	LJu	4	**9.02**	6.8
				LJc	3	**7.00**	4.1
		Frankston	AUS	LJu	4	**7.39**	7.4
				LJc	3	**4.24**	7.0
		Pennant Hills	AUS	LJu	4	**4.87**	7.9
				LJc	3	**2.56**	7.3
		Rockhampton	AUS	LJu	4	**16.34**	7.7
				LJc	3	**4.98**	5.2
		South Johnstone	AUS	LJu	4	**3.49**	5.7
				LJc	3	**5.23**	5.1
		Toowoomba	AUS	LJu	4	**20.69**	6.8
				LJc	3	**8.51**	3.4
		Yarralumla	AUS	LJu	4	**31.61**	8.7
				LJc	3	**3.48**	7.0
		Mount Isa	AUS	LJu	4	**43.03**	11.0
				LJc	3	**15.88**	11.0
		Townsville	AUS	LJu	4	**6.43**	5.3
				LJc	3	**2.06**	5.0
English oak	*Quercus robur*	Hamburg	D	DL	11	**1.56**	6.5
		Hamburg shade	D	DL	11	**1.35**	6.1
		Reulbach	D	DL	11	**1.83**	n.a.
		Stuttgart	D	DL	11	**1.66**	n.a.
		Freiburg	D	DL	11	**1.52**	n.a.
		4 German sites	D	DL	17	**1.70**	6.6
		Ghent	B	ALJ	5	**5.67**	n.a.
		Borås	S	MLu	21	**4.00**	10.0
				MLb	20	**1.33**	10.0
European oak	*Q. robur/ Q. petraea*	Ås	N	DL	8	**2.50**	n.a.
		Oslo	N	DL	9	**3.00**	*8.0*
		Bergen	N	DL	8	**1.67**	n.a.

[1]mean value or median (in italics) / *srednja vrijednost ili medijan (u kurzivu)*; n.a. = not available / *nije dostupno*

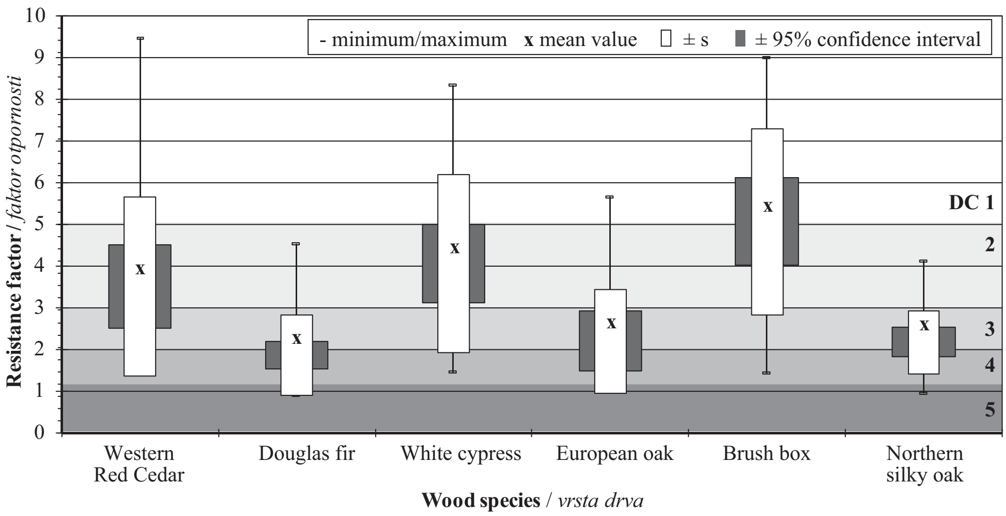


Figure 3 Variation of resistance factors of six selected wood species and corresponding durability classes (DC) according to EN 350-1 (CEN, 1994).
Slika 3. Varijacija čimbenika otpornosti za šest različitih vrsta drva i odgovarajuće klase trajnosti prema EN 350-1 (CEN, 1994).

Table 8 Service life related data from above-ground field tests according to Tab. 1 Softwoods.
Tablica 8. Podaci o životnom vijeku povezani s testovima izloženosti drva iznad zemlje prema tablici 1. za meke vrste drva

Wood species *Vrsta drva*	**Botanical name** *Botanički naziv*	**Site** / *Mjesto*	**Country code** *Kod zemlje*	**Test method** *Metoda*	**Test ID**	**Resistance factor** *Faktor otpora*	$SL_{Reference}$ [1]
Norway spruce heart	*Picea abies*	Hamburg	D	DL	19	**0.96**	6.5
		Hamburg shade	D	DL	19	**0.78**	6.1
		Stuttgart	D	DL	19	**0.89**	n.a.
		Freiburg	D	DL	19	**0.75**	n.a.
Norway spruce	*Picea abies*	Oslo	N	DL	9	**1.19**	*8.0*
		Hannover	D	BuA	22	**0.82**	*4.0*
				BuB	23	**0.92**	n.a
				BuC	24	**0.96**	n.a.
				BuD	25	**1.00**	*4.0*
		Borås	S	LpJ	1	**1.00**	8.0
				MLu	21	**1.00**	10.0
				MLb	20	**1.00**	10.0
		Ghent	B	ALJ	5	**2.16**	n.a.
Norway spruce, 6 mm rings	*Picea abies*	Ås	N	DL	8	**0.48**	n.a.
		Bergen	N	DL	8	**1.11**	n.a.
Norway spruce, 3 mm rings	*Picea abies*	Ås	N	DL	8	**0.56**	n.a.
		Bergen	N	DL	8	**1.20**	n.a.
Norway spruce, 1 mm rings	*Picea abies*	Ås	N	DL	8	**1.36**	n.a.
		Bergen	N	DL	8	**1.25**	n.a.
Norway spruce, standing rings	*Picea abies*	Ås	N	DL	8	**1.00**	n.a.
		Bergen	N	DL	8	**0.94**	n.a.
Norway spruce sap	*Picea abies*	Hamburg	D	DL	19	**0.79**	6.5
		Hamburg shade	D	DL	19	**0.98**	6.1
		Stuttgart	D	DL	19	**0.67**	n.a.
		Freiburg	D	DL	19	**0.45**	n.a.
Scots pine	*Pinus sylvestris*	4 German sites	D	DL	18	**1.34**	6.6
		Ghent	B	ALJ	5	**9.31**	n.a.
		Hamburg	D	DL	10	**1.37**	6.4
		Hamburg shade	D	DL	10	**1.18**	*7.8*
		Borås	S	LpJ	1	**1.25**	8.0
				MLu	21	**4.00**	10.0
				MLb	20	**1.00**	10.0
Scots pine resinous	*Pinus sylvestris*	Borås	S	MLu	21	**4.00**	10.0
				MLb	20	**1.14**	10.0
Scots pine, slow grown	*Pinus sylvestris*	Oslo	N	DL	9	**3.79**	*8.0*
Scots pine, normal	*Pinus sylvestris*	Oslo	N	DL	9	**3.27**	*8.0*
Scots pine, 3 mm rings	*Pinus sylvestris*	Ås	N	DL	8	**1.00**	n.a.
		Bergen	N	DL	8	**1.50**	n.a.
Scots pine, 1 mm rings	*Pinus sylvestris*	Ås	N	DL	8	**1.15**	n.a.
		Bergen	N	DL	8	**1.25**	n.a.
Scots pine heart + sap	*Pinus sylvestris*	Ås	N	DL	8	**1.07**	n.a.
		Bergen	N	DL	8	**1.11**	n.a.
Douglas fir	*Pseudotsuga menziesii*	4 German sites	D	DL	18	**1.45**	6.6
		Hamburg	D	DL	12	**1.25**	6.5
		Hamburg shade	D	DL	16	**2.14**	7.1
		Hamburg	D	DL	10	**4.17**	6.4
		Hamburg shade	D	DL	10	**2.12**	*7.8*
		Stuttgart shade	D	DL	13	**1.22**	6.0
		Freiburg shade	D	DL	13	**1.08**	7.3
		Reulbach shade	D	DL	13	**2.50**	*8.1*
		Hinterzarten	D	DL	16	**3.18**	n.a.
		Bühlertal	D	DL	16	**3.98**	*7.7*
		Garston	GB	DL	14	**1.63**	*6.1*

[1]mean value or median (in italics) / *srednja vrijednost ili medijan (u kurzivu)*
[2]based on estimated median service life / *utemeljeno na procjeni medijana životnog vijeka*
n.a. = not available / *nije dostupno*

Table 8 cont'd: Service life related data from above-ground field tests according to Tab. 1 Softwoods.
Tablica 8. (nastavak) Podaci o životnom vijeku povezani s testovima izloženosti drva iznad zemlje prema tablici 1. za meke vrste drva

Wood species *Vrsta drva*	**Botanical name** *Botanički naziv*	**Site** / *Mjesto*	**Country code** *Kod zemlje*	**Test method** *Metoda*	**Test ID**	**Resistance factor** *Faktor otpora*	$SL_{Reference}$ [1]
		Portsmouth	GB	DL	15	**4.54**	6.0
		Ljubljana	SI	DL	16	**3.31**	3.2
		Zagreb	HR	DL	14	**3.38**	4.3
		Madison, WI	USA	CB	6	**> 2.31**[2]	*13.0*
		Starkville, MI	USA	CB	7	**> 2.00**[2]	*10.0*
		Beerburrum	AUS	LJu	4	**1.74**	5.1
				LJc	3	**1.12**	3.7
		Dalby	AUS	LJu	4	**1.29**	6.8
				LJc	3	**1.28**	4.1
		Frankston	AUS	LJu	4	**1.40**	7.4
				LJc	3	**1.39**	7.0
		Pennant Hills	AUS	LJu	4	**1.34**	7.9
				LJc	3	**1.36**	7.3
		Rockhampton	AUS	LJu	4	**1.20**	7.7
				LJc	3	**1.16**	5.2
		South Johnstone	AUS	LJu	4	**0.96**	5.7
				LJc	3	**1.17**	5.1
		Toowoomba	AUS	LJu	4	**1.14**	6.8
				LJc	3	**1.43**	3.4
		Yarralumla	AUS	LJu	4	**1.33**	8.7
				LJc	3	**1.58**	7.0
		Mount Isa	AUS	LJu	4	**0.90**	n.a.
				LJc	3	**1.79**	11.0
		Townsville	AUS	LJu	4	**1.28**	11.0
				LJc	3	**1.95**	5.3
Douglas fir (Norway)	*Pseudotsuga menziesii*	Bergen	N	DL	8	**1.88**	n.a.
Douglas fir (N-America)	*Pseudotsuga menziesii*	Bergen	N	DL	8	**2.31**	n.a.
Western Red Cedar	*Thuja plicata*	Madison, WI	USA	CB	6	**> 2.30**[2]	*13.0*
		Beerburrum	AUS	LJu	4	**3.03**	5.1
				LJc	3	**4.53**	3.7
		Dalby	AUS	LJu	4	**3.54**	6.8
				LJc	3	**7.97**	4.1
		Frankston	AUS	LJu	4	**3.04**	7.4
				LJc	3	**2.22**	7.0
		Pennant Hills	AUS	LJu	4	**1.98**	7.9
				LJc	3	**2.06**	7.3
		Rockhampton	AUS	LJu	4	**2.93**	7.7
				LJc	3	**3.59**	5.2
		South Johnstone	AUS	LJu	4	**2.19**	5.7
				LJc	3	**1.97**	5.1
		Toowoomba	AUS	LJu	4	**2.14**	6.8
				LJc	3	**9.48**	3.4
		Yarralumla	AUS	LJu	4	**2.00**	8.7
				LJc	3	**3.68**	7.0
		Mount Isa	AUS	LJu	4	**1.52**	n.a.
				LJc	3	**3.44**	11.0
Western Red Cedar	*Thuja plicata*	Townsville	AUS	LJu	4	**2.23**	11.0
				LJc	3	**6.69**	5.3
WRC (Norway)	*Thuja plicata*	Ås	N	DL	8	**0.88**	n.a.
		Bergen	N	DL	8	**1.67**	n.a.
WRC (N-America)	*Thuja plicata*	Bergen	N	DL	8	**2.00**	n.a.

[1]mean value or median (in italics) / *srednja vrijednost ili medijan (u kurzivu)*
[2]based on estimated median service life / *utemeljeno na procjeni medijana životnog vijeka*
n.a. = not available / *nije dostupno*

Although most of the results are still preliminary, they indicate that the resistance factor, and hence the relative durability of different species, is not necessarily the same at climatically different places. This is confirmed by the results for European oak (*Quercus robur* / *Quercus petraea*): While the resistance factors for eight German test sites differed only between 1.35 and 1.83, a variation between 1.67 and 3.00 was found for three Norwegian sites. As there were only a few species for which multiple recordings were available, no clear relationship between the test site and resulting relative durability was discernible. Significantly more durability recordings from different sites are needed. As previously discussed, chemical and anatomical properties of different species may influence the extent to which they are affected by climate variables, and this topic requires further investigation.

Another example is illustrated in Fig. 4, where the resistance factors of eight wood species determined in L-joint tests have been compared between ten test sites in Australia. Many additional wood species were installed at the Beerburrum site, while only nine wood species were installed at all ten sites. It would be ideal if resistance factors for the nine species tested at all sites could be used to gauge the performance of the additional species at Beerburrum, if they were used at the other locations. No simple relationship between relative resistance factors and test location was observed that represented all species. The higher the resistance factor - and thus the expected service life - the higher was the site-specific variation. In extreme, the factors differed between 4 and 32. For those wood species, showing resistance factors below 5, which is equivalent to durability class 2 = 'durable' according to EN 350-1 (CEN, 1994), the variation between most of the sites diminished, while differences between sites for the species with higher resistance factors showed the opposite. The test sites represent a wide range of climatic conditions, and preliminary analysis revealed that there is a strong relationship between climate variables and relative durability of each wood species exposed at different locations (Francis and Norton, 2006). The influence of the analyzed climate variables differed amongst the eight species. Further research is required to explore the possibility of using resistance factors to predict durability between different locations based on indicating wood species that are selected to represent groups of wood species with similar properties. For example, the resistance factors for spotted gum may more accurately predict the service life of dense hardwoods that contain extractives that are highly toxic to decay fungi, while resistance factors for brush box may be used to predict the service life of dense hardwoods that contain moderately toxic extractives.

To further examine the potential relationship between the severity of a test site and respective durability of timber species, resistance factors were correlated with the service life (mean or median) of the reference wood species for all sites at which these data were available. As shown exemplarily for three softwoods and three hardwoods in Fig. 5, no clear relationship was obtained. It leads to the conclusion that other factors than the site-specific decay intensity determine the relative resistance, such as climatic peculiarities, different decay types, or detoxifying agents.

In addition to potential site-specific effects, the test method and especially the durability measure seem to influence the resistance factors. While no clear differences between the use of mean or median service lives on the one hand and decay rates after certain exposure times on the other hand were observed, the use of mass loss differences led to significant outliers for

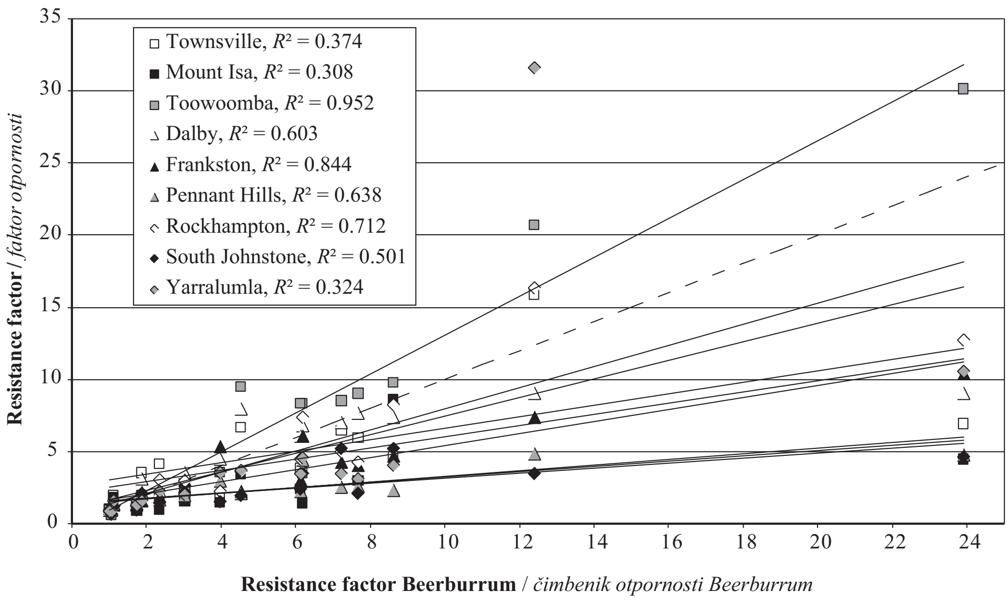


Figure 4 Relationship between resistance factors of eight wood species determined in L-joint trials for ten Australian test sites. Dashed line refers to resistance factors determined for Beerburrum (ideal line).
Slika 4. Odnos između čimbenika otpornosti za osam vrsta drva određenih testom L-spoja za deset lokacija u Australiji. Isprekidana se linija odnosi na čimbenike otpornosti određene za Beerburrum (idealna linija).

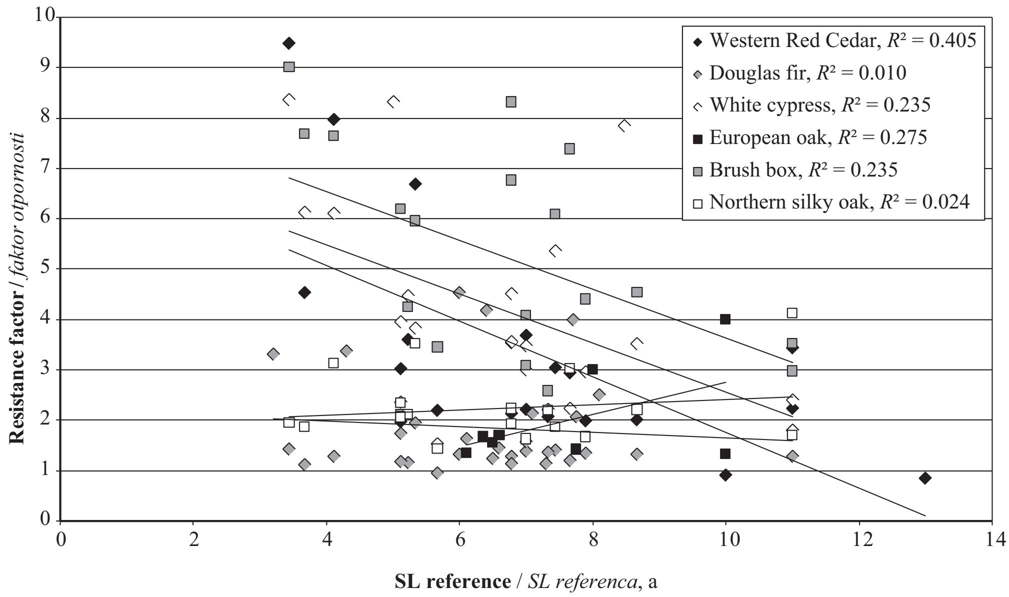


Figure 5 Resistance factors of six selected wood species related to the mean or median service life in years of the reference species
Slika 5. Čimbenici otpornosti za šest vrsta drva u odnosu prema srednjoj vrijednosti ili medijanu životnoga vijeka referentne vrste drva

English oak (*Quercus robur*), Scots pine and Norway spruce (*Picea abies*) and the relative effects of durability measures, therefore, need to be verified.

The influence of the test methods on the resulting resistance factors of a certain wood species is superposed by the effect of climatic conditions. Basically it is the microclimate within a wood specimen that determines the conditions for fungal growth and decay. Consequently, the combination of mesoclimate (environmental conditions at the test site) and the design of the respective test set up affect the microclimate. This is demonstrated by considering resistance factors calculated for Douglas fir, which varied as follows: in double layer tests between 1.08 and 4.54, in uncoated L-joint tests between 0.90 and 1.74, in coated L-joint tests between 1.12 and 1.95, and in cross brace tests between 2.00 and 2.13 (Tab. 8). Obviously the variation within one test method was higher compared to the variation between the different test methods, which coincides with the findings of De Groot (1992), who exposed Southern yellow pine sapwood in Mississippi, USA, and in a rainforest in Panama using 18 different test designs. While he found a significant impact of the test design in the temperate location, differences diminished in the tropical rainforest. Within this study, test data from different test methods at the same test location were available only for a few wood species, so the potential effect of the test configurations was not quantifiable.

4 CONCLUSIONS
4. ZAKLJUČCI

We do not claim that this literature and data survey on above ground durability tests is complete. This is mainly due to the fact that many studies around the world are known to exist, but respective data are not freely available. The lack of freely available data is strongly indicated through the fact that 80 % of durability records used for this study was unpublished. Furthermore, in many cases information was too condensed and incomplete, which is inescapable for journal articles, but prevented the data transformation necessary to calculate specimen service life measures.

The range of test results observed for each wood species further highlighted that the current timber durability classification systems, which assign a species to a durability class irrespective of site and design, are not precise enough for many scientific and engineering purposes. Data need to meet a number of requirements in terms of specificity, background information and formatting.

We conclude that further research into the relative effects of climate on decay progress amongst different species is required, and future comparative studies should focus not only on differences between test sites, but also on different test configurations at the same location to determine the effects of structural design on timber durability. To facilitate this goal, a suitable platform is needed to increase the quantity and availability of useful data. Service life related durability recordings should be shared amongst the scientific community to allow the exchange and advancement of knowledge in this field. The value of these durability data is expected to rise through collaborative comparative studies and meta analyses.

Similar or even more complex challenges are faced for predicting the service life of modified and preservative treated wooden material because additional information of treatment agents and processes are needed. Wood used outdoors is commonly treated with different wood preserving agents and formulations, and field studies on the durability of preservative treated and modified timber include additional parameters, including preservative type, penetration and retention.

For these reasons, a proposal for a 'Durability Data Base' has been made to the 'International Research Group on Wood Protection, IRG-WP' (Brischke *et al.* 2012). Requirements and feasible formats for durability recordings have been suggested for all types of wood products: naturally durable timber, thermally and chemically modified timber, water repellent and preservative treated timber as well as for composite products. The database shall allow availability of test results from field and laboratory studies dealing with wood-degrading fungi, insects, and marine borers.

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Analysis of the Investment in Wood Processing and Furniture Manufacturing Entities by Key Factors of Competitiveness

Analiza investicijskih ulaganja proizvodnih subjekata prerade drva i proizvodnje namještaja primjenom ključnih čimbenika konkurentnosti

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ABSTRACT • *Processing of wood and manufacture of wood and cork products, excluding furniture, manufacture of straw and plaiting goods (C16) and manufacture of furniture (C31) were the most competitive activities of the Republic of Croatia in the European market in the late 1980s and early 1990s. Those activities began losing their market share at the end of 1994, and no significant positive change in market competitiveness has been recorded since then. The question is how to achieve and maintain competitiveness, which is the condition of survival in an increasingly demanding environment. Preliminary and previous research on investments points to the assumption that the problem of competitiveness in the observed economic branch essentially boils down to a problem in the quality and efficiency of the investments of associated business entities. This paper tries to give answers to the following questions: What is the investment policy, is there an internal factor for lagging behind in competitiveness, what the other reasons are and how competitiveness can be achieved. By analyzing the investment in key factors of competitiveness in the period 2007 to 2010, consistently established by this paper, the existing data on investment of wood processing and furniture manufacturing entities will be identified, and an AHP investment model will be proposed that takes into account the simultaneous influence of all of the key factors of competitiveness and is the best indicator of the direction to be taken, with the final aim of achieving competitiveness.*

Key words: *wood processing, furniture manufacturing, AHP investment model, competitiveness*

SAŽETAK • *Prerada drva i proizvoda od drva i pluta, osim namještaja; proizvodnja proizvoda od slame i pletarskih materijala (C16) i proizvodnja namještaja (C31) Republike Hrvatske u kasnim 1980-ima i ranim 1990-im godinama bili su konkurentna aktivnost na europskom tržištu. Nakon 1994. godine te djelatnosti počinju gubiti*

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svoje tržišne udjele i do danas nije zabilježena znatnija pozitivna promjena tržišne konkurentnosti. Postavlja se pitanje kako ostvariti i održati konkurentnost, što je uvjet opstanka u sve zahtjevnijem okruženju. Preliminarna i prethodna istraživanja investicijske aktivnosti upućuju na pretpostavku da se problem konkurentnosti promatranoga gospodarstva u osnovi svodi na problem kvalitete i učinkovitosti investicijskih ulaganja pripadajućih gospodarskih subjekata. Kakva je investicijska politika i je li ona unutarnji čimbenik zaostajanja u konkurentnosti, koji su drugi razlozi i kako postići konkurentnost, pitanja su na koja odgovor daje ovaj rad. Analizom ulaganja u ključne čimbenike konkurentnosti u razdoblju od 2007. do 2010. godine, konzistentno utvrđene ovim radom, identificirat će se postojeći model investicijskih ulaganja gospodarskih subjekata prerade drva i proizvodnje namještaja te predložiti AHP model investicijskih ulaganja koji uzima u obzir istodobni utjecaj svih ključnih čimbenika konkurentnosti i najbolji je pokazatelj u kojem smjeru treba krenuti radi postizanja konačnog cilja – osiguranja konkurentnosti.

Ključne riječi: *prerada drva, proizvodnja namještaja, AHP model investicijskih ulaganja, konkurentnost*

1 INTRODUCTION
1. UVOD

Wood processing and manufacture of wood and cork products, excluding furniture, the manufacture of straw and plaiting goods (C16) and manufacture of furniture (C31) were the most competitive activities of the Republic of Croatia in the European market in the late 1980s and early 1990s. C16 and C31 are tags for wood processing sectors according to National Classification of Activities - *Nacionalna Klasifikacija Djelatnosti* (NKD, 2007). These activities began losing their market share at the end of 1994, and no significant positive change in market competitiveness has been recorded since then.

It is a generally accepted fact that socioeconomic development greatly depends on investment, and therefore long-term development can only be achieved through investment, because well targeted investment activity is the primary assumption for all aspects of competitiveness. The above mentioned context makes the problem of investing in wood processing and furniture manufacturing more complicated.

Due to the importance of the observed economic branches and the necessity of adapting to new market relations, a need to establish the key factors of competitiveness in terms of investment arises.

The specific characteristics of wood processing and furniture manufacturing are based on a SWOT analyses and recommendations in the strategic and development documents of the Government of the Republic of Croatia and the European Union (2004). A short analysis of the relative importance of the key factors of competitiveness in wood processing and furniture production provides the justification for investing in those key factors, which comprise of: *f1* - staff education, *f2* - marketing and promotional activities, *f3* - products, services and production processes innovation, *f4* - wood processing and furniture manufacturing technology, *f5* - environmental protection technology, *f6* - energy efficiency technology, *f7* - spatial capacities.

Two pilot studies (Debelić *et al*., 2009a and Debelić *et al*., 2009b) warned about the lack of investment policy for wood processing and furniture manufacture and provided a starting point for the assumption that the orientation and quality of investment is questionable. This paper deals with the research of vindication of the aforementioned subject.

This paper also presents the analysis of competitiveness of wood processing and furniture manufacturing and of the influence of the global economic recession on their operations. This will further add to the vindication of investment in support of competitiveness as well as to the justification of investment in support of the country's regional development.

The main goal of the study is to create an optimizing and efficient investment model that will have practical application in wood processing and furniture manufacturing (Ojurović, 2010).

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

The method was chosen on the basis of the problem, goals and tasks: selection and classification of the sample, choice of the method and instruments of the research, collection and processing of the data.

The goal will be accomplished through a comparison of the existing state and the investment model, gained by applying the selected mathematical methods.

2.1 Selection and classification of the sample
2.1. Izbor i klasifikacija uzorka

By analyzing the data, it was established that in practice the majority of business entities do not actually conduct their officially registered activity, according to NKD 2007 (theoretical classification).

Based on the non-sustainability of these classifications and in order to obtain results that would provide a realistic picture of the priority of investments by organizing them according to the specific area of the investor, which is not the case considering the presented shares of the investors, the acceptability of the empirical starting point was established. In order to set the empirical starting point of the classification of the sample and using the facts that confirm the unacceptability of the theoretical classification, two criteria were defined:

Criterion 1: Finished wood products, the definition and content using customs tariff numbers,

Criterion 2: Technological complexity of the product.

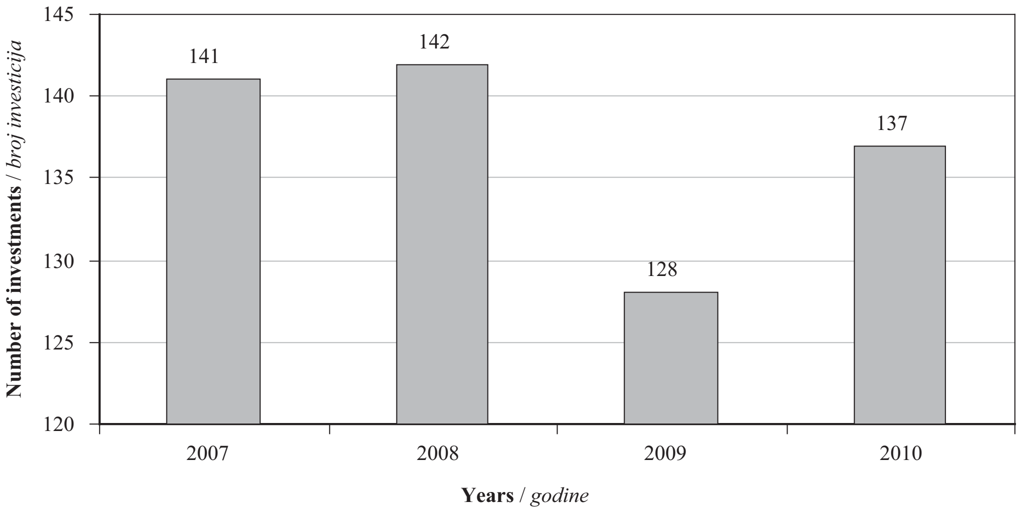

Figure 1 Number of investments per year in the period 2007 to 2010
Slika 1. Broj investicijskih ulaganja po godinama u razdoblju od 2007. do 2010.

According to the empirical starting point, the sample is classified into three subareas of the population:

1. Primary product (PP) – sawn timber, elements,
2. Semi-finished product (SF) – veneer, palettes, packaging, wood houses, briquettes, parquets, floor and ceiling lining,
3. Finished product (FP) – furniture, finished parquet, wood accessories, construction joinery, funeral equipment.

The selection method for units of the sample is stratified sampling. By choosing from the population subareas (PP, SF and FP) and after several selections by means of analyzing the acceptability while taking into account the character of the research and analyzing the investments per investor, 548 investments were gained without annual repetition in the period 2007 to 2010, which represents the size of the research sample and the basis for establishing the existing investment model of wood processing and furniture manufacturing entities (Figure 1).

Sorting the investments according to subareas, the largest number of them (309) belongs to subarea FP. This is logical when the need for systematic and diverse investment in the structure of production of goods with a higher level of finalization is taken into account, and it also demonstrates the limited investment in subarea PP. The ratio in favour of PF and FP, which together give a size of 436 units (investments), when compared to the 112 PP units, affirms the quality of the sample (Figure 2).

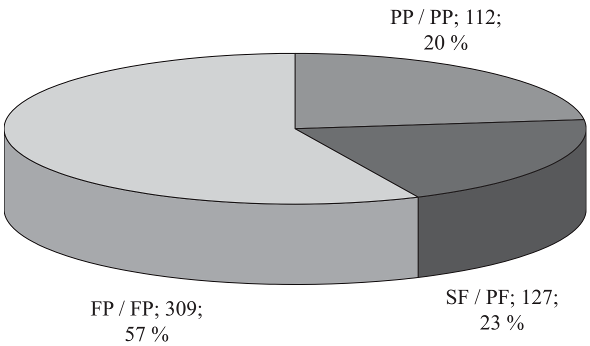

Figure 2 Number of investments per subarea in the period 2007 to 2010
Slika 2. Broj investicijskih ulaganja prema područjima u razdoblju od 2007. do 2010.

2.2 Choice of method and instruments of research
2.2. Izbor metode i instrumenata istraživanja

In all areas of business, at higher levels of decision-making, the process of making decisions, according to their characteristics, belongs to multi-criteria decision-making. Decisions connected to situations in the business environment depend on a large number of mutually-connected and often entirely conflicting criteria. The problem that arises is how to correctly evaluate the importance of the factors and how to create a priority system that can lead to good decisions when choosing the best alternatives. The best known methods for comparing and ranking alternatives in decision-making problems are ELECTRE, PROMETHEE and AHP (Analytic Hierarchy Process).

The most commonly used multi-criteria method, both in individual and group decision-making, is AHP.

In establishing the new scientific investment model, the AHP method was used, supported by the computer program Expert Choice. The method has often been described in detail in literature in the field of mathematics and related fields, so the rest of this paper only contains the basic characteristics (Saaty, 1980).

2.2.1 AHP Method
2.2.1. AHP metoda

AHP is one of the best known methods for making decisions through consistent evaluation of the hierarchy. Since this is an accurate mathematical model realized as PC software with full technical support, in the Expert Choice information format, it is applicable in multi-criteria decision-making. Solving complex decision-making problems is based on their division into components: goals, criteria, sub-criteria, alterna-

Table 1 Scale for determining relevant importance (Saaty, 1980)
Tablica 1. Prikaz skale za određivanje relativnih važnosti (Saaty, 1980)

Verbal evaluation *Verbalna procjena*	**Intensity of importance** *Intenzitet važnosti*	**Explanation** / *Objašnjenje*
extreme preference *ekstremna preferencija*	9	Favouring of one activity over another is proved at the highest level. / *Na najvišoj je razini dokazana prednost jedne aktivnosti pred drugom.*
very strong preference *vrlo stroga preferencija*	7	One activity is strongly favoured over another and its dominance is proved in practice. / *Jedna se aktivnost izrazito favorizira u odnosu prema drugoj i njezina je dominacija dokazana u praksi.*
strong preference *stroga preferencija*	5	On the basic of experience and judgement, strong preference is given to one activity. / *Na osnovi iskustva i procjene daje se izrazita prednost jednoj aktivnosti.*
moderate preference *umjerena preferencija*	3	On the basic of experience and judgement, a slight preference is given to one activity. / *Na osnovi iskustva i procjene mala se prednost daje jednoj aktivnosti.*
equal importance *jednaka važnost*	1	Two activities contribute equally to the goal. *Dvije aktivnosti jednako pridonose cilju.*
intermediate values *međuvrijednosti*	2, 4, 6, 8	Compromise between respective adjacent value judgements. *Kompromis među odgovarajućim susjednim vrijednosnim procjenama.*

tives and decision-makers, which are connected to the model with several levels (hierarchical structure), whereby the goal is at the top and the main criteria are on the first lower level. An important component of AHP is the possibility to account for the priorities (weights) of elements that are on the same level of the hierarchical structure.

An AHP evaluation is based on the decision maker's judgment about the relative importance of each criterion in terms of its contribution to the overall goal, as well as their preferences for the alternatives relative to each criterion. First we set up the decision hierarchy and then generated the input data consisting of comparative judgment (i.e. pairwise comparisons) of decision elements. A mathematical process (eingenvalue method) was used to calculate priorities of the criteria relative to the goal and priorities for the alternatives to each criterion. These priorities were then synthesized to provide a ranking of the alternatives in terms of overall preference.

In order to rank the priorities of investments, a questionnaire was developed that contains investment categories and intensity of importance. Due to its size, only a part of the questionnaire is presented in this paper. The fundamental scale to be used in making the comparison consists of verbal judgments ranging from equal to extreme. Corresponding to those verbal judgments are numerical judgments (1, 3, 5, 7, 9) and compromises (2, 4, 6, 8) between these judgments. The scale for determining relevant importance is shown in Table 1 and an example of a part of the questionnaire for pairwise comparison in Figure 3.

Based on the results of the questionnaire, with the aid of a computer program, rankings of the observed investments were made.

2.3 Collection and processing of data
2.3. Prikupljanje i obrada podataka

The data collection method, within the research base period 2007 to 2010, entails the sample method as the main method, the content analysis as the secondary method and the questionnaire conducted amongst a representative sample of investors for obtaining primary data in the category of economic, social and financial indicators of investors. The method of data collection is in compliance with the goals and the method of the research, and it entails the sample method as the main method and content analysis as the secondary method. The source and type of data are primary and secondary.

Primary data are presented by category, size and structure of investments and the structure and size of the production program. The data was obtained from the following primary sources: investors – official fi-

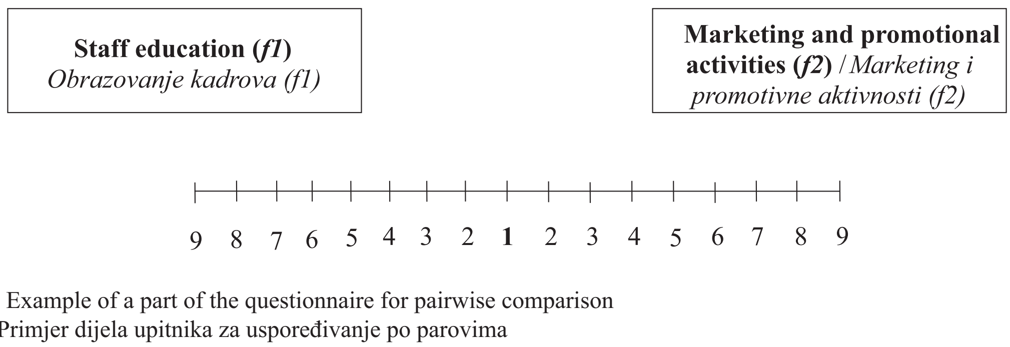

Figure 3 Example of a part of the questionnaire for pairwise comparison
Slika 3. Primjer dijela upitnika za uspoređivanje po parovima

nancial and bookkeeping records and the relevant Ministry – official data contained in development projects, studies, pre-investment and investment projects of investors who applied, during the four-year period, for the awarding of specific-purpose grants of capital aid (horizontal state aid). Indicators for defining the main production program of investors, on the basis of which they are sorted into one of the three subareas of the population, also enter into the primary data.

Secondary data are presented by size of investor, number of employees on the basis of work hours, total revenue, share and structure of exports in total revenue. The data were gained from secondary sources: Central Bureau of Statistics - *Državni zavod za statistiku* (DZS, 2007) and the Financial Agency - *Financijska agencija* (FINA, 2006).

3 RESEARCH RESULTS
3. REZULTATI ISTRAŽIVANJA

3.1 Existing investment model
3.1. Postojeći model investicijskih ulaganja

The priority range of categories of investment of the population in the observed period 2007 to 2010 shows that the category *f4* and *f6* account for the largest share of investment (27 %) and (26 %), respectively, followed by *f7* (21 %), with significant variation from the other lower value categories. Then follow *f5* (12 %) and *f2* (11 %), with approximately the same values. The penultimate category according to the value is *f3* (2 %), and the last category is *f1* (1 %) with an explicitly low share in the number of investments (Table 2).

Table 2 Number of investments according to factors from 2007 to 2010
Tablica 2. Broj investicija prema čimbenicima od 2007. do 2010. godine

Factors *Čimbenici*	Year / *Godina*				Σ
	2007	2008	2009	2010	
f1	1	1	1	0	3
f2	19	12	14	18	63
f3	2	2	5	4	13
f4	28	34	37	50	149
f5	11	21	14	16	62
f6	49	29	32	30	140
f7	31	43	25	19	118
Σ	141	142	128	137	548

3.2 AHP investment model of wood processing and furniture manufacturing entities
3.2. AHP model investicijskih ulaganja gospodarskih subjekata prerade drva i proizvodnje namještaja

The main goal of this research is to establish the AHP investment model of wood processing and furniture manufacturing entities.

For the pairwise comparison, five professionals were recruited with expert knowledge in biotechnology, wood technology, social sciences and economics.

By using the questionnaire for Saaty's scale for comparing items in pairs and the AHP method, supported by the program Expert Choice, five preference matrixes were obtained on the basis of which the weights (priorities) of the alternatives were calculated.

The tabular presentation (Figure 5) gives the priorities of the alternatives by Expert A, whereby variable L is the priority of each alternative. Value 1 is the sum of the priorities. The Saaty scale is used to compare it (Table 1). For example, number 2 in the preference matrix of Expert A (Figure 4) shows that slight favour on the scale 1 to 9 is given to alternative *f2* in relation to alternative *f1*. The value of number 3 shows that on a scale 1 to 9 favour is given to alternative *f3* and not to alternative *f2*. Looking at the ranking of the alternatives by Expert A, it is undoubtedly evident that the largest priorities are alternative *f1* (0.337), followed by alternative *f3* (0.202).

The identification of the variation in individual judgements of the priority of the alternatives as part of the described method of the research in question was not carried out because of the possibility of visual observation of the homogeneity of the group. All five clusters are mutually very close in terms of their preferences, which demonstrates the homogeneity of the group.

3.3 Comparative analysis of the existing and AHP investment model
3.3. Usporedna analiza postojećeg modela i AHP modela investicijskih ulaganja

The main goal of the research in this paper was to develop an optimising and efficient investment model (AHP model) that would have practical application in wood processing and furniture manufacturing in the Republic of Croatia and would confirm the (un)acceptability of the existing investment model. The AHP model should be accepted as a pattern of ranking alternatives (priorities of investments in key factors of com-

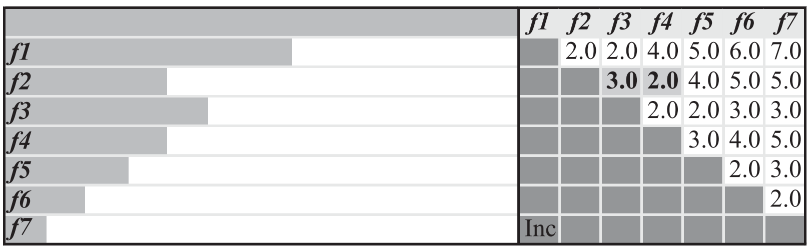

Figure 4 Preference matrix of expert A
Slika 4. Matrica preferencija eksperta A

Prioriteti ulaganja Expert A
- *f1* (L: 0.337)
- *f2* (L: 0.152)
- *f3* (L: 0.202)
- *f4* (L: 0.160)
- *f5* (L: 0.069)
- *f6* (L: 0.045)
- *f7* (L: 0.034)

Figure 5 Ranking of alternatives of expert A
Slika 5. Rangiranje alternativa eksperta A

Table 3 Group decision by experts A, B, C, D and E
Tablica 3. Skupna odluka eksperata A, B, C, D i E

Factors *Čimbenici*	**Year** / *Godina*							**Rank** *Rang*
	A	B	C	D	E	Σ	Σ/5	
f1	0.337	0.394	0.328	0.333	0.413	1,805	0.361	1
f2	0.152	0.128	0.147	0.152	0.146	0.725	0.145	4
f3	0.202	0.156	0.244	0.245	0.09	0.937	0.187	2
f4	0.160	0.174	0.147	0.152	0.196	0.829	0.166	3
f5	0.069	0.032	0.068	0.057	0.062	0.288	0.058	5
f6	0.045	0.046	0.043	0.038	0.062	0.234	0.047	6
f7	0.034	0.07	0.024	0.022	0.032	0.182	0.036	7
Σ	0.999	1.000	1.001	0.999	1.001	5.000	1.000	

Table 4 Comparison of the existing and AHP investment models
Tablica 4. Usporedba postojećeg modela i AHP modela investicija

Rank *Rang*	**Existing investment model** / *Postojeći investicijski model*	**AHP investment model** / *AHP investicijski model*
1	*f4*	*f1*
2	*f6*	*f3*
3	*f7*	*f4*
4	*f2*	*f2*
5	*f5*	*f5*
6	*f3*	*f6*
7	*f1*	*f7*

petitiveness) that provides competitiveness in the long run, as determined by scientific knowledge. The results of comparison of the existing and of the AHP investment models are shown in Table 4.

Non-conformity in the priority ranking of five alternatives and the conformity of two alternatives of the observed investment models, confirm as follows:

1. the existing investment model of wood processing and furniture manufacturing entities in the Republic of Croatia does not support competitiveness and sustainable development,
2. investing in staff education, as a presumed key factor of competitiveness, is not at a satisfactory level and is an internal factor of wood processing and furniture manufacturing lagging behind in terms of competitiveness,
3. the systemisation and quality of investments have an effect on the achievement of excellence in business and production, which also contributes to preparedness for market changes,
4. the recommendations for the development of wood processing and furniture manufacturing in the Republic of Croatia, in terms of focussing on investments, as defined by the industrial wood and paper development strategy, are not operational.

4 DISCUSSION AND CONCLUSION
4. DISKUSIJA I ZAKLJUČAK

The existing model of ranking the key factors of competitiveness set the following ranking of priorities, from the highest to the lowest: wood processing and furniture manufacturing technology, energy efficiency, environmental protection, spatial capacities, marketing, innovation and, lastly, knowledge. The above presented ranking of priorities deviates entirely from the AHP investment model, which is accepted as a pattern of new development. This leads to the conclusion that the existing model is not acceptable for supporting the competitiveness and sustainable development of wood processing and furniture manufacturing.

The AHP investment model, which is established on scientific bases and takes into consideration generally-accepted knowledge and understanding and the results of expert and economic analyses, establishes the following ranking of the priority of key factors of competitiveness, from high to low: knowledge, innovation, wood processing and furniture manufacturing technology, marketing, environment, energy efficiency and, lastly, spatial capacities.

The AHP investment model should primarily be viewed within the context of the semi-finished and finished product subareas because the level of investment in the primary product subarea is limited. Products of a higher technological processing level and added value are a need imposed by the demands of the open market, but the fact that the primary processing level is essential for these products should not be neglected, or in other words, not all business entities can deal with value added products.

The new development direction has the logic of a series of key factors of competitiveness, according to which each lower factor in the series is dependent on the how the previous factor, of higher importance, is embedded into it.

Knowledge is the starting point of ‘everything’ and of all the factors of competitiveness. On the basis of knowledge, the idea of innovativeness is created - which new products, services, processes – at what time - on which market - and how. Appropriate technology is required to produce something new. A new product needs to be directed at the market with the aim of being accepted and expecting an increasing demand for it, followed by marketing and promotional activities. When implementing the aforementioned factors of competitiveness, the principle of environmental protection must be observed, this being the basis of business and development strategies. Adherence to environmental standards and products, production and technology that are characterised by high energy efficiency are increasingly important elements of competitiveness, which requires the implementation of factors of energy efficiency technologies and, finally, spatial capacities as a material necessity.

The AHP optimising investment model is an indicator of the direction to be taken by wood processing and furniture manufacturing with the ultimate goal of achieving competitiveness and sustainability. The model demands systematic and simultaneous investment in all key factors of competitiveness, respecting the ranking of priorities as well as the size, efficiency and effectiveness of investment. Raising the level of competiveness and productivity through the development of modern types of production and expansion and at the same time the improvement of export quality can be achieved primarily through actions related to human potential. The following measures are essential to improve competitiveness: raising the general level of education, and in particular the development of human resources for the specific needs of business and production; systematic training aimed at improving the necessary knowledge and skills; the creation of an environment that encourages development and innovation; and a better networking of scientific institutions.

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The Dilemma Whether to Produce Glued or Sawn Wooden Beams?

Dilema: proizvoditi lijepljene ili piljene drvene grede?

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ABSTRACT • *This article gives an overview of the contemporary development of wood production in the Czech Republic with the focus on the production of static structural members. This issue refers to literary sources of several authors dealing with the history and development of sawmills and adaptations of production strategies to the current trends. The study is based on information collected and assessed during the sawmill operations used by wood processing companies to make strategic decisions. Interaction of these input data and information acquired from the available literature indicates the possibility of development and specialization of the existing sawmills in upcoming years. Nearly 20 per cent of round timber is processed into static structural members, wooden beams. Considering the rising prices of input raw material, the question of the extent of cost-effectiveness and economy of sawn structural members arises. This article is aimed to clarify the seissues and compare the production costs of sawn and glued structural members used in common wooden constructions, such as roof frames, prefabricated houses, etc. This may have an impact not only on sawmills but also on the extent of use of thistype of wooden construction products. The question is whether the new restructuring of sawmills is coming or not?*

Key words: *production of static structural members, trends, production of BSH and KVH, sawn wooden beams, timber costs, wooden structures, cost-effectiveness.*

SAŽETAK • *U radu se daje pregled suvremenog razvoja drvne proizvodnje na području Republike Češke, s naglaskom na proizvodnju statičkih strukturnih elemenata.U pregledu se navode radovi nekoliko autora koji obrađuju povijest i razvoj pilana te strateške prilagodbe proizvodnje trendovima. Studija se koristi informacijama prikupljenima tijekom proizvodnje u pilani, na temelju kojih tvrtke za preradu drva donose strateške odluke. Povezivanjem tih ulaznih podataka i informacija iz dostupne literature dobiva se perspektiva razvoja i specijalizacije suvremenih pilana u idućim godinama. Gotovo 20 % volumena oblog drva prerađuje se u statičke strukturne elemente – drvene grede. S obzirom na rast cijena ulazne sirovine, postavlja se pitanje isplativosti i ekonomičnosti proizvodnje piljenih strukturnih elemenata.Cilj je ovog članka objasniti tu problematiku i usporediti troškove proizvodnje piljenih i lijepljenih strukturnih elemenata koji se obično upotrebljavaju u drvenim konstrukcijama kao što su krovne konstrukcije, montažne kuće i sl. To može utjecati ne samo na proizvodnju u pilanama, već i na masovnost uporabe takvih vrsta drvenih građevnih proizvoda. Pritom se nameće pitanje hoće li doći do novog preustroja pilana ili ne.*

Ključne riječi: *proizvodnja statičkih strukturnih elemenata, trendovi, proizvodnja BSH i KVH greda, piljene drvene grede, troškovi drvne sirovine, drvene konstrukcije, isplativost.*

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1 INTRODUCTION
1. UVOD

Every man dealing with wood processing is sure to be familiar with the timber market in the central Europe and the impact it has on wood processing companies. The current development does not meet the expectations of sawmills. The price of unprocessed timber and wood chips has been rising throughout the last two years and this fact has affected adversely the development of sawmills and advanced processing plants. During the past few years, sawmill production has gone through significant changes, and a large number of small-scale production plants were set up as a response to the changing demands of customers. Due to the new technology, such as the use of mobile saws, entrepreneurs had to redirect their production to a new way of cutting wood corresponding to new customers' requirements. However, as a result of the price of timber, a large number of companies have some serious financial difficulties and are on the verge of bankruptcy. However, such stagnation is equally damaging for some medium sawmills dealing with the production of structural members. Low demand for these products, which used to be a cash cow for many companies in the building market, resulted in the fact that nowadays wood-companies are incapable of sustaining their volume of production, as the increase of end product prices is considerably lower than the rise of costs of input raw materials. Naturally, large-scale sawmills have also been facing the price increase of input materials and annual turnover drop. The dynamic expansion of sawmills in the Czech Republic has been replaced by stagnation or decline, which is still going on. Many companies have gone in search of new products hoping that a wider product range would make them more successful. A possibility might be the production of glued structural members. The objective of this article is to show how the Czech sawmills can benefit from such a production and why a glued static structural member (i.e. a structural member that bears static load) can replace a sawn static structural member. The point I want to make here is that the production of glued static elements has the potential to initiate a new development in this business.

Lumbering has undergone great changes both in the working procedures and extraction technology in the past decade. We have been witnessing a rapidly increasing proportion of harvester logging and, as far as round logs are concerned, logs of 3 to 6 m have become the most common sawmill products. A large number of sawmill companies currently processing logs of this length and do not have to shorten them in further process of long round timber. Nowadays, they can purchase logs of the required quality, length and diameter. On the contrary, the companies processing long logs have to deal with the problem of requiring the assortment whose price has risen along with its demand. Looking for timber, they have to face its price increase caused by rising demand. The development of the sawmill product range is one of the reasons for the stagnation of the Czech sawmill industry. In the recent years (2007-2009), the average round timber price was EUR 65.5 (shipping included). In the following years, the price has rapidly increased to EUR 94 (shipping included). Such an astonishing increase of the round log price occurred in only two years and consequently many companies may go out of business. Figure 1 gives a survey of the recent development of round timber price, according to data of the three largest Czech wood industry companies.

As the German website (www.euwid-holz.de) reads, the development of the timber price in Poland, Germany, Austria, Sweden, Norway and Great Britain has been quite similar. The timber market has been at a standstill as well. So, for instance, a significant decline in lumber output can be noticed in Austria in the third quarter of the last year (www.euwid-holz.de).

Table 1 presents an overview of the Czech sawmills in order of their annual wood processing capacity. The data come from several sources (Pražan *et al*, 2007; Bomba *et al*, 2009). Based on the results of the

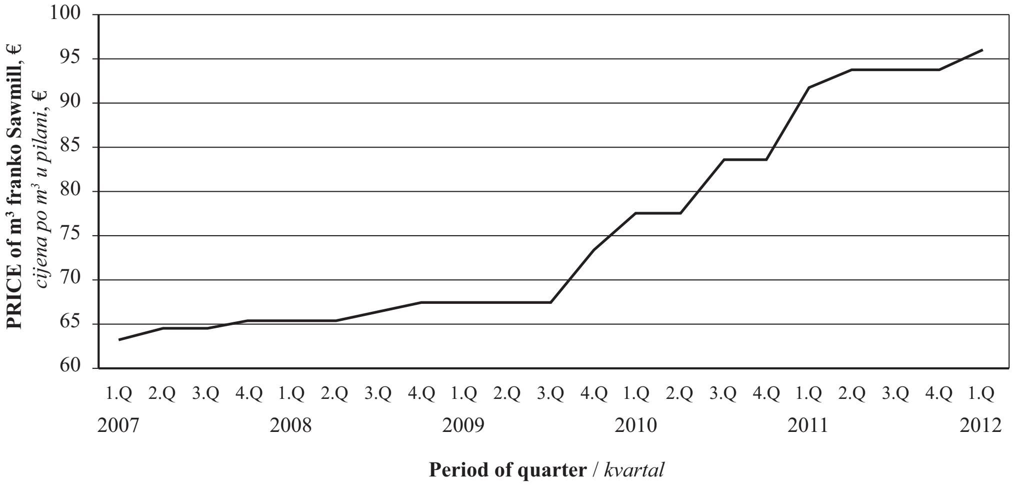

Figure 1 Development of round timber price in the Czech Republic
Slika 1. Rast cijena oblovine u Republici Češkoj

Table 1 Survey of Czech sawmills based on their timber capacity (Pražan *et al*, 2007; Bomba *et al*, 2009)
Tablica 1. Podjela čeških pilana na temelju kapaciteta (Pražan *et al*, 2007; Bomba *et al*, 2009)

Company size *Veličina pilane*	**Annual timber capacity, thousands of cubic meters a year** *Godišnji kapacitet proreza izražen u tisućama kubičnih metara*	**Annual timber output, cubic meter a year** *Godišnji izlaz piljene građe izražen u kubičnim metrima*	**Number of companies within the category** *Broj tvrtki*
The largest sawmills *najveće pilane*	200-1,100	3,760,000	5
	80-100	370,000	4
	50-75	295,000	5
Medium sawmills *srednje velike pilane*	20-50	1,000,000	30
Small sawmills *male pilane*	10-20	750,000	60
The smallest sawmills *najmanje pilane*	<10	1,000,000	1,400-2,000

research, assessment was made of most small or medium sawmills dealing with the production of sawn static structural members, or to be specific, the production of structural beams for building purposes. Building timber or beams for building purposes (roof frames, carpenter's structures, etc.) account for 52 % of the output of these sawmills. This means that almost 20 % of sawmill round timber is processed into structural lumber by the logging companies in the Czech Republic. It represents an inconceivable volume of timber that ends up in the building industry market. The falling demand for the sawn static structural members has a strong impact on small and medium wood processing companies. In addition to that, the growing price of the input raw material intended for cutting structural members and the struggle to break into this market caused the increase of the end prices of structural and building timber. The prices of end products, such as beams and structural timber, increased by 25 % in average, although the price of the round wood entering the production rose by 43 %. The decrease of price of end products has forced the companies to put the product prices down. Consequently, this should have led to the optimization of timber processing, or possibly to a modification of the procedure technology. Unfortunately, due to low technology equipment of most small and medium plants, their managers or owners were not able to cut down on expenses and it resulted in the fact that such companies are on the verge of bankruptcy or going out of business.

As a consequence of ever increasing round wood prices, there is a serious increase of prices of end products, such as beams, structural elements of great size and length. These products are facing strong competition of products such as KVH (structural extended timber) and BSH (layered lamellar timber) at these times. According to Table 2, the products BSH are being available in the market at extraordinarily low prices. The general scheme of glued beam technology is shown in Figure 2.

Comparing the characteristics of BSH, KVH beams and sawn beams, the glued beams proved to have significantly higher strength than the sawn beams, as shown in Table 3. Evidently, the use of glued structural members of KVH or BSH would save material in a common building construction (roof frames, ceilings, wooden constructions and so on). Another benefit of glued structural members is that it enables to select the visual aspect quality or industrial quality. What do those terms stand for? Visual aspect quality puts an emphasis on re-

Table 2 Survey of prices of BSH beams in Germany (http://www.euwid-holz.de)
Tablica 2. Pregled cijena BSH drvenih greda u Njemačkoj (http://www.euwid-holz.de)

EUWID Preis mirror of BSH beams in Germany December 2011					
in €/m³	22.12.2011	17.11.2011	29.9.2011	2.12.2010	comp.% 2011/2010
Beams SI					
60x100-160 mm	390-400	400-410	405-410	405-415	-4
80x100-200 mm	385-400	395-410	400-410	400-410	-3
100/120x120-320 mm	380-385	390-395	390-395	395-405	-4
140/160x140-400 mm	375-380	385-390	385-390	395-405	-6
180/240x200-400 mm	370-380	380-390	385-390	390-400	-5
Total price SI	380-395	390-405	395-405	400-410	-4
Total price nSI	365-375	375-385	375-385	385-395	-5
Commissions					
Commissions SI	395-410	405-415	405-420	410-435	-5
Total price of beams SI/nSI of all standard profiles selected, length selected < 3 m³ contract volume average purchase price in stores, franco					
2011 Europischer Wirtschaftsdienst GmbH					

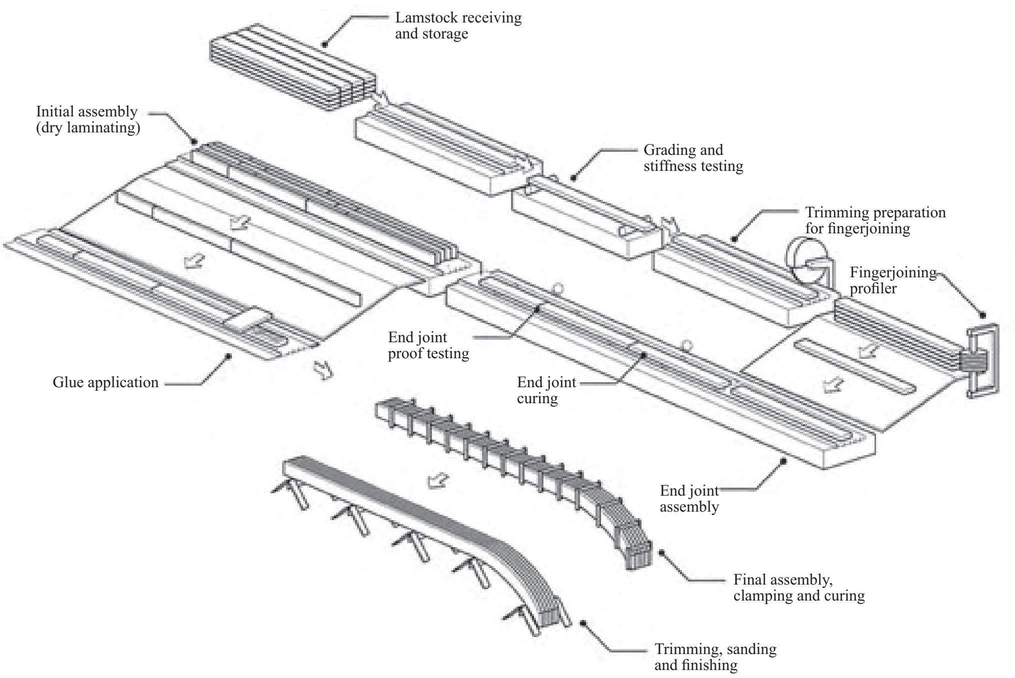

Figure 2 Manufacture of glued beams BSH (http://www.cwc.ca/index.php/en/wood-products/glulam/manufacture)
Slika 2. Shema proizvodnog procesa lijepljenih greda BSH (http://www.cwc.ca/index.php/en/wood-products/glulam/manufacture)

moval of flaws that could lower the strength as well as flaws that could lower the aesthetic quality or visual appearance of the beam. The greatest concerns are related to coloring, dark knots, outpouring of resin, etc. As opposed to it, industrial beam quality can include the above mentioned aesthetic flaws, which do not affect the strength. A significant aspect of the visual quality is the fact that follow-up processing, such as fixing of aesthetic flaws, is not necessary. Apart from the differences mentioned above, the end price makes the main difference between the visual aspect and industrial quality.

The quality of the industrial and visual aspects can also be found in sawn structural members. To be specific, the quality of the visual aspect does not include any roundness. The industrial beam usually includes such a roundness without lowering the timber strength. The roundness that originates from a round trunk provides higher strength based on the fact that wood fibers have not been broken by cutting. However, the industrial quality production of sawn beams was almost given up by lumbermen, although it considerably increases the cutting yield and lowers the end product costs. The reason lies in its poor marketability. Most customers consider that a sawmill manager wants to cheat them trying to sell them the beam below the required quality and strength because it has no edges. As there is almost no way to change the customer's mind, nothing else remains but to meet his demands.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Twelve sawmill companies and three major manufacturers of BSH and KVH products were questioned directly for the purpose of this research, which was conducted in the period 2009-2011. In addition to it, contact was made with the structural engineer who carried out the calculation of the carrying capacity of sawn wood beams as well as glued beams KVH and BSH. Furthermore, other thirty sawmill companies were interviewed in order to collect information on the development of round timber purchase price in the years 2007-2012. This way significant and essential information was obtained with the aim to develop an analytical model for comparing the beams of BSH, KVH and sawn beams.

On the basis of static calculations, comparison was made between the carrying capacity of glued beams and sawn wood beams. The static calculations were applied to the constructions of ten different house roofs in order to compare the material savings when using sawn beams or glued beams. Subsequently, comparison was made between the manufacturing technologies of sawn beams and glued beams in terms of the production costs and timber yield. These data were then transferred into the economic calculation of the end product price – for this purposes, a computing model was built complemented with timber yield data, the actual price of input materials and the actual production costs. The actual prices and production costs were obtained from the manufacturers in the Czech Republic. For the sake of objectivity, using different technological systems, only the above average values of the production expenses were used in the calculations. In conclusion of this research, comparison was made of all available information and general conclusions that might be used in practice.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

According to Table 3, the glued structural members show better strength than sawn wood beams. This

Table 3 Comparison of mechanical properties of sawn beams and glued beams of KVH and BSH (ČSN EN 1995-1-1, Praha 2006)
Tablica 3. Usporedba mehaničkih svojstava piljenih i lijepljenih greda, KVH i BSH

Properties / *svojstva*	**Sawn wood** $_{w=50\%}$	**KVH** $_{w=15\%}$	**BSH** $_{w=12\%}$
Bending strength $f_{m,k}$, MPa / *Čvrstoća* *savijanja, MPa*	22	24	24
Fracture strength parallel with fibers $f_{t,0,k}$, MPa *Čvrstoća loma paralelno s vlakancima, MPa*	13	14	16.5
Fracture strength vertical to fibers $f_{t,90,k}$, MPa *Čvrstoća loma okomito na vlakanca, MPa*	0.5	5	0.4
Compressive strength parallel with fibers $f_{c,0,k}$, MPa *Čvrstoća na tlak paralelno s vlakancima, MPa*	20	21	24
Compressive strength vertical to fibers $f_{c,90,k}$, MPa *Čvrstoća na tlak okomito na vlakanca, MPa*	2.4	2.5	2.7
Shear strength $f_{v,k}$, MPa / *Čvrstoća na smicanje, MPa*	2.4	2.5	2.7

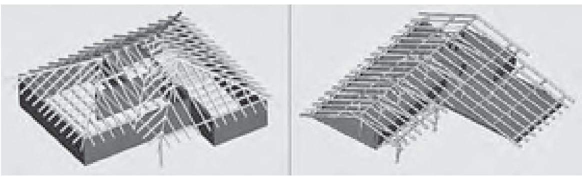

Figure 3 Roof construction
Slika 3. Krovne konstrukcije

implies that it is possible to economize with wood material used in building industry. To prove this point, the static calculation was carried out in order to compare sawn beams and glued beams under the same static load and the same span. To provide practical evidence, the computing was accomplished on several construction models of a no name company. Gable and hip roof constructions of bungalows including a habitable attic and a wooden ceiling were also considered. Using statistical computing tools, the expected economic effects of the material used for the construction in question were proven with the roof frame or the ceiling load. A better use was confirmed of both KVH and BSH beams compared to sawn wood beams. However, the efficiency of KVH beams was only proven if used for structural members of the roof frame such as rafters and purlins of small size. Given the range of commonly produced dimensions of KVH beams, it was not possible to substitute all structural members of calculated constructions. In contrast to it, with the help of commonly available dimensions of BSH beams, the structural members in question could be fully replaced.

All structural elements of the roof frame such as rafters, purlins, ribbands, collar-beams and piers were gradually substituted by the glued BHS beams. In this way significant savings of material were achieved ranging from 12.5 to 25 % of the total volume. Table 4 can be used as an illustration, as it presents the results of all static calculations of the structural members made of sawn beam and BSH beam. Positive economic effects can be readily identified.

Taking into account the economic effects, comparison was made of production costs of sawn wood beams and glued BSH beams based on static calculations. If the end price of BSH products used for a wooden construction is lower or equal, this new strategy can have an impact on future trends and development of sawmills.

The production of glued and sawn beams is already characterized by the process of sawing. Comparing all the three technologies of beam production, most similarities are found between the sawn prism and glued prism of KVH, although there are some differences as well. On the contrary, the manufacturing of BSH beams is completely different because it is made of 40-52 mm thick lamellas. It is the first variance that can influence cutting.

Table 4 Comparison of static computation results for sawn and glued BSH beams
Tablica 4. Usporedba statičkih izračuna za piljene i lijepljene BSH grede

	Sawn wood/ *Piljena greda*					**BSH** / *Lamelirana greda BSH*					**Economy** *Ušteda* %
	b mm	*h* mm	*l* mm	*S* m²	*V* m³	*b* mm	*h* mm	*l* mm	*S* m²	*V* m³	
Purlin / *Sljeme*	180	260	8000	0.047	0.3744	160	260	3000	0.0416	0.3328	12.5
	180	240	7000	0.043	0.3024	160	240	7000	0.0384	0.2688	12.5
	160	200	5400	0.032	0.1728	140	200	5400	0.028	0.1512	14.3
Rafter / *Krovna greda*	100	180	7000	0.018	0.126	80	180	7000	0.0144	0.1008	25.0
	100	160	6000	0.016	0.096	80	160	6000	0.0128	0.0768	25.0
	120	180	8000	0.022	0.1728	80	200	3000	0.016	0.128	35.0
Pier / *Stup*	160	160	3000	0.026	0.0768	152	152	3000	0.0231	0.0693	10.8
	140	140	3000	0.020	0.0588	135	135	3000	0.0182	0.0546	7.5

b – beam width / *širina grede*; *h* – beam height / *visina grede*; *l* – beam length / duljina grede; S – cross-sectional area / *površina poprečnog presjeka*; *V* – beam volume / *volumen grede*.

Whereas cutting of sawn and KVH beams show similarities, their manufacturing is completely different. The first difference lies in drying. The sawn beam is left to dry out spontaneously, while the KVH beam is dried artificially to the moisture of 15 ± 3 %. The process of drying indicates that during the production of KVH beams, the cutting should go through the beam centre in order to cut out the beam pith. If the pith is left inside the beam, it can leave wider cracks after drying. During manufacturing of structural timber, beams with cracks must be shortened in order to sustain the strength of the final product. The best way of manufacturing KVH beams is to remove the pith by inserting a central plank or board. Unfortunately, putting any component inside KVH timber influences adversely the size of the prism loading area. This loading area is growing and therefore the round timber with bigger pin diameter must be chosen. It lowers the timber yield during the production of KVH prism and raises the production costs. With the price of round timber, which is rising proportionally to the increase of round timber diameter, the costs of input raw material for the production of KVH prisms are also increasing. Therefore, the money spent on round timber, cutting, drying and manufacturing of KVH reaches the same value or higher than the production of BSH prisms.

Subsequently, the costs were compared of entry raw material intended for the production of KVH and BSH prisms with dimensions 100x180x6000 mm, which can be used for a common roof rafter. For cutting KVH, which requires cutting through the pith and putting two prisms next to each other, round timber is needed with the cog diameter of 31 cm (bark excluded) and the length of 3.7 m (based on available technology). This length can more or less cover the cogged joint and shortening of flaws. On the contrary, BSH beam can be cut into 5 pieces of round timber with cog diameter of 13 cm and the length of 3 m. Despite the fact that it is necessary to saw more logs from large round timber volume, significant economic effects can be achieved, reaching approximately EUR 16, due to lower raw material costs (the difference in thickness 1a:2b).

Comparing the cutting of timber intended for manufacturing of sawn prisms and KVH or BSH prisms of the same dimensions, the following conclusion was made. Assuming that sharp-edged timber is produced with the help of standard technology, cutting of 20-55 cm cog diameter by frame saw and of 10-20 cm cog diameter by prism or aggregate assembly line, the production of KVH beams would have the biggest cog diameter of cut timber as shown in Figure 3. This fact arises the question of production effectiveness of KVH beams.

Apart from cutting, the drying process is also crucial as due to large cutting dimensions it must be performed slowly so as to prevent creating big cracks. Drying increases the costs 2.5 to 3.5 times compared to lamellar cutting intended for the production of BSH beams (Janik, 1960). The current rise of energy prices has an adverse effect on the costs of KVH prism production. The expenses of drying of lamellar cutting are approximately EUR 15.5 for 1 cubic meter down to a

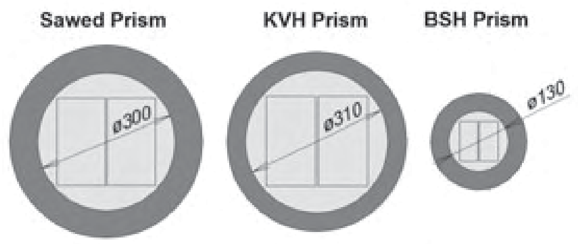

Figure 3 Different crosscuts
Slika 3. Razlike u presjeku piljenja

moisture of 10 %, whereas the cost of a KVH beam dried down to a moisture of 15 % is approximately EUR 52. The above are average prices and differ with respect to cutting dimensions, type of heating, drying procedure technology, input moisture, outside temperature, etc. Anyway, the manufacturing costs of KVH prisms reach the expenses of manufacturing BSH prisms, which is a far more complex and demanding procedure. The question remains whether it is still convenient to produce structural beams (KVH) for building purposes and carpenter structures since the economic effects of the use of KVH of larger dimensions are not up to our expectations.

The question of production effectiveness of KVH prism is and will be left to answer by the very manufacturers of this product. The following paragraphs are focused on BSH beams and sawn static beams, particularly an illustrative comparison, optimization and production calculations.

For comparing a sawn beam and a glued beam (BSH), it is necessary to consider all their characteristics. The consideration must be based on the following facts. The sawn beam has to be cut with an excess for drying. Such excesses are determined by the Czech State Norm (CSN 49 1109). The glued timber is dried (the temperature is usually above 60 °C), meaning that after such drying no insect embryos or fungi can be left hidden. This is why at least the costs of wood impregnation (Kozárek, 2009) via soaking must be added to the end price of the sawn beam. The BSH beam has no flaws, such as excessive or rotten knots, which would decrease its strength. BSH beams can be ruled out because they are made in accordance with CSN EN 386. Therefore, the use of sawmill round timber of AB quality guarantees to eliminate all flaws that can reduce the strength. Another advantage of the BSH beam is the planed surface. This is why it can also be used in constructions requiring visual quality. When comparing the beam properties, the roof construction with visual elements was taken into consideration, and hence the price of sawn beams has been increased by the price of planing.

Czech state standards were used for the calculation and optimization of manufacturing of sawn beams and glued BSH beams. These standards specify excesses required due to drying, timber takeover, BSH prism production procedures, sawn prism production procedures (Fronius, 1989; Friess, 2003), etc. According to these standards it is possible to make impartial judgments of timber and manufacturing parameters. The

Table 5 Dependence of the yield on diameter and length (Fronius, 1991)
Tablica 5. Ovisnost iskorištenja o promjeru i duljini trupaca (Fronius, 1991)

Tenon *Promjer na tanjem kraju* cm	**Area** *Površina* m^2	**Side** *Strana* cm	**Square area** *Površina kvadrata* m^2	**Yield** *Iskorištenje* %	**Maximum theoretical yield depending on length** *Najveće teorijsko iskorištenje ovisno o duljini trupca,* %			
					3 m	4 m	5 m	**6 m**
14	0.015394	9.90	0.0098	63.66	51.93651	48.74120	45.83195	43.17560
16	0.020106	11.31	0.0128	63.66	53.21622	50.30082	47.61860	45.14534
18	0.025447	12.73	0.0162	63.66	54.24452	51.56620	49.08145	46.77206
20	0.031416	14.14	0.0200	63.66	55.08879	52.61320	50.30082	48.13760
22	0.038013	15.56	0.0242	63.66	55.79429	53.49374	51.33261	49.29984
24	0.045239	16.97	0.0288	63.66	56.39262	64.24452	52.21687	60.30082
26	0.053093	18.38	0.0338	63.66	56.90644	54.69222	52.98307	51.17182
28	0.061575	19.80	0.0392	63.66	57.35247	55.45666	53.65331	51.93651
30	0.070686	21.21	0.0450	63.66	57.74329	55.95291	54.24452	52.61320
32	0.080425	22.63	0.0512	63.66	58.08854	56.39262	54.76989	53.21622
34	0.090792	24.04	0.0578	63.66	58.39575	56.78491	55.23982	53.75694
36	0.101788	25.46	0.0648	63.66	58.67088	57.13707	55.66262	54.24452
38	0.113411	26.87	0.0722	63.66	58.91870	57.45493	56.04505	54.68643
40	0.125664	28.28	0.0800	63.66	59.14308	57.74329	56.39262	55.08879

data on manufacturing of glued structural members and input costs of cutting is gained from the statistics made by three companies operating in the Czech Republic and Germany.

The possibility of reducing the production price of long beams lies in cutting, trunk convergence and price of input round timber. Based on the statistical analysis of electronic takeovers of timber carried out in six companies, it can be affirmed that the convergence of spruce round timber commonly exceeds 1 cm/m. This finding confirms the affirmation that the yield of central beam falls proportionally to its length. For the purpose of objectivity, the theoretical convergence value of 1 cm/m, set by the Czech state standard, was lowered in our calculations proportionally to the beam length especially in case sharp-edged beams (with no rounding). No claim is made that convergence of short cuttings does not equally affect the yield. The effect is absolutely the same, yet the yield of central cutting is a little higher. It can be concluded that in cutting long static structural members the yield falls but the price of the very product rises. As opposed to it, in cutting the lamellas for the production of BSH beams, short round timber can be used because lamellas can be extended up to the required length with the help of cogged joints in the production of beams. For BSH beams with smaller diameter, cutting can be made with smaller tenon diameter and the length of 3- 4 m. In this way, the costs of input round timber are reduced. Despite the lower yields achieved with smaller diameters of round timber, it is always suitable to select such round logs because their input price is significantly lower. Proportionality of the yield to the diameter and length is presented in Table 5 (Fronius, 1991). The difference between the price of cutting long beams and lamellas can pay the manufacturing of the BSH glued beams.

Based on the above, many calculations have been executed considering timber cutting at the length of 3 or 4 meters. Subsequently, it was concluded that a good price difference can be achieved in cutting provided that the cut beam is longer than 5 meters. Price difference of input raw materials grows with the increase of the beam length and the production of BSH beams is becoming less costly than the production of sawn beam. This is the turning point when, due to its economic efficiency, the production of glued beams instead of sawn beams started to be taken into consideration. This is why the following comparison and calculation will be only carried out with the beams longer than 5 meters.

The illustrative example of calculation and comparison is made with standard dimensions of a rafter at the crosscut of 100x180 mm and the length of 7 meters. The static computing proves that a glued beam with the diameter of 80x180 mm and the length of 7m can be used for supporting the same load. Using the glued prisms brings the savings of the volume of 0.025 m^3 per 1 piece. As for the whole roof frame construction, in which 34 pieces are used, the saving of 0.857 m^3 can be achieved. Compared with sawn beams, manufacturing of BSH beams with the diameter of 80x180x7000 mm requires more timber. This is the result of excesses caused by planing and drying. In spite of that, the input timber costs of manufacturing BSH beams are lower than the costs of sawn beams.

As far as cutting is concerned, the glued beam is produced from lamellas with the diameter of 40x90 mm and dimensions installed 38x85 mm (the excess for drying is specified by the standard). The installed size is cut to final dimensions 36x80 mm by planing. The thickness of 36 mm is obtained after manufacturing of an "endless" lamella and the width of 80 mm after sticking a beam. As opposed to that, the sawn beam is manufactured with the excess intended for drying, specified by the standard, and with the excess for planing, and namely the sawn dimensions of 107x189 mm. Just one prism is cut and then it is split into two beams. Thereby, an almost square cut is obtained raising the yield of central cutting. To make such cutting and manufacture sharp-edged lumber, it is necessary to provide round timber with the length of 7 m and pin diameter of 31 cm.

The volume of round timber intended for manufacturing beams is 0.654 m^3. The price of the beam is derived from the cutting calculation. The total is reached by summing the average cutting price per 1 m^3 (in the Czech Republic it comes to EUR 32.6), and the volume of the cut piece multiplied by the central cutting yield (43.28 %) and the input price of round timber (93.8 EUR/m^3 x 0.654 m^3). The price of two central cutting beams equals EUR 48.9. After adding the price of planing (2 EUR/m^2), the total price of EUR 16.9 is obtained. Then the price of colorless impregnation is added, which provides protection against ligniperdous insects and fungi. The going price is 20.4 EUR/m^3 so the total cost of impregnation amounts to EUR 5.4. Altogether the price of two beams installed with the dimensions of 100x180 mm comes to EUR 48.9 + EUR 16.9 + EUR 5.4 = EUR 71.2. It corresponds to the price of EUR 279 recalculated to 1m^3 of timber according to dimensions installed. Cost price and standard profit of about 20 % makes the total price of 334.6 EUR/m^3.

The manufacturing of BSH beams is again an issue. It is necessary to make a sufficient quantity of lamellas with the dimensions 40x90 mm. There are two options for manufacturing the beam. The first is to cut a thin round timber, namely lamellas of 40x90 mm, and the second is to cut a thick round timber, lamellas of 42x180 mm. It can raise the question why to cut these lamellas to a specific size when it is possible to glue the prism of the dimension 166x180 mm and then split it up and plane. Unfortunately, this alternative is financially more demanding. This leads back to the idea of cutting the lamellas to the size of 40x90 mm. Two lamellas have to be cut in parallel in order to get sharp-edged cuttings. Round timber with the length of 3 m or 4 m and of C quality is used for cutting. When calculating timber required for the production of lamellas, bonding timber must also be taken into account and it ranges from 78 to 85 %, planing excluded (cutting the flaws). Better quality of timber results in a better yield. In this paper, the yield of 78 % will be taken into account. To achieve objectivity and efficiency, the computing is related to the manufacturing of two beams. It means that 15 pieces needed to be cut out of a 3 meter long round timber with the pin diameter of 13 cm, or 11.2 pieces out of 4 meter long round timber. The volume of cut round timber is 0.741 m^3 with 3 m round timber and 0.793 m^3 with 4 m round timber. Despite the larger volume of round timber compared to the manufacturing of sawn beams, the cost of timber is considerably lower. This is due to the fact that the price of round timber for the C quality with the thickness class 1a amounts to EUR 59.2. Hereby, the difference can be seen between input raw material needed for glued beams and sawn beam: 93.8 EUR/m^3 against 59.2 EUR/ m^3. Although the consumption of input round timber is higher by approximately 0.139 m^3, the savings are still considerable. The price of timber, assuming the same price of cutting, comes to EUR 43.3 with 3 m round timber and EUR 45 with 4 m timber. However, to reach the final product, the BSH beam, there is still a long way to go. The cut timber needs to get dry. Drying is done according to the set of rules for this procedure, namely at the maximum temperature of 90 °C. Based on our own statistics (information from 5 woodworking companies) of timber drying, the average price of drying 40 mm thick timber is approximately 16.5 EUR/m^3. Then timber is processed with the aim to eliminate the flaws such as knots, cross-grains, rot, etc. After that, timber is planed to the desired thickness and shortened to desired length. The adhesive is then applied on each lamella and then comes the pressing in a vertical press. After pressing, the beam is planed to the right thickness in order to match the second set of dimensions. In order to calculate the production of BSH beams, renowned manufacturers of these products were contacted and they provided the data for the calculation and optimization. The computing includes melamine-formaldehyde adhesive and the recommended layer applied on 1 m^2, which ranges around 380 g/m^2. The amount of adhesive consumed in the production of two beams comes to the price of EUR 4.1. Production costs for 1 m^3 of glued structural member range between 40 and 62 EUR/m^3 depending on the dimensions of the manufactured product. The price of this manufacturing section was statistically derived and it is 49-53 EUR/m^3. For the purpose of this paper, the higher value (53 EUR/m^3) is taken into account and therefore the manufacturing price of EUR 62.6 is reached for two beams. By adding the profit of 20 %, the price of 373 EUR/m^3 of a glued BSH beam is obtained on the condition that 3 meter round timber is used and 383 EUR/m^3 if 4 m round timber is used. The price of the glued BSH beam can be checked in Table 2, where the marketable price of the beams with the dimensions of 80x100-200 mm amounts to around EUR 385.

The price difference of comparable products, as far as their quality and load is concerned, such as sawn and glued BSH prisms, is approximately EUR 48 in favor of sawn beams. It means that the production of the glued BSH beams still seems to be less profitable. However, if the price is calculated with respect to consumption of the material consumed during construction, a very interesting conclusion can be made. An actual roof frame breakdown was used to illustrate the comparison of volumes and prices of the sawn and glued BSH beams, longer than 5 m, as shown in Table 6. The other beams were kept in the form of sawn static structural members.

Based on the comparison, computing and calculations mentioned above, certain conclusions can be drawn. These conclusions can have an impact on the decision-making as to whether to produce the glued or sawn beams. As mentioned above, a limiting factor is given by the length of the beam. The limiting length from which it is profitable to manufacture glued beams is 5 meters. Furthermore, it is convenient to use glued beams instead of sawn beams with larger diameter exposed to bending and spacing from square section cut-

Table 6 Overview of savings: sawn beam vs. glued BSH beam
Tablica 6. Pregled ušteda: usporedba piljenih i lijepljenih BSH greda

Structural Member *Strukturni element*	**Sawn beam** *Piljena greda*					**Glued beam** *Lijepljena greda*			**Prism price** *Cijena prizme*		**Total costs** *Ukupni trošak*	
	Height *Visina* m	Width *Širina* m	Lenght *Duljina* m	Pieces *Kom.*	Volume *Volumen* m³	Height *Visina* m	Width *Širina* m	Saving *Ušteda* %	Sawn *Piljena* €/m³	BSH €/m³	Sawn *Piljena* €	BSH €
Joist / *greda*	0.180	0.260	9.50	15	6.669	0.160	0.260	11	338	379	2 254	2 247
Purlin / *sljeme*	0.160	0.200	7.80	5	1.248	0.140	0.200	13	345	391	431	434
Prop *potporanj*	0.140	0.160	4.10	8	0.735							
Pier / *stup*	0.140	0.140	2.00	4	0.157							
Wall beam *zidna greda*	0.140	0.100	36.00	1	0.504							
Rafter *krovna greda*	0.100	0.180	7.00	34	4,284	0.080	0.180	20	335	383	1 435	1 313
Rafter *krovna greda*	0.100	0.180	6.10	8	0.878	0.080	0.180	20	335	383	294	269
Skew prop *kosi potporanj*	0.100	0.120	1.70	6	0.122							
Collet / *kolut*	0.080	0.180	7.20	30	3,110	0.070	0.180	13	338	405	1 051	1 119
Collet / *kolut*	0.060	0.160	2.00	18	0.346							
Sum / *zbroj*											5 465	5 382

ting. Cutting such beams decreases the yield and increases the production costs.

It can be concluded that it is advantageous to manufacture glued beams if the height and width ratio is approximately 2:1. In such a case, the round timber with significantly smaller tenon diameter can be used for cutting compared to cutting of sawn beams. Trying to get as close as possible to square cutting, cutting two beams in one cutting is preferred. This way, the costs of input raw material can be considerably lower, and by using prism or aggregate technology, cutting costs can also be decreased.

On the contrary, the selection of glued beams is not quite convenient for manufacturing piers because most of them are used as angle braces, less than 5-meter long. In case of cutting round timber under 5 m, the economy achieved by trunk convergence is not reached and this is why the economic effect of cutting is markedly lower. The limiting factor for manufacturing piers is the volume economy (influence of different strengths of two referred products), which is confirmed by the pier dimensions of 220x220x3000 mm when the economic effect comes to 17 % of the volume. Shorter piers with smaller diameters do not yield effects that could justify the replacement of sawn piers by glued piers.

In producing roof frame structures intended for traditional family houses and industrial buildings, 50-80 % of sawn beams can be replaced by glued beams. In all-wooden structures such as prefabricated family houses, pergolas, garages, etc. this value is lowered to the range of 20 to 50 %. The decrease is caused by a small span of such constructions and a large number of piers and crosswise beams of short span used in such constructions. What matters is the quantity of structural members and their parameters made by a particular sawmill. On the basis of available data, it can be stated that sawmills can replace 37 to 63 % of sawn beams by glued beams. This volume is large enough to make the sawmill managers consider the significance of glued lamellar structural members (BSH). These findings could lead to a drastic change of sawmill development in the Czech Republic and Europe.

4 CONCLUSION
4. ZAKLJUČAK

Although it is not possible to achieve economic effects in producing each glued structural member, the costs are nearly equal and this fact could induce the sawmill managers to consider the possibility of producing structural elements and introduce serious changes in sawmill production. The optimization of producing BSH beams can result in further economic effects and however it has been ruled out. Anyway, using the glued beam technology, the sawmill managers could meet the orders of large diameter and span structures.

To conclude, in producing sawn timber for wooden constructions such as roof frames or whole prefabricated houses, it is effective to combine sawn and glued structural members despite the rising price of round timber. Such a change can yield higher profit or financial effects, which will be appreciated by end costumers.

The question, whether the glued beams should be produced by sawmills or purchased from renowned producers, remains to be answered by sawmill managers.

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Normirane metode određivanja i procjenjivanja sadržaja vode u drvu u Republici Hrvatskoj*

Standardized Methods for Determining and Estimating Wood Moisture Content in the Republic of Croatia*

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SAŽETAK • *Ispravan način određivanja i procjenjivanja sadržaja vode u drvu vrlo je važan za drvno-industrijske proizvodne procese kako bi se drvo na adekvatan način osušilo bez nastanka grešaka i do željenoga konačnog sadržaja vode te da bi se tako povećala kvaliteta sušenja i kvaliteta finalnog proizvoda. Stoga je u ovom članku napravljen detaljan pregled svih harmoniziranih važećih normi u Republici Hrvatskoj koje se odnose na postupke određivanja i procjenjivanja sadržaja vode u drvu. Navedeni su ispravni postupci i preporuke za ispravno provođenje mjerenja sadržaja vode u drvu te su napravljene usporedbe različitih metoda određivanja i procjenjivanja sadržaja vode. Također se navodi za koje je praktične primjene pojedina metoda pogodna.*

Ključne riječi: *sadržaj vode u drvu, gravimetrijska metoda, elektrootporna metoda, kapacitativna metoda*

ABSTRACT • *It is of great importance for wood industrial production processes to provide the correct way of determining and estimating the moisture content of wood, in order to dry wood adequately without the occurrence of drying defects and achieve the desired final moisture content, to increase the quality of the drying process and final product quality. Therefore, this paper gives a detailed review of all applicable harmonized standards in the Republic of Croatia related to the procedures for determining and estimating wood moisture content. It outlines the correct procedures and recommendations for the proper implementation of wood moisture content measuring, and presents the comparison between different methods. Suggestions are also given as to practical application of specific methods.*

Key words: *Wood moisture content, oven-dry method, electrical method, capacitance method*

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1. UVOD
1 INTRODUCTION

Fizikalna svojstva drva, poroznost i higroskopnost čimbenici su koji omogućuju da drvo sadržava određenu količinu vode u slobodnome i vezanom obliku. U drvu se voda nalazi u tri osnovna oblika: kao slobodna voda, vezana voda i kemijski vezana voda. Slobodna je voda sadržana u lumenima, i to uglavnom prozenhimatskog staničja drva (u trahejama, traheidama), a s fiziološkog je gledišta važna za živo stablo jer je nosilac rastopljenih hranjivih tvari u drvu. Vezana se voda nalazi u staničnim stijenkama. Kemijski vezanu vodu sadržavaju spojevi od kojih je izgrađeno drvo, o njoj se ne vodi briga jer se njezin sadržaj tijekom sušenja ne mijenja, zato što je sušenje fizikalni, a ne kemijski proces. Prilikom sušenja drva mijenjaju se samo količine slobodne i vezane vode, te je podjela na slobodnu i vezanu vodu općenito prihvaćena (Krpan, 1965). S tehnološkoga gledišta, u procesima obrade i prerade drva vezana je voda važnija od slobodne, kao i tijekom finalne uporabe drva. U procesima sušenja slobodna voda ispari, kao i dio vezane vode, dok u drvu uvijek ostane određena količina vezane vode koju nazivamo konačnim sadržajem vode u drvu i koji ciljano nastojimo postići procesima sušenja. Konačni sadržaj vode u drvu važan je zato što se finalni drvni proizvod prilagođava mikroklimatskim uvjetima okoline u kojoj se nalazi (temperaturi i relativnoj vlazi zraka). S promjenom mikroklimatskih uvjeta sadržaj vode u drvu raste ili pada, a drvo nastoji postići stanje ravnoteže s okolnim uvjetima. Konačni željeni sadržaj vode u drvu ovisi o namjeni finalnog drvnog proizvoda. Gledajući raspored vode unutar sekundarnog ksilema, najveći dio slobodne vode nalazi se u bjeljici, koja je fiziološki aktivni dio debla. Stoga prilikom određivanja sadržaja vode u drvu valja voditi brigu o tome da će bjeljika i srž istog komada drva imati bitno različit sadržaj vode. U svakom pojedinom stablu raspored sadržaja vode znatno varira, tako da postoji razlika čak i između vrha stabla i korijena, kao što postoji i između srži i bjeljike. Prilikom određivanja sadržaja vode u drvu potrebno je voditi brigu o navedenim čimbenicima, kao što je važno da se sam postupak određivanja sadržaja vode provede na ispravan način. Utvrđivanje sadržaja vode u drvu na ispravan i uniforman način iznimno je važno za provođenje hidrotermičkih procesa pri obradi drva (sušenje i parenje drva i dr.), te valja slijediti upute za ispravno utvrđivanje sadržaja vode u drvu koje propisuju norme. To su dokumenti doneseni konsenzusom i odobreni od mjerodavnog tijela Republike Hrvatske. One daju pravila i upute za opću i višekratnu uporabu, odnosno značajke aktivnosti i njihovih rezultata te jamče najviši stupanj uređenja u danim uvjetima, tj. njima se sprečavaju nered i nesporazumi na tržištu. Primjena normi u Republici Hrvatskoj nije obvezna, već se hrvatska normizacija temelji na načelu dragovoljne primjene, uz napomenu da, sukladno Zakonu o normizaciji (NN 163/03), sva autorska prava i prava korištenja normi u Republici Hrvatskoj pripadaju hrvatskom normirnom tijelu (HZN-u), te je zabranjeno umnožavanje ili raspačavanje dijelova ili cjeline bilo koje hrvatske norme bez suglasnosti hrvatskoga normirnog tijela. Sredinom 1990-ih godina Europski odbor za normizaciju (CEN – European Committee for Standardization) započeo je harmoniziranje normi vezanih za kvalitetu sušenja u zemljama Europske Unije. Na taj su se način počeli postavljati temelji za uklanjanje barijera između europskih zemalja u smislu određivanja sadržaja vode u drvu i kvalitete sušenja drva.

U ovome će članku biti prikazan detaljan pregled svih normiranih metoda određivanja i procjenjivanja sadržaja vode u drvu u Republici Hrvatskoj, koje će biti opisane uz dodatne iskustvene savjete i upute. Postoji velik broj metoda za određivanje i procjenjivanje sadržaja vode u drvu koje nisu obuhvaćene normama, koje su možda zbog svoje nepraktičnosti, netočnosti ili visoke cijene koštanja teško primjenjive ili neisplative u svakodnevnim uvjetima u praksi, te one u ovome članku neće biti obrađene. Neće biti obrađeni ni fiksni sustavi za automatsko utvrđivanje sadržaja vode u linijskoj proizvodnji iako je takav kapacitativni sustav obuhvaćen jednom od navedenih hrvatskih normi.

Cilj članka jest pružiti uvid u provedbu mjerenja sadržaja vode na ispravan način. Ispravno određivanje i procjenjivanje sadržaja vode u drvu ima veliko značenje za drvnoindustrijske procese jer je važno da se drvo osuši na ispravan način, bez grešaka (bez promjene boje, promjene oblika, pukotina i dr.) i da se pripremi sirovina za proizvodnju finalnog proizvoda s odgovarajućim konačnim sadržajem vode.

2. NORMIRANE METODE ODREĐIVANJA I PROCJENJIVANJA SADRŽAJA VODE U DRVU
2 STANDARDIZIED METHODS FOR DETERMINING AND ESTIMATING WOOD MOISTURE CONTENT

U Republici Hrvatskoj normirnim su sustavom obuhvaćene tri metode određivanja i procjenjivanja sadržaja vode u drvu: gravimetrijska metoda, elektrootporna metoda i kapacitativna metoda. Norme koje definiraju te mjerne metode sastavio je tehnički odbor *CEN/TC 175 – Round and sawn timber*, te su ih prihvatile članice Europskog odbora za normizaciju (CEN), čija je članica i Republika Hrvatska, a njezin predstavnik Hrvatski zavod za norme (HZN). Unutar hrvatskoga normirnog tijela te norme pripadaju u djelokrug rada tehničkog odbora *HZN-TO 218: Drvo*, koji je navedene norme prihvatio u izvorniku, na engleskom jeziku.

Mjerne metode određivanja i procjenjivanja sadržaja vode u drvu i norme koje ih definiraju jesu:

1. gravimetrijska metoda određivanja sadržaja vode u drvu, definirana hrvatskom normom HRN EN 13183-1:2008 Moisture content of a piece of sawn timber – Part 1: Determination by oven dry method,
2. elektrootporna metoda procjenjivanja sadržaja vode u drvu, definirana hrvatskom normom HRN EN 13183-2:2008 Moisture content of a piece of sawn timber – Part 2: Estimation by electrical resistance method,

3. kapacitativna metoda procjenjivanja sadržaja vode u drvu, definirana hrvatskom normom HRN EN 13183-3:2008 Moisture content of a piece of sawn timber – Part 3: Estimation by capacitance method.

Sam izbor riječi u nazivima normi naznačuje da je gravimetrijska metoda referentna metoda. Za gravimetrijsku metodu upotrijebljena je engleska riječ *determination*, što znači *određivanje*, dok je za druge dvije metode upotrijebljena engleska riječ *estimation*, što znači *procjenjivanje*. Uporabom određenih riječi u nazivu norme gravimetrijska je metoda označena kao metoda kojom se određuje sadržaj vode u drvu, dok se uz pomoć ostalih dviju metoda samo procjenjuje sadržaj vode u drvu.

Važno je napomenuti da u Republici Hrvatskoj postoji još jedna važeća norma (HRN ISO 3130:1999 Wood – Determination of moisture content for physical and mechanical tests), koja propisuje postupak određivanja sadržaja vode gravimetrijskom metodom u uzorcima drva na kojima će se provoditi ispitivanja fizikalnih i mehaničkih svojstava. Sam postupak provođenja gravimetrijske metode prema toj normi ne razlikuje se bitno od norme HRN EN 13183-1:2008, već se detaljnije daju upute o pripremi i izradi uzoraka, te o postupanju s uzorcima drva na kojima će se utvrđivat fizikalna i mehanička svojstva drva. Stoga norma HRN ISO 3130:1999 neće biti obrađena u ovome članku.

2.1. Gravimetrijska metoda određivanja sadržaja vode u drvu
2.1 Oven-dry method for determining wood moisture content

Odgovarajuća norma definira tu metodu kao referentnu metodu za utvrđivanje sadržaja vode u drvu, jer je ona najtočnija i najpouzdanija od trenutačno poznatih metoda primjenjivih u praksi. Dakle, u slučaju spora vezanoga za sadržaj vode u drvu među strankama na tržištu (proizvođač – krajnji potrošač, proizvođač – prekupac, prekupac – krajnji potrošač) kao metoda za utvrđivanje sadržaja vode u drvu se odabire gravimetrijska metoda i samim time se sadržaj vode izmjeren isključivo tom metodom smatra vrijednošću o kojoj se može razgovarati. Norma se odnosi na piljeno drvo te na drvo koje je blanjano ili površinski mehanički obrađeno drugim sredstvima. Cijeli postupak određivanja sadržaja vode u drvu treba provesti prema proceduri opisanoj u navedenoj normi. Gravimetrijska metoda obuhvaća mjerenje količine odstranjene vode do 0 % konačnog sadržaja vode u drvu (drvo u apsolutno suhom stanju), izražene postocima u odnosu prema drvu u apsolutno suhom stanju. Gravimetrijska je metoda precizna, ali nepraktična jer zahtijeva uzimanje uzoraka iz složajeva drva, njihovo djelomično razaranje te ne omogućuje trenutačno određivanje sadržaja vode u drvu. Naime kontrolni se uzorak mora sušiti do konstantne mase, što traje određeno vrijeme.

2.1.1. Aparatura
2.1.1 Apparatus

Gravimetrijska metoda provodi se uz pomoć sušionika (sl. 1) i vage (sl. 2). Potrebno je da vaga bude određene točnosti s obzirom na masu kontrolnog uzorka koji se važe. Ako je masa kontrolnog uzorka na kojemu se provodi ispitivanje veća od 100 g u apsolutno suhom stanju, potrebno je uzorak izvagati na vagi točnosti $d = 0,1$ g, a ako je masa kontrolnog uzorka u apsolutno suhom stanju manja od 100 g, vaga treba biti točnosti $d = 0,01$ g. Vaga koja se upotrebljava u industriji za određivanje sadržaja vode u drvu tijekom kontrole procesa proizvodnje mora imati samo prvu ovjeru, koju je dužan osigurati dobavljač, dok trenutačno ne postoji zakonska obveza daljnjeg umjeravanja, ali uz uvjet da se ne provode nikakve izmjene na vagi. Korisnik vage može sam i o vlastitom trošku zatražiti ovjeru vage. Ako se vaga rabi i u trgovačkim poslovima pri kojima se cijena prodane robe odnosno pružene usluge određuje na temelju mjerenja, vaga se mora redovito ovjeravati sukladno ovjernim razdobljima. Bez obzira na trenutačno važeće zakonske propise, preporučuje se povremeno umjeravanje vage ili kontrola točnosti, kako se ne bi provodila pogrešna mjerenja. Sušionik u kojemu se kontrolni uzorak suši mora biti izrađen na način da osigurava slobodnu unutrašnju cirkulaciju zraka te da je u mogućnosti održavati konstantnu temperaturu od 103 ± 2 °C. U današnje vrijeme već postoje specijalni sušionici koji imaju ugrađen uređaj za mjerenje mase, te se sadržaj vode u drvu automatski prikazuje na ekranu, što znatno olakšava provedbu gravimetrijske metode i smanjuje mogućnost ljudske pogreške prilikom rukovanja kontrolnim uzorkom. Međutim, točnost rezultata takvih automatiziranih uređaja treba uzimati sa zadrškom. Sušionik mora imati instrument za mjerenje temperature kojim se kontrolira temperaturno stanje unutar njega. U novijim se sušionicima za praćenje temperature uglavnom upotrebljavaju

Slika 1. Sušionik (foto: Pervan i Klarić)
Figure 1 Oven-dryer (photo: Pervan and Klarić)

Slika 2. Precizna vaga (foto: Pervan i Klarić)
Figure 2 Precise balance (photo: Pervan and Klarić)

termoelementi, dok kao kontrolni instrumenti služe termometri punjeni tekućinom. Termometri punjeni živom pogodniji su od termometara punjenih alkoholom. Treba napomenuti da će, u skladu s budućim europskim direktivama i europskim tendencijama za sve većom zaštitom ljudi i okoliša, termometri punjeni živom vjerojatno biti povučeni iz uporabe. Termometar treba imati gornju granicu mjernog raspona postavljenu barem na 200 °C, kako bi se izbjeglo njegovo pucanje zbog nepredviđenog porasta temperature unutar sušionika prouzročenog kvarovima ili propustima radnika. Termometar u sušioniku također je preporučljivo periodički kalibrirati kako bi se izbjegla mogućnost pogrešnog očitanja temperaturnog stanja.

Iako norma ne zahtijeva uporabu eksikatora, bilo bi ga preporučljivo imati. Eksikator je (sl. 3) najčešće staklena posuda s brušenim poklopcem za sušenje ili zaštitu tvari od vlage uz pomoć nekoga higroskopnog sredstva, najčešće silicijeva dioksida SiO_2 (silika gel). Eksikator može sadržavati i tubus za izjednačavanje tlaka i lakše otvaranje poklopca ili za stvaranje podtlaka u eksikatoru. Kada sušenje u sušioniku završi, temperatura kontrolnog uzorka je oko 100 °C, i ako se takav uzorak stavlja na preciznu vagu, može oštetiti osjetljive dijelove vage ili rezultat može biti netočan. Drvo više temperature u apsolutno suhom stanju također brže apsorbira vlagu iz okolnog zraka. Zato se preporučuje upotreba eksikatora u koji se odlažu vrući kontrolni uzorci koji se kontrolirano hlade, bez mogućnosti da apsorbiraju vlagu.

2.1.2. Primjena
2.1.2 Application

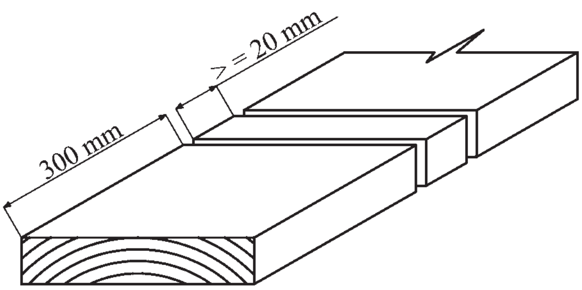
Gravimetrijskom se metodom može pouzdano odrediti sadržaj vode u drvu s vremenskim odmakom potrebnim da se završi sušenje kontrolnog uzorka ako posjedujemo potrebnu i umjerenu aparaturu. Uz pomoć gravimetrijske metode može se voditi proces sušenja drva u klasičnim komornim sušionicama starije izvedbe ili u novijim sušionicama u kojima nije instalirana automatika za vođenje procesa ni ostali mjerni uređaji kako bi se smanjili troškovi investicije. U najmodernijim kompjutorski vođenim sušionicama preporučuje se kontrola procesa sušenja uz pomoć kontrolnih uzoraka

Slika 3. Stakleni eksikator bez tubusa (foto: Pervan i Klarić)
Figure 3 Glass desiccator without tubus (photo: Pervan and Klarić)

gravimetrijskom metodom određivanja sadržaja vode u drvu. Ako se na takav način vodi ili kontrolira proces sušenja, mogu se koristiti i uzorci za određivanje rasporeda sadržaja vode u obliku tankih listova ili u obliku drvnih ostataka nakon bušenja. Takav način kontrole omogućuje precizniju lokalizaciju i vrednovanje tipa i rasporeda sadržaja vode u vlažnome ili sušenom drvu te omogućuje prepoznavanje pretjeranog isušivanja površine, rasporeda naprezanja, skorjelosti i grešaka sušenja. Gravimetrijskom se metodom može obavljati kalibracija mjernih uređaja koji rade na načelu ostalih dviju normiranih metoda, i to na način da se u testnom uzorku pojedinačnim vlagomjerom izmjeri vlaga, a zatim se sadržaj vode u tom istom uzorku odredi gravimetrijskom metodom.

2.1.3. Procedura
2.1.3 Procedure

Iz uzorka drva koji smo izabrali da na njemu provedemo postupak određivanja sadržaja vode potrebno je ispiliti kontrolni uzorak (sl. 4). Poželjno je da se ispiljivanje kontrolnog uzorka obavi na uređajima što manje brzine rezanja, te sa što oštrijim alatom, kako tijekom piljenja zbog sila koje nastaju i stvaranja topline ne bi ispario dio vode iz kontrolnog uzorka na kojemu se provodi ispitivanje. Kako je kontrolni uzorak malih dimenzija, i ono malo vode što ispari na takav način na kraju mjerenja može rezultirati razlikama u vlazi i do nekoliko postotaka sadržaja vode, čime mjerenje postaje netočno. Bitno je i da se nakon ispiljivanja kontrolni uzorak odmah izvaže, jer ako se uzorak nosi od mjesta piljenja do mjesta vaganja, iz prostorije u prostoriju, iz proizvodne hale u drugu proizvodnu



Slika 4. Pozicija kontrolnog uzorka (izvor: Pervan i Straže, 2006)
Figure 4 Position of the test slice (source: Pervan and Straže, 2006)

halu ili u kontrolnu prostoriju sušionice, također isparava voda iz uzorka i time mjerenje postaje netočno. Ako nije moguće trenutačno izmjeriti masu uzorka, preporučuje se stavljanje uzorka u zabrtvljeni spremnik kako bi se usporila promjena sadržaja vode te kontrolni uzorak izvagati najkasnije dva sata od izrezivanja. No ako nije dostupan ni zabrtvljeni spremnik, kontrolni se uzorak može umotati u PVC foliju. Umotavanje u PVC foliju ne znači da će se spriječiti isparavanje vode iz drva, već će se ono samo malo usporiti. Uzima li se uzorak drva na kojemu će se provoditi određivanje sadržaja vode gravimetrijskom metodom na terenu (u slučaju reklamacije i sl.), svakako ga je potrebno stavljati u zabrtvljeni spremnik ili, što je manje preporučljivo, umotati u PVC foliju, a prilikom transporta ne smije biti izravno izložen suncu ili utjecaju vjetra.

Kontrolni uzorak ne smije imati greške u strukturi drva, te ne smije biti drvo koje sadržava smolu, koje ima kvrge, koru, smolne džepove te druge strane materijale. Kontrolni se uzorak ispiljuje s bilo kojeg kraja uzorka drva, 0,3 m od kraja uzorka, ili u sredini uzorka ako je uzorak kraći od 0,6 m, i to tako da obuhvati cijeli poprečni presjek i da je dug najmanje 20 mm gledajući u smjeru žice drva (sl. 4). Ako ispiljeni kontrolni uzorak obuhvaća neku od nedopuštenih greška, ponovno se ispiljuje na način da se pomičemo do najbližeg dijela bez grešaka, prema sredini uzorka.

2.1.3.1. Sušenje i vaganje kontrolnog uzorka
2.1.3.1 Test slice drying and weighting

Kontrolni se uzorak suši u sušioniku, na temperaturi 103 ± 2 °C do apsolutno suhog stanja (konstantne mase). Smatra se da je kontrolni uzorak u apsolutno suhom stanju kada je razlika mase između dva uzastopna vaganja u intervalu od dva sata manja od 0,1 %. Kao što vrijedi pravilo da se kontrolni uzorak prije sušenja mora izvagati odmah nakon ispiljivanja, tako vrijedi i pravilo da se kontrolni uzorak mora izvagati odmah nakon vađenja iz sušionika kako bismo dobili točne rezultate, osim kada se rabi eksikator. Tada se nakon odlaganja uzorka u eksikator čeka određeno vrijeme da se uzorak ohladi. Ako se suši drvo koje sadržava visoke količine hlapljivih spojeva (smole, i dr.), da bi se dobili točni rezultati, norma preporučuje da se takvi kontrolni uzorci suše u uvjetima podtlaka (tlak < 100 Pa (0,001 bar)) i pri nižim temperaturama (maksimalno 50 °C) ili u eksikatoru koji sadržava higroskopnu tvar.

2.1.3.2. Izračun sadržaja vode u drvu
2.1.3.2 Calculation of wood moisture content

Izračunavanje sadržaja vode, *u* odnosno *ω,* u kontrolnom uzorku kao postotka s obzirom na masu uzorka u apsolutno suhom stanju provodi se jednostavnim formulama (1) i (2). Obje formule daju jednak rezultat, razlika je samo u oznakama. Formula (1) ima oznake u izvornom obliku, kako ih navodi odgovarajuća norma, dok formula (2) ima oznake koje se tradicijski upotrebljavaju u praksi na našim prostorima. Prednost primjene izvorne formule (1) jest to što će izračun biti univerzalno razumljiv svima, što je iznimno važno u međunarodnom poslovanju.

$$\omega = \frac{m_1 - m_0}{m_0} \cdot 100 \, [\%] \tag{1}$$

$$u = \frac{m_s - m_0}{m_0} \cdot 100 \, [\%] \tag{2}$$

u, ω – sadržaj vode u drvu, % / *wood moisture content, %*

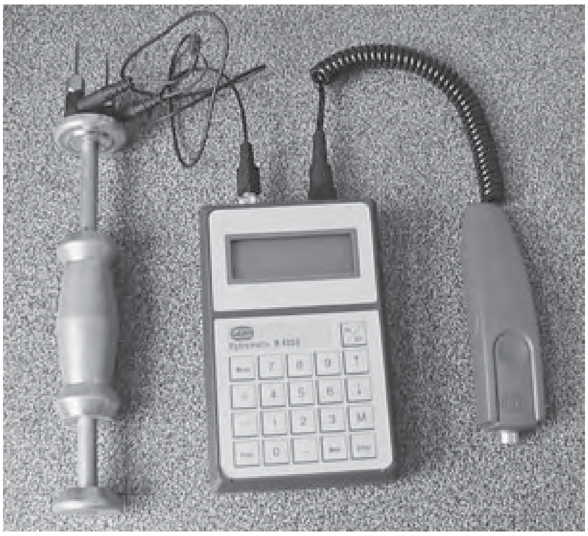
m_s, m_1 – masa kontrolnog uzorka u sirovom stanju (prije sušenja), g / *mass of the test slice before drying, g*

m_0 – masa kontrolnog uzorka u apsolutno suhom stanju, g / *mass of the oven-dry test slice, g*

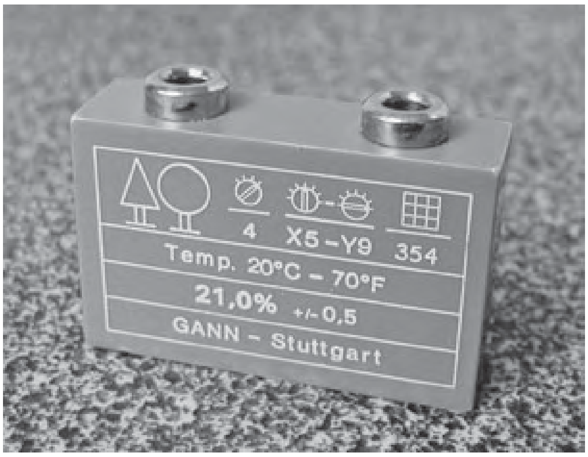
Rezultat se iskazuje na najbližih 0,1 %. Ako se rabi sušionik s automatskim očitanjem sadržaja vode, takav način izračuna nije nužan jer se vrijednost sadržaja vode u drvu može očitati izravno s ekrana na sušioniku.

2.2. Elektrootporna metoda procjenjivanja sadržaja vode u drvu
2.2 Electrical resistance method of estimation of wood moisture content

Odgovarajuća se norma odnosi na piljeno drvo i drvo koje je blanjano ili površinski mehanički obrađeno drugim sredstvima. Iako odgovarajuća norma karakterizira tu metodu kao nedestruktivnu, ona je ipak na neki način djelomično destruktivna. Naime, da bi se tom metodom izmjerio sadržaj vode u drvu, potrebno je zabiti elektrode u objekt mjerenja. Stoga metoda nije pogodna za mjerenje sadržaja vode u svakom komadu drva tijekom kontrole procesa proizvodnje. U praksi se tijekom proizvodnih procesa sadržaj vode u drvu uglavnom mjeri električnim vlagomjerima koji rade na načelu mjerenja električnog otpora što ga drvo pruža prolasku električne energije. Prijenosni vlagomjeri tog tipa pokazali su se jednostavnima za uporabu te dovoljno preciznima za kontrolu tijekom proizvodnje. Drvo je po svojoj prirodi dielektrik, što znači da je vrlo dobar izolator prolasku električne struje. Zbog svojih fizikalnih svojstava poroznosti, higroskopnosti i sadržaja vode drvo uvijek sadržava određenu količinu vode u jednome ili u više osnovnih oblika (slobodnu, vezanu ili kemijski vezanu vodu), ovisno o tome nalazi li se unutar ili izvan higroskopnog područja. Što drvo sadržava veću količinu vode, to će pružati manji otpor prolasku električne struje. Tom se zakonitošću u svom radu koriste elektrootporni vlagomjeri. Za te vlagomjere vrlo je bitno da su opremljeni lako zamjenjivim standardiziranim baterijama kako naknadni trošak zamjene baterija ne bi bio visok.



Slika 5. Izvedba prijenosnog uređaja za elektrootporno određivanje sadržaja vode (foto: Pervan i Klarić)
Figure 5 Design of a portable device for determining wood moisture content on the basis of electrical resistance (photo: Pervan and Klarić)



Slika 6. Kalibrirani otpornik za provjeru točnosti vlagomjera (foto: Pervan i Klarić)
Figure 6 Resistance check box for determining moisture meter precision (photo: Pervan and Klarić)

2.2.1. Aparatura
2.2.1 Apparatus

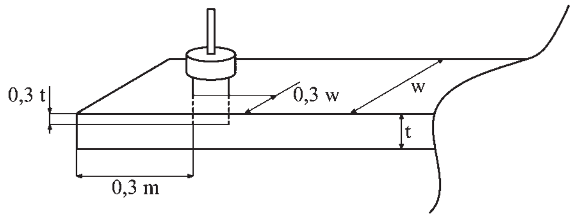
Elektrootporni vlagomjeri sastoje se od uređaja opremljenoga zasebnom drškom s dvije ili više zamjenjivih elektroda i udaračem na dršci koji omogućuje lakše zabijanje elektroda u drvo. Elektrode moraju biti izolirane, a samo vršak elektrode mora biti neizoliran. Elektrootporni vlagomjer treba biti popraćen proizvođačevim uputama za upotrebu i korekcijskim tablicama za različite vrste drva i temperaturu. Kvalitetniji vlagomjeri opremljeni su automatskim kompenzatorima temperature, automatskom korekcijom s obzirom na vrstu drva te priključnom sondom za određivanje temperature objekta kojemu mjerimo sadržaj vode. U tako opremljenih vlagomjera nema potrebe za uporabom korekcijskih tablica. O cijeni vlagomjera ovisi i stupanj njegove opremljenosti. Na vlagomjerima kojima se kontrolira sadržaj vode u drvu ne treba štedjeti jer se pokazalo da neadekvatan vlagomjer može prouzročiti vrlo velike greške i troškove u proizvodnji, da ne spominjemo gubitak ugleda na tržištu zbog prodaje drvnih proizvoda neadekvatnog sadržaja vode.

2.2.2. Primjena
2.2.2 Application

Opisani su uređaji prema odgovarajućoj normi najpogodniji za primjenu na drvu čiji je sadržaj vode od 7 % do točke zasićenosti vlakanaca (TZV), s približno oko 30 % sadržaja vode (prosječna vrijednost TZV) u odnosu prema drvu u apsolutno suhom stanju, što ne znači da se ne mogu upotrebljavati i za vlažnije drvo, uz nešto manju točnost očitanja. Također, proizvođači mogu navesti i drugačije raspone sadržaja vode za određene tipove svojih uređaja. Praktičnom se uporabom pokazalo da se tim uređajima uglavnom teško očitava sadržaj vode drva manji od 6 %. Ako je drvo kojemu se mjeri sadržaj vode tretirano bilo kojom vrstom zaštitnog sredstva, usporivačem širenja plamena (retardantom) ili bilo kojim drugim kemijskim sredstvima, to može utjecati ta točnost mjerenja, pa je u takvim slučajevima potrebno provesti posebnu kalibraciju uređaja za svaku vrstu tretmana drva posebno. Prije provođenja mjerenja važno je provjeriti točnost očitanja vlagomjera prema uputama proizvođača. Za ispitivanje preciznosti instrumenta može se upotrebljavati kalibrirani otpornik za provjeru točnosti (sl. 6).

2.2.3. Procedura
2.2.3 Procedure

Prije početka mjerenja vlagomjer je potrebno prilagoditi vrsti drva kojoj namjeravamo mjeriti sadržaj vode prema korekcijskim tablicama priloženima uz vlagomjer. Također je potrebno napraviti korekciju temperature na način da se prilagodi prosječna temperatura drva kojemu ćemo mjeriti sadržaj vode. Korekcija temperature može se obaviti priključnom sondom koja mjeri temperaturu drva, a ako uređaj nije opremljen sondom, napravi se približna usporedba temperature drva s okolnom temperaturom. Obično se mjerenje provodi na način da se smjer struje između elektroda podudara sa smjerom žice drva, a mjerenje okomito na smjer žice drva provodi se samo ako je tako naznačeno u priručniku proizvođača mjernog instrumenta. Prilikom mjerenja bitno je da se upotrebljavaju izolirane elektrode s neoštećenom izolacijom jer na rezultat mjerenja znatno može utjecati površinski sadržaj vode te varijacije sadržaja vode na poprečnom presjeku. Mjerne se elektrode zabijaju u drvo na mjestu koje je najmanje 0,3 m udaljeno od bilo kojeg kraja uzorka ili na sredini uzorka ako je uzorak kraći od 0,6 m odnosno na udaljenosti od 1/3 širine uzorka od ruba, a da vrhovi elektroda penetriraju na dubinu do 1/3 debljine uzorka (sl. 7). Područje na kojemu se obavlja mjerenje ne smije sadržavati nikakve komponente koje mogu utjecati na rezultate mjerenja kao što su greške strukture drva, drvo ne smije sadržavati smolu, imati koru, kvrge, smolne džepove, pukotine, raspukline ili mokro drvo. Ako područje mjerenja obuhvaća neku od nedopuštenih grešaka, mjerenje se obavlja na najbližem čistom području prema sredini uzorka. Rezultat mjerenja očitava se 2 - 3 sekunde nakon



Slika 7. Mjesto mjerenja (izvor: Pervan i Straže, 2006)
Figure 7 Place of measurement (source: Pervan and Straže, 2006)

što se prikaže na ekranu uređaja. Procijenjena vrijednost sadržaja vode u drvu izražava se zaokruživanjem na najbliži puni postotak.

Norma daje i informativnu uputu kako procijeniti sadržaj vode šarže ili pošiljke drva. Povećanje broja mjerenja na jednom kontrolnom uzorku ne povećava značajno točnost rezultata kada se procjenjuje sadržaj vode određene šarže ili pošiljke. Ako je potrebno procijeniti sadržaj vode pojedinog komada ili šarže, uzorkovanje i broj mjerenja trebaju biti u skladu s tablicom 1.

Tablica 1. Uzorkovanje i broj mjerenja
Table 1 Sampling and testing frequencies

Količina testiranih uzoraka / *Number of tested pieces*	**Broj mjerenja po testnom uzorku*** / *Number of measurements per test piece**
1	3
2	3
3	2
4	2
5	2
> 5	1

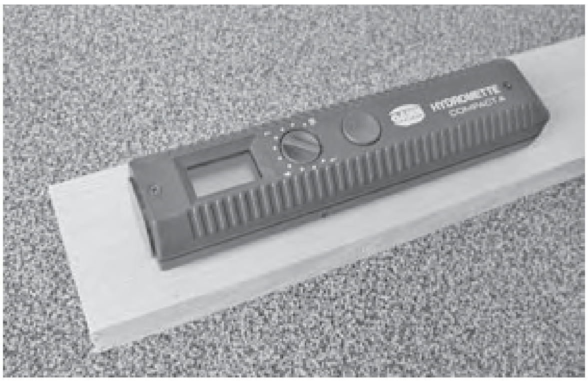
* Područja mjerenja odabiru se sporadično duž cijele duljine uzorka izuzimajući 0,3 m na svakom kraju (na sredini uzorka ako je uzorak kraći od 0,6 m). Svi rezultati mjerenja moraju se notirati.
** Measurements should be taken at random along the length excluding 0.3 m at each end (or at the midpoint of pieces less than 0.6 m long). All results of measurement should be noted.*

Zajedno s individualnim rezultatima mjerenja, moraju biti notirane i ove informacije: specifikacije šarže ili pošiljke drva (broj, interna šifra, dobavljač, kupac i dr.), vrsta i dimenzije drva, datum, tip upotrijebljenog instrumenta, postavke vrste drva, postavke temperature, dubina penetracije elektroda.

2.3. Kapacitativna metoda procjenjivanja sadržaja vode u drvu
2.3 Capacitance method of estimation of wood moisture content

Drvo ima svojstva dielektrika, tj. električni je izolator, što je svojstvo na kojemu se temelji kapacitativna metoda procjenjivanja sadržaja vode uz pomoć dielektrične konstante. Dielektrična je konstanta mjera sposobnosti tvari da smanji elektrostatičke sile između dva nabijena tijela, a kod drva se povećava s povećanjem gustoće, temperature i sadržaja vode. Ta međusobna ovisnost dielektrične konstante i sadržaja vode omogućuje procjenu sadržaja vode u drvu.

Odgovarajuća norma odnosi se na piljeno drvo i drvo koje je blanjano ili površinski mehanički obrađeno drugim sredstvima.



Slika 8. Kapacitativni ručni vlagomjer (foto: Pervan i Klarić)
Figure 8 Capacitance hand-held wood moisture meter (photo: Pervan and Klarić)

2.3.1. Aparatura
2.3.1 Apparatus

Prijenosni kapacitativni uređaj opremljen je kondenzatorskom pločom, površinskim opružnim elektrodama ili specijalnim neinvazivnim mjernim sondama. Treba biti graduiran barem do 30 % u jedinicama od maksimalno 1 % sadržaja vode. Obično su kapacitativni vlagomjeri opremljeni podešivačem korekcije gustoće drva i prilagodljivi su za različite debljine drva. Ako vlagomjer nema funkciju podešavanja gustoće drva, korekcija se može izvesti i uz pomoć posebnih tablica ili formula koje osigurava proizvođač mjernog instrumenta.

2.3.2. Primjena
2.3.2 Application

Opisana je metoda procjene sadržaja vode u drvu prema odgovarajućoj normi prikladna za mjerenja u rasponu od približno 7 do 30 % sadržaja vode u odnosu prema drvu u apsolutno suhom stanju, dok proizvođači mogu navesti i drugačije raspone sadržaja vode za određene tipove svojih uređaja. Ako je drvo tretirano bilo kojom vrstom bipolarnog sredstva, usporivačem širenja plamena (retardantom), nekim drugim kemijskim sredstvom ili je samo površinski tretirano, to može utjecati na točnost mjerenja i u takvim je slučajevima potrebno provesti posebnu kalibraciju uređaja za svaku vrstu tretmana drva posebno. Na procjenu sadržaja vode u drvu uvelike može utjecati tip i doseg senzorskog sustava uređaja, raspodjela sadržaja vode i gustoća drva neposredno ispod senzora, operativni modus, dimenzije uzorka drva na kojemu se obavlja mjerenje i vještine osobe koja provodi mjerenje. Postojanje zračnog prostora (procjepa) između površine drva i senzorske jedinice uređaja drastično će utjecati na točnost očitanja. Vrlo grubo piljena ili neravna površina može se mjeriti samo ako oblik kondenzatorske ploče ili sonde osigurava dobar kontakt.

2.3.3. Procedura
2.3.3 Procedure

Prije svakog mjerenja točnost vlagomjera mora se provjeriti prema naputcima proizvođača mjernog instrumenta. Prilikom mjerenja potrebno je odabrati gustoću drva, a ako je stvarna gustoća mjerenog uzorka drva nepoznata, prema naputku proizvođača odabere se prosječna gustoća drva za vrstu koja se mjeri. Potrebno je osigurati da instrument koji se rabi bude prikladan za debljinu drva na kojemu se mjeri sadržaj vode ili, ako je moguće, treba namjestiti odgovarajuću debljinu. Ako je debljina uzorka drva manja od debljine za koju je namješten uređaj, dobiti će se netočni rezultati mjerenja jer će materijal na kojemu uzorak stoji ili ruka koja drži uzorak drva utjecati na točnost mjerenja. Potrebno je izbjegavati zračne prostore ili nepotpun kontakt između uređaja i drva na kojem se provodi mjerenje. Ako je površina uzorka grubo i valovito obrađena, osjetni element neće imati dobar kontakt s površinom i rezultati mjerenja biti će netočni. Mjerenje je pogrešno i onda kada se postupak blanjanja drva ne provodi adekvatno, te kada postoje velike cikloide. Tada uređaj neće imati dobar kontakt s površinom drva i mjerenja će biti pogrešna, što lako može dovesti u zabludu osobu odgovornu za kontrolu kvalitete proizvodnje. I male cikloide utječu na točnost mjerenja, pa se općenito može zaključiti sljedeće: što su cikloide veće, to će biti manja točnost mjerenja navedenom vrstom mjernog uređaja. Također treba paziti da se vlaga mjeri na dijelu uzorka na kojemu nema grešaka u strukturi drva koje bi mogle utjecati na točnost mjerenja, kao što su kora, kvrge, smolni džepovi, pukotine, odnosno da površina kontrolnog uzorka ne bude navlažena. Mjerenje se obavlja u točki 300 mm udaljenoj od bilo kojeg kraja uzorka, a ako na tome mjestu postoji greška koja bi mogla utjecati na točnost mjerenja, mjerna se točka pomiče na najbliži dio bez grešaka, u smjeru sredine uzorka. Za uzorke kraće od 600 mm mjerenje se obavlja na sredini dužine uzorka. Procijenjeni rezultat mjerenja izražava se najbližim punim postotkom.

Norma daje informativnu uputu o tome kako procijeniti sadržaj vode šarže ili pošiljke drva, te se provodi na isti način kao za elektrootpornu metodu.

3. DISKUSIJA I ZAKLJUČAK
3 DISCUSSION AND CONCLUSIONS

Svi koji su u doticaju s proizvodnjom i preradom piljenog drva svjesni su da drvo treba biti propisno osušeno kako bi se osigurala dimenzionalna stabilnost i trajnost proizvoda. Stoga je sadržaj vode u osušenome piljenom drvu ključno svojstvo koje ima velik učinak na ponašanje drva u uvjetima krajnje uporabe (Welling, 2002). Nepravilno utvrđivanje sadržaja vode u drvu može rezultirati nepravilnim vođenjima procesa sušenja ili proizvodnjom finalnih proizvoda neodgovarajućega konačnog sadržaja vode, što za poslodavca u najboljem slučaju znači određeni postotak škarta tijekom procesa sušenja ili, što je gore, rizik od spora s kupcem finalnih proizvoda, a samim time i nezadovoljnim kupcima, a to vodi gubitku ugleda, identiteta, a time i tržišta. Sve jača konkurencija i sve oštrija bitka za svakog kupca ili korisnika usluga postavlja poslovanje na višu razinu i tjera poduzeća da se svojim identitetom služe sve češće i na sve više razina (Bičanić i dr., 2009). Proizvođač bez ugleda, identiteta i tržišta proizvođač je u stečaju. Kako bi se izbjegli negativni učinci neadekvatnog sušenja drva, dobro je pridržavati se naputaka iz normi. Iako u pripadajućim normama vezanim za određivanje i procjenu sadržaja vode u drvu postoji mnogo elemenata koji nisu definirani ili su nedovoljno definirani, ipak bi precizno pridržavanje naputaka važećih normi već bio velik napredak u poboljšanju kvalitete drvnih proizvoda i način izbjegavanja grešaka u proizvodnji vezanih za sadržaj vode u drvu.

Dugoročno gledano, primjena normi ima pozitivne učinke na održavanje kvalitete proizvoda, te na sigurnost i zadovoljstvo krajnjih potrošača, koji se osiguravaju putem ciljeva normizacije. To su:

1. povećanje razine sigurnosti proizvoda i procesa, čuvanje zdravlja i života ljudi te zaštita okoliša,
2. promicanje kakvoće proizvoda, procesa i usluga,
3. osiguranje svrsishodne uporabe rada, materijala i energije,
4. poboljšanje proizvodne učinkovitosti, ograničenja raznolikosti, osiguranje spojivosti i zamjenjivosti,
5. otklanjanje tehničkih zapreka u međunarodnoj trgovini.

Visoka kvaliteta drvnih proizvoda nameće potrebu detaljnog poznavanja normi u preradi drva (Pervan i Straže, 2006). Velika prednost primjene normi jest olakšanje međunarodne komunikacije s kupcima i poslovnim partnerima jer se norme usklađuju na europskoj razini. Uz dobro poznavanje normi vezanih za određivanje sadržaja vode u drvu, potrebno je svim zaposlenima u proizvodnom procesu osigurati trajnost i dostupnost ispravnih radnih procedura, što bi se moglo osigurati sustavom ISO 9001. Mnoga drvnoindustrijska poduzeća imaju implementiran ISO 9001 sustav ili ga planiraju uvesti. Navedeni sustav također zahtijeva da se u međusobnoj interakciji proizvođača i kupca, bilo obradom reklamacija i unaprjeđenjem proizvodnje, bilo utvrđivanjem želja i zahtjeva kupaca te nastojanjem da se te želje ispune trajnim prihvaćanjem novih i poboljšanih postupaka i procedura u proizvodnji, proizvodnja unapređuje i problemi rješavaju. U tom je smislu preporučljivo da se ispravni postupci utvrđivanja sadržaja vode u drvu, sukladni s naputcima normi, implementiraju kao radne upute ili postupnici u sustav ISO 9001.

Uz adekvatno definirane radne procedure, potrebni su i odgovarajući uređaji i mjerna oprema. Smanjivanje troškova proizvodnje štednjom na kupnji adekvatne i novije mjerne i pomoćne opreme ušteda je samo za kratko vrijeme jer dugoročno gledano takav način štednje može prouzročiti višestruke gubitke. Prividno velika početna investicija vrlo će se brzo isplatiti smanjenjem škarta i proizvodnjom finalnih proizvoda odgovarajućega konačnog sadržaja vode te smanjenjem stresa među upravljačkim kadrom, uz uvjet da se svi radnici pridržavaju ispravnih procedura. Preporuka je da se investira u adekvatnu mjernu opremu kao što su sušionik, precizna vaga, eksikator, stolarska pila s mogućnošću regulacije brzine vrtnje i u elektrootporni vlagomjer kao osnovnu opremu za kvalitetno mjerenje sadržaja vode u drvu. Ulaganje u noviju opremu osigurava kontinuiranu i uspješnu proizvodnju, a time i ostvarivanje profita.

Gravimetrijska metoda najpreciznija je od navedenih metoda. Elektrootporna metoda je, pak nešto manje precizna, ali je najpogodnija za kontrolu sadržaja vode u drvu u svakodnevnom poslovanju (na pilani i stovarištu građe, u skladištima, prije ulaska građe u sušionice ili u proizvodnju i sl.). Kapacitativna je metoda nepreciznija od gravimetrijske i elektrootporne, ali je vrlo prikladna za linijske proizvodnje kao što su proizvodnja parketa i sl., u kojima se njome može vrlo jednostavno i bez oštećivanja proizvoda kontrolirati sadržaj vode u drvu. Ako se prilikom kontrole proizvodnje kapacitativnom metodom utvrde nepravilnosti u sadržaju vode, preporučuje se provesti kontrolu na istom uzorku i na drugim uzorcima iz šarže elektrootpornom metodom. Utvrdi li se i tom metodom neadekvatan sadržaj vode, tada se već s velikom sigurnošću može pretpostaviti da je sadržaj vode neadekvatan te da se šarža građe može povući iz proizvodnje i zamijeniti drugom dok se ne provede kontrola gravimetrijskom metodom, čime se dobivaju najprecizniji rezultati. Postoji li potreba za preciznim određivanjem sadržaja vode u drvu, uvijek se potrebno koristiti gravimetrijskom metodom. Za linijsku se proizvodnju (npr. za proizvodnju parketa) preporučuje kupnja kapacitativnoga ručnog vlagomjera za nedestruktivnu kontrolu sadržaja vode na poluproizvodima ili gotovim proizvodima. Osim kupnje opreme važno je educirati i osobe koje će provoditi mjerenja. Nakon svega navedenoga može se također zaključiti da je bez određenih troškova nemoguće održavati ili povećavati razinu kvalitete proizvoda, a bez odgovarajuće kvalitete teško je zadržati kupce. Kontrola sadržaja vode u drvu ključna je za povećanje kvalitete i minimaliziranje troškova sušenja i, općenito, poslovanja.

4. LITERATURA
4 REFERENCES

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10. *** Zakon o normizaciji, NN 163/03.
11. *** Zakon o tehničkim zahtjevima za proizvode i ocjenjivanju sukladnosti, NN 20/10.
12. *** Naredba o ovjernim razdobljima za pojedina zakonita mjerila i načinu njihove primjene i o umjernim razdobljima za etalone koji se upotrebljavaju za ovjeravanje zakonitih mjerila, NN 47/05 i 38/11.

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Godišnja znanstvena konferencija COST Akcije FP 0904, Iasi, Rumunjska

Annual scientific conference of COST Action FP 0904, Iasi, Romania

U rumunjskom gradu Iasiju, u Institutu za makromolekularnu kemiju "Petru Poni", od 9. do 11. travnja 2013. održana je treća godišnja znanstvena konferencija COST Akcije FP 0904 pod naslovom *Vrednovanje, prerada i predviđanje ponašanja termo-hidro-mehanički obrađenog drva primjenom eksperimentalnih i numeričkih metoda*.

Glavni cilj savjetovanja u sklopu te COST Akcije bio je pridonijeti boljem razumijevanju mehaničkih i kemijskih transformacija drva tijekom hidrotermičkih (TH) / termo-hidro-mehaničkih (THM) obrada suradnjom znanstvenika s različitih područja znanosti o drvu i poznavanja materijala. Navedena akcija potiče istraživanje i omogućuje suradnju među istraživačkim skupinama iz akademske zajednice i industrije te pomaže u primjeni znanstvenih rezultata u praksi odnosno u industrijskoj proizvodnji, pridonosi poboljšanju procesa, razumijevanju odnosa među parametrima obrade, svojstava materijala i razvoja novih proizvoda.

COST Akcija FP0904 sastoji se od tri radne skupine:

WG1: Identifikacija kemijske razgradnje drva tijekom hidrotermičke obrade

WG2: Modeliranje termo-hidro-mehaničkih procesa tijekom obrade drva

WG3: Inovacije i novi proizvodi termo-hidro-mehaničke obrade.

Tijekom konferencije predstavljeno je trenutačno stanje THM i TH obrade, prikazane su nove analitičke

Slika 1. Institut za makromolekularnu kemiju "Petru Poni"

Slika 2. Usmeno izlaganje Miljenka Klarića, dipl. ing.

metode koje pridonose razumijevanju kemijskih reakcija što se tijekom procesa obrade zbivaju u drvu, iznesena su predviđanja uspješnosti nekog određenog proizvoda na temelju procesnih parametara te su identificirani problemi u prijenosu rezultata laboratorijskih istraživanja u industrijsku proizvodnju, s ciljem boljeg razumijevanja potreba obrade, razvoja novih ideja, novih proizvoda i mogućnosti širenja na nova tržišta. Konferencija je okupila stručnjake i mlade znanstvenike s europskih sveučilišta i iz industrije, kao i iz drugih zemalja.

Na savjetovanju su izloženi sljedeći radovi:

Carmen-Mihaela Popescu, Maria-Cristina Popescu
Two dimensional correlation spectroscopy applied for evaluation of the structural changes in wood

Lothar Clauder, Alexander Pfriem
Determination of dimensional stability of thermally modified beech and spruce wood

Cornelia Vasile, Manuela-Tatiana Nistor, Silvia Florica Patachia
Thermal behaviour of some wood species treated with ionic liquid

Aniela Garcia Perez, Emilia-Adela Salca, Bobadilla Maldonado, Salim Hiziroglu
Evaluation of surface quality of wood composites as function of weathering

Daniela Soya, Venetia Sandu, Ioan-Bogdan Bedelean
The correlation between wood moisture content and air state properties during drying

Michael Altgen, Jukka Ala-Viikairi, Antti Hukka, Timo Tetri, Holger Militz
Wood anatomical changes on thermally modified surfaces of Norway spruce and Scots pine

Kevin Candelier, Stephane Dumarcay, Anelie Petrissans, Philippe Gerardin, Mathieu Petrissans
Comparison of chemical composition of heat treated wood cured at a same temperature under different inert atmospheres: nitrogen, vacuum and steam pressure

David Mannes, Walter Sonderegger, Eberhard Lehmann
On-line monitoring of hygroscopicity and dimensional changes of wood during thermal modification by means of neutron imaging methods

Dan Ridley-Ellis, Barbara Keating, Carmen-Mihaela Popescu
Comparison of acoustic NDT for assessment of small stiffness changes during low temperature thermal treatment

Patrick Perre, Joseph Gril
Modelling the isolated and combined effects of chemical modification and hygro-thermo-mechanical loading of wood

Dominique Derome
The role of water in the HTM behavior of wood

Susanna Källbom, Magnus Wålinder, Kristoffer Segerholm, Dennis Jones
Physico-chemical characterization of THM modified wood using inverse gas chromatography (IGC)

Omar Saifouni, Rostand Moutou Pitti, Jean-François Destrebecq, Frédéric Dubois
A pseudoelastic mechanosorptive model for wood material

Floran Pierre, Giana Almeida, Julien Colin, Patrick Perré
Heat treatment of wood for energy purpose: effect of the treatment intensity on mechanical resilience measured by a new impact device

Julien Froidevaux, Joseph Gril, Parviz Navi
Strength prediction of mild thermo-hydro treatments and extrapolation for natural ageing

Rostand Moutou Pitti, Frédéric Dubois, Eric Fournely, Jean-François Destrebecq
Experimental and numerical detections of cracks appear in green wood during drying process

Jakub Sandak, Anna Sandak, Dusan Pauliny, Maria Paola Riggio, Ilaria Santoni
About some chemical changes to wood due to densification Jakub Sandak, Anna Sandak, Dusan

Miha Humar, Frederick A. Kamke, Andreja Kutnar
Reducing set recovery of densified wood with heat treatment

Ghonche Rassam
Prediction and evaluation of mechanical properties of densified Iranian poplar after heat treatment

Muhammad Muzamal, Anders Rasmuson
Finite element modeling of deformation in fiber bundle during steam explosion of wood

Charalampos Lykidis, Petros Konstantakos, Stavros Tsalikis
Effects of closed system hydrothermal treatment conditions on colour and hardness of European beech wood

Kristiina Laine, Lauri Rautkari, Borut Kričej, Matjaž Pavlič, Marko Petrič, Mark Hughes, Andreja Kutnar
Adhesion of polyurethane coating on surface densified Scots pine wood

Wim Willems, Holger Militz
From chemical process monitoring to direct control of thermally modified wood properties

Callum Hill, James Ramsay, Lauri Rautkari, Mark Hughes, Kristiina Laine
The Behaviour of Sorption Hysteresis in the Water Vapour Sorption Isotherm of Thermally Modified Wood

Luigi Todaro, Silvia Ferrari, Paola Cetera, Ottaviano Allegretti, Nicola Moretti, Achille Pellerano
Effect of thermal vacuum treatment on bond shear strength. A comparison among Norway spruce, White ash and Turkey oak wood

Mohamed Elaieb, Kevin Candelier, Stéphane Dumarcay, Philippe Gerardin, Mathieu Petrissans
Durability and chemical modifications of four Tunisian wood species after heat treatment

Róbert Németh, László Tolvaj, Miklós Bak, Diána Csordós
Effect of treatment medium on the colour change of heat treated wood during natural weathering

Jussi Ruponen, Martin Rhême, Silvia Ferrari, Lauri Rautkari, Mark Hughes
Studies on post-welding heat-treated vibrational welded wood

Jörg Wehsener, Peer Haller, Jens Hartig, Tom-Egmont
Continuous Wood Densification Process of Circular Profiles

Lars Blomqvist, Jimmy Johansson, Dick Sandberg
Shape stability of THM processed laminated veneer products glued with bio-based adhesive systems

Nebojša Todorović, Goran Milić, Zdravko Popović
Application of FT-NIR spectroscopy in chemometric modeling of heat-treated beechwood properties

Miljenko Klarić, Stjepan Pervan, Silvana Prekrat, Aleš Straže, Željko Gorišek
Determination of Thermo-modified Oak Wood Emissivity Properties in the Infrared Spectral Wavelength Range 7.5-13 μm

Aleš Straže, Željko Gorišek, Stjepan Pervan, Anna Sandak, Jakub Sandak
Characterisation of chemical and physical properties of thermo-modified wood by FT-NIR spectroscopy

Martin Rhême, John Botsis, Joël Cugnoni, Parviz Navi
Experimental and numerical investigations of mechanical properties of welded joint using the Arcan setup

Jimmy Johansson, Lars Blomqvist, Dick Sandberg
Challenges using dielectric heating for THM processing of solid wood

Andreja Kutnar, Robert Widmann, Iris Brémaud
Using Dynamic Mechanical Analysis (DMA) for fundamental understanding of thermo treatments of wood

Omar Saifouni, Rostand Moutou Pitti, Jean-François Destrebecq, Julien Froidevaux, Parviz Navi

Experimental study of mechanosorptive hygro-lock effect in wood subjected to variable loading and relative humidity

María Inés Placencia Peña, Carmen Mihaela Popescu, Frédéric Pichelin, Antonio Pizzi
Thermal and Analytical Characterization of Welded Beech

Carmen-Mihaela Popescu, Gabriela Lisa, Julien Froidevaux, Parviz Navi, Maria-Cristina Popescu
Thermal behaviours of THM densified wood

Pavlo Bekhta, Stanislaw Proszyk, Tomasz Krystofiak
Surface characteristics of thermo-mechanically densified veneers

Andreja Kutnar
Environmental impact assessment of THM products

Cristoph Manthy, Edeltraut Guenther, Andreas Heiduschke, Peer Haller
Structural, economic and environmental performance of fibre reinforced wood profiles vs. solutions made of steel and concrete

Kristiina Laine, Lauri Rautkari, Mark Hughes
Set-recovery of densified and thermally modified wood under repeated soaking-drying cycles

Andreja Kutnar, Aleš Ugovšek, Frederick A. Kamke, Milan Sernek
Bonding performance of densified VTC beech bonded with liquefied wood

Alexander Pfriem, Mario Zander, Lothar Clauder
Baltic Sea network for efficient and sustainable wood processing based on wood modification processes

Georg Behr, Holger Militz, Frederick A. Kamke, Andreja Kutnar
Fatigue behaviour of VTC and untreated beech wood

Anne Lavalette, Gérard Elbez, Alain Cointe, Régis Pommier, Michel Danis
Gluing ability of Pinus Pinaster depending on its moisture content

Viktor Savov, Julia Mihailova, Cvetelin Evstatiev
Influence of hot-pressing regimes at MDF production

Abdoulaye Samake, Patricio Palmili, Mustapha Taazount, Philippe Audebert, Maxime Audebert, Abdelhamid Bouchaïr
Thermo-Hydric behaviour of dowelled and bolted steel-to-timber connections exposed to fire

Dennis Jones, Edo Kegel
Products meeting Needs: Applying Thermal Modification and Thermo-Hydro Mechanical Processing of Wood to its Fullest Potential

Silvia Ferrari, Luigi Todaro, Ignazia Cuccui, Ottaviano Allegretti, Mario Marra
Preliminary tests of combined steaming and thermal-vacuum treatment on Turkey oak (Quercus cerris L.) wood.

Detalji o Akciji COST FP 0904 nalaze se na web stranici http://www.cost-fp0904.ahb.bfh.ch/cost/en/home

Prof. dr. sc. Stjepan Pervan
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Slika 3. Sudionici konferencije

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MILANO –DIZAJN I TRENDOVI 2013

Od 9. do 14. travnja 2013. godine Milano je ponovno potvrdio status međunarodne prijestolnice dizajna. Izložbeni prostor Rho, kao i događaji izvan sajma bili su mjesta susreta kreativaca i poduzetnika iz cijelog svijeta. U navedenom razdoblju 52. put održan je poznati *I Saloni*, koji je na prostoru Rho objedinio međunarodni sajam namještaja i opreme (*Salone Internazionale del Mobile*), bijenalne sajmove uredskog namještaja (*Salone Ufficio*) i rasvjete (*Euroluce*) te nezaobilazne radove mladih dizajnera (*Salone Satellite*). Na 142 209 m^2 svoje je proizvode pokazalo 1 269 izlagača, a više od 285 000 posjetitelja imalo je priliku vidjeti najnovije trendove u spomenutim područjima.

Najveći dokaz da Milano u navedenom razdoblju živi kao pravi dizajnerski grad jesu događanja koja su u sklopu milanskog Tjedna dizajna organizirana izvan samog sajma. Tzv. *Fuori Salone* obuhvatio je brojne umjetničke inicijative, radionice i izložbe po cijelom gradu – u gradskom središtu i u industrijskim zonama, na Ventura Lambrate, Tortoni i drugim zanimljivim lokcijama (sl. 1, 2).

Sagledavajući dojmove u oba prostora – na sajmu (*I Salone*) ili izvan njega (*Fuori Salone*), Milano je u mnogočemu odisao prirodom, ekologijom i zelenilom. Bez obzira na to je li se radilo o ulicama Milana (sl. 3) i dizajnerima na *Fuori Salone* (sl. 4) ili o „službenom“ *I Salone* (sl. 5), ekologija i prirodan izgled potpuni su hit u unutrašnjemu i vanjskom uređenju prostora. Zelenilo je neizostavno u svim prostorima, a dekoracije naglašene volumenom prostirale su se i u visinu i u dužinu, naglašavajući vezu prirode i stanovanja.

Slika 1. Atmosfera na ulicama u zoni Tortona

Slika 2. Atmosfera unutar paviljona u zoni Tortona

Slika 3. Detalji dvorišnih prostora Milana

Uz prirodnost zelenila, sveprisutne boje kretale su se u nijansama od svjetlosive preko bež tonova do tamnosmeđe. Dojam prirodnoga naglašen je upotrebom masivnog drva u detaljima, osobito hrasta i oraha, u kontrastu s bijelom, tirkizno plavom ili tamnoružičastom. Plava boja, u rasponu od petrolej plave do tirkizno plave, mogla se vidjeti u gotovo svim detaljima, od dekorativnih elemenata poput jastuka, vaza, tepiha, sve do ojastučenih dijelova namještaja i stolica, vratnih krila korpusnog namještaja nadalje. Plava je kombinirana sa žutom, zelenom ili narančastom. Ljubičasta i boja ciklame nisu više tako česte, a zamjenjuju ih ružičasti tonovi a primjesom nijanse cigle.

Razvoj tehologija usavršio je i 3D obradu materijala te unio dinamiku u površinsku obradu pročelja korpusnog namještaja, kako u tisku (umjetni materijali), tako i u obradi drva. Drvo sve više dominira milanskim sajmom, kako u detaljima, tako i u cjelovitim elementima namještaja (sl. 6).

Slika 4.a) i b). Detalj zelenila, *Fuori Salone*

Slika 5. Detalji prirode na izložbenom štandu,*I Salone*

Prostor je u najvećem dijelu u službi čovjeka i njegovih potreba, ispunjen zelenilom i prirodom.

Brandovi su u Milanu nezaobilazni. Novitete je pokazala nekolicina izlagača: Kartell (sl. 7), Moroso (sl. 8), Missoni (sl. 9), Moooi i brojni drugi koji na svojim izlagačkim prostorima okupljaju dizajnere današnjice, imena poput Patricie Urquiole, Phillipa Starcka, Rona Arada, Doshi & Leviena, Wernera Aisslingera, Rossa Lovegrovea, Marcela Wandersa, Nike Zupanc i drugih. Instalacija Patricie Urquiole pod nazivom *The Revolving Room*, izložena u Morosovoj prodavaonici na Via Pontaccio u Milanu, osvojila je Milano Design Award 2013 za najbolji izlagački projekt.

Slika 6. Primjena drva kao funkcionalno-dekorativnog detalja na namještaju

Slika 7. Kartellov genijalno osmišljen izlagački prostor, u kojemu je svaki dizajner dobio jednakovrijednu ulogu kao glumci u kazališnoj predstavi

Slika 8.a) i b) Morosov štand ispunjen kreacijama nekolicine današnjih dizajnerskih imena


Slika 9.a) i b) Missonijev prepoznatljiv stil pratit će dizajnere stoljećima, bez obzira na nedavno preminulog začetnika toga izuzetnog inspirativnog stila

Euroluce

Euroluce, sajam rasvjete koji se održava bijenalno, kao i sajam uredskog namještaja ove je godine okupio gotovo 500 izlagača i pokazao nove trendove i inovacije u svijetu rasvjete, svijetu u kojem su energetska učinkovitost i inovativni dizajn najvažniji pojmovi. LED rasvjeta je nezaobilazna i nudi bezbrojna dizajnerska rješenja, kombinacije, funkcionalno-svjetlosne igre i efekte u prostoru. Primjenom jednog elementa, složivoga u nekoliko funkcionalnih kombinacija, dizajneri otvaraju neograničen svijet funkcije i mašte. Velika su rasvjetna tijela i dalje u trendu, ali se voluminoznost postiže kombinacijom i spajanjem manjih elemenata koji čine skladnu cjelinu (sl. 10). Primjer je rasvjetnog tijela Stick za tvrtku Fabbian, dizajn Matali Craset (sl. 11).

Rasvjetna su tijela već niz godina doživljena kao dekorativni predmeti u prostoru. Zidne i stropne svjetiljke često se sastoje od multiplicirane kompozicije pojedinačnih elemenata. Igra volumena u kombinaciji s rasvjetom stvara dinamične igre svjetlosti (sl. 12), no i skladnu dekoraciju na zidu kada nisu u funkciji rasvjete.

Slika 10. Voluminoznost rasvjetnog tijela dobivena povezivanjem manjih elemenata, *Euroluce 2013*.

Slika 11. Rasvjeta Stick, dizajn: Matali Crasset, proizvođač: Fabbian, *Euroluce 2013*.

Slika 12. Skulpturalni efekti suvremene LED rasvjete, *Euroluce 2013*.

Salone Ufficio

Sajam uredskog namještaja ove je godine prikazao proizvode stotinjak izlagača i njihove najnovije trendove u svijetu uredskog namještaja (sl. 13). Kako i u ostale dijelove stanovanja, i u taj svijet polako ulazi trend prirodnosti i živih boja u detaljima

Slika 13. Novi uredski koncept dizajnera Karima Rashida za New Form, *Salone Ufficio*

Slika 14. Tvrtka Las pokazala je nekolicinu noviteta, *Salone Ufficio*

U uredskim prostorima uz drvo prevladavaju bijela i siva boja te prozirno staklo. Uredi se međusobno pregrađuju potpuno prozirnim staklenim pregradama, akustičnim ojastučenim pregradama ili ih uopće nema. Pojavljuju se samostalni prostorni elementi koji se mogu pomicati u prostoru, a sadržavaju jedinice za održavanje sastanaka, radnu zonu ili čajnu kuhinju, što čini prostor fleksibilnim i prilagodljivim za radne procese (sl. 14).

Radni prostor dizajnom postaje sve sličniji prostoru stanovanja, što je ove godine pokazao arhitekt Jean Nouvel, dobitnik Pritzkerove nagrade 2008. godine. Na površini od 2 000 m^2 Nouvel je u svojoj realizaciji projekta *Ured za život* (*Office for living*) pokazao moguće pristupe u oblikovanju ureda budućnosti (sl. 15). Njegov je cilj bio pokazati zadovoljstvo življenja u radnom prostoru, istraživanje novih materijala i novih tehnologija za stvaranje udobnoga, efikasnog, korisnog i ekološki prihvatljivog rješenja. Klasični stan, industrijska skladišta, privatne kuće, neboderi i industrijska platforma postali su prototip za životna radna mjesta u budućnosti.

Salone Satellite

Salone Satellite izložba je inovativnih proizvoda mladih dizajnera do 35 godina, na kojoj svake godine nekoga od njih prepozna određena velika tvrtka, čime dobivaju priliku za realizaciju svojih ideja. Ovogodišnja tema bila je *Dizajn i obrtništvo - zajedno za industriju*. Da uobičajena atmosfera entuzijazma i pozitivne energije u sektoru namještaja traje unatoč krizama, pokazao je i ovogodišnji *Salone Satellite* brojnim dizajnerskim idejama i novitetima (s. 16).

Slika 15.a),b),c). Projekt *Ured za život*, Jan Nouvela, *Salone Ufficio*

Hrvatski dizajneri u Milanu

U posljednje tri godine hrvatski dizajneri hrabro izlaze na talijansku scenu u sklopu dizajnerskih događaja koji se za vrijeme poznatoga međunarodnog sajma namještaja *I Salone* događaju u središtu Milana pod imenom milanski Tjedan dizajna.

Ove je godine od 9. do 14. travnja Centar za dizajn Hrvatske gospodarske komore organizirao izložbu *SOLID ACTS – Design from Croatia* kojom se nacionalna selekcija industrijskog dizajna predstavila na Tjednu dizajna u Milanu. Izložba je održana u Superstudiu Più – Temporary Museum for New Design 2013 (zona *Tortona*), jednoj od najposjećenijih lokacija na cijelome milanskom Tjednu dizajna (sl. 17).

Hrvatski postav (sl. 18) koji je dizajnirao Neven Kovačić (Redesign), a vizualnu komunikaciju popratio

Slika 16.a), b), c), d) Kreativne inspiracije mladih dizajnera, *Salone Satellite*

Slika 17. Ulaz u jednu od najposjećenijih zona u Milanu za vrijeme milanskog sajma – zona *Tortona*, Superstudiu Più – Temporary Museum for New Design

Studio Hamper (Ivana Vučić i Tom Jurica Kačunić) predstavio je 30 dizajnera i 32 rada podijeljena u devet tematskih cjelina: Karakteri u masivnom drvetu (Elementary, Tactile i Sensible), Svakodnevno, Posjet tradiciji, Aktivnost sjedenja i spavanja, Rođeni iz arhitekture, Vještina ručne izrade, Interakcija, Nove forme poznatog i Oblici rasvjete. Kako je najavljeno u Centru za dizajn Hrvatske gospodarske komore, „Solid Acts objedinjuje naznačene zajedničke temelje radova komunicirajući hrvatsku kulturu znanja i proizvodnje kroz novi hrvatski dizajn. Dizajneri koji sudjeluju na izložbi su Nina Bačun, Ivana Borovnjak, Lidia Boševski, Roberta Bratović, Svjetlana Despot, Filip Gordon Frank, Grupa (Filip Despot, Tihana Taraba, Ivana Pavić), Tea Janković, Zoran Jedrejčić, Nikolina Jelić, Luka Jelušić, Iva Frank (arhitektica), Ksenija Jurinec, Ada Kezić, Krunoslav Kovač, Sanja Kovačić, Neven Kovačić, Maja Mesić, Maja & Mejra Mujičić, MVA arhitekti (Marin Mikelić,

Slika 18. a), b), c), d), e), f) Postav izložbe *SOLID ACTS – Design from Croatia* hrvatskih dizajnera, zona *Tortona*

Tomislav Vreš), Numen/ForUse (Christoph Katzler, Sven Jonke, Nikola Radeljković), Ruđer Novak-Mikulić, Marija Ružić i Ana Tevšić".

Nadamo se da će ove kreativne i kvalitetne proizvode prepoznati hrvatski ili inozemni proizvođači te da će ostvariti konkurentnu nišu u kojoj je hrvatski dizajn etabliran kao kvalitetan i konkurentan, koji stvara proizvode utemeljene na hrvatskoj tradiciji i baštini i koji se koristi domaćom sirovinom – masivnim drvom, lokalnim resursima i onim bitnim – potencijalom hrvatskih dizajnera koji su inspirirani prirodnim i kulturološkim motivima oblikovali suvremenu predmetnu okolinu.

Izložba u istom sastavu i postavu moglo se razgledati od 8. svibnja do 7. lipnja 2013. u Centru za dizajn Hrvatske gospodarske komore (Draškovićeva 45).

dr. sc. Danijela Domljan, magistrica dizajna
Fotografije: dr. sc. Danijela Domljan;
press materijali *I Salone*, *Fuori Salone*

Aucoumea klaineana Pierre (okumé)

UDK: 674.031.752.242

NAZIVI I NALAZIŠTE

Drvo vrste *Aucoumea klaineana* Pierre iz botaničke porodice *Burseraceae* potječe iz tropske Afrike. Prirodno je rasprostranjeno u Gabonu, Republici Kongo i Ekvatorskoj Gvineji. Trgovački i lokalni nazivi su mu okumé, okoumé (Belgija, Njemačka, Francuska, Nizozemska), gaboon, gabun (Njemačka), angouma, okaka (Gabon), angum, ongoumi, moukoumi, zonga. U Gabonu je to glavna vrsta drva uporabne namjene.

Okumé zasad nije na popisu CITES-a (Convention on International Trade in Endangered Species of Wild Fauna and Flora), no okumé je zbog uzastopne sječe u Gabonu i okolnim područjima dospio na Crvenu listu međunarodnog saveza za zaštitu prirode IUCN-a (International Union for Conservation of Nature) kao ranjiva vrsta.

STABLO

Okumé je listača srednje visine, naraste između 30 i 40 m visoko, rijetko kad više. Promjer debla kreće se od 90 do 240 cm. Stabla imaju veliko žilište visine i do 3 m. Debla su obično blago zakrivljena, a ipak cilindrična. Visina do prve grane iznosi više od 21 m. Kora je bjelkastosiva i glatka, slična bukvinoj kori na mlađim stablima. Kasnije postaje crvenkastosiva. Debljina kore kreće se od 0,5 do 1,3 cm.

DRVO

Makroskopska obilježja

Bjeljika je bijela ili bljedosiva, a srž svjetloružičasta do ružičastosmeđa i crvenkastosmeđa. S vremenom postupno mijenja boju tako da izgledom postaje slična mahagoniju. Žica je slabo dvostruko usukana ili ravna, a ponegdje može biti kovrčava i valovita. Tekstura je srednje do umjereno fina i nije osobito privlačnog izgleda.

Godovi su dobro uočljivi zbog vlakanaca veće gustoće u kasnom drvu. Pore su vidljive običnim okom. Tekstura je srednje fina, drvo je bez izrazitog mirisa i okusa. Drvni su traci na radijalnim površinama tamnog sjaja. Površina drva ima fini satenski sjaj.Vlakanca su ravna, dvostruko usukana i tangencijalno valovita.

Mikroskopska obilježja

Okumé je rastresito porozno drvo. Prevladavaju pojedinačne pore i pore u paru, a rjeđe u radijalnim skupinama. Promjer pora iznosi od 55...150...245 mikrometara. Gustoća pora kreće se od 2…10…25 po cm^2 poprečnog presjeka, što znači da su slabo brojne do brojne. Volumni je udjel pora 11...19...27 %. Tile su rijetke i tankostjene. Aksijalni je parenhim paratrahealno rijedak, a udjel mu je do 3 %. Staničje drvnih trakova je heterogeno, s 1 do 4 niza uspravnih rubnih stanica traka. Drvni su traci difuzno raspoređeni i u nepravilnim slojevima. Visoki su od 3 do 20 stanica, a široki od 1 do 2 (3). Gustoća trakova je 2… 5…9 na mm, a volumni udjel trakova iznosi 7...12...18 %. Vlakanca su isključivo libriformska i septirana, a raspored im je na poprečnom presjeku radijalan. Debljina stijenki vlakanaca kreće se od 1 do 4,5 mikrometra, a promjer lumena je 5,5...18,5...26,5 mikrometara. Duljina vlakanaca iznosi 635...1110...1810 mikrometara. Volumni udjel vlakanaca kreće se od 60...66...68 %. U stanicama trakova mogu se naći (ne često) kristali prizmatičnog oblika. U pojedinoj se stanici nalazi više od jednog kristala. Stanice s kristalima normalne su veličine. U stanicama trakova ima i silicija u obliku granula.

Fizikalna svojstva

Gustoća standardno suhog drva, ρ_0	310...410...570 kg/m^3
Gustoća prosušenog drva, ρ_{12-15}	320...430...590 kg/m^3
Gustoća sirovog drva, ρ_s	500...650 kg/m^3
Poroznost	oko 72 %
Totalno radijalno utezanje	2,5...3,8...5,5 %
Totalno tangentno utezanje	4,0...5,7...7,9 %
Totalno volumno utezanje	6,6...9,7...13,5 %

Mehanička svojstva

Čvrstoća na tlak	33...39...66 MPa
Čvrstoća na savijanje	27...72...107 MPa
Čvrstoća na vlak paralelno s vlakancima	22,5...58...125 MPa
Čvrstoća na vlak okomito na vlakanca	1,5...1,8...2,1 MPa
Tvrdoća prema Brinellu paralelno s vlakancima	26...34 MPa
Tvrdoća prema Brinellu okomito na vlakanca	oko 12 MPa
Modul elastičnosti	oko 3 GPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Drvo okumé lako se obrađuje ručnim i strojnim alatima. Izblanjane su površine često čupave. Zato se preporučuje da rezni kut alata bude 20°. Okumé i bez predbušenja dobro drži čavle. Dobro se brusi, politira i lijepi. Sadržava silicij u količini od 0,12 do 0,16 %. Udio silicija u drvu od 0,05 % dovoljno je visok da znatno otupi oštricu alata.

Sušenje

Okumé se brzo i dobro suši, uz nastanak vrlo malo grešaka. To su uglavnom neznatne pukotine i blaga iskrivljenja. Stabilnost dimenzija drva je dobra, a jednom prosušeno drvo umjereno radi.

Trajnost i zaštita

Drvo okumé je prirodno slabo otporno prema truleži, a srž je podložna napadu morskih štetnika. Trupce nerijetko napadaju strizibube, a bjeljiku bjeljikari i potkornjaci. Srž nije premeabilna i teško se impregnira zaštitnim sredstvima za drvo.

Uporaba

Okumé se uglavnom upotrebljava za proizvodnju furnira i ukrasnih furnira, furnirskih ploča i ploča iverica, za izradu obloga, unutarnjih konstrukcija, (finog) namještaja i njegovih dijelova, kutija za cigare te služi kao građevni materijal za različite konstrukcije. Drvo je osobito prikladno za izradu vodootpornih ploča u brodogradnji (i, općenito, za upotrebu u moru), a cijenjeno je i u izgradnji malih zrakoplova. Gitare izrađene od okuméovine imaju slična akustička svojstva kao i one od javorovine, a istodobno mogu biti znatno lakše.

Napomena

Okuméovina može sadržavati kancerogene tvari.

Prema izvještaju međunarodne organizacija ITTO (The International Tropical Timber Organization), okumé je važna sirovina za proizvodnju građe i izvoz. Vrste sličnih svojstava okuméu su *Virola surinamensis*, *Tetraberlinia tubmaniana*, *T. bifoliolata*, *Terminalia brassii*.

Kao zamjena za okumé u proizvodnji furnirskih ploča preporučuje se *Canarium schweinfurthii*, *Antrocaryon micraster*, *Antrocaryon klaineanum*. Kao potencijalne zamjene za okumé navode se *Bombax brevicuspe*, *Virola surinamensis*.

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Upute autorima

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Predaja rukopisa podrazumijeva uvjet da rad nije već predan negdje drugdje radi objavljivanja ili da nije već objavljen (osim sažetka, dijelova objavljenih predavanja ili magistarskih radova odnosno disertacija, što mora biti navedeno u napomeni) te da su objavljivanje odobrili svi suautori (ako rad ima više autora) i ovlaštene osobe ustanove u kojoj je istraživanje provedeno. Kad je rad prihvaćen za objavljivanje, autori pristaju na automatsko prenošenje izdavačkih prava na izdavača te na zabranu da rad bude objavljen bilo gdje drugdje ili na drugom jeziku bez odobrenja nositelja izdavačkih prava.

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

Upute

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

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

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

Znanstveni i stručni radovi moraju biti sažeti i precizni. Osnovna poglavlja trebaju biti označena odgovarajućim podnaslovima. Napomene se ispisuju na dnu pripadajuće stranice, a obrojčavaju se susljedno. One koje se odnose na naslov označuju se zvjezdicom, a ostale uzdignutim arapskim brojkama. Napomene koje se odnose na tablice pišu se ispod tablica, a označavaju se uzdignutim malim pisanim slovima, abecednim redom.

Latinska imena trebaju biti pisana kosim slovima (italicom), a ako je cijeli tekst pisan kosim slovima, latinska imena trebaju biti podcrtana.

U uvodu treba definirati problem i, koliko je moguće, predočiti granice postojećih spoznaja, tako da se čitateljima koji se ne bave područjem o kojemu je riječ omogući razumijevanje ciljeva rada.

Materijal i metode trebaju biti što preciznije opisane da omoguće drugim znanstvenicima ponavljanje pokusa. Glavni eksperimentalni podaci trebaju biti dvojezično navedeni.

Rezultati trebaju obuhvatiti samo materijal koji se izravno odnosi na predmet. Obvezatna je primjena metričkog sustava. Preporučuje se upotreba SI jedinica. Rjeđe rabljene fizikalne vrijednosti, simboli i jedinice trebaju biti objašnjeni pri njihovu prvom spominjanju u tekstu. Za pisanje formula valja se koristiti Equation Editorom (programom za pisanje formula u MS Wordu). Jedinice se pišu normalnim (uspravnim) slovima, a fizikalni simboli i faktori kosima (italicom). Formule se susljedno obrojčavaju arapskim brojkama u zagradama, npr. (1) na kraju retka.

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

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

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

Naslovi slika i crteža ne pišu se velikim tiskanim slovima. Crteži i grafikoni trebaju odgovarati stilu časopisa (fontovima i izgledu). Slova i brojke moraju biti dovoljno veliki da budu lako čitljivi nakon smanjenja širine slike ili tablice. Fotomikrografije moraju imati naznaku uvećanja, poželjno u mikrometrima. Uvećanje može biti dodatno naznačeno na kraju naslova slike, npr. "uvećanje 7500 : 1".

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

Primjeri navođenja literature

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

Primjer

Kärki, T., 2001: Variation of wood density and shrinkage in European aspen (*Populus tremula*). Holz als Roh- und Werkstoff, 59: 79-84. http://dx.doi.org/10.1007/s001070050479.

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

Primjeri

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

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

Ostale publikacije (brošure, studije itd.)

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

Web stranice

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

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

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Submission of a paper implies that the work has not been submitted for publication elsewhere or published before (except in the form of an abstract or as part of a published lecture, review or thesis, in which case it must be stated in a footnote); that the publication is approved by all co-authors (if any) and by the authorities of the institution where the research has been carried out. When the paper is accepted for publication, the authors agree to the transfer of the copyright to the publisher and that the paper will not be published elsewhere in any language without prior consent of the copyright holders.

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Details

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

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

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

Scientific and professional papers shall be precise and concise. The main chapters should be characterized by appropriate headings. Footnotes shall be placed at the bottom of the same page and consecutively numbered. Those relating to the title should be marked by an asterix, others by superscript Arabic numerals. Footnotes relating to the tables shall be printed under the table and marked by small letters in alphabetical order.

Latin names shall be printed in italics and underlined.

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

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

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

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

Figures should be inserted into the text. They should be of 600 dpi resolution, black and white (color photographs only on request and extra charged), in jpg or tiff format, completely clear and understandable without reference to the text of the contribution.

All graphs and tables shall be black and white (unless requested otherwise with additional payment). Tables and graphs should be inserted into the text in their original format in order to insert them subsequently into the Croatian version. If this is not possible, original document should be sent in the format in which it was made (excel or statistica format).

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Discussion and conclusion may, if desired by authors, be combined into one chapter. This text should interpret the results relating to the problem outlined in the introduction and to related observations by the author(s) or other researchers. Repeating the data already presented in the "Results" chapter should be avoided. Implications for further studies or application may be discussed. A conclusion shall be expressed separately if results and discussion are combined in the same chapter. Acknowledgements are presented at the end of the paper. Relevant literature shall be cited in the text according to the Harvard system ("name – year"), e.g. (Bađun, 1965). In addition, the bibliography shall be listed at the end of the text in alphabetical order of the author's names, together with the title and full quotation of the bibliographical reference. The list of references shall be selective, and each reference shall have its DOI number (http://www.doi.org) (check at http://www.crossref.org).:

Example of references

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

Example:
Kärki, T., 2001: Variation of wood density and shrinkage in European aspen (*Populus tremula*). Holz als Roh- und Werkstoff, 59: 79-84. http://dx.doi.org/10.1007/s001070050479.

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

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

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

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

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