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Beata Fabisiak[1]

Characteristics of Design Process Organization in Selected Furniture Manufacturing Companies

Obilježja organizacije procesa dizajniranja proizvoda u odabranim tvrtkama za proizvodnju namještaja

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ABSTRACT • *The aim of the study was to conduct and present an analysis for the characteristics of new products development process in selected furniture manufacturing companies, focusing on the competences and vocational training of individuals designing furniture. The results of survey conducted among 75 furniture factories were presented. The obtained data was elaborated statistically taking into consideration for example the size of the company. It was shown that designing of furniture in medium-sized and large enterprises is increasingly often performed by multidisciplinary design teams composed of designers and engineers. However, at the same time a vast number of furniture companies use the artistic talents of employed engineers. These results constitute an important signal, indicating the directions of changes for providing adequate education for students of engineering faculties of universities to meet modern market requirements.*

Key words: *design, furniture companies, new product development process*

SAŽETAK • *Cilj istraživanja bio je provesti i prezentirati analizu procesa razvoja novog proizvoda u odabranim tvrtkama za proizvodnju namještaja, s naglaskom na kompetencije i stručno osposobljavanje osoba koje rade u procesu dizajniranja namještaja. Predstavljeni su rezultati ankete provedene u 75 tvrtki za proizvodnju namještaja. Dobiveni su podaci statistički obrađeni, pri čemu je uzeta u obzir, primjerice, veličina tvrtke. Pokazalo se da dizajniranje namještaja u srednjim i velikim poduzećima sve češće obavljaju multidisciplinarni dizajnerski timovi sastavljeni od dizajnera i inženjera. No istodobno se velik broj tvrtki za proizvodnju namještaja koristi umjetničkim talentima svojih inženjera. Dobiveni su rezultati važan pokazatelj kako je nužno promijeniti obrazovne ponude za studente tehničkih fakulteta kako bi se na odgovarajući način udovoljilo zahtjevima suvremenog tržišta rada.*

Ključne riječi: *dizajn, tvrtke za proizvodnju namještaja, proces razvoja novog proizvoda*

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1 INTRODUCTION
1. UVOD

As a result of the high competition on the market, increasing attention is focused on the development of new products. This trend can also be observed in furniture industry. Enterprises, in order to effectively operate on the market, have to continuously change the assortment of their products, adapting them to consumers' expectations (Mruk and Rutkowski, 2001). Obviously, no product may be manufactured in an unchanged form for an arbitrarily long time. Enterprises, which intend to enjoy a long-term competitive edge, have to carefully observe changes occurring on the market and continuously modify their range of offered products (Krawiec, 2000; Rutkowski, 2006). These decisions are connected with the process of development of new products, including the withdrawal from the market, modification of already existing products or introduction of new products that determine the survival and development of the enterprise (Urban and Hauser, 1993; Stabryła, 2002; Rutkowski, 2006). It is increasingly difficult for enterprises to maintain their present position or reach a better, only by providing good quality products, or reducing their manufacturing costs. Easy access to modern technologies and their extensive use make it possible for most companies to manufacture a given product at a similar level of quality and manufacturing costs (Sosnowska, 2003). Therefore, enterprises should develop an innovative approach to processes of preparation and manufacture of products and orientation towards continuous work on updating the offered basket of goods. Considerable emphasis is placed not only on the reduction of the process of product preparation, but at the same time on the extension of the assortment of offered products and creation of products capable of meeting as best possible the growing needs of consumers. Additionally, globalization has resulted in a situation where companies more and more frequently operate on many markets and thus they have to differentiate the range of their products offered to consumers. Such a situation obviously requires the development of new ideas, and thus products and services. The creation of global companies has also resulted in the need to search for new, original ways of competing available for smaller enterprises, searching for market niches (Jerzyk *et al.*, 2004). Contemporary enterprises tend to differentiate their products as much as possible. This objective may be reached thanks to the use of design, which is considered to be one of the most important factors influencing company activity in this field (Trueman and Jobber, 1998; Gemser and Leenders, 2001; Buil *et al.*, 2005), enabling at the same time to gain the competitive advantage on the market.

The process of product development is also of crucial importance for furniture manufacturing companies. However, there is still a lack of research concerning this subject. The literature overview indicates that the analysis of implementation of design skills in furniture manufacturing companies was performed by Berginc *et al.* (2011) and Fabisiak (2011). Berginc *et al.* (2011) presented the characteristics of the cooperation between furniture industry and designers with the focus on its strengths and weaknesses. Fabisiak (2011) studied the frequency of using design services, factors determining the cooperation with designers and the ways in which furniture manufacturing companies find new designers/design studios.

The aim of this paper is to conduct and present an analysis of the method for the preparation and development of new products in selected furniture factories, focusing on the competences and vocational training of individuals designing furniture.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

The investigation involved several selected furniture manufacturing companies located in Poland. The analysed sample of enterprises was selected on the basis of a quota selection method. It was divided into layers according to the following criteria: the level of employment and the geographical localisation so that the firms represented well the structure of furniture industry in Poland. In the described analysis, data from 75 enterprises were examined. The investigation was carried out using the survey method and direct interviews conducted at furniture manufacturers located in specific regions of Poland. The data collected were subjected to statistical analysis with the use of SPSS 16.0 and STATISTICA 10.0 PL software.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

When analysing the organization of the process of furniture manufacturing, first of all, it should be established whether there is a department in the factory involved in designing of new products. Results of the investigation showed that 53 % of analysed enterprises had a design department in their structure, while in the others it was most often combined with the engineering department. The main reasons for the decision not to have a separate design department, in case of most micro- and small enterprises, were economic considerations and occasionally even the fact that such investment "does not yield profits".

The graphic presentation of the performed statistical clustering indicates that the existence of the design department in an enterprise is connected with its size (Figure 1). It was stated that only 11 % micro-enterprises and 30 % small businesses had a design department. This dependence was far more advantageous in medium-sized and big enterprises, in which the discussed levels were 67 % and 77 %.

The conducted correspondence analysis confirmed the results obtained using statistical clustering and the chi-square test. It needs to be stressed that the existence of the design department in enterprises is not a condition required for the achievement of the leading position on the market in terms of design application. For micro- and small enterprises, there are several al-

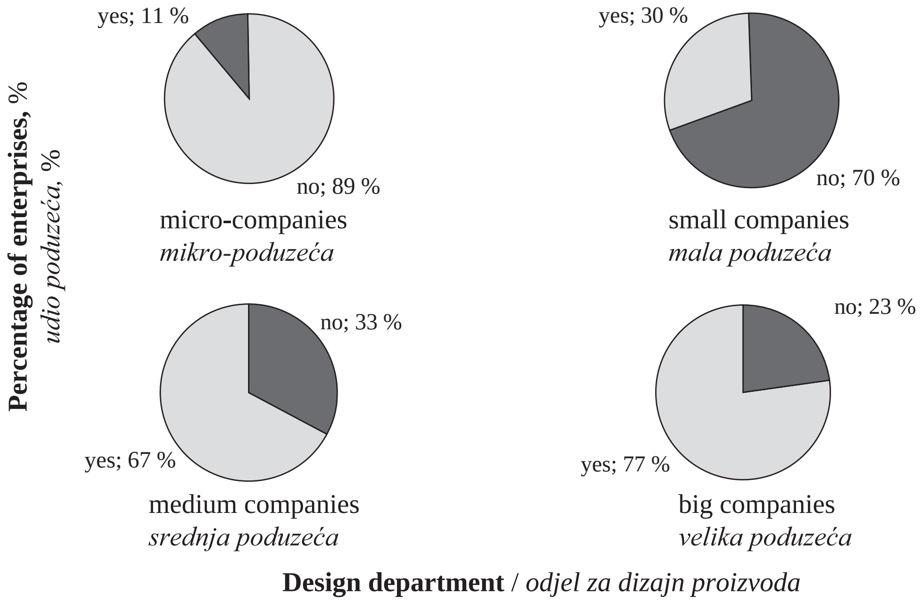

Figure 1 Structure of analysed furniture enterprises depending on the existence of a design department
Slika 1. Struktura analiziranih tvrtki za proizvodnju namještaja s obzirom na postojanje odjela za dizajn proizvoda

ternative solutions available. As previously mentioned, the design department may be combined with the engineering department or the performance of design services may be commissioned (outsourcing).

It was also decided to investigate if the existing globalization processes, and connected with them easier and faster transfer of knowledge, human resources and capital have impact on the number of foreign designers working for Polish companies. In order to gather that information, the nationality of furniture designers in the studied companies was defined. The results of the performed analysis showed that 37 % of studied enterprises employed foreign designers or design studios. The detailed analysis, conducted within the companies employing foreign designers, revealed that this kind of investment was chosen mainly by big companies (Figure 2). However, it is worth to highlight that this group of companies included also medium, small and even micro-companies (Fabisiak, 2011).

Important information concerning the use of design in analysed companies is also supplied by the analysis of internal processes in designing and manufacturing of furniture, such as e.g. data on contractors, participants in these processes. They may be designers,

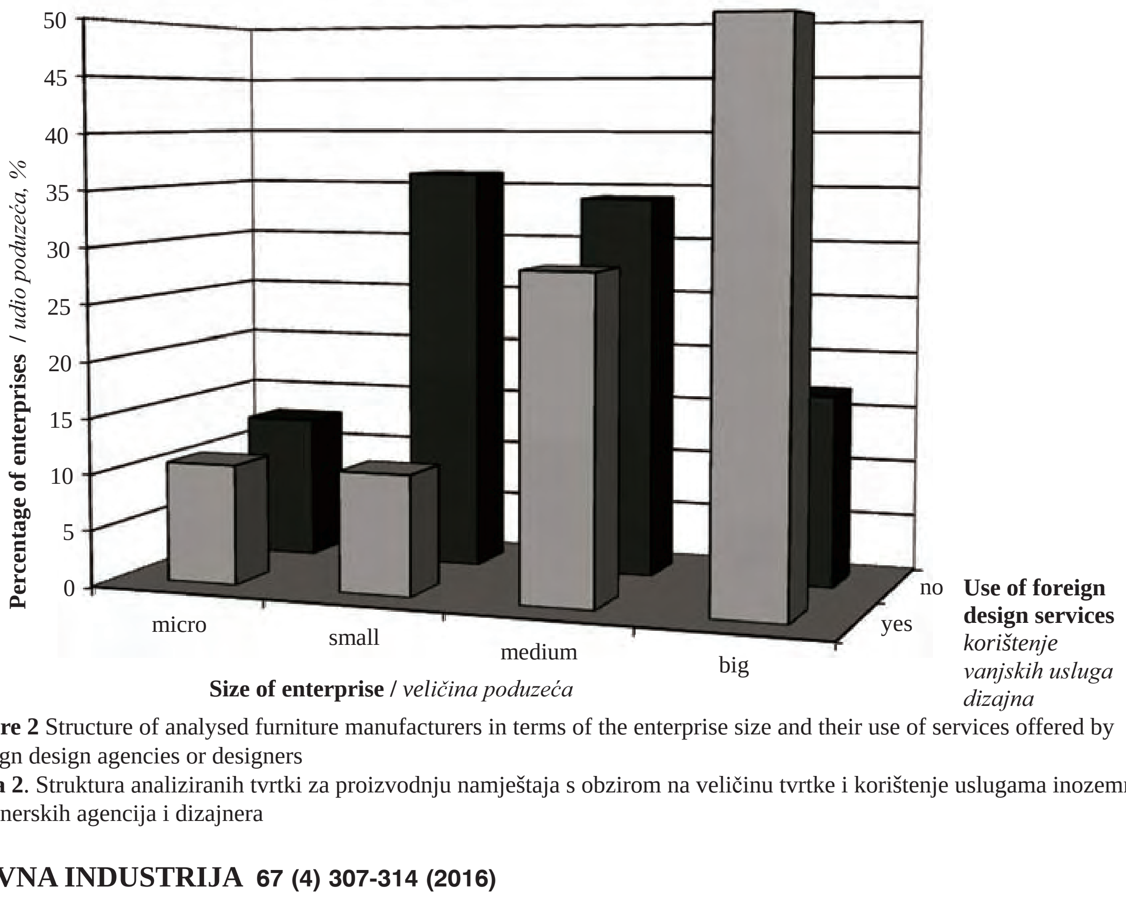

Figure 2 Structure of analysed furniture manufacturers in terms of the enterprise size and their use of services offered by foreign design agencies or designers
Slika 2. Struktura analiziranih tvrtki za proizvodnju namještaja s obzirom na veličinu tvrtke i korištenje uslugama inozemnih dizajnerskih agencija i dizajnera

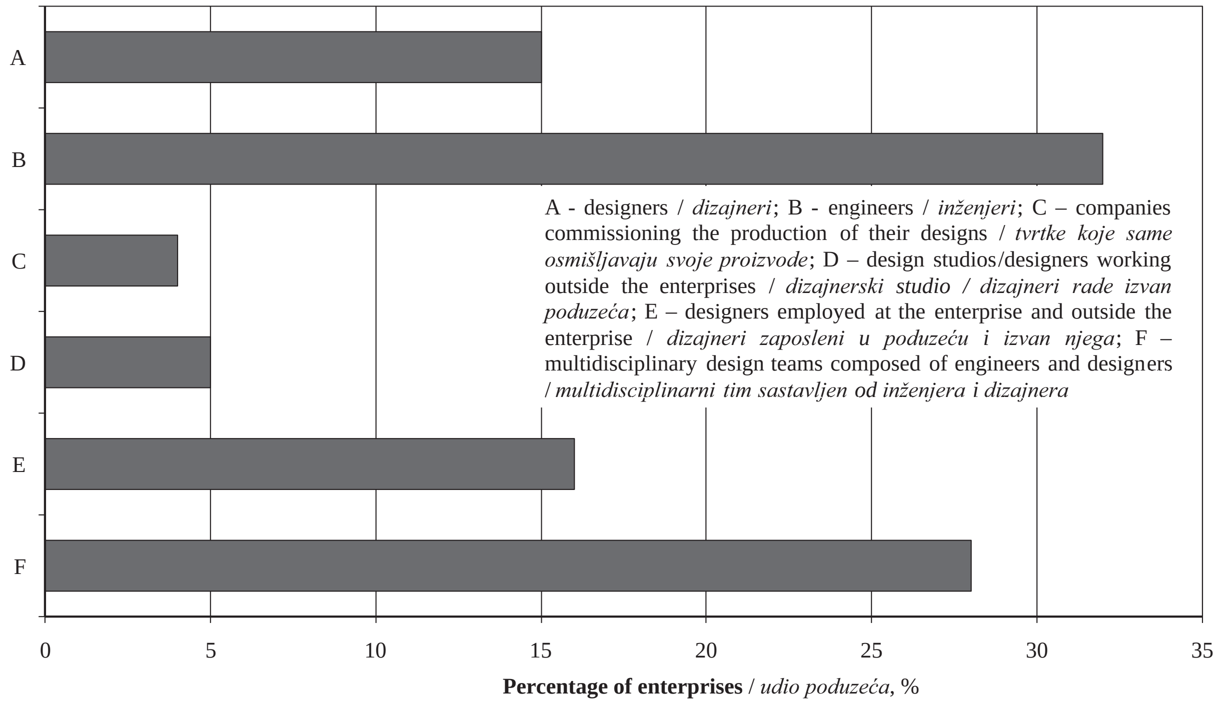

Figure 3 Structure of analysed furniture manufacturers depending on the group of design performers
Slika 3. Struktura analiziranih tvrtki za proizvodnju namještaja ovisno o tomu tko radi na dizajnu proizvoda

engineers, constructors, companies commissioning the production of their designs, design studios/designers working outside the enterprises, teams of designers employed at the enterprise and outside the enterprise, multidisciplinary design teams composed of engineers, design constructors and designers. Figure 3 presents the structure of examined enterprises depending on the groups mentioned above. The individual groups of design performers are labelled with A-F letters.

Based on the presented data, it can be noticed that engineers and constructors were responsible for creating projects of new furniture in 32 % of examined enterprises. Furthermore, nearly 15 % of companies employed designers and in 16 % of furniture manufacturers

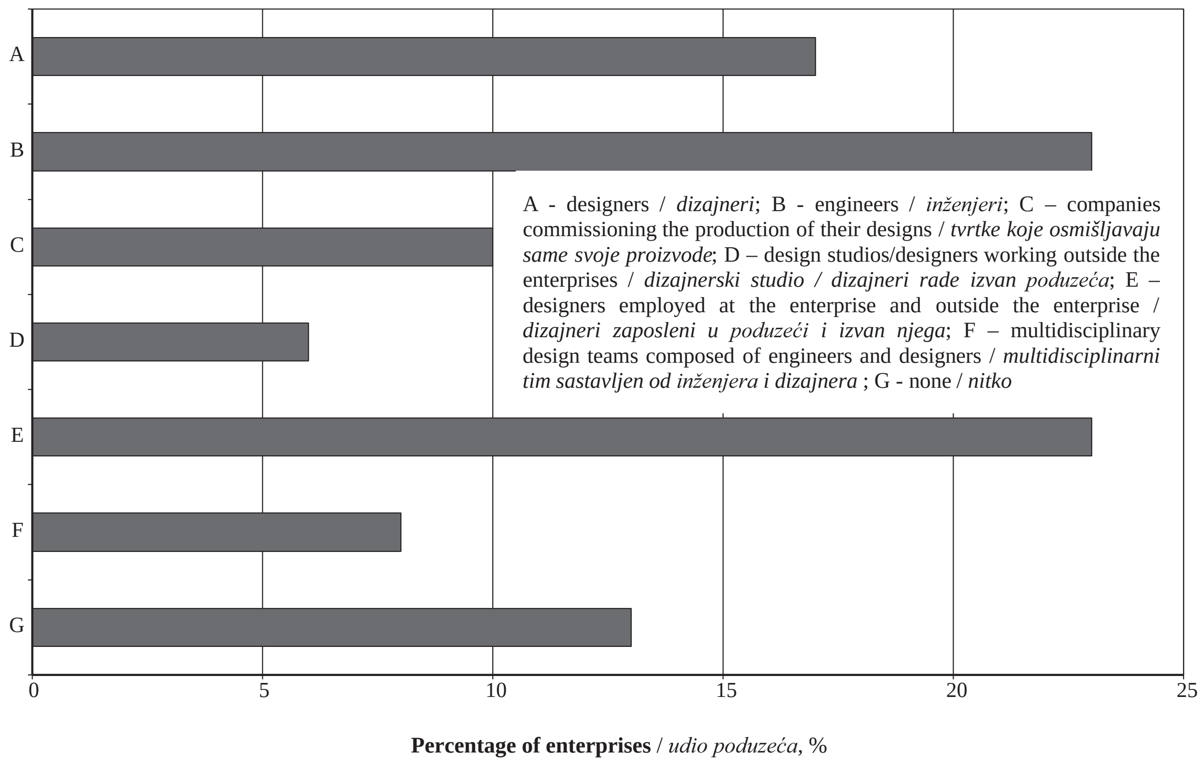

Figure 4 Structure of analysed furniture enterprises depending on the type of design activity the enterprise plans to develop within 3 years since the period of the study
Slika 4. Struktura analiziranih tvrtki za proizvodnju namještaja ovisno o aktivnostima dizajniranja proizvoda koje tvrtka planira pokrenuti unutar tri godine od provedenog istraživanja

design performers were both designers employed in the given company and external design studios. It is worth to highlight that often (28 % of cases) a multidisciplinary team was responsible for the new product development. Only in 4 % of cases, the analysed companies manufactured furniture only based on designs provided by companies commissioning the given production. Slightly over 5 % of examined enterprises decided to invest in purchase of services offered by external design studios or designers.

The analysis of the organization of design activities in furniture factories also tried to determine in which direction managers of enterprises were planning to develop the design activities in their units (Figure 4).

It was found that 23 % of companies are planning a development of design activities consisting in the use of both services of designers employed in the enterprise and design studios. The same percentage of enterprises intends to focus on engaging engineers and constructors employed in these companies in the process of furniture design. It also results from these investigations that 8 % of enterprises will extend the work of design teams consisting of designers and engineers. These results constitute an important signal, on the basis of which it is possible not only to prepare an adequate education programme for students of engineering faculties of universities, but also offer curricula for graduate studies or even courses aimed at improving the skills in terms of aesthetic modification of furniture forms, computer aided design, the latest trends in design, ergonomics, functionality, and first of all work in a multidisciplinary design team.

It should be noted that only one enterprise among the small ones, the group of 11 % of enterprises concerned, which declared the willingness to develop furniture design activity using designs supplied by other companies, intends to focus on the development of only this activity. The other factories, apart from the described activity, are also planning investments in other forms of organization of the process of creating furniture. This is a positive sign, since it implies that these companies will not create furniture only based on designs prepared by other enterprises, but rather attempt to design new collections themselves.

Based on statistical grouping method, analysis of directions of design activity development was performed depending on the enterprise size (Figure 5).

Half of the examined micro-enterprises plan to develop design activity using artistic talents of engineers employed in the company. It is also important to highlight that the group of companies not planning to develop any design activity was mostly made of micro- and small companies.

Analysis of the vocational training of individuals designing furniture in analysed enterprises showed that in 29 % of factories the creation of new products was performed by graduates of the Faculty of Wood Technology, while in 17 % of cases they were graduates of the Academy of Fine Arts (Figure 6). In the same group of companies, multidisciplinary design teams, consisting of graduates of the Academy of Fine Arts and the Faculty of Wood Technology or the University of Technology and the Faculty of Wood Technology, all from Poland, participated in the process of designing furniture. In 20 % of factories, the vocational training of individuals designing furniture differed from the above mentioned education profiles. According to a detailed analysis of the discussed problem, conducted using the statistical clustering methods, it can be stated that such a situation was found mainly in micro- and small enterprises, where furniture design was conducted e.g. by company owners, who usually used their experience gained in the furniture sector. Multidisciplinary design teams were mostly characteristic of medium-sized and large-sized furniture factories.

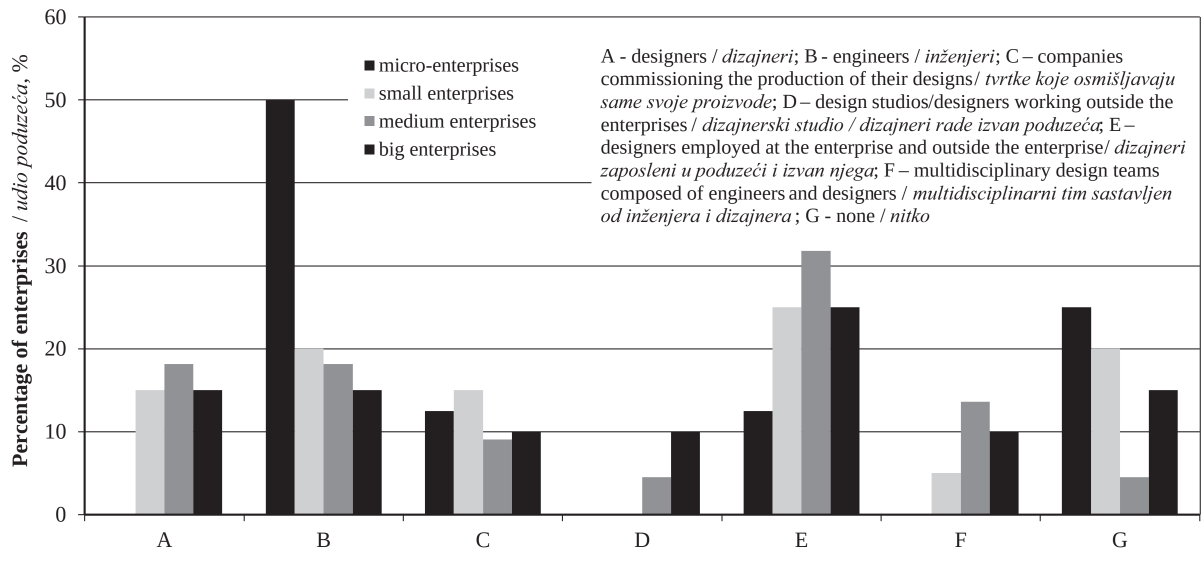

Figure 5 Structure of analysed furniture enterprises depending on the size of the enterprise and the type of design activity the enterprise plans to develop within 3 years since the period of the study
Slika 5. Struktura analiziranih tvrtki za proizvodnju namještaja ovisno o veličini tvrtke i aktivnostima dizajniranja proizvoda koje tvrtka planira pokrenuti unutar tri godine od provedenog istraživanja

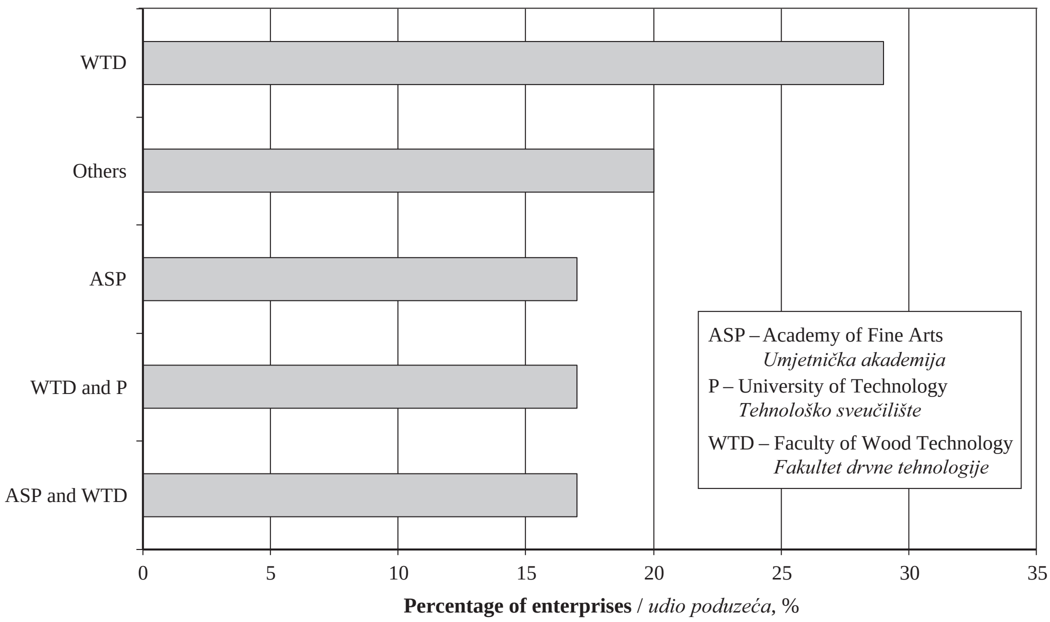

Figure 6 Structure of analysed furniture enterprises depending on the vocational preparation of individuals designing furniture
Slika 6. Struktura analiziranih tvrtki za proizvodnju namještaja ovisno o stručnoj osposobljenosti pojedinaca koji dizajniraju namještaj

The coexistence of individual variants of the discussed variables was analysed using the analysis of correspondence. Results were then verified using cluster analysis. The data presented in Table 1 indicate that the choice of 2 dimensional solution space allows to explain 92.2 % of inertia. Moreover, the implementation of 2 dimensional solution space in the performed analysis was also indicated by the Cattell scree plot (Figure 7).

Graphic presentation of the results of the correspondence analysis indicates the occurrence of differences between 3 groups of enterprises depending on their size and vocational skills of individuals involved in furniture design (Figure 8). The first group is made of micro-enterprises, in which designing of furniture is usually performed by individuals with no university education in the field of design or manufacture of furniture. The second group is made of small and medium-sized enterprises, in which new furniture design is only prepared by designers - graduates of the Academy of Fine Arts or engineers graduated from the Faculty of Wood Technology. The third group is formed by large furniture factories, in which most typically multidisciplinary design teams, composed of graduates from different universities educating furniture designers and

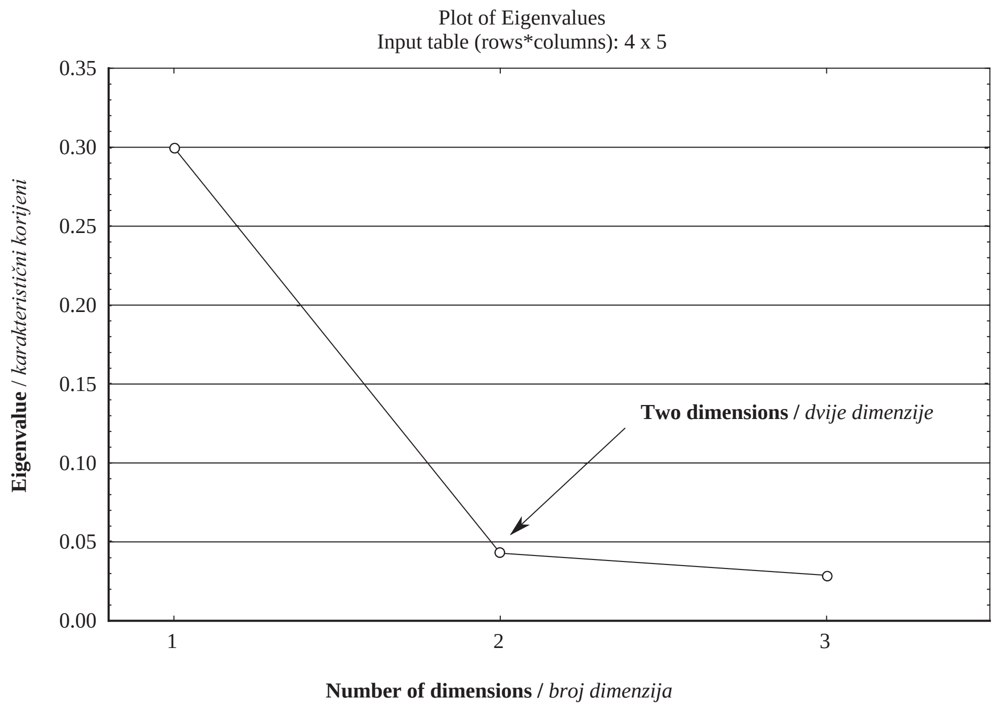

Figure 7 Scree plot for variables: size of company and educational background of individuals designing furniture
Slika 7. *Scree plot* za varijable: veličina tvrtke i obrazovanje pojedinaca koji dizajniraju namještaj

Table 1 Statistical characteristics of evaluation of choice of solution space for variables: size of company and educational background of individuals designing furniture
Tablica 1. Statističke vrijednosti procjene izbora rješenja za varijable: veličina tvrtke i obrazovanje pojedinaca koji dizajniraju namještaj

Number of dimensions *Broj dimenzija*	**Singular values** *Singularne vrijednosti*	**Eigen values** *Karakteristični korijeni*	**Percentage of inertia** *Postotak inercije*	**Cumulative percentage** *Kumulativni postotak*
1	0.5475	0.2997	80.7017	80.7017
2	0.2070	0.0429	11.5390	92.2407
3	0.1698	0.0288	7.7593	100.0000

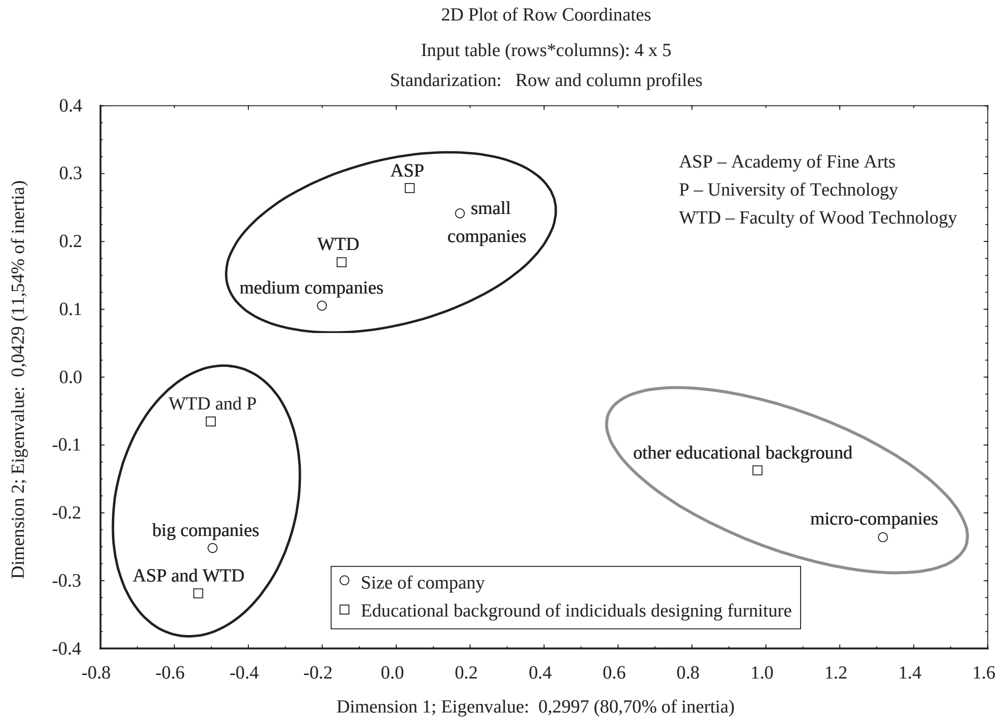

Figure 8 Graphic presentation of results of correspondence analysis of variables: size of enterprise and vocational training of individuals designing furniture
Slika 8. Grafički prikaz rezultata analize korespondencije za varijable: veličina tvrtke i stručno osposobljavanje pojedinaca koji dizajniraju namještaj

design engineers, are involved in the process of designing new products. The trend discussed above, connected with the vocational training of individuals designing new products in furniture enterprises, has also been observed in other European countries, e.g. in Portugal (Nogueira, 2008).

In order to verify the character of links between individual variants of analysed variables, a hierarchical classification was performed for cluster analysis according to Ward (Figure 9). Results of correspondence analysis were confirmed, and consequently 3 groups of co-existing traits were identified.

Furniture manufacturers participating in the study stressed the importance of cooperation of experts representing different fields in the process of designing and manufacturing furniture. It needs to be stressed that, already in the early 1990s, some studies (Potter *et al.*, 1991; Walsh *et al.*, 1992) indicated the correlation between a good design, good financial standing, and the use of multidisciplinary teams in the design process. These results are of great importance since the opinion is strengthening that the development of new products of the highest standard is only possible on the basis of cooperation between exerts representing a broad spectrum of specializations.

4 CONCLUSIONS
4. ZAKLJUČAK

To sum up, it may be concluded that the conducted analysis shows that designing of furniture in Polish medium-sized and large enterprises is increasingly often performed by multidisciplinary design teams composed of specialists - graduates of the Academy of Fine Arts, University of Technology or Faculty of Wood Technology from Poland. New designs of furniture in micro-enterprises are most commonly created by owners of these companies. A large proportion of furniture companies use the artistic talents of employed engineers and design engineers. The importance of the multidisciplinary character of the process of designing and manufacturing furniture has been outlined. These results constitute an important signal, on the basis of which an adequate education program may be developed, preparing graduates to work in a multidisciplinary design team.

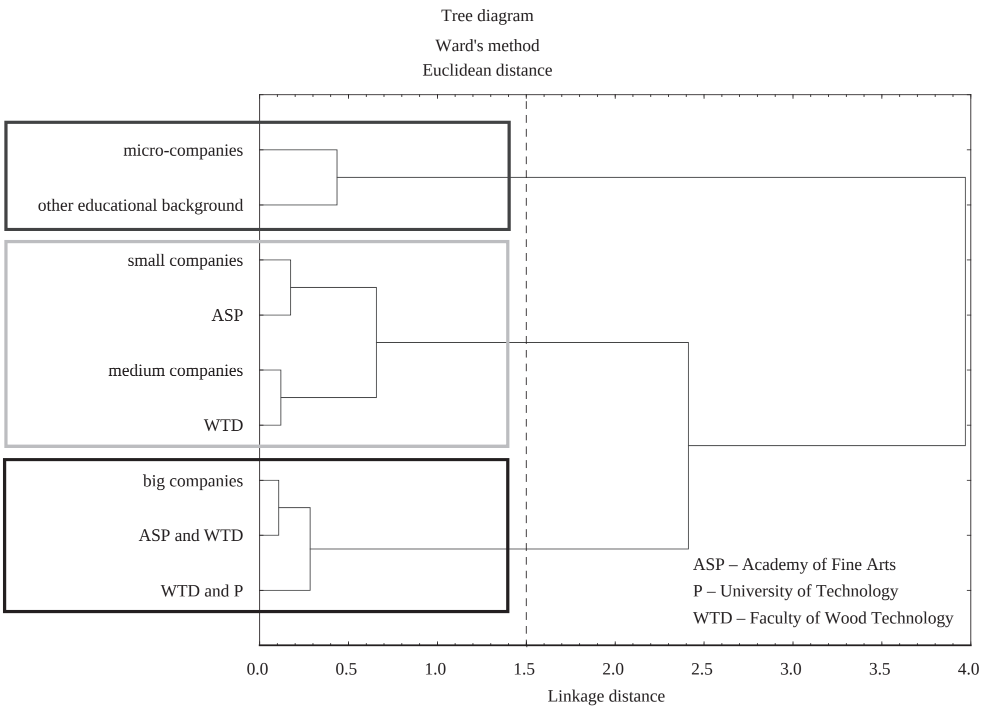

Figure 9 Graphic presentation of results of cluster analysis for variables: size of enterprise and vocational training of individuals designing furniture
Slika 9. Grafički prikaz rezultata klasterske analize za varijable: veličina tvrtke i stručno osposobljavanje pojedinaca koji dizajniraju namještaj

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Wood Waste Turned Into Value Added Products: Thermal Plasticization by Benzylation Process

Pretvorba drvnog otpada u proizvod dodane vrijednosti: toplinsko plastificiranje primjenom procesa benzilacije

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ABSTRACT • *Sawdust is usually considered as waste in wood-using industries. These materials can be converted into value added thermoplastics by means of benzylation. Products can be utilized in different applications where plastics are used. Thermoplasticization process was carried out with benzyl chloride under different alkaline conditions, 15, 25 and 35 %, respectively. Alkali ions and concentration affect the substitution reaction. Tailored material structure was remarkably changed. In order to detect changes, crystallinity index of the materials and thermal properties were analyzed. In FTIR spectra, the peaks appeared at 698 cm^{-1} and 740 cm^{-1}, which indicates the aromatic C-C angular deformation. Multiple peak appears at 3030 cm^{-1}, which indicates benzylation of the materials. The peak increase can be observed at 1596 cm^{-1} due to the aromatic deformation. Benzyl groups attached to hydroxyl to form ether groups increase the peak intensity. As a result of that, hydrogen bond energy changes and crystallinity of the materials is reduced. This substitution of functional groups changes the decomposition temperature of modified materials. It reduces the decomposition temperature to between 330 and 350 ºC. Thermogravimetric analysis revealed that modified products were characterized by poorer thermal stability compared to raw materials.*

Keywords: *thermoplastic resin, hydrogen bond energy, crystallinity, thermal properties*

SAŽETAK • *Piljevina se u drvoprerađivačkoj industriji često smatra otpadom. Međutim, ona se postupkom benzilacije može pretvoriti u termoplastični materijal kao proizvod dodane vrijednosti. Tako dobiveni materijal moguće je upotrijebiti za različite namjene za koje se obično rabe plastične mase. Toplinski postupak plastificiranja provodi se benzil kloridom pri različitim lužnatim uvjetima (15, 25 ili 35 %). Koncentracija lužnatih iona utječe na reakciju supstitucije. Struktura materijala značajno se mijenja. Radi otkrivanja promjene, analizirani su indeks kristaliničnosti materijala i toplinska svojstva. U infracrvenom dijelu spektra pikovi su se pojavili na 698 cm^{-1}*

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i 740 cm^{-1}, što upućuje na aromatske C-C kutne deformacije. Višestruki maksimum pojavljuje se pri 3030 cm^{-1}, što označava benzilaciju materijala. Zbog aromatske deformacije porast pika može se primijetiti na 1596 cm^{-1}. Benzilne skupine vezane na hidroksilne skupine tvore eterske skupine i povećavaju intenzitet pika, zbog čega se mijenja energija vodikove veze i kristaliničnost materijala se smanjuje. Taj postupak supstitucije na funkcionalnim skupinama mijenja temperaturu razgradnje modificiranih materijala. Smanjuje se temperatura dekompozicije na 330 i 350 °C. Termogravimetrijska analiza pokazala je da modificirani proizvodi imaju lošiju toplinsku stabilnost nego sirovina od koje su proizvedeni.

Ključne riječi: *termoplastične smole, energija vodikove veze, kristaliničnost, toplinska svojstva*

1 INTRODUCTİON
1. UVOD

Increased utilization of wood results in more waste due to debarking, cutting, shaving, sanding, etc. How to deal with this waste is an important issue. Environmental concern and deficiency in natural resources impose solutions that involve reducing waste and recovering and recycling this material to conserve natural resources. Progress has been made in efforts to reduce waste, but additional works need to be done to solve this problem.

Sawdust and wood shavings are produced by a number of sectors and this raw material is part of the municipal waste stream. A tremendous range of products can be obtained from these lignocellulosic waste materials due to complexity of cell wall structure. Lignocellulosic materials refer to woody and nonwoody plants that are composed of cellulose, hemicellulose, and lignin. Chemical properties of these materials make them suitable for a large number of products. The utilization of lignocellulosic materials in the production of plastic and composites is becoming more and more attractive (Biswas *et al.*, 2006; Bodirlau *et al.*, 2008; Çöpür *et al.*, 2007; Ebringerova and Heinze, 2000; Hassan *et al.*, 2001; Hon and Luis, 1989; Hon and Ou, 1989; Pereira *et al.*,1997; Rowell, 1990; Su *et al.*, 2015).

Plastics are being favored for many applications in place of other materials due to formability, light weight and strength properties (Hon and Shiraishi, 2001). In order to plasticize, lignocelullosic materials are chemically modified. Chemical modification of cell wall polymers is usually carried out either in acidic or alkali conditions (Chen *et al.*, 2012; Huang *et al.*, 2014; Qu *et al.*, 2014). Chemical alteration of hydroxyl groups can reduce the interaction among the chain segments, creates free volume and changes the thermal properties of the material (Nakano, 1994). New modified lignocellulosic materials have thermoplasticity, when large or many side-chains are introduced by chemical modification.

Thermoplastic materials are usually produced from petrochemicals, which is dependent on limited source of fossil fuels whose price is fluctuating and may be running out. In addition to that, fossil fuels release gases which cause the greenhouse effect. One solution is to use tailored renewable resources. Therefore, the objectives of this paper were to explore the chemical modification of Turkish red pine sawdust *via* etherification to impart thermoplasticity. Thermoplasticity was achieved by benzylation process, and characterization of the material was accomplished with crystallinity index and thermogravimetric analysis.

2 MATERIAL AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Turkish red pine (TRP) sawdust were obtained from the Isparta region in Turkey. Materials were dried under room temperature. Meal samples were prepared using a Wiley mill and ground to pass various mesh screens (60-80 mesh).

2.2 Methods
2.2. Metode

2.2.1 Alkali treatment
2.2.1. Lužnata obrada

Sawdust was treated with different concentrations of sodium, lithium, potassium hydroxide and guanidine for 24 hrs at room temperature. After treatment, materials were rinsed and dried at 102±3 ºC and tested with Fourier transform infrared spectroscopy (FTIR).

2.2.2 Benzylation process
2.2.2. Proces benzilacije

Benzylation process was used similarly to Hon and Ou process. Dried and ground samples (3 grams) were pretreated with various alkali concentrations (15, 25, 35 %) for preswelling. The slurry was transferred to a 250 ml round bottom flask containing benzyl chloride (BC) (27.6 ml). The reaction was conducted at 110 ºC for 6 hours with continuous stirring. The crude benzylated material was collected by filtration and exhaustively washed with water to remove any residuals and finally washed with ethanol to remove any residual benzyl alcohol. The final product was dried overnight at 40 ºC.

2.2.3 Fourier transform infrared spectroscopy (FTIR)
2.2.3. Fourierova transformacija infracrvene spektroskopije

FTIR spectra were obtained on untreated and benzylated substrates from KBr pellet using Perkin Elmer spectrum one model FTIR spectrometer. Each sample was scanned 10 times between 4000 and 400 cm^{-1} and changes in the chemical structure were recorded.

2.2.4 Thermal properties
2.2.4. Toplinska svojstva

Perkin Elmer Diamond model thermogravimetric analyzer (TGA) was used to study the thermal properties of etherified samples. The heating rate was set at 10 ºC/min and the temperature ranged from 25 to 600 ºC. Measurements on 4 mg samples were carried out under nitrogen atmosphere (100 ml/min).

2 RESULTS AND DISCUSSION
2. REZULTATI I RASPRAVA

The degree of crystallinity is an important parameter for plasticization of lignocellulosic materials. Cell wall polymers contain significant amounts of hydroxyl groups. Chemical modification of lignocellulosic materials usually takes place between these hydroxyl groups of the cell wall polymers and chemical reagent with or without catalyst (Rowell, 1990). Tailored hydroxyl groups can help lignocellulosic materials to exhibit thermoplastic properties due to change in hydrogen bonding ability.

Introducing new chemicals to cell wall polymers causes breaking up of some hydrogen bonds and changes crystallinity. This change indicates the possibility of plasticization and can be detected with FTIR spectroscopy. In order to detect the change in crystallinity, different peak ratios and hydrogen bond energy can be used (Poletto *et al*., 2013; Akgul *et al.,* 2007). The ratio between the heights of the bands at 1370 cm^{-1} and 2900 cm^{-1} was used to determine the total crystalline index (TCI), and the ratio between the areas of the bands at 1430 cm^{-1} and 896 cm^{-1} was used to determine lateral order index (LOI) of the materials (Akerholm, *et al*., 2004; Ma, 2007). The energy of the hydrogen bonds *EH* for the OH stretching band was calculated using equation 1:

$$EH = \frac{1}{K} \cdot \left[\frac{(v_o - v)}{v_o} \right] \quad (1)$$

Where v_o is the standard frequency corresponding to free OH groups (3650 cm^{-1}), v is the frequency of the bonded OH groups, and K is a constant ($1/K = 2.625 \cdot 10^2$ kJ).

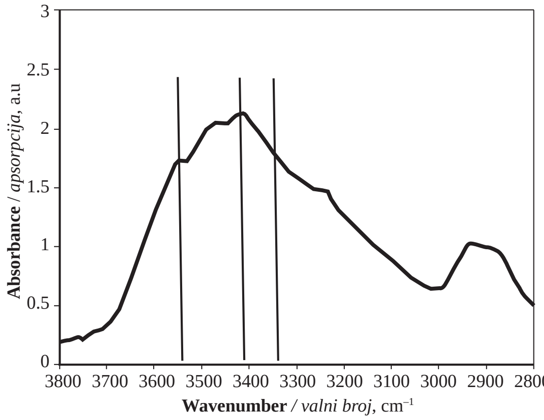

Figure 1 Assignment of hydroxyl bands in FTIR spectra for untreated Turkish red pine
Slika 1. Raspored hidroksilnih skupina na infracrvenom dijelu spektra za netretiranu piljevinu od drva turskoga crvenog bora

In order to increase reactivity and swell lignocellulosic materials before modification, the material was treated with alkaline solution. Alkaline treatments contracts microfibrils in the cell wall and changes the dimension (Nakano, 2010). The mechanism of microfibril contraction and anisotropic dimensional changes of cells in wood are treated with aqueous NaOH solution. As a result, chemical reagent can reach and react with hydroxyl groups on cell wall polymers. In untreated materials, there are free, intra and inter hydrogen bonded hydroxyl groups available (Figure 1). The intramolecular hydrogen bond in lignin can be observed at 3560-3580 cm^{-1} (Kondo, 1997; Poletto *et al*., 2012). Intramolecular hydrogen bond in cellulose appears around 3430 cm^{-1} and 3340 cm^{-1} (Kondo, 1997; Poletto *et al.*, 2014). After alkaline treatment, these hydroxyl groups affected crystalline structure changes. Table 1 shows the crystallinity and hydrogen bond energy change after alkaline treatment (Table 1).

There is a small difference in crystallinity index and hydrogen bond energy (EH) of the materials. TCI

Table 1 Crystallinity of alkaline treated materials of Turkish red pine (TRP)
Tablica 1. Kristaliničnost materijala piljevine turskog crvenog bora (TPR) tretiranog lužinama

	Crystallinity of raw materials / *Kristaliničnost sirovine*					
	TCI	LOI	EH (kJ)	δυ (cm^{-1}) 2	δυ (cm^{-1}) 3	δυ (cm^{-1}) 6
Untreated Turkish red pine	0.43	0.36	15.75	2.80	2.79	2.77
15 % NaOH TRP sawdust	7.99	2.18	13.59	2.80	2.78	2.77
25 % NaOH TRP sawdust	5.56	2.81	12.87	2.80	2.78	2.77
35 % NaOH TRP sawdust	5.04	21.63	14.38	2.80	2.78	2.77
15 % KOH TRP sawdust	1.50	9.43	16.54	2.80	2.78	2.77
25 % KOH TRP sawdust	2.07	2.73	17.69	2.80	2.78	2.77
35 % KOH TRP sawdust	2.24	10.74	17.04	2.80	2.78	2.77
15 % LiOH TRP sawdust	3.61	1.17	16.54	2.80	2.78	2.77
25 % LiOH TRP sawdust	1.96	1.37	17.98	2.80	2.78	2.77
35 % LiOH TRP sawdust	2.14	1.44	20.35	2.80	2.78	2.77
15 % Guanidine TRP sawdust	3.60	20.20	16.54	2.80	2.78	2.77
25 % Guanidine TRP sawdust	4.70	0.25	17.40	2.80	2.78	2.77
35 % Guanidine TRP sawdust	0.89	4.05	16.54	2.80	2.78	2.77

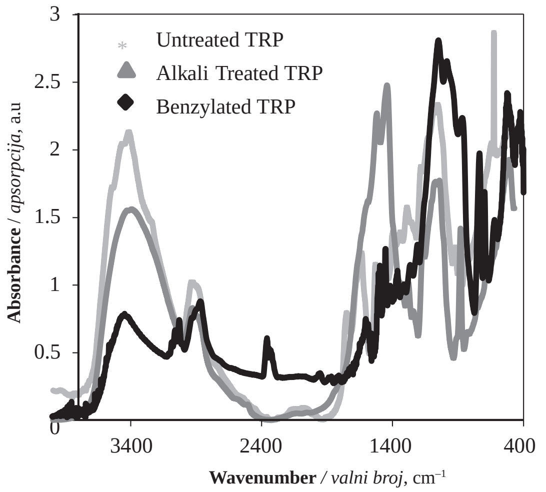

Figure 2 FTIR spectra of untreated and chemically treated TRP sawdust of Turkish red pine (TRP)
Slika 2. FTIR spektar netretirane i kemijski tretirane piljevine od drva turskoga crvenog bora

and LOI of the untreated sample were lower than those of alkaline treated materials. In contrast, hydrogen bond energy was high considering the alkaline treated materials. Alkaline treated samples change the crystalline structure and hydrogen bond energy and the degree of this change increases as NaOH < KOH ≤ Guanidine < LiOH at the same concentration. Wood powder mercerization under alkaline conditions and the polymorphic transition take place under the alkaline solution. As the concentration of alkali, in particular NaOH, increases, TCI decreases. In contrast to that, LOI increased with the NaOH, KOH and LiOH concentration. It is probably due to the transition between cellulose polymorph and the effect of alkali ion (Nakano, 2010; Borysiak and Doczekalska, 2005). The lowest TCI and LOI values were observed on untreated materials, which may indicate that the amorphous region is higher in untreated materials than after alkali treatment when mercerization takes place. Hydrogen bond energy indicates the interaction between the adjacent cellulose chains (Poletto *et al.*, 2012). It increases when cellulose chains approach each other, and the packing density also increases. There was a slight difference among bond distances in alkali treated materials. Hydrogen bond energy increased with alkali concentration.

After alkali treatment, the slurry was transferred to a round bottom flask containing benzyl chloride. The benzylation process proceeded with continuous stirring. Untreated and chemically treated samples show different FTIR spectra (Figure 2). Benzylation of the materials caused a reduction of hydroxyl peaks at 3400 $cm^{-1}$and an increase of the aromatic C-C axial deformations around 1595 cm^{-1} (Figure 3). In addition to that, aromatic multiple peak appeared at 3030-3100 cm^{-1}. This could be due to monosubstituted benzyl rings. Guanidine showed spectra similar to those of untreated materials.

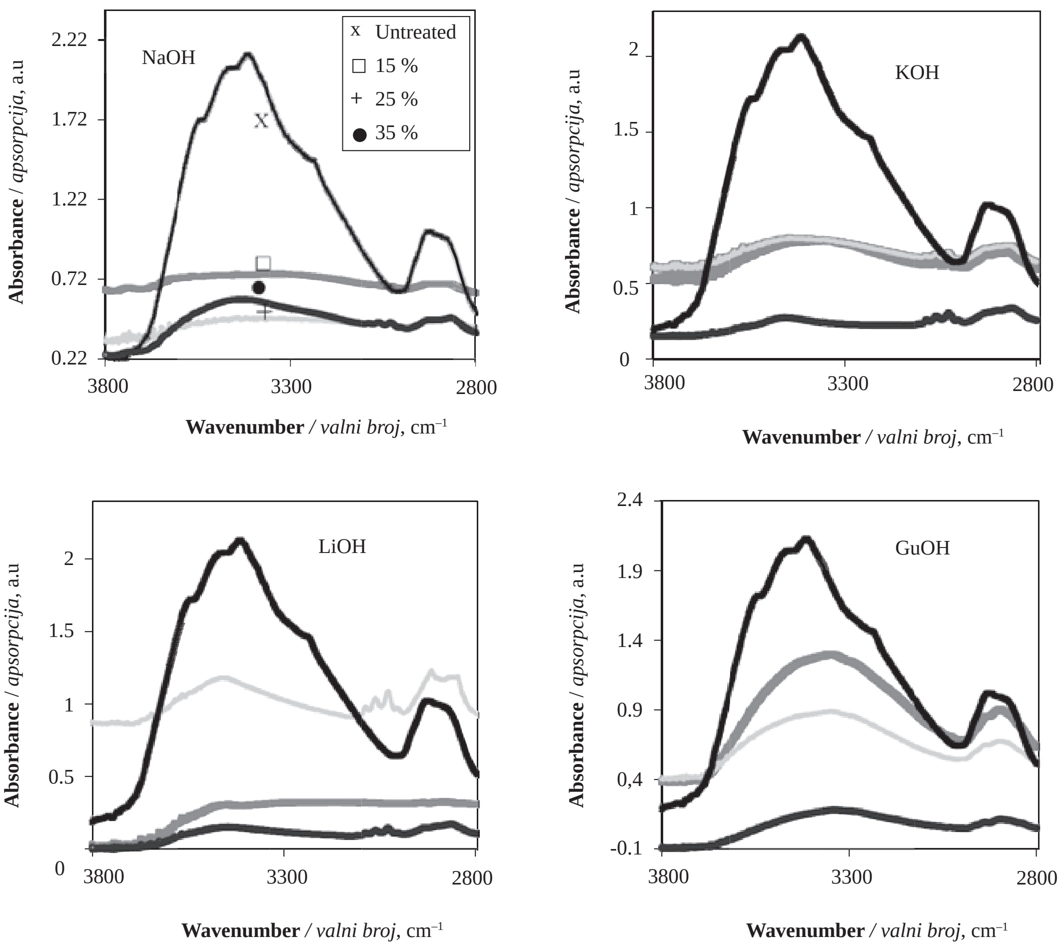

Figure 3 Aromatic stretch at 3030 - 3050 cm^{-1} due to monosubstituted benzyl rings
Slika 3. Aromatski dio na 3030 – 3050 cm^{-1} zbog monosupstitucije benzilskih prstenova

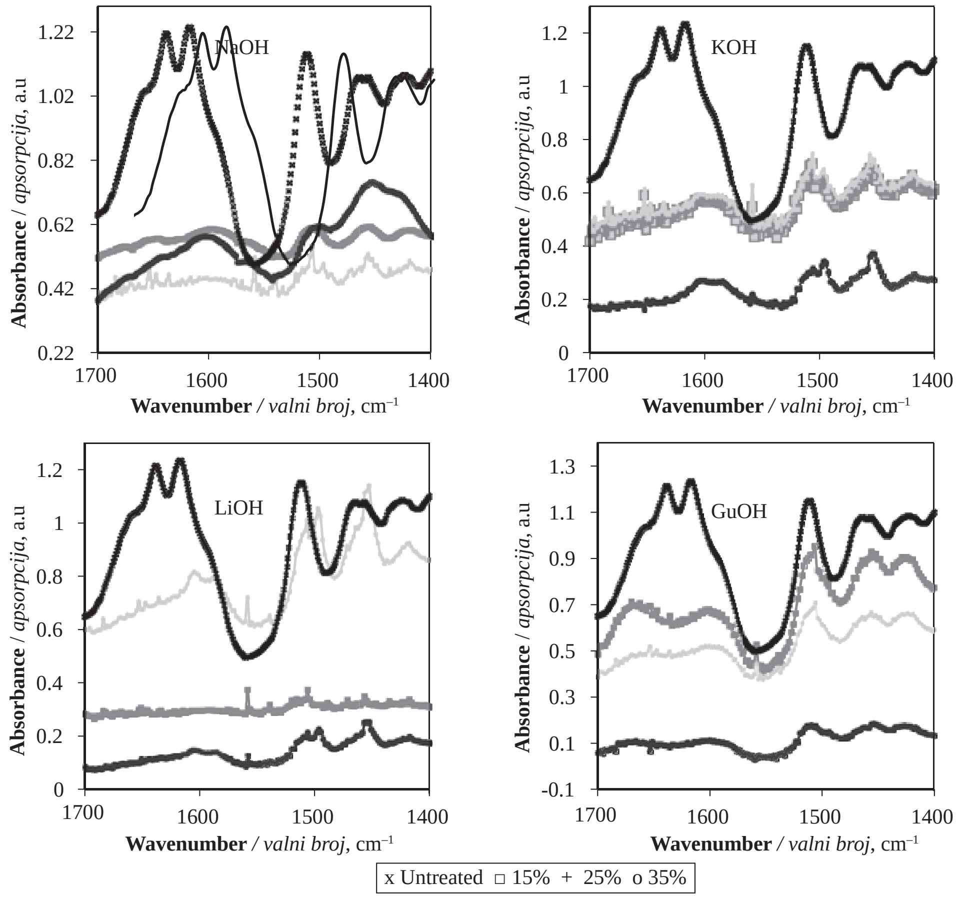

Figure 4 Increase of aromatic C-C axial deformations around 1595 cm^{-1} due to benyzlation
Slika 4. Porast aromatske C-C aksijalne deformacije oko 1595 cm^{-1} zbog benzilacije

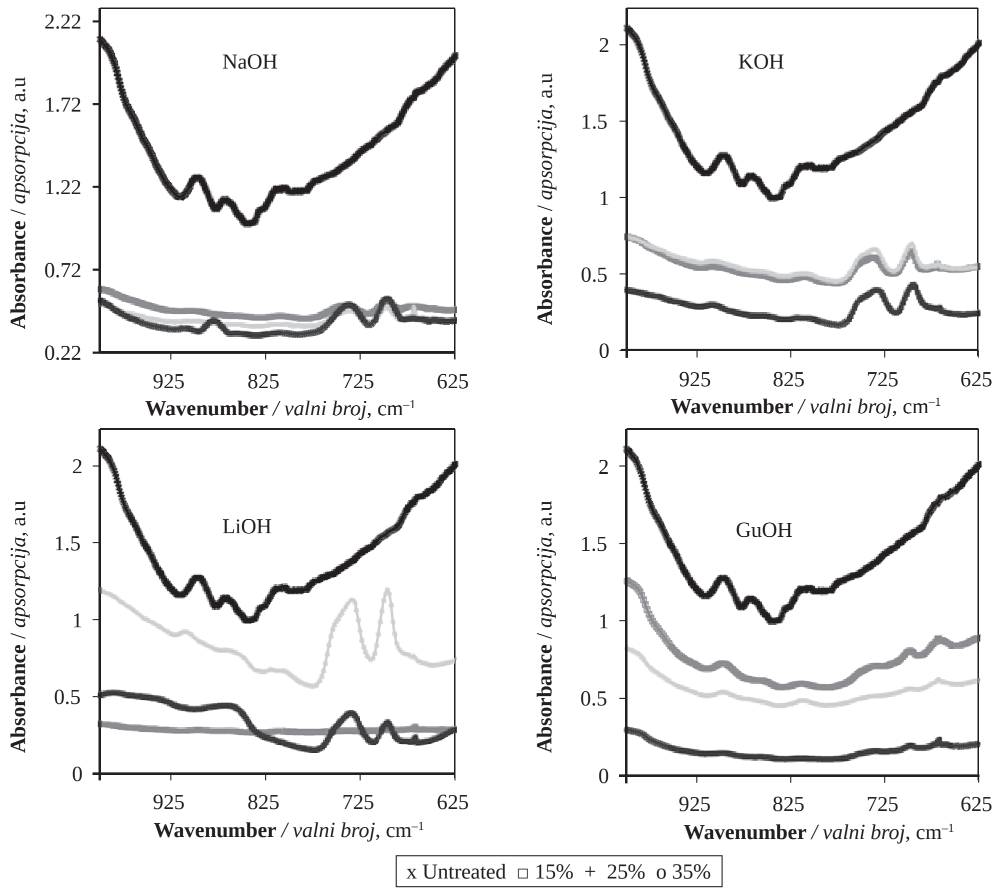

Figure 5 Appearance of bands at 698 cm^{-1}, 740 cm^{-1}
Slika 5. Pojava skupina na 698 cm^{-1}, 740 cm^{-1}

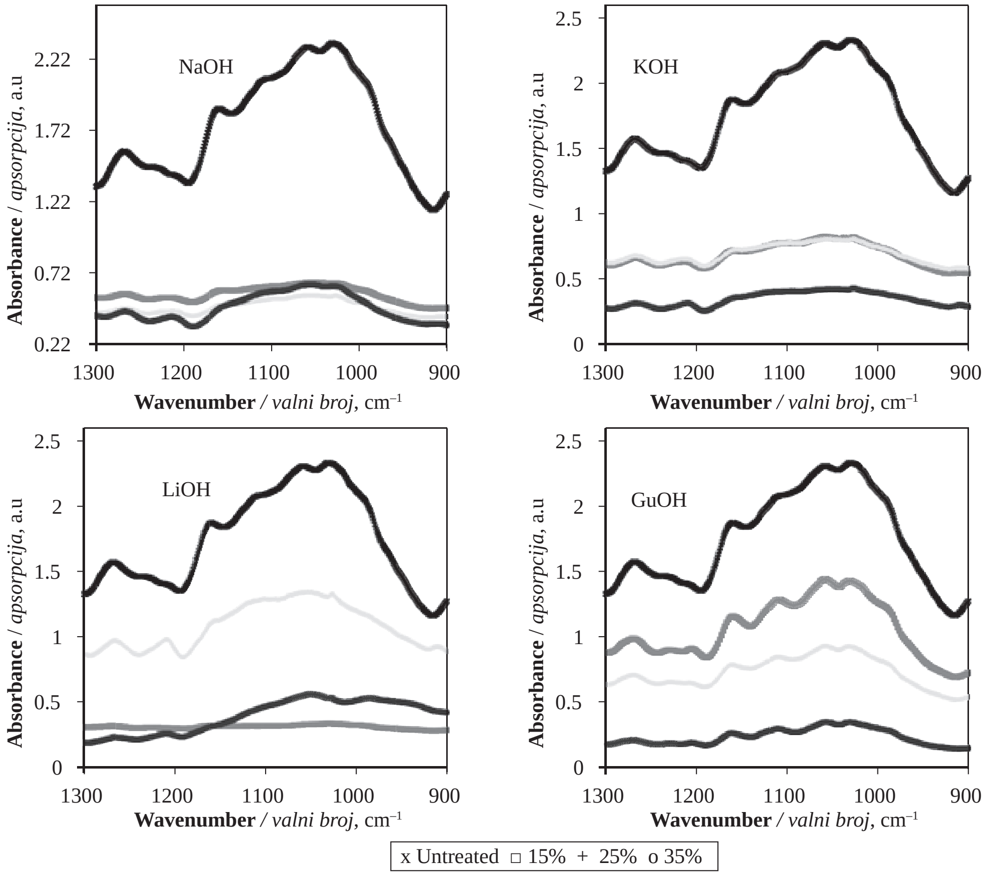

Figure 6 C-O stretch of the substituted benzyl ether
Slika 6. C-O dio etera koji je supstituiran benzilom

The peak at 670 cm^{-1} gives information on C–OH out of plane bending (Ma, 2007). Spectra of the samples showed a reduction of peak intensity at 670 cm^{-1}. In contrast, peak appears at 698 cm^{-1} due to aromatic C-C angular deformation in treated materials (Figure 5). In addition to that, benzyl group can be detected at 740 cm^{-1}. The guanidine peak is lower compared to others. Even though it is strong alkali, the size of the molecule may restrict the entrance into the cell wall. After the reaction, an increase of aryl ether band at 1265 cm^{-1} and of alkyl ether band at 1155-1060 cm^{-1} (due to C-O stretch from the substituted benzyl ether) was observed. (Figure 5). This absorbance band implied the substitution of hydroxyl groups in materials with benzyl groups.

Cellulose is the main component in wooden materials and it controls the thermal properties of wood (Hon and Shiraishi, 2001). Hydrogen bonds between cellulose chain and in the chain shift to melting temperature over decomposition temperature. Modification of wood helped to disrupt any hydrogen bonds between adjacent chains and in the chain. Therefore, it helps wood to become thermoformable.

Figure 7 shows differential thermogravimetric analysis (DTGA) curves of alkali treated with different alkali ions, concentration and untreated materials. The first step of weight loss, from room temperature to 120 °C, was related to the evaporation of absorbed water. The second step ends near 410 °C, and can be described by an abrupt mass loss stage that was related to the main thermal decomposition process. A derivative weight loss curve can be used to tell the point at which weight loss is most apparent (Figure 8). According to the results obtained, raw materials begin to decompose at a higher temperature (T_i = 380 °C) when compared to modified materials (T_i = 330-340 °C).

It was seen that there was a significant difference between modified and untreated materials in relation to their respective thermal decomposition temperatures, which may be related to the difference in crystallinity between untreated and modified materials. Tailored hydroxyl groups change the crystalline structure of the materials, when the intra and intermolecular hydrogen bonds between chains are broken. Rearrangement of the bonding ability of the treated materials reduces the decomposition temperature. As a result, the crystalline domains in the untreated materials show a higher thermal stability, when compared to modified materials.

4 CONCLUSION
4. ZAKLJUČAK

Sawdust is a very promising source of raw materials for commercial products such as cellulose, plastics, etc. for many countries due to its availability and abundance. However, it is considered as waste. Thermoplasticization can be achieved by benzylation. Alkaline species and alkali concentration affect the substitution reaction and change the material properties. These changes are significant with NaOH, and it can be detected with crystallinity, hydrogen bond energy change and thermal analysis. Hydroxyl groups were substituted

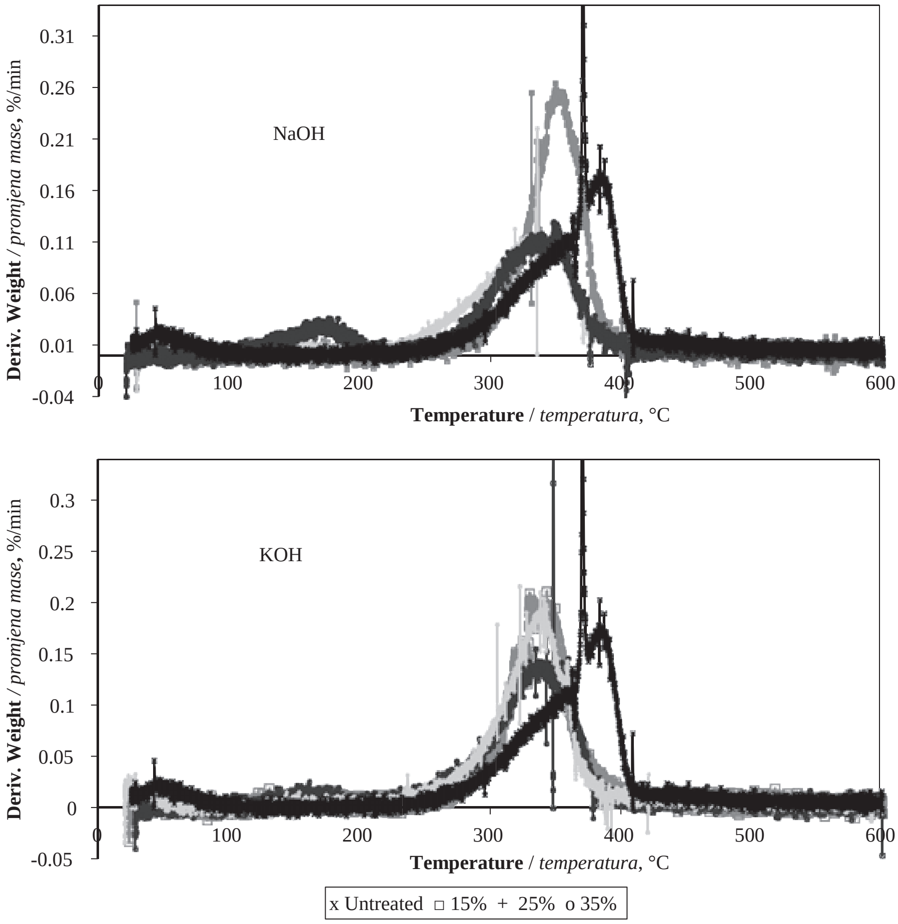

Figure 7 DTGA thermogram of untreated and benzylated wood with different alkali
Slika 7. DTGA termogrami netretiranog drva i drva benziliranoga različitim lužinama

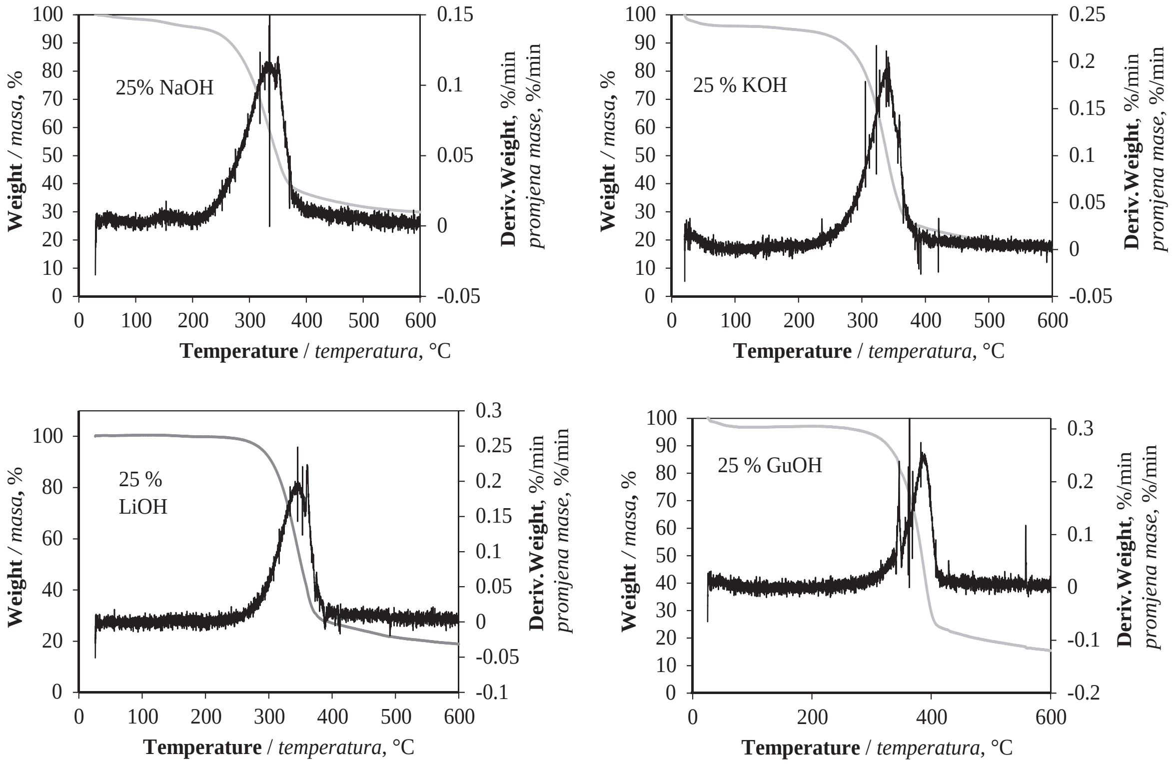

Figure 8 DTG thermograms of benzylated materials under different alkali concentrations
Slika 8. DTG termogrami benziliranog materijala pri različitim koncentracijama lužine

with benzyl groups and this caused the change of FTIR spectra. Guanidine shows different trends. This could be due to the molecule size. It cannot penetrate the pore on the cell wall, because the pore size could be smaller than the molecule size. Na Li and K are effective on thermoplasticization. Multiple peaks appear at around 3030 cm^{-1} indicating benzylation of the materials. The appearance of the peak at 698 cm^{-1} and 740 cm^{-1} indicates the aromatic C-C angular deformation. Thermogravimetric analysis revealed that modified products were characterized by poorer thermal stability compared to raw materials. Deformed crystallinity of the materials reduced significantly the decomposition temperature, and the reduction of the decomposition temperature ranged between 40 to 60 ^{o}C.

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Functionality and Aesthetics of Furniture - Numerical Expression of Subjective Value

Funkcionalnost i estetika namještaja – metode mjerenja subjektivnog doživljaja

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ABSTRACT • *In the recent years the habits of buying furniture have changed. The fabrication of individual pieces of furniture is increasingly coming to the forefront. A personal contact is being established between the customer and the furniture, which is a relationship of one (product) to one (customer). In order to satisfy the individual demands, higher quality as well as higher prices appeared as a necessity. The competition is beginning on the market, where emotion becomes a significant factor in decision-making process. Therefore, functionality and aesthetic functions, determinative forms and fashionable style play a very important role in furniture design and production. The objective of the paper is to report research results on how functionality and aesthetics of different styles of furniture could be determinated, measured and how they influence customer requirements and demands. To establish the proportion of functionality and aesthetic features, a numerical expression of the functions was defined by using various designers' methods such as Ranking Method Quality Development (RMQD) and Failure Mode and Effects Analysis (FMEA). It is shown that both methods could be used very effectively for designed and marketing oriented furniture, for modelling customer satisfaction as well as in connection with aesthetic functions, assuring the quality of the product in the planning stage.*

Key words: *functionality, aesthetic functions, furniture, designers' methods, customer demands, proportion*

SAŽETAK • *U posljednjih nekoliko godina promijenile su se navike kupovanja namještaja. Naime, u praksi je sve češća izrada pojedinačnih komada namještaja . Uspostavlja se osobni kontakt između kupca i namještaja, što podrazumijeva odnos jedan (proizvod) na jedan (kupac). Kako bi se zadovoljili pojedinačni zahtjevi, kao nužnost se nameće veća kvaliteta, a taj zahtjev prate i više cijene. Konkurentnost na tržištu počinje u trenutku kad emocije postanu važan čimbenik u procesu odlučivanja. Stoga funkcionalnost i estetske funkcije namještaja, kao i određeni oblici odnosno trendovski stil dobivaju vrlo važnu ulogu u dizajniranju i proizvodnji namještaja. Cilj rada bio je prikazati rezultate istraživanja mogućnosti određivanja i mjerenja funkcionalnosti i estetike u različitim stilovima namještaja te o njihovu utjecaju na potražnju i zahtjeve kupaca. Da bi se uspostavio omjer funkcionalnosti i estetskih obilježja namještaja, numerički iskaz funkcije definiran je primjenom različitih dizajnerskih metoda poput Ranking Method Quality Development (RMQD) i Failure Mode and Effects Analysis (FMEA). Utvrđeno je da se*

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obje metode vrlo učinkovito mogu primijeniti za dizajnirani i marketinški orijentiran namještaj, za oblikovanje zadovoljstva kupaca, kao i za povezivanje s estetskim funkcijama i osiguravanje kvalitete proizvoda u fazi planiranja proizvoda.

Ključne riječi: *funkcionalnost, estetska funkcija, namještaj, dizajnerske metode, zahtjevi kupaca, proporcije*

1. INTRODUCTION
1. UVOD

The world of furniture market is getting more complex than it was before. In order to measure consumers needs, preferences and habits, it is important to improve contemporary values of furniture. In recent years, it is evident that the habits of bying and using furniture have been changed (Domljan *et al.*, 2006; Horvat *et al.*, 2008). The fabrication of individual pieces of furniture is increasingly coming to the forefront. A personal contact is being established between the customer and the furniture, which is a relationship of one (product) to one (customer). In order to satisfy the individual demands, higher quality as well as higher prices appeared as a necessity. In the competition that occurs on the market, when choosing furniture, preference is given to individuality and emotions (Domljan and Grbac, 2014). Of course, there are various factors that also influence customer decisions when buying furniture: price, quality, reliability, etc. (Raport DTI, 2005). Therefore, functionality and aesthetic functions, determinative forms and fashionable style play a very important role in furniture design and production. Those parameters, usually connected with visual parameters of the design, are measureable, as well as other designers parameters appearing in the product, by using special designers methods such as Function analysis, Questionnaire research, Ranking Method Quality Development (RMQD) and Failure Mode and Effects Analysis (FMEA) (Antal, 2007; Laurel, 2003).

The objective of this paper is to report research results on how function and aesthetics of different styles of furniture could be determinated, measured and how could they influence the customer requirements and demands by using RMQD and FMEA methods.

1.1. Definition of functionality and aesthetic functions
1.1. Definicija funkcionalnosti i estetskih funkcija

Function can be expressed as the properties related to the use of a product. These properties include the relation between a product and a consumer (Antal, 2007).

On the basis of purchasing motivation, the system of functions can be divided into:
- functionality (e.g. utility and practical function) and
- aesthetic functions (e.g. visual sensation, emotions).

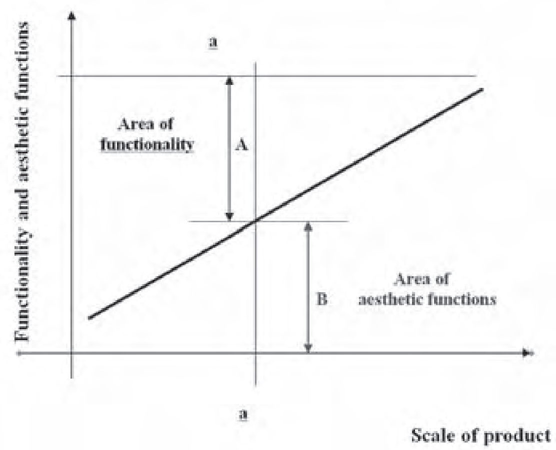
Aesthetic value is considered to be the effect (or style) of objects as to what degree they can teach us to perceive or understand the appeal of beauty (Eco, 2004). Nevertheless a designed object, such as a piece of furniture, can be evaluated regarding whether beauty is involved in it, or not.

Aesthetic value means the complexity of the properties of objects, devices or equipment, which provide appeal, pleasure and good experience when it comes to sensation, action or indirectly, to the general human state of health related to a given object (Antal, 2007).

In industrial design, objects are created with the intention to satisfy not only aesthetic criteria but also criteria of utility and practical function (Papanek, 2005). These features are inseparable. In the products such as furniture they can only appear jointly. "Being useful also means being beautiful. (...) There is no separate usefulness and beauty, but what is useful is considered beautiful as well" (Lissák, 1997). There has to be a suitable combination of usefulness and beauty. In contemporary world, people generally buy furniture in order to use it as well as to take pleasure in it. It is essential, however, to determine the proportion of functionality and aesthetic functions in case of furniture? This proportion has to be determined to satisfy consumer demands. To establish this proportion, both functionality and aesthetic functions have to be measured. It is important to notice that there is still no exact method that could determine precisely the proportion of these functions. A number of experiments have been carried out, but the exact definition of aesthetic functions has been based on modelling consumers' value judgements (Antal, 2007). The quality of two similar products can be measured on the level of function satisfaction. The satisfaction measure determines which product is better, more beautiful and more attractive (Lissák, 1997).

Optimal aesthetic quality of a product depends on the proportion of *A/B*, represented in the section *a-a*. This proportion is to be designed according to customer demand, i.e. in an optimal way.

Figure 1 presents the essence of the success of a product. This idea is being emphasised, regarding all



a-a: position of furniture on the scale
A/B: proportion of functionality and aesthetic value

Figure 1 Representation of proportion of functionality and aesthetic functions (Hegedűs, 1983)
Slika 1. Prikaz udjela funkcionalnosti i estetskih funkcija (Hegedűs, 1983.)

kinds of products, particularly in the current interpretation of a product's value attributed by the customer. It means that the value (*V*) is the ratio of the function (*F*) and charge of function (*CF*);

V (Value) =*F/CF* (function/charge of function).

If value concerns to the whole product, all functions of the product have to be taken into consideration. If it affected only one or two functions or group of functions, *F* and *CF* would have to be determined according to the examined functions.

1.2 Optimization of proportion of functionality and aesthetic functions
1.2. Optimizacija udjela funkcionalnosti i estetskih funkcija

A product consists of subsets of functionality and aesthetic functions, which mostly means the aesthetic quality of the product. The proportion of functionality and aesthetic functions is optimal if it meets the demands of consumers (Antal, 2007).

According to Hegedűs (1994), aesthetic functions are analysed separately from functionality. Both functionality and aesthetic functions have their own values.

As an example, if functionality of a product is taken as:

$H_1, H_2, \ldots H_i \ldots H_n$;

and the aesthetic functions of a product are:

$E_1, E_2, \ldots E_j \ldots E_m$;

it follows that:

h_i is the value of H_i; and e_j is the value of E_j

If these functions are linked to the product, which is supposed to satisfy the customers' needs, it can be expressed as follows:

$$\varepsilon_j = \begin{cases} 1, \text{ if } E_j \text{ is carried by the product} \\ 0, \text{ if } E_j \text{ is not carried by the product} \end{cases}$$

$$\delta_i = \begin{cases} 1, \text{ ha } H_i \text{ is carried by the product} \\ 0, \text{ ha } H_i \text{ is not carried by the product} \end{cases}$$

Using these values, the proportion of functionality and aesthetic functions can be expressed by the formula:

$$\frac{\sum_{i=1}^{n} \delta_i h_i}{\sum_{j=1}^{m} \varepsilon_j e_j} = opt. \qquad (1)$$

Table 1 Selected functions of a product that could be analysed
Tablica 1. Odabrane funkcije proizvoda koje se mogu analizirati

Functionality / *Funkcionalnost*	**Aesthetic functions** / *Estetska funkcija*
$H_1 = F_2$ Satisfy of ergonomics needs *zadovoljenje ergonomskih potreba*	$E_1 = F_2$ Satisfy of ergonomics needs / *zadovoljenje ergonomskih potreba*
$H_2 = F_4$ Help for work / *pomoć pri radu*	$E_2 = F_1$ Accommodate to the house / *prikladnost smještanja u kući*
$H_3 = F_5$ Measure up to the medical regulations *udovoljavanje medicinskim propisima*	$E_3 = F_3$ Satisfy aesthetic needs / *zadovoljenje estestkih potreba*
$H_4 = F_6$ Orientate to the ambience / *orijentacija na prostor*	$E_4 = F_6$ Orientate to the ambience / *orijentacija na prostor*
$H_5 = F_8$ Corporate identity / *identitet tvrtke*	$E_5 = F_8$ Corporate identity / *identitet tvrtke*
	$E_6 = F_7$ Carry style / *osnovni stil*

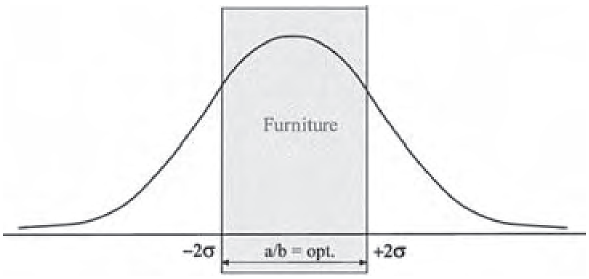


Figure 2 Optimization of criteria in furniture (Antal, 2007)
Slika 2. Optimizacija kriterija vezanih za namještaj (Antal, 2007.)

As an example, Table 1 shows the selected functions of a product that could be observed and analysed.

Using the formula (1) and data presented in Table 1, it can be written as follow:

$$\frac{\delta_2 h_2 + \delta_4 h_4 + \delta_5 h_5 + \delta_6 h_6 + \delta_8 h_8}{\varepsilon_1 e_1 + \varepsilon_2 e_2 + \varepsilon_3 e_3 + \varepsilon_6 e_6 + \varepsilon_7 e_7 + \varepsilon_8 e_8} = \frac{a}{b} = opt. \qquad (2)$$

The optimization means a constriction within an interval on the basis of a criterion. With numerous sampling, a/b rates can be defined and evaluated, as well as the customer satisfaction (rate of satisfaction). The probability value of weighted rate shows the optimum scale (proportion).The type and specifics of distribution can be determined and by means of the bottom and upper limits of confidence intervals of e.g. 95 % (Figure 2).

For example, if the value is: $-2\sigma < a/b < +2\sigma$, it can be declared that

a) furniture is aesthetically acceptable or
b) furniture is exclusive.

Aesthetic numbers for the practical expression of the relation can be suggested and the applicability of the theoretical relation for furniture can be reviewed.

1.3 Designers' methods applied to measure requirements and optimal proportion of the product
1.3. Dizajnerske metode primjenjive za mjerenje zahtjeva i optimalan omjer proizvoda

Customers needs are the first step in defining a number of requirements of the product. It means that it is necessary to establish designers' factors such as functionality, aesthetics, ergonomy, economy, technology and many others for the development of a product (Domljan *et al.*, 2006). Identifying customer needs means creating a high-quality information channel from the customers to the product developers. It will ensure that those who directly control the details of the product, including product designers, understand the needs of a customer. These needs have to be organised into a hierarchical list in order to be more understandable. The methods (for example designer's or manager's methods) that can be used for identifying customer needs are interviews, focus groups, observing the product in use or simmilar.

The customer needs are helpful to define the functions of a product. To achieve it, the needs have to be transformed into functions. Functions are abstractions of what a product should "do". A limited number of elementary or general functions on a high level of abstraction create a function structure. The functions are organised into a hierarchical order, in a so called "tree structure" (Antal, 2007).

From designers' point of view, it is very important to know what kind of methods are used to determine an optimal proportion of the product requirements and for what purposes the proportion could be used. Some of designers' methods are presented below.

1.3.1 Function Analysis
1.3.1. Analiza funkcija

Function analysis is a method for analysing and developing a function structure. A function structure is an abstract model of the new product, without material features such as shape, dimensions and materials used. It describes the functions of the product and its parts and indicates the mutual relations. In function analysis, the product is considered as a technical-physical system. The product functions consist of a number of parts and components, which fulfil sub-functions and the overall function. By choosing the appropriate form and materials, a designer can influence the sub-functions and the overall function. The principle of function analysis is to specify what the product should do and then to infer what the parts - which are yet to be developed - should do as well (Boeijen *et al.*, 2013).

By selecting aesthetic functions from the tree structure and by using them in Failure Mode and Effects Analysis (FMEA), the aesthetic quality of the product in the planning stage can be assured. The measure of the aesthetic functions has become possible by functions value and the weight numbers of determinative style.

1.3.2 Failure Mode and Effects Analysis (FMEA)
1.3.2. Metoda pogrešaka i analiza učinka (FMEA)

Failure Mode and Effects Analysis (FMEA) is a model used to take priority potential defects based on their severity, expected frequency, and likelihood of detection. The FMEA can be integrated into product development or product manufacturing process and used to improve the design or process robustness. The FMEA highlights weaknesses in the current design or process in terms of the customer needs and is an excellent tool to take priority and organise continuous improvement efforts in areas that offer the greatest return. The process is very straightforward and begins by identifying all of the probable failure modes. The analysis is based on experience, review and brainstorming and should use actual data, if possible (MoreSteam, 2014).

The Failure Mode and Effects Analysis model can help teams decrease project scope and complexity by focusing on the primary failure modes of a process. The FMEA can be best created by coordinating a cross-functional team and using objective and subjective knowledge to identify accurate properties about the identified failure modes.

This method can be used by taking into consideration only aesthetic functions combined with function analysis. It means that both the aesthetic functions of furniture could be determined and the aesthetic characteristics and forms of furniture could be analysed. A

Table 2 Severity (Importance of failure)
Tablica 2. Jačina (značenje) neuspjeha

Detection of the value of aesthetic function, % *Otkrivanje vrijednosti estetske funkcije, %*	**Degree of failure's effect** *Stupanj učinka neuspjeha*	**Weight number** *Broj jačine (značenja)*
(The customer completely perceives the value of aesthetic function) / (*Kupac u potpunosti opaža vrijednost estetske funkcije)* 90-100	Very high / *vrlo visok*	10
80-90	Very high / *vrlo visok*	9
70-80	High / *visok*	8
60-70	High / *visok*	7
50-60	Medium / *srednji*	6
40-50	Medium / *srednji*	5
30-40	Medium / *srednji*	4
20-30	Low / *nizak*	3
10-20	Low / *nizak*	2
0-10 (The customer hardly perceives the function value) *(kupac jedva opaža vrijednost funkcije)*	Very low / *vrlo nizak*	1

function structure of the furniture can be created in the FMEA process in order to select the aesthetic functions and to locate the critical characteristics. The functions with failed result are assigned by the elements of the furniture. For these functions the potential failures are identified as well as the effects and reasons of failures. The control is established for preventing all potential failures. The effect and the level of satisfaction of the customer is analysed by the experts team if one of the aesthetic function is not satisfied. In this occasion, the disappointment of the customer is measured. For the aesthetic functions, the measurer relevance numbers are determined. The severity of the failure with these numbers is preferred. Example: if an aesthetic function is not satisfied, this is marked as a failure. The importance of the failure's effect (severity) can be expressed by a weight number. Scoring is made from the customer's perspective, on a scale from 1 to 10 (10 if the customer perceives the aesthetic value 100 %, 1 if the customer hardly perceives the value) (Table 2).

The next step is to assign a value on a 1-10 scale for the probability of occurrence, as well as for the probability of detection for each of the potential failure modes. After assigning a value, the three numbers for each failure mode are multiplied together to yield a Risk Priority Number (RPN). The RPN becomes a priority value to rank the failure modes, with the highest number demanding the most urgent improvement activity.

During the analysis determining the aesthetic functions of furniture and taking into consideration their realization rate, possibility will open to measure aesthetic functions and to improve the aesthetic quality of the furniture. The quality is optimized by eliminating all possible failures, locating their impacts and reasons before getting to the customers.

1.3.3 Ranking Method Quality Development (RMQD)
1.3.3. Metoda rangiranja razvoja kvalitete (RMQD)

The *Ranking Method Quality Development* (RMQD) is a method used for matching and comparison of furniture and concurrency analysis. The realisation of the functions of the determinative forms is defined by this method and ranked by the correspondence percent.

A threshold value can be defined as:

- The pieces of furniture that are situated above this threshold value meet the requirements (e.g. they are exclusive).
- The pieces of furniture that are situated below this threshold value do not meet the requirements (e.g. they are not exclusive).

Through the determining forms, the aim is to detect the proportion of aesthetic and functional properties by certain properties. The *assessment factors* can be measured by using some properties which are not of equal weight, but are ranked by the RMQD. This can help to create a basis for comparison, based on which it can be established whether these properties are included in the furniture and to what degree they are present.

An *assessment method* based on the overall emotions can be created. The method is aimed at determining the range of style properties for a given furniture collection. The algorithm presented below is suitable for applying this assessment method (*Figure 3*).

1.3.4 Questionnaire Research
1.3.4. Istraživanje anketnim upitnikom

The answer to the question: "What kind of furniture properties allow determining the style of a group of furniture" could be obtained with a questionnaire. On the basis of the answers, an order of rank may be formed and

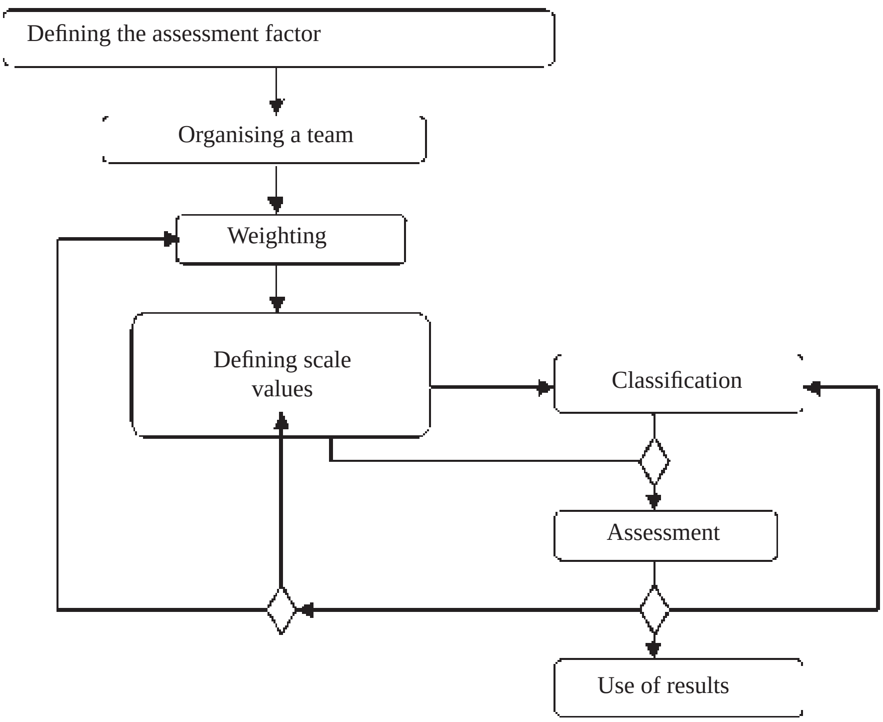


Figure 3 The algorithm for applying the assessment method (Antal, 2007)
Slika 3. Algoritam za primjenu metode procjene (Antal, 2007.)

the first ten properties could be considered. The answers should provide some information on the fact to what degree (what percentage) the given pieces of furniture meet the criteria of a given style and what kind of weighted order should be arranged. The RMQD surveying system is also suitable for this kind of complex measurement.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Samples and team members
2.1. Uzorci i članovi tima

For this research, five groups of furniture were selected as the samples from different points of view. (style, price, materials). The rank of selection was high quality furniture made from solid wood. Quality in this occasion means high aesthetic, construction, technology and economics level of requirements. Groups of furniture samples used for the RMQD analysis were ranked from A to E (Figure 4 – 8).

During the research, a team of five experts (two designers, one wood engineer, one ergonomists and one design manager) from Hungary and Croatia was established with members from 34 to 50 years old.

2.2 Research phase
2.2. Faza istraživanja

The first phase (preparation phase) in the research was to organise a team and determine the parameters.

The agreement coefficient of the team was over 90 %. The distribution of the team members' evaluation was ± 10 %.

The process of the research was determined by the steps as follows:

– determine the task, meeting of team members,
– study the collected documentation of the selected furniture,
– study and accept previous steps of research as input results; e.g. 7 items out of 10 style properties were considered as characteristic of the style,
– classify and weigh - compare properties and requirements,
– select, analyse and compose 5 groups of furniture and rank their value on a 5-1 scale (5 equals the assessment factor of the furniture that complies best with the requirements),
– evaluate the assessment factors individually (each member of the team), by means of the/an assessment list (Table 4)


Figure 4 Seltzfurniture (A). Source: http://www.meubles-seltz.fr
Slika 4. Seltzfurniture (A); izvor: http://www.meubles-seltz.fr


Figure 5 Porada furniture (B). Source: www.porada.it
Slika 5. Namještaj Porada (B); izvor: www.porada.it

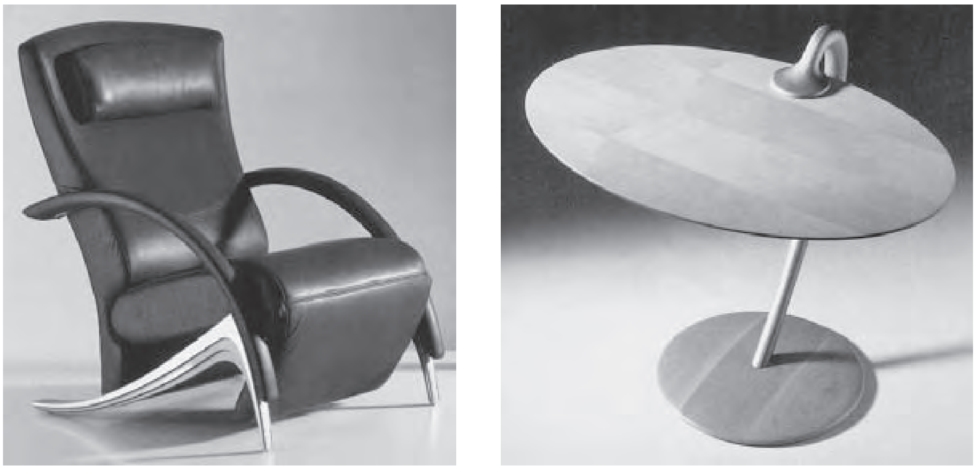


Figure 6 Rolf Benz furniture (C). Source: www.rolf-benz.com
Slika 6. Namještaj Rolf Benz (C); Izvor: www.rolf-benz.com

Figure 7 Ceccotti furniture (D). Source: http://www.ceccotticollezioni.it
Slika 7. Namještaj Ceccotti (D); izvor: http://www.ceccotticollezioni.it

Figure 8 Sixay furniture (E). Source: http://www.sixay.com
Slika 8. Namještaj Sixay (E); izvor: http://www.sixay.com

– analyse all the data by special computer programm of RMQD using CAT (Computer Aided Teamwork), PATTERN (Plaining Assistance Trough Evaluation of Relevance Numbers), COMBINEX (Ranking Method), QPA (Quality Price Analysis), KIPA (Complex Matching Method), presented in tables and diagrams
– analyse partial results and performe common assessment as required.

3 RESULTS AND DISCUSSION
3. REZULTATI I DISKUSIJA

After analytical data processing, the research results appear as follows:

The agreement coefficient is over the required 90 %. The team member whose assessment range was over the standard threshold value was excluded by the computer when arranging the results.

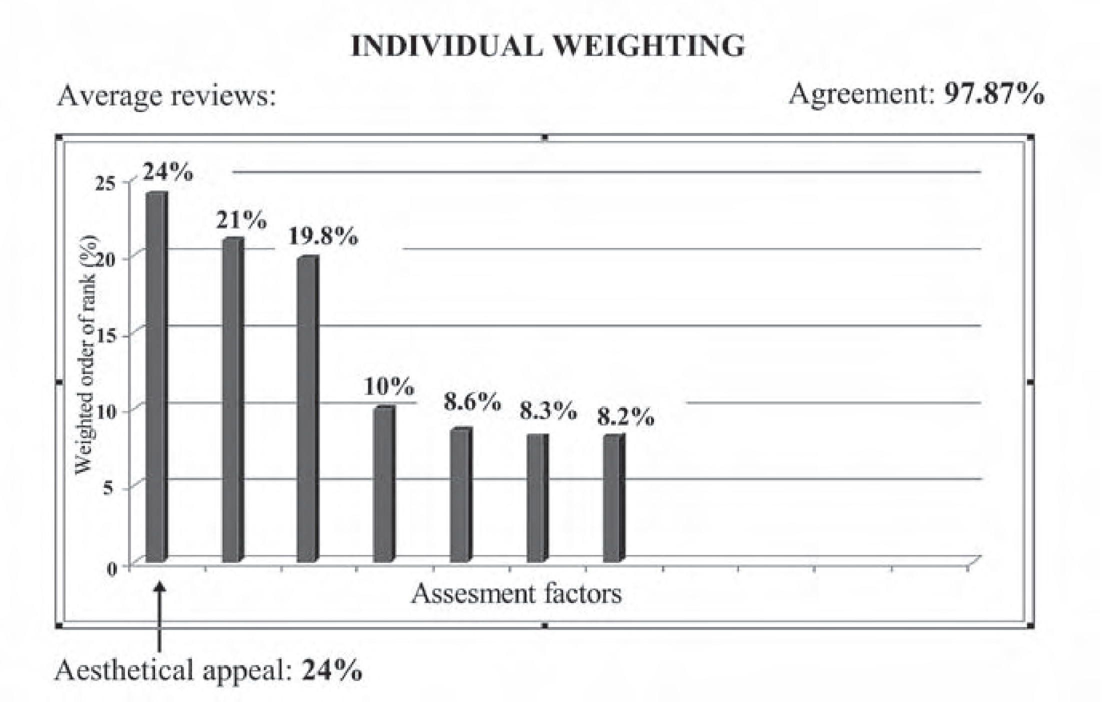


Figure 9 Weighted order of assessment factors
Slika 9. Ponderirani redoslijed faktora procjene

Table 3 Weighted order of assessment factors
Tablica 3. Ponderirani redoslijed faktora procjene

Assessment factors *Faktori procjene*	**Weighted order of rank** *Ponderirani redoslijed ranga*
aesthetic appeal *estetska dopadljivost*	24.00
material-colour harmony *harmoničnost materijala i boja*	21.05
visible style properties *vidljiva obilježja stila*	19.84
harmonious appearance *skladnost izgleda*	9.97
typical rate of proportions *tipična mjera proporcija*	8.65
smartness / *dotjeranost*	8.33
pureness of style / *čistoća stila*	8.16

The weighted order of the assessment factors are presented in Table 3 and Figure 9.

The list of one of the assessing team members is shown as an example in Table 4.

The comparison of alternatives (two groups of furniture) is presented in Figure 10 and 11, taking into consideration the assessment factors.

Table 5 Order of samples from the most exclusive to the least exclusive furniture according to results
Tablica 5. Poredak uzoraka prema rezultatima (od najekskluzivnijih prema manje ekskluzivnima)

Score/number *Rezultat/broj*	**Sample/product** *Uzorak/proizvod*	**Result/percents** *Rezultat/postotak*
1	D (Ceccotti)	94.3 %
2	C (Rolf Benz)	90.6 %
3	E (Sixay)	89 %
4	B (Porada)	82.5 %
5	A (Seltz)	72.7 %

The final results of the survey are shown in Table 5. The five groups of furniture are in compliance with the former established criteria and assesments (Table 4).

Based on the results, a threshold value, e.g. 70 %, was determined. Over this value, the furniture may be considered as exclusive.

6 CONCLUSION
6. ZAKLJUČAK

The demands of costumers are maximally satisfied when the proportion of functionality and aesthetic

Table 4 Assessment list
Tablica 4. Lista procjene

Assessment factors / *Lista procjene*	**Furniture** / *Namještaj*				
	A	B	C	D	E
aesthetic appeal / *estetska dopadljivost*	4	4	4	5	4
material-colour harmony / *harmoničnost materijala i boja*	3	4	4	5	4
visible style properties / *vidljiva obilježja stila*	2	4	3	4	4
harmonious appearance / *skladnost izgleda*	4	4	4	5	4
typical rates of proportions / *tipična mjera proporcija*	3	4	4	4	4
smartness / *dotjeranost*	3	4	3	4	4
pureness of style / čistoća stila	3	5	4	5	4

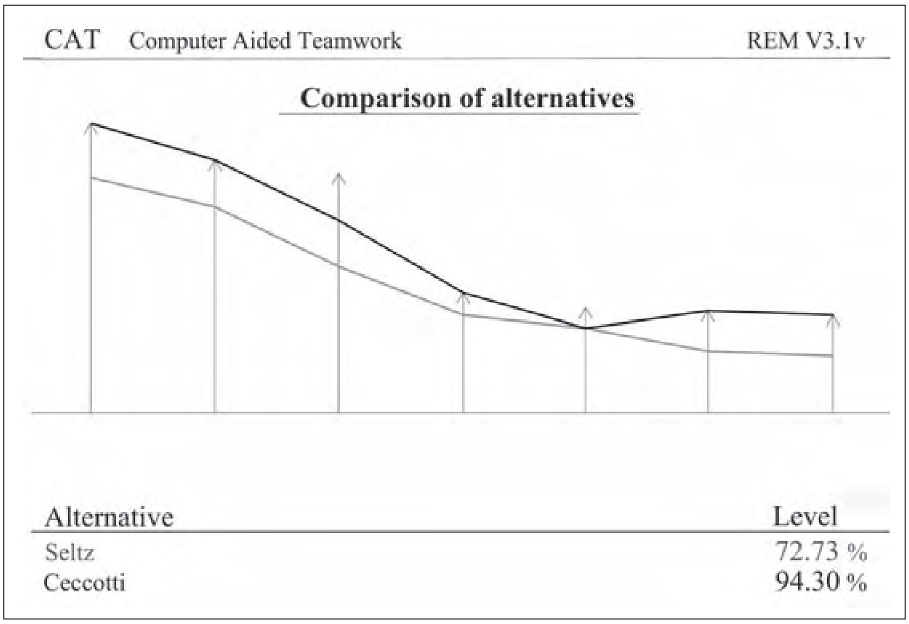


Figure 10 Comparison of groups of furniture; Seltz (A) v.s. Ceccotti (D)
Slika 10. Usporedba grupe namještaja: Seltz (A) prema Ceccotti (D)

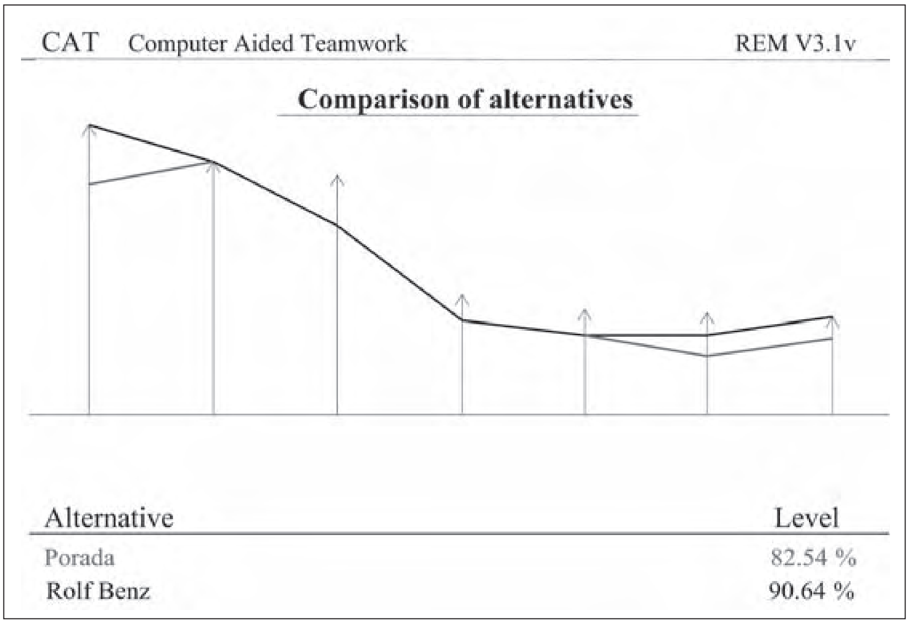


Figure 11 Comparison of groups of furniture; Porada (B) v.s. Rolf Benz (C)
Slika 11. Usporedba grupe namještaja: Porada (B) prema Rolf Benz (C)

functions converge to the expectations of customers. The numerical expression of the subjective value judgment by designing furniture can be used for concurrency analysis and for quality examinations.

An evaluating algorithm can be developed by using the RMQD. This method can be used very effectively for designed and marketing oriented furniture as well as for modelling customer satisfaction. FMEA could also be used in connection with aesthetic functions, assuring the quality of the product in the planning stage.

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Selection of Most Suitable Candidates for the Talent Pool in a Furniture Manufacturing Company

Izbor najtalentiranijih kandidata u tvrtki za proizvodnju namještaja

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ABSTRACT • *This paper deals with the question of identification and development of talents in the company. The aim of the article is to find one of the possible solutions to increase the objectivity of identifying talents and finding valuable input data for planning effectively their further development. The objective is achieved by estimates of the weights of criteria and by the multicriteria decision making method. The proposed model for solving this problem is specific for companies in furniture industry, as well as for companies in other sectors. For this reason, the selected methods have been applied to a specific example of the Czech company operating in furniture industry for over twenty years.*

Key words: *talent, talent pool, furniture industry, multicriteria decision, talent management*

SAŽETAK • *Pitanje identifikacije i razvoja talenata u tvrtki trenutačno je jedna od tema o kojoj se najviše raspravlja. Cilj članka bio je pronaći jedno od mogućih rješenja za povećanje objektivnosti identifikacije talenata i pronalaženja vrijednih ulaznih podataka za učinkovito planiranje njihova daljnjeg razvoja. Taj se cilj postiže procjenom težine kriterija i metodom višekriterijskog odlučivanja. Predloženi model rješenja tog problema specifičan je za poduzeća koja proizvode namještaj, ali se može primijeniti i u drugim sektorima. Izabrane metode primijenjene su na predlošku češke tvrtke koja posluje u industriji proizvodnje namještaja dulje od dvadeset godina.*

Ključne riječi: *talent, grupa talenata, proizvodnja namještaja, višekriterijsko odlučivanje, upravljanje talentima*

1 INTRODUCTION
1. UVOD

Talent management is not a new concept. The talent management concept was introduced around the 1990s and became popular with McKinsey's War for Talent survey in 1997 (Maycock and Ikuomola, 2015). The subject of discussion in scientific articles is mainly defined and understood as the extent of integration of talent management (Sojka, 2013) with the "strategy of the company as well as resolving the lack of talents in general" (Stephan *et al.*, 2014). The problem is not just the lack of talents, but difficult identification to create a talent pool in the organization, as well as efficient planning of their training and development (Grenčíková *et al*. 2015).

Experts engaged in searching talents are hesitant since companies should be more focused on identify-

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ing and developing talents (Briscoe and Hall, 1999). The investment in learning and development of talents (Garavan *et al*. 2012) has been justified as a source of competitive advantage. Garavan (2012) concluded that external talent acquisition strategy has proven to be unsuccessful in the long run with many organisations (Merková *et al*., 2013). Lepak and Snell (1999) and Stacho and Stasiak-Betlejewska (2014) determined relative advantage of organisations developing their workforce internally. In their article, Maycock and Ikuomola (2015) show that it is more efficient to focus on talents within the company (use internal resources) and then to invest in their training and development (Hitka and Štípalová, 2011). It opens serious questions in the practical implementation of company's talent management (Stacho *et al*., 2013):

– Who is the talent for the company and what type of talent the company needs?
– How can a talent be properly identified and developed?
– What will be the return of the cost of the talent pool for the company?
– How to motivate the talent pool for further learning and development?

1.1 Identification of talents
1.1. Identifikacija talenata

Lukáč (2009) defines talent as a combination of skills, personal qualities and qualifications, which are enriched by the potential of their further development. According to the CIPD (2007), Kropivšek *et al*. (2011) and Kucharčíková (2014), talented individuals are the ones who can highly contribute to the performance of the company by immediate contributing to the performance or longer-term demonstration of high potential. Hitka and Lejsková (2015) indicate that, in practice, the problem area of talent management (the processes of talent management is shown in Fig. 1) is insufficient setting of talents, as well as its imprecise definition of the competencies required for talent pooling (Farkašová *et.al.*, 2013). The next problem area determined as defective is the wrong choice of a talent for the company based on set criteria (competencies), which usually results in an irretrievable investment. Therefore, the key element (Kampf *et al.*, 2014) in identifying talents in a company is to define the required and needed competencies (selection criteria). These competencies should be in accordance with the business strategy (Sojka, 2013) and this way to ensure the effectiveness of the selection of talents in the organization for their further use in the company as key personnel. Authors Ali Taha and Sikorová (2012), Bolfíková *et al.* (2010) and Nováková (2011) discuss the following areas of competencies (criteria):

• behavioral aspects (for example: „I can - I will do“),
• knowledge, skills and abilities,
• soft skills,
• cognitive skills (eg. diversity of thought),
• experiences,
• recognized values.

Every company has its own characteristics (Weberova, 2013) and specificities to be taken into account in determining competencies. In view of this fact, it is natural that some of the required competencies have higher weight (are more important) than other competencies (Olexová *et al.*, 2011). When identifying talents (Hitka *et al.*, 2013), it is not only important to determine what competencies are expected from talents, but also to define their priority. (Zámečník, 2014). From this perspective, it is possible to comprehensively assess candidates when building a talent pool (Kampf *et al.*, 2015). When evaluating workers in search of talents, different methods are used (Rebeťák and Farkašová, 2015; Lukáč, 2009):

1. Assessment of previous performances and achieved objectives;
2. References of senior staff;
3. Evaluation 360^{o} (inside the organization) or 540^{o} (outside the company, in the form of verification of references);
4. In-depth structured interview;
5. Performance and other tests;
6. Assessment and Development Centre, Leadership Assessment.

The quality of the assessment depends on the emphasis on objectivity and takes into account the costs that the company plans to invest in the talent pool for the future.

Figure 1 Talent management processes in the company
Slika 1. Procesi upravljanja talentima u poduzeću

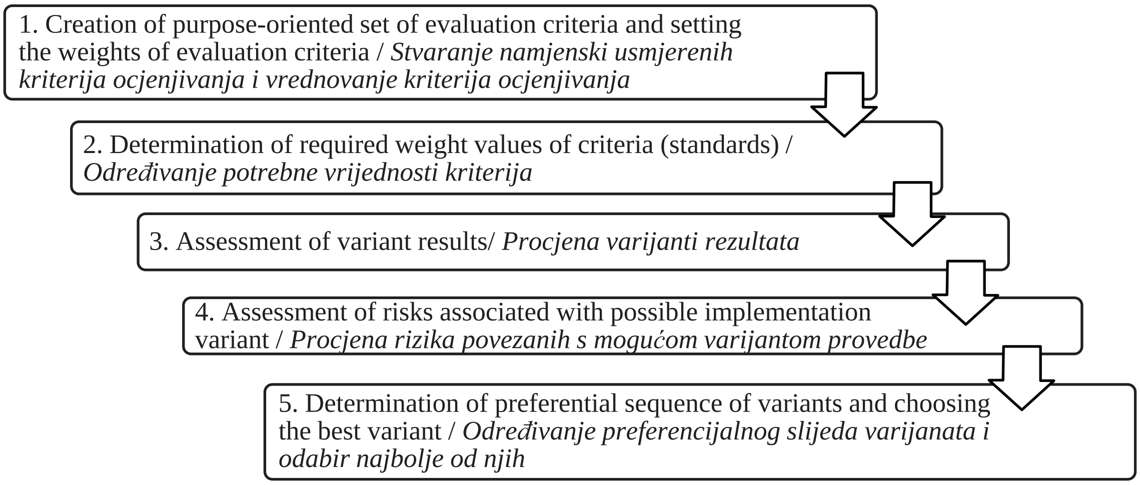

Figure 2 The steps of using multicriteria decision method (Clemen, 1991)
Slika 2. Koraci u primjeni višekriterijskog odlučivanja (Clemen, 1991.)

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

The aim of the article is to find one of the possible solutions to increase the objectivity of identifying talents in the company and finding valuable input data for effective planning of their further development. The objective is achieved by estimating the weights of criteria and by using the method of multicriteria decision making.

The suitability of methods for optimizing the selection of talent pool will be considered based on the type of input data to be processed and usability conclusions of optimization method. Using methods of multicriteria decision, the sequence of steps shown in Fig. 2 must be respected. The selected methods have been applied to a specific example of the Czech company operating in furniture industry with a twenty-year tradition.

2.1 Methods for determining criteria weightings
2.1. Metode određivanja težine kriterija

For accurate diagnosis and selection of talents in the company, it is necessary to clearly determine the required competence. Due to the limited selection resulting from a lack of talents, the company should consider the prerequisites of candidates for obtaining some competencies. It requires categorizing competencies with respect to their weight of importance in accordance with the strategy of the company. It is often difficult to obtain weight importance in numerical form. For this reason, the use of estimates of weights of the criteria will facilitate the assessment of the evaluators. The best known methods (Jablonský, 2002) are the Method of Ranking, Scoring Method, Method of Fuller Triangle and Saaty´s Method. The method of ranking and scoring method are based on direct evaluation criteria (Stopka *et al.*, 2014). In the method of ranking, the evaluator sets ranking of most important criteria (assigning a value *k*, where *k* is the number of criteria), from the most important *k-1*, *k-2* ... to the least important, which is assigned a value of 1. Consequently, as the assigned value i-th criterion is marked as p_i, it is possible to estimate scales (*Eq. 1*) by calculating (Jablonský, 2002):

$$v_i = \frac{p_i}{\sum_{i=1}^{k} p_i} \quad i = 1, 2, \ldots, k \qquad (1)$$

The requirement that the evaluator can qualitatively evaluate the importance of the pre-determined scoring scale (eg. 1 to 10) is essential for the suitability of the scoring method. The higher the score, the higher importance will be placed on that criterion. If the value assigned *i*-th criterion is denoted as *p*, it is possible to weight the criteria calculated according to Eq. 1. These methods are not entirely favorable for the evaluator because clear assessment criteria are less accurate and do not reflect the relationships of criteria with each other. Methods based on pairwise comparison criteria are more appropriate for the solution of the question of talents identification. Principle Fuller triangle is based on mutual comparison criteria arranged in a triangular scheme (Fig. 3), where each pair occurs only once. The evaluator selects important criterion of each pair (Jablonský,

Y1 **Y2**	**Y1** Y3	Y1 **Y4**	Y1 **Y5**	**Y1** Y6
	Y2 **Y3**	**Y2** Y4	**Y2** Y5	Y2 **Y6**
		Y3 **Y4**	Y3 **Y5**	Y3 Y6
			Y4 **Y5**	Y4 Y6
				Y5 Y6

Figure 3 The scheme of the Fuller's Triangle Method (Jablonsky, 2002)
Slika 3. Shema metode Fullerova trokuta (Jablonsky, 2002.)

2002), and highlights it. Unless both criteria are of equal importance, the evaluator will highlight both. Subsequently, the evaluator calculates the number of highlighted *i*-th criteria identified as *p* and obtains an estimate of the weights criteria according to Eq. 1.

Saaty´s method (Saaty, 2008) is the most sophisticated of the described methods and allows for broader consideration of the impact of preference criteria based on pair comparison. The degree (Jablonský, 2002) of importance of the criteria *v* is assessed on a scale from 1 to 9, where value 1 indicates that the criteria are of equal importance and value 9 expresses the absolute preference of one criterion to another. If the first criterion is less important than the other, this relationship is expressed by the inverse of the scales (1 / 1-9). Consequently, the final evaluation can be entered in Saaty´s matrix, where each element S_{ij} (*Eq. 2 - 4*) can be obtained as the ratio of estimating of weights for the *i*-th and *j*-th criterion (Saaty, 2000):

$$s_i \approx \frac{v_i}{v_j} \quad (i, j = 1, 2, 3, \ldots, k) \tag{2}$$

$$v_i' = \left(\prod_{j=1}^{k} s_{ij} \right)^{1/k} \quad i = 1, 2, \ldots, k \tag{3}$$

$$v_i = \frac{v_i'}{\sum_{i=1}^{k} v_i'} \quad i = 1, 2, \ldots, k \tag{4}$$

Substituting the calculated elements (Saaty, 1988) of the matrix into the Eq. 3 and 4 allows for calculating the weighting of importance of the particular criteria. Saaty´s method is the most appropriate form of determining (Kampf *et al.*, 2012) the weighting of criteria for the purposes of identifying the talent pool in the particular furniture company, since it respects the complicated relationships between individual criteria. Based on the obtained weightings, it is possible to assess the suitability of each candidate and reduce the complexity and frequent inaccuracies of evaluators' decision. As input data, utilization of the results of assessment and development centre, where several evaluators can imitate the conditions to fulfill the criteria of individuals, who are subjected to multiple types of tasks, seems to be the optimal decision. This evaluation fulfils the condition of the comprehensive evaluation.

2.2 Methods based on selecting the most suitable variant
2.2. Metode utemeljene na odabiru najprikladnije varijante

There are a lot of methods for selecting the most suitable variant within multi-criteria analysis and they are based on different principles (Filová *et al.*, 2012). The most common methods are AHP method (Analytic Hierarchy Process), ELECTRE methods PROMETHEE method, WSA method, the complex utility function method, TOPSIS method and others (Klaric *et al.*,2015) (Kampf, 2003). In this paper, the AHP method has been selected. It is based on the principle of paired comparisons of elements in each level of a hierarchical structure. This represents a model of the particular decision-making problem. Given the objectives of the paper, this method is selected to obtain the cardinal information and accessibility for the evaluators, due to the possibility of using the verbal evaluation.

3 RESULTS
3. REZULTATI

3.1 Application of Saaty´s method to conditions of a specific company operating in furniture industry
3.1. Primjena Saatyjeve metode u uvjetima konkretne tvrtke koja posluje u industriji proizvodnje namještaja

Practical application of Saaty´s method in this article is to evaluate the importance of the required criteria of talents in a company of furniture industry. Companies producing furniture have some specific features (Mateides and Ďaďo, 2002, Greger *et. al.*, 2013). Taking into account these specifics, it will become possible to increase the efficiency in the management of their talents. The specifics that affect the business strategy of companies of furniture industry are mainly determined by the nature of their product. These specifics are transformed into the production process and situation in furniture trade (Potkány and Giertl, 2014). Managers have to be able to identify these specific features and take them into account. The example has been made on the basis of the data found in a Czech company, manufacturing furniture for over 20 years. Determination and subsequent valuation criteria discussed in this example were obtained in 2015 from the five key managers (the values given are arithmetic average). In accordance with the objectives and strategies of the company, the key criteria (competencies) were determined:

K1 - ability to work under stress / *sposobnost rada pod stresom*
K2 - analytical and logical thinking / *analitičko i logično razmišljanje*
K3 - creativity and openness to new ideas / *kreativnost i otvorenost prema novim idejama*
K4 - expertise (expertise in furniture production field) / *stručnost*
K5 - communication skills / *komunikacijske vještine*
K6 - team thinking / *timsko razmišljanje*
K7 - reliability and responsibility / *pouzdanost i odgovornost*
K8 - experience / *iskustvo*
K9 - ability to react flexibly to changes / *sposobnost fleksibilne reakcije na promjene*
K10 - purposefulness / *svrhovitost*.

Based on these defined competencies for identifying talents in the organization and assessment of their importance by paired comparison (Eq. 2), Saaty´s matrix could be made. It is presented in Tab. 1.

The values of obtained weights K1 - K10 determine the importance of the required competencies for the talent. These weights can be used for decision making in the selection of talents in several ways. The simplest and the most commonly used method, in practice, is rating (Tab. 2). The resulting values of rating are obtained by multiplying the assessment of candidate competencies (V_j) and the value of the criteria weight (K_i). The matrix was tested for consistency (CR

Table 1 Calculation of criteria weights by using the Saaty´s matrix
Tablica 1. Izračun vrednovanja kriterija uz pomoć Saatyjeve matrice

Criterion *Kriterij*	**K1**	**K2**	**K3**	**K4**	**K5**	**K6**	**K7**	**K8**	**K9**	**K10**	v_i'	v_i
K1	1	1.40	7.00	8.20	0.36	2.40	1.40	7.80	1.80	2.20	2.225067	0.169436
K2	0.71	1	2.40	7.00	0.33	3.40	1.20	6.40	2.00	4.00	1.957774	0.149082
K3	0.14	0.42	1	4.80	0.13	0.90	3.00	7.80	0.39	1.40	0.920863	0.070122
K4	0.12	0.14	0.21	1	0.12	0.37	0.13	2.00	0.28	0.55	0.304126	0.023159
K5	2.80	3.03	7.46	8.13	1	3.20	2.40	7.60	2.20	1.40	3.137958	0.238951
K6	0.42	0.29	1.12	2.70	0.31	1	1.40	7.00	2.20	1.60	1.148321	0.087443
K7	0.71	0.83	0.33	7.46	0.42	0.71	1	8.40	1.80	2.00	1.295477	0.098649
K8	0.13	0.16	0.13	0.50	0.13	0.14	0.12	1	0.16	0.12	0.188370	0.014344
K9	0.56	0.50	2.56	3.59	0.45	0.45	0.56	6.28	1	1.80	1.127485	0.085856
K10	0.45	0.25	0.71	1.82	0.71	0.63	0.50	8.13	0.56	1	0.826767	0.062957
											∑ =	1.000000

= 0.096). According to Saaty (2000), the permissible tolerance is max. 10 %, therefore the consistency condition is satisfied.

The input data (obtained score of competencies of candidates - V_j) are in this case obtained by means of development centre and 360° evaluations (Tab. 2). Candidates (n = 6) were evaluated by five evaluators, who rated the range of 1-9 (where 1 - very poor, 9 - very strong). The resulting value is the average of the assessment of all evaluators.

Another option of decision making is AHP method, based on the principle of Saaty´s matrix. In making use of Saaty´s matrix, the candidates are compared (Eq. 2) for each criterion in a separate matrix (Tab. 3). The advantage of this method is more comprehensive assessment of deviations between meeting individual criteria. A comparison of the candidates for each criterion in a single matrix is shown in Table 3. The values in the matrix are obtained based on the ratio of compared assessment of candidates to the selected criterion (Eq. 2). Thus obtained results for individual candidates are used to calculate the final evaluation of the candidates as shown in Table 4.

The method of rating is a quick option for obtaining rapid and relatively acceptable results. Tab. 2 shows this recalculation for each criterion of the monitored candidates (V1 -V6). The fields marked in grey show the highest values for the evaluated criteria. Consequently, it is possible to determine the final evaluation of candidates and their sequence of suitability. The three best ratings of candidates are marked in grey. In this case, the most suitable candidates are V2, V4 and V1.

The maximum calculated values obtained by using the resulting weights of candidates and the criteria (Table 4) are highlighted in bold. Based on the sum of preferential index values of each candidate, the optimum sequence can be determined in identifying talents in the organization. In this case, the optimal candidate is V2, and V4 is the second, which corresponds to the rating of the first method (Table 2).

The resulting sequence obtained by the AHP method differs in the determination of other suitable candidates, namely: V6 is the third most optimal candidate (in Table 2 it is V1), followed by V3, V1 and V5.

4 DISCUSSION AND CONCLUSION
4. RASPRAVA I ZAKLJUČAK

Using the estimate of weights methods for each criterion in identifying talents improves the quality of talent selection. It this article, Saaty´s method is evaluated as the most appropriate method. The application of

Table 2 Evaluation of candidates and recalculation by weight of criteria (rating)
Tablica 2. Ocjenjivanje kandidata i izračun vrijednosti kriterija (ocjena)

Criterion *Kriterij*	**Evaluation of candidates** *Ocjenjivanje kandidata*						**Weight of criteria** *Vrijednost kriterija*	**Candidate evaluation recalculatiion by criteria weight** / *Preračunavanje ocjenjivanja kandidata i vrijednosti kriterija*					
	V1	V2	V3	V4	V5	V6		V1	V2	V3	V4	V5	V6
K1	7.4	3.6	2.8	8.0	5.4	6.2	0.169436	1.254	0.610	0.474	1.355	0.915	1.051
K2	8.0	6.0	8.2	7.4	5.0	4.6	0.149082	1.193	0.894	1.222	1.103	0.745	0.686
K3	3.4	7.2	6.4	4.2	8.2	3.0	0.070122	0.238	0.505	0.449	0.295	0.575	0.210
K4	8.0	6.0	2.8	5.4	2.8	8.4	0.023159	0.185	0.139	0.065	0.125	0.065	0.195
K5	3.2	7.0	6.0	4.2	3.2	5.4	0.238951	0.765	1.673	1.434	1.004	0.765	1.290
K6	4.6	7.6	6.0	5.2	4.6	5.0	0.087443	0.402	0.665	0.525	0.455	0.402	0.437
K7	7.0	6.8	3.6	7.4	7.2	8.4	0.098649	0.691	0.671	0.355	0.730	0.710	0.829
K8	7.8	7.4	3.8	4.0	7.0	8.4	0.014344	0.112	0.106	0.055	0.057	0.100	0.120
K9	7.4	7.4	8.0	8.4	8.2	5.0	0.085856	0.635	0.635	0.687	0.721	0.704	0.429
K10	4.6	5.2	5.8	5.4	3.6	8.0	0.062957	0.290	0.327	0.365	0.340	0.227	0.504
Total score / *Ukupan rezultat*								5.764	6.225	5.631	6.185	5.208	5.751
Sequence / *Redoslijed*								3	1	5	2	6	4

Table 3 Conversion of candidates' suitability by AHP method
Tablica 3. Izračun prikladnosti kandidata primjenom AHP metode

K1	V1	V2	V3	V4	V5	V6	v_i'	v_i	K6	V1	V2	V3	V4	V5	V6	v_i'	v_i
V1	1	2.06	2.64	0.93	1.37	1.19	1.42060	0.22156	**V1**	1	0.61	0.77	0.88	1.00	0.92	0.85019	0.13939
V2	0.49	1	1.29	0.45	0.67	0.58	0.69110	0.10778	**V2**	1.65	1	1.27	1.46	1.65	1.52	1.40466	0.23030
V3	0.38	0.78	1	0.35	0.52	0.45	0.53752	0.08383	**V3**	1.30	0.79	1	1.15	1.30	1.20	1.10894	0.18182
V4	1.08	2.22	2.86	1	1.48	1.29	1.53578	0.23952	**V4**	1.13	0.68	0.87	1	1.13	1.04	0.96108	0.15758
V5	0.73	1.50	1.93	0.68	1	0.87	1.03665	0.16168	**V5**	1.00	0.61	0.77	0.88	1	0.92	0.85019	0.13939
V6	0.84	1.72	2.21	0.78	1.15	1	1.19023	0.18563	**V6**	1.09	0.66	0.83	0.96	1.09	1	0.92412	0.15152
K2	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	v_i'	v_i	**K7**	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	v_i'	v_i
V1	1	1.33	0.98	1.08	1.60	1.74	1.25532	0.20408	**V1**	1	1.03	1.94	0.95	0.97	0.83	1.07392	0.17327
V2	0.75	1	0.73	0.81	1.20	1.30	0.94149	0.15306	**V2**	0.97	1	1.89	0.92	0.94	0.81	1.04324	0.16832
V3	1.03	1.37	1	1.11	1.64	1.78	1.28670	0.20918	**V3**	0.51	0.53	1	0.49	0.50	0.43	0.55230	0.08911
V4	0.93	1.23	0.90	1	1.48	1.61	1.16117	0.18878	**V4**	1.06	1.09	2.06	1	1.03	0.88	1.13529	0.18317
V5	0.63	0.83	0.61	0.68	1	1.09	0.78457	0.12755	**V5**	1.03	1.06	2.00	0.97	1	0.86	1.10460	0.17822
V6	0.58	0.77	0.56	0.62	0.92	1	0.72181	0.11735	**V6**	1.20	1.24	2.33	1.14	1.17	1	1.28871	0.20792
K3	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	v_i'	v_i	**K8**	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	v_i'	v_i
V1	1	0.47	0.53	0.81	0.41	1.13	0.67600	0.10494	**V1**	1	1.05	2.05	1.95	1.11	0.93	1.27841	0.20313
V2	2.12	1	1.13	1.71	0.88	2.40	1.43154	0.22222	**V2**	0.95	1	1.95	1.85	1.06	0.88	1.21285	0.19271
V3	1.88	0.89	1	1.52	0.78	2.13	1.27248	0.19753	**V3**	0.49	0.51	1	0.95	0.54	0.45	0.62281	0.09896
V4	1.24	0.58	0.66	1	0.51	1.40	0.83506	0.12963	**V4**	0.51	0.54	1.05	1	0.57	0.48	0.65559	0.10417
V5	2.41	1.14	1.28	1.95	1	2.73	1.63036	0.25309	**V5**	0.90	0.95	1.84	1.75	1	0.83	1.14729	0.18229
V6	0.88	0.42	0.47	0.71	0.37	1	0.59647	0.09259	**V6**	1.08	1.14	2.21	2.10	1.20	1	1.37675	0.21875
K4	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	v_i'	v_i	**K9**	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	v_i'	v_i
V1	1	1.33	2.86	1.48	2.86	0.95	1.57659	0.23952	**V1**	1	1.00	0.93	0.88	0.90	1.48	1.01421	0.16667
V2	0.75	1	2.14	1.11	2.14	0.71	1.18244	0.17964	**V2**	1.00	1	0.93	0.88	0.90	1.48	1.01421	0.16667
V3	0.35	0.47	1	0.52	1.00	0.33	0.55181	0.08383	**V3**	1.08	1.08	1	0.95	0.98	1.60	1.09645	0.18018
V4	0.68	0.90	1.93	1	1.93	0.64	1.06420	0.16168	**V4**	1.14	1.14	1.05	1	1.02	1.68	1.15127	0.18919
V5	0.35	0.47	1.00	0.52	1	0.33	0.55181	0.08383	**V5**	1.11	1.11	1.03	0.98	1	1.64	1.12386	0.18468
V6	1.05	1.40	3.00	1.56	3.00	1	1.65542	0.25150	**V6**	0.68	0.68	0.63	0.60	0.61	1	0.68528	0.11261
K5	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	v_i'	v_i	**K10**	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	v_i'	v_i
V1	1	0.46	0.53	0.76	1.00	0.59	0.69228	0.11034	**V1**	1	0.88	0.79	0.85	1.28	0.58	0.87182	0.14110
V2	2.19	1	1.17	1.67	2.19	1.30	1.51437	0.24138	**V2**	1.13	1	0.90	0.96	1.44	0.65	0.98554	0.15951
V3	1.88	0.86	1	1.43	1.88	1.11	1.29803	0.20690	**V3**	1.26	1.12	1	1.07	1.61	0.73	1.09926	0.17791
V4	1.31	0.60	0.70	1	1.31	0.78	0.90862	0.14483	**V4**	1.17	1.04	0.93	1	1.50	0.68	1.02345	0.16564
V5	1.00	0.46	0.53	0.76	1	0.59	0.69228	0.11034	**V5**	0.78	0.69	0.62	0.67	1	0.45	0.68230	0.11043
V6	1.69	0.77	0.90	1.29	1.69	1	1.16823	0.18621	**V6**	1.74	1.54	1.38	1.48	2.22	1	1.51621	0.24540

Table 4 Resulting suitability variants by AHP method
Tablica 4. Izračun prikladnosti pojedinih inačica primjenom AHP metode

Crite-rion *Krite-rij*	**Weights of the candidates (v_i)** / *Vrijednosti kandidata (v_i)*						**Weight of criteria** *Vrijed-nost kriterija*	**Preferential index of variations (w_{ji})** / *Preferencijalni indeks varijanti (w_{ji})*					
	V1	**V2**	**V3**	**V4**	**V5**	**V6**		**V1**	**V2**	**V3**	**V4**	**V5**	**V6**
K1	0.22156	0.10778	0.08383	0.23952	0.16168	0.18563	**0.16944**	0.03754	0.01826	0.01420	**0.04058**	0.02739	0.03145
K2	0.20408	0.15306	0.20918	0.18878	0.12755	0.11735	**0.14908**	0.03042	0.02282	**0.03119**	0.02814	0.01902	0.01749
K3	0.10494	0.22222	0.19753	0.12963	0.25309	0.09259	**0.07012**	0.00736	0.01558	0.01385	0.00909	**0.01775**	0.00649
K4	0.23952	0.17964	0.08383	0.16168	0.08383	0.25150	**0.02316**	0.00555	0.00416	0.00194	0.00374	0.00194	**0.00582**
K5	0.11034	0.24138	0.20690	0.14483	0.11034	0.18621	**0.23895**	0.02637	**0.05768**	0.04944	0.03461	0.02637	0.04449
K6	0.13939	0.23030	0.18182	0.15758	0.13939	0.15152	**0.08744**	0.01219	**0.02014**	0.01590	0.01378	0.01219	0.01325
K7	0.17327	0.16832	0.08911	0.18317	0.17822	0.20792	**0.09865**	0.01709	0.01660	0.00879	0.01807	0.01758	**0.02051**
K8	0.20313	0.19271	0.09896	0.10417	0.18229	0.21875	**0.01434**	0.00291	0.00276	0.00142	0.00149	0.00261	**0.00314**
K9	0.16667	0.16667	0.18018	0.18919	0.18468	0.11261	**0.08586**	0.01431	0.01431	0.01547	**0.01624**	0.01586	0.00967
K10	0.14110	0.15951	0.17791	0.16564	0.11043	0.24540	**0.06296**	0.00888	0.01004	0.01120	0.01043	0.00695	**0.01545**
u(X_i) Total benefit of variations / *Ukupna korist varijante* ($\sum v_j$=1,000)								0.16263	0.18236	0.16340	0.17618	0.14766	0.16777
Sequence of preference / *Redoslijed izbora*								5	**1**	4	**2**	6	**3**

Saaty´s method is shown in the real case of talent selection in the Czech company operating in furniture industry. The accuracy of selection can be optimized by selecting the appropriate method for determining the correct option (the candidate) based on several criteria.

AHP methods were compared based on Saaty´s matrix with simple rating (multiplying assessment of candidates and weight of criteria). Different ranking of candidates was obtained by using these methods. Divergence of results was caused by detailed paired comparison of competencies of individual candidates. The need for planning development and training of identified talents was associated with increased costs, creating a need for an optimized selection. Optimized selection of candidates can be inaccurate particularly in the case of:

– changes in priorities and objectives of furniture manufacturer,
– inaccurate or biased assessment of candidates, by the evaluators,
– incorrect or incomplete consideration of the required competencies.

The aim of the article was to find opportunities to improve the quality of decision-making when identifying talents in a furniture manufacturing company. For this reason, the determining of criteria for choosing talents has to be established in view of specific production process and company objectives. These requirements also depend on the character and situation in the furniture market. To meet the set target, several methods could be used to estimate the weights of the criteria. Saaty´s method was determined as the most appropriate in view of obtaining cardinal information that can be further used. In this article, AHP method was chosen for identifying the best option, which allows a comparison of the candidates on the basis of verbal evaluation by several experts. Another reason was that AHP method was to provide accurate outputs that can form the basis for further targeted development planning of talents. The use of these optimization methods provides the accuracy of the results obtained and the subsequent decisions represent a reduction in investment risk for the development of the talent pool.

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Bending Creep Behavior of Hornbeam Wood

Puzanje drva graba pri savijanju

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ABSTRACT • *This study examined the effect of altitude on bending creep behavior of hornbeam lumber (Carpinus betuluse). For this purpose, 9 hornbeam trees from three different altitudes (400, 800 and 1100 m) in the northern forests of Iran were selected. Clear samples were cut from mature wood in diameter at breast height (DBH). 108 prepared samples (dimensions: 2.5 × 2.5 × 41 cm) were conditioned at room temperature of 20 ºC and two relative humidities (RH) of 65 % and 95 %. First, the maximum bending load was determined by three-point static bending tests in acclimatized room and then flexural creep parameters, such as relative creep, creep modulus and creep factor, at 20 % of the maximum bending load, were calculated. Results indicated that at 65 % RH, the effect of altitude on creep parameters was significant. The maximum values of relative creep and creep factor were observed at the altitude of 800 m, and the minimum values at the altitude of 400 m. The maximum values of creep modulus were observed at the altitude of 400 m and the minimum values at the altitude of 800 m. Also, at 95 % RH, the effect of altitude on creep modulus was significant but it was not significant on relative creep and creep factor. The maximum creep modulus was observed at the altitude of 400 and the minimum at the altitude of 800 m.*

Keywords: *altitude, Carpinus betuluse, creep factor, creep modulus, relative creep, relative humidity*

SAŽETAK • *U radu su prikazani rezultati istraživanja utjecaja nadmorske visine staništa stabala na puzanje drva graba (Carpinus betuluse) pri savijanju. Za istraživanje je odabrano devet stabala graba iz šuma na sjeveru Irana, i to na tri različite lokacije – nanadmorskoj visini 400, 800 i 1100 m. Uzeti su čisti uzorci zrelog drva na visini prsnog promjera (DBH). Ukupno 108 pripremljenih uzoraka (dimenzija 2,5 × 2,5 × 41 cm) kondicionirano je pri sobnoj temperaturi od 20 °C i uz dvije relativne vlažnosti zraka (RH), 65 i 95 %. Najprije je napravljen statički test savijanja u tri točke te određeno maksimalno opterećenje (čvrstoća na savijanje) u aklimatiziranoj prostoriji. Potom su izračunani parametri puzanja pri savijanju kao što su relativno puzanje, modul puzanja i faktor puzanja u području 20 % maksimalnog opterećenja savijanja. Rezultati istraživanja na uzorcima kondicioniranim pri 65 % relativne vlažnosti zraka pokazali su da je utjecaj nadmorske visine na parametre puzanja bio značajan. Maksimalne vrijednosti relativnog puzanja i faktora puzanja zabilježene su za uzorke s nadmorske visine 800 m, a minimalne vrijednosti za uzorke s nadmorske visine 400 m. Maksimalne vrijednosti modula puzanja zabilježene su za uzorske drva s nadmorske visine 400 m, a minimalne za one s nadmorske visine 800 m. Također, na uzorcima kondicioniranim pri 95 % relativne vlažnosti zraka utjecaj nadmorske visine na modul puzanja bio je značajan, ali se taj utjecaj nije pokazao značajnim za parametre relativnog puzanja i faktora puzanja. Najveći modul puzanja zabilježen je na uzorcima s nadmorske visine 400 m, a najmanji na uzorcima s nadmorske visine 800 m.*

Ključne riječi*: nadmorska visina, Carpinus betuluse, faktor puzanja, modul puzanja, relativno puzanje, relativna vlažnost zraka*

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1 INTRODUCTION
1. UVOD

In most developing countries, demand for raw materials has been increasing in recent years. Considering the limited resources, especially in natural resources sector, the supply of needed raw material of wood for industry has been one of the most important problems in recent decades. Attention should be focused on the improvement of wood specifications and modification of some properties of wood, so as to provide better consumption of wood.

One of the most important characteristics affecting wood products is their time-dependent behavior. Generally, time dependent deformation of a material under sustained load is referred to as creep. If the load is large and the duration is long, failure will occur. Creep is one of the principal characteristics of wood resulting in poor performance in certain applications. It is essential to consider creep and creep rupture (load duration behavior) if wood is to be subjected to short and long-term loads. Wood has been characterized as viscoelastic material governed by creep behavior (Fridley, 1992a; Fridley, 1992b). Creep of these materials occurs as a result of a combination of elastic deformation and viscous flow, commonly known as viscoelastic deformation (Bodig and Jayne, 1993). The creep behavior of wood depends on a variety of factors including stress level, composite formulation, temperature, and last but not least, moisture content (Liu, 1993; Chen and Lin, 1997; Christopher *et al*., 2004; Zhang *et al.*, 2007). High temperature and changes of humidity make wood prone to creep and can lead to problems of lowered resistance and capability of use (Van der put, 1989). When wood is exposed to moisture changes, the resulting deformation is higher than when wood is exposed to environmental conditions for the same time (Bazant and Meiri, 1985; Nakano, 1999). Simultaneous effect of the load and changes of wood moisture is called mechanical absorption effect (Kaboorani *et al.*, 2013). This effect is very important in the use of wood for construction and causes failure and deformation in wooden beam (Kaboorani and Blanchet, 2014). The creep caused by mechanical absorption has been reported in different articles (Armstrong and Christensen, 1960, 1962; Armstrong and Kingston, 1962; Armstrong, 1972; Kowalski and Kowal, 1998; Hanhijarvi and Hunt, 1998).

Hornbeam, a diffuse-porous hardwood, covers about 33 % of forests in northern Iran. The wood of this tree species is semi-hard to hard with high shrinkage and swelling, and working with it is hard (Kiaei, 2012). Considering the extent of this species and necessity of its right use, it must be given more attention. Therefore, the aim of this research is to: a) evaluate the effect of altitude on the flexural creep behavior of hornbeam wood (*Carpinus betulus* L.) harvested from Nowshahr Mashelek site, b) examine the relationship between physical and biometrical properties and displacement.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Three hornbeam trees, of almost the same age of about 30 years, were chosen from three altitudes (400, 800 and 1100 m). Nine logs (diameter: 25 and length: 70 cm) at DBH were cut. Environmental characteristics, climate conditions habitat and specification of trees are presented in Table 1.

2.1 Preparing the samples
2.1. Priprema uzoraka

Sawn logs were stored in covered storage and environmental conditions. At first, logs were cut to 45 boards with 3.2 cm thicknesses from mature wood section (from ring 18 onwards, Makhmalbaf *et al.,* 2007), then they were kept in environmental conditions for a period of two weeks. 108 final samples (dimensions: 2.5 × 2.5 × 41 cm) were prepared (54 samples for creep test and 54 samples for bending test). Samples were placed in an acclimatized room (65 % and 95 % RH, temperature of 20±3 ºC) for at least 3 weeks. All tests were done in the same conditions.

2.2 Physical and biometrical properties
2.2. Fizikalna i biometrijska svojstva

Oven-dried density and basic density were measured according to ISO 3131 (2.5 × 2 × 2 cm). The weight and size of samples were measured in the water (soaking for 48 hours) and then in the oven (24 hours).

Franklin's method (1946) was used for separating fibers. In this method, a 50/50 % ratio of acetic acid and hydrogen peroxide was used. First, the sample wood picks were placed inside a microquant, then the prepared acetic acid and hydrogen peroxide were poured on the wood samples by a calibrated pipette and the microquant was placed in an oven and heated for 48 h at 64 °C. After whitening, the samples from the microquant were washed 4 to 5 times by a calibrated pipette with distilled water until the odor of hydrogen

Table 1 Characteristics of study sites and trees
Tablica 1. Obilježja staništa i stabala uključenih u istraživanje

Site *Lokacija*	**Elevation** *Nadmorska visina* m	**Annual temperature** *Prosječna godišnja temperatura* ºC	**Annual rainfall** *Godišnje padaline* mm	**Tree height** *Visina stabla* m	**Tree diameter** *Promjer stabla* cm
Mashelak forest-Nowshahr	400	13.5	1345	17.6	29
	800	11.5	1300	17.3	29
	1100	8.5	1300	17.2	28

peroxide and acetic acid was completely removed. Fiber dimensions were measured by optic microscope (Nikon microscopic, Eclipse 50i, for the fiber length of 10x and for fiber diameter, cell wall thickness and lumen diameter of 40x).

2.3 Bending properties
2.3. Svojstva drva pri savijanju

In order to determine the maximum bending load, three-point static bending tests were carried out in accordance with ASTM D 143-94 (2000). Three replicates of each sample were tested using a computer-controlled INSTRON (Model Universal PT 20L) machine. The speed of the crosshead was set at 1.3 mm/min. Data were collected and used to calculate the modulus of elasticity (MOE) and short-term strength (modulus of rupture or MOR).

2.4 Creep properties
2.4. Svojstva puzanja drva

Using flexural creep equipment, creep tests were performed in accordance with ASTM D 6815-09. The immediate displacement, maximum displacement and permanent displacement at the mid-span of samples were measured by an extensometer during creep and recovery time. Total time to complete every test was one overnight (14 hours creep and 10 hours recovery). The stress was at 20 % of the maximum bending load and was constant throughout the test. Based on measuring indications, creep factor, relative creep and creep modulus were calculated in accordance with equations 1, 2 and 3.

Immediate displacement is the range of displacement in one minute after loading; the maximum displacement is the range of displacement in 840 minutes after loading; immediate return is the range of returned displacement in one minute after removing the load; and permanent displacement is the range of remaining displacement in 600 minutes after removing the load (return).

$$K_t = \frac{J_t}{J_0} \qquad (1)$$

$$R_c = \frac{j_t - J_0}{J_0} \cdot 100 \qquad (2)$$

$$E_c = \frac{L^3 \cdot F}{4 \cdot b \cdot h^3 \cdot J_t} \qquad (3)$$

Where K_t, is creep factor; R_c, is relative creep in percentage; E_c, is creep modulus in MPa, J_t, is displacement in time of t in mm; J_o, is displacement in one minute after loading; L, is length loading span in mm; F, is in Newton; b, is width of sample in mm and h, is thickness of sample in mm.

2.5 Parabolic equations
2.5. Parabolične jednadžbe

To predict creep behavior, researchers depend on good judgment supported by available models. A number of empirical and theoretical methods have been developed to express time-dependent creep strains. Various researchers have investigated modeling of viscoelastic materials. Response linear and non-linear viscoelastic materials have been documented and a number of equations have been presented (Bodig and Jayne, 1993). The creep model, used in our research, is the power law proposed by Findley *et al*. (Findley *et al*., 1989; Kobbe, 2005). This model is simple and has been proven to apply to viscoelastic materials loaded at moderate levels. The general form of model is given as:

$$\mu_1 = \mu_0 + a \cdot t^m \qquad (4)$$

Where μ_1 is the time dependent creep strain, μ_0 is the instantaneous strain, a is the coefficient of time-dependent strain, t is the time after loading and m is the exponential material constant. The analysis of the creep behavior of wood was performed based on the Findley *et. al* power law, adjusting the experimental values to the equation:

$$\log(\mu_1 - \mu_0) = \log a + m \log t \qquad (5)$$

The data were plotted as $\log(\mu_1 - \mu_0)$ against $\log t$, where m and a were obtained from the regression line.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Physical and biometrical properties
3.1. Fizikalna i biometrijska svojstva

Analysis of variance (ANOVA) results indicated that the effect of altitude on fiber length, basic density and oven dried density was significant, but it was not significant on cell wall thickness, lumen diameter and fiber diameter (Table 2). Duncan's test included the value of fiber length related to the altitudes of 400 and 1100 m in one group and the value related to the alti-

Table 2 Average results of physical and biometric properties of hornbeam wood at different altitudes
Tablica 2. Prosječni rezultati fizikalnih i biometrijskih svojstava drva graba sa staništa na različitim nadmorskim visinama

Altitude *Nadmorska visina* m	**Cell wall thickness** *Debljina stanične stijenke* µm	**Lumen diameter** *Promjer lumena* µm	**Fiber diameter** *Promjer vlakanaca* µm	**Fiber length** *Duljina vlakanaca* µm	**Basic Density** *Osnovna gustoća* kg/m^3	**Dry density** *Gustoća suhog drva* kg/m^3
400	5.16	12.22	22.55	1341.41^b	627.85^b	720.89^c
800	4.94	13.64	23.54	1212.97^a	549.46^a	628.09^a
1100	5.05	12.82	22.92	1370.06^b	587.36^a	679.06^b
F	0.476^{ns}	2.667^{ns}	2.538^{ns}	10.416**	3.424*	48.972**

** - Significant at 1 % level / *signifikantno na razini 1 %;* * - Significant at 5 % level / *signifikantno na razini 5 %;* ns - not significant / *nije signifikantno*

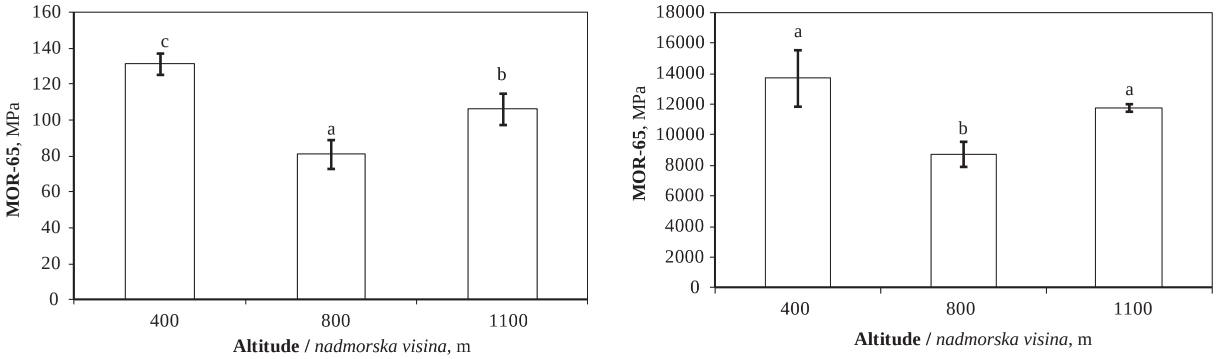


Figure 1 Hornbeam wood bending properties at three altitudes (65 % RH)
Slika 1. Svojstva drva graba pri savijanju za uzorke s tri nadmorske visine (65 % RH)

tude of 800 m in another group. For basic density, Duncan's test also included the value of fiber length related to the altitudes of 800 and 1100 m in one group and the value related to the altitude of 400 m in another group. For oven dried density, however, these values were divided into three separate groups. The maximum average oven dried density, basic density and cell wall thickness were observed at the altitude of 400 m, maximum fiber diameter and lumen diameter were observed at the altitude of 800m and, finally, the maximum fiber length was observed at the altitude of 1100 m. Different factors such as site, cell wall thickness and early wood/late wood ratio affect density of wood (Zobel and Van Buijtenen, 1989; Zobel and Sprague, 1998; Koubaa *et al*., 2000; Koga and Zhang, 2002; Zhu *et al*., 2008). The increase of density at the altitude of 400 m is due to higher cell wall thickness (5.16 μm) and lower lumen diameter (12.22 μm), which are comparable with the results of Kiaei (2013).

3.2 MOE and MOR
3.2. MOE i MOR

At 65 % RH, ANOVA results indicated that the effect of altitude on MOR and MOE was significant. The maximum and minimum average MOR and MOE were found at the altitude of 400 and 800 m, respectively. Duncan's test considered the value of MOE at altitudes of 400 and 1100 m in one group and at the altitude of 800 m in another group. However, the results of MOR were divided into 3 separate groups (a, b, c) (Fig.1).

At 95 % RH, ANOVA results indicated that the effect of altitude on MOR and MOE was significant. The maximum and minimum MOR and MOE were observed at the altitude of 400 and 800 m, respectively. Duncan's test included the value of MOR and MOE in two classes of altitude - 400 and 1100 m in one group (b) and 800 m in another group (a) (Fig. 2).

At 65 % and 95 % RH, the increase of MOE and MOR at the altitude of 400 m is due to the increase of wood density. As well known, there is a direct correlation between density and mechanical properties of wood (Zhang and Zhong, 1990; Zhang, 1997; Treacy *et al*., 2000; Charifo Ali, 2011). Also, average MOE and MOR is higher at 65 % RH than at 95 % RH, which is compatible with the results of Kaboorani *et al*., (2013) and Ishmaru *et al*. (2001).

3.3 Creep / Recovery behavior
3.3. Puzanje / povratak u početno stanje

At 65 % RH, creep/recovery curve related to the altitude of 800 m was formed in a higher level and curves related to the altitudes of 400 m and 1100 m were formed in a lower level, so that curves of these two classes of altitude almost overlap (Fig. 3a). At 95 % RH, the highest and lowest curves of creep/recovery were observed at altitudes of 800 m and 400 m, respectively (Fig. 3b). Considering the effects of MOE and MOR on creep behavior of materials (Kaboorani *et al*., 2013), placing the creep/recovery curves of hornbeam wood samples resulting from the altitude of 800 m in an upper level can be due to the deficiency of bending properties at this altitude. Also, placing the curve of the altitude of 400 m in a lower level can be due to the increase of the MOE and MOR at this altitude.

At 65 % RH, equilibrium moisture content (EMC) of samples at altitudes of 400, 800 and 1100 m

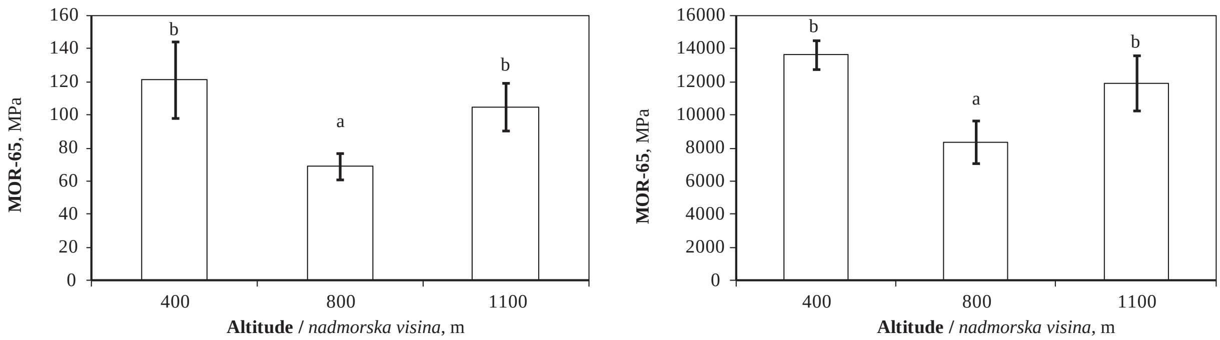
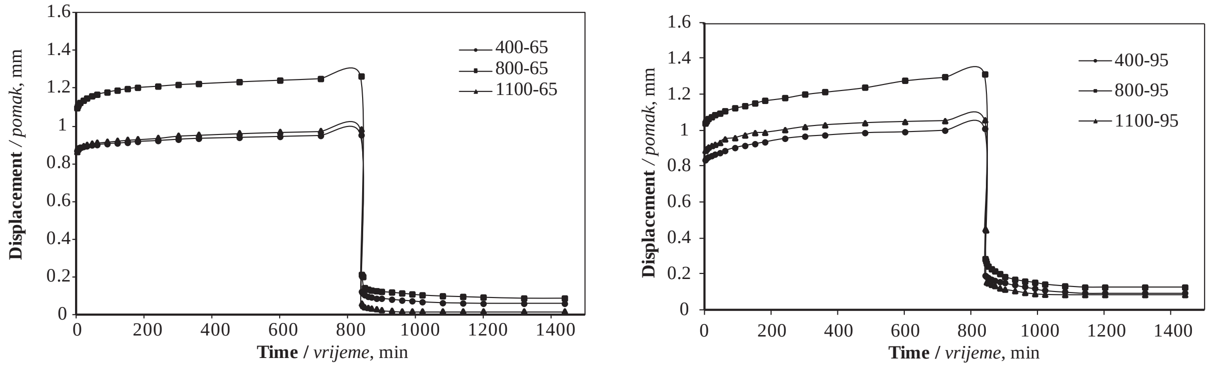


Figure 2 Hornbeam wood bending properties at three altitudes (95 % RH)
Slika 2. Svojstva drva graba pri savijanju za uzorke s tri nadmorske visine (95 % RH)



(a) (b)

Figure 3 Creep/Recovery curves of hornbeam wood samples at different altitudes at (a) 65 % and (b) 95 % RH
Slika 3. Krivulje puzanja/oporavka uzoraka drva graba sa staništa na različitim nadmorskim visinama kondicioniranih pri: a) 65 % RH i b) 95 % RH

was 30 %, 30 % and 29 %, respectively. ANOVA results indicated that altitude had a significant effect only on creep coefficient, while this factor had no significant effect on immediate displacement, maximum displacement, immediate return, permanent displacement and percentage of return (Table 3). According to Duncan's test, the average creep coefficient obtained from the altitude of 800 m and 1100 m was classified in one group, and the results obtained from the altitude of 400 m were classified in another group. The maximum average immediate displacement, maximum displacement, immediate return and permanent displacement and creep coefficient were observed at the altitude of 800 m and the maximum average return percentage was observed at the altitude of 1100 m.

At 95 % RH, EMC of samples at altitudes of 400 m, 800 m and 1100 m were 34 %, 35 % and 33 %, respectively. ANOVA results indicated that the effect of altitude on immediate displacement, maximum displacement, immediate return permanent displacement and percentage of return and creep coefficient was not significant. The maximum average immediate displacement, maximum displacement, permanent displacement and creep coefficient were observed at the altitude of 800 m and the maximum average immediate return and percentage of return were observed at the altitude of 1100 m (Table 4).

3.4 Relationship between wood properties and immediate creep and maximum creep
3.4. Odnos između svojstava drva s neposrednim puzanjem i s maksimalnim puzanjem

Pearson's correlation results indicated that there was no relationship between fibers dimensions, density and bending properties and immediate and maximum displacement at 95 % RH. At 65 % RH, MOE had a significantly reverse relationship with immediate and maximum creep. A negative and significant relationship was also observed between densities and maximum displacement (Table 5).

Table 3 Values of hornbeam creep displacement at three altitudes (65 % RH)
Tablica 3. Veličine pomaka pri puzanju uzoraka drva graba sa staništa na različitim nadmorskim visinama (65 % RH)

Altitude *Nadmorska visina* m	RH %	**EMC** %	**ID**[a] mm	**MD**[b] mm	**IR**[c] mm	**PD**[d] mm	**RP**[e]	**CC**[f]
400	65	30	0.86	0.95	0.12	0.05	84.61	1.097[a]
800		30	1.09	1.26	0.21	0.08	93.02	1.15[b]
1100		29	0.86	0.98	0.06	0.01	98.18	1.13[b]
F			3.532[ns]	4.420[ns]	4.848[ns]	0.985[ns]	1.591[ns]	20.069[*]

a - Immediate displacement / *neposredni pomak*; b - Maximum displacement / *najveći pomak*; c - Immediate return / *neposredni povratak*, d - Permanent displacement / *trajni pomak*; e - Return percentage / *postotak povratka*, f - Creep coefficient / *koeficijent puzanja*; * - Significant at 5 % level / *signifikantno na razini 5 %*; ** - Significant at 1 % level / *signifikantno na razini 1 %;* ns - not significant / *nije signifikantno*

Table 4 Values of hornbeam creep displacement at three altitudes (95 % RH)
Tablica 4. Veličine pomaka pri puzanja uzoraka od drva graba sa staništa na različitim nadmorskim visinama (95 % RH)

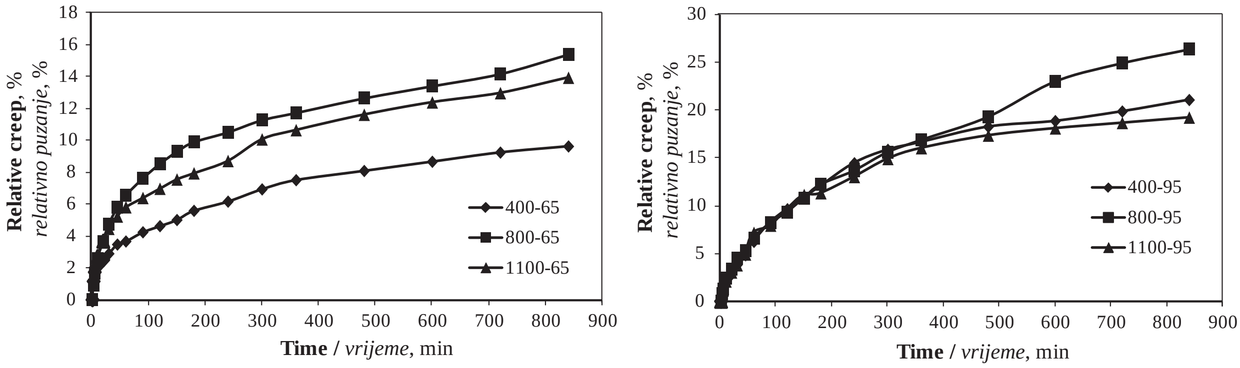
Altitude *Nadmorska visina* m	**RH** %	**EMC** %	**ID**[a] mm	**MD**[b] mm	**IR**[c] mm	**PD**[d] mm	**RP**[e]	**CC**[f]
400	95	34	0.38	1	0.18	0.09	91.53	1.20
800		35	1.02	1.31	0.28	0.12	91.08	1.25
1100		33	0.88	1.055	0.24	0.08	92.58	1.19
F			1.831[ns]	1.727[ns]	0.572[ns]	0.184[ns]	0.035[ns]	0.953[ns]

a - Immediate displacement / *neposredni pomak*; b - Maximum displacement / *najveći pomak*; c - Immediate return / *neposredni povratak*, d - Permanent displacement / *trajni pomak*; e - Return percentage / *postotak povratka*, f - Creep coefficient / *koeficijent puzanja*; ns - not significant / *nije signifikantno*

Table 5 Relationship between wood properties and immediate and maximum creep of hornbeam wood at two levels of RH – 65 % and 90 %
Tablica 5. Odnos između svojstava drva s neposrednim i s maksimalnim puzanjem za uzorke od drva graba kondicionirane pri 65 i 95 % relativne vlažnosti zraka

RH *Relativna vlažnost zraka* **%**	**Creep** *Puzanje* mm	**MOE**	**MOR**	**Dry density** *Gustoća suhog drva* kg/m³	**Lumen diameter** *Promjer lumena* µm	**Cell wall thickness** *Debljina stanične stijenke* µm	**Fiber length** *Duljina vlakanaca* µm	**Fiber diameter** *Promjer vlakanaca* µm
65	I[a]	-0.679*	-0.589	-0.643	0.490	-0.473	0.405	-0.215
	M[b]	-0.718*	-0.662	-0.700*	0.461	-0.439	0.385	-0.269
95	I	-0.481	-0.614	-0.635	0.249	0.017	0.354	-0.235
	M	-0.414	-0.529	-0.618	0.203	0.073	0.322	-0.295

a - Immediate / *neposredno*; b - Maximum / *maksimalno*; * - Significant at 5 % level / *signifikantno na razini 5 %*



(a) (b)

Figure 4 The effect of altitude on relative creep at 65% (a) and 95% RH (b)
Slika 4. Utjecaj nadmorske visine staništa na relativno puzanje uzoraka drva graba kondicioniranih pri: a) 65 % RH i b) 95 % RH

3.5 Relative creep
3.5. Relativno puzanje

At 65 % RH during loading, the highest and lowest curves of relative creep at altitudes of 800 m and 400 m were observed (Fig. 4a). At 95 % RH until 480 minutes, the percentage of relative creep at each of the three altitudes showed small differences. From this time onwards, the maximum value of relative creep was observed at the altitude of 800 m, and the minimum value of relative creep was observed at the altitude of 1100 m (Fig. 4b).

Figure 5 shows the interactional effect of the three altitude classes at two levels of RH (65 % and 95 %) on relative creep. Results indicated that curves of relative creep at 95 % RH, related to each of the three altitudes, were higher than relative creep curves at 65 % RH.

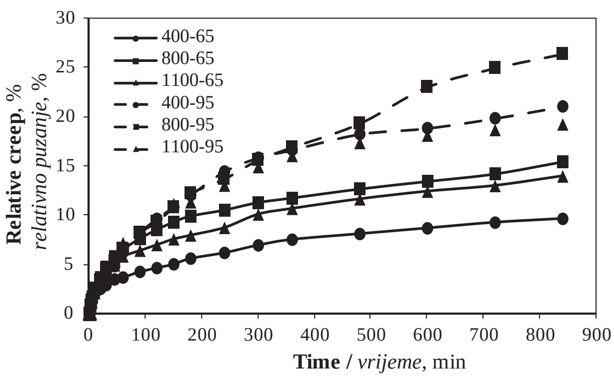


Figure 5 Interaction effects of altitudes and RH on relative creep in hornbeam wood
Slika 5. Interakcija utjecaja nadmorske visine staništa i relativne vlažnosti zraka pri kondicioniranju uzoraka na relativno puzanje drva graba

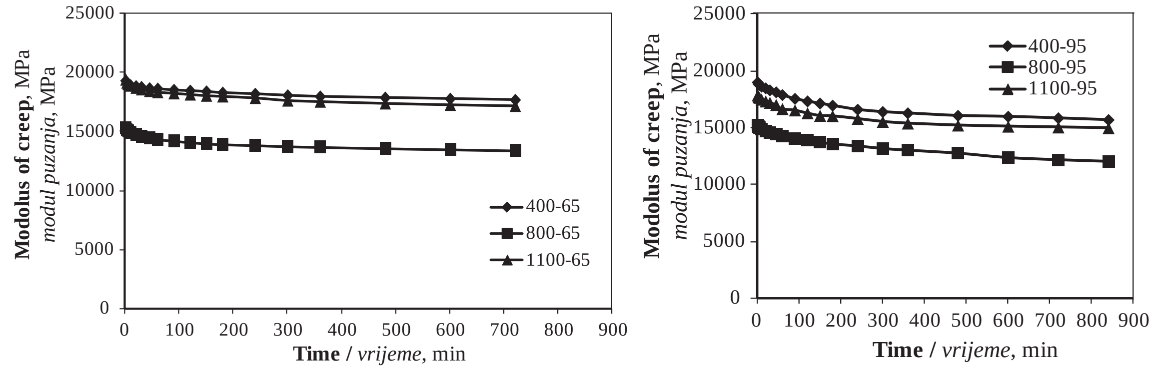
3.6 Creep modulus
3.6. Modul puzanja

At two levels of RH (65 % and 95 %) all the time, the highest and the lowest curves of creep modulus were observed at the altitude of 400 m and 800 m, respectively (Fig. 6a and b). Figure 7 shows the interaction effect of three altitude classes at RH of 65 % and 95% on relative creep. The curves of creep modulus obtained at 65 % RH were above the curves of this parameter at 95 % RH.

3.7 Creep factor
3.7. Faktor puzanja

At 65 % RH during loading, the highest and the lowest curves of creep factor were observed at the altitude of 800 m and 400 m, respectively (Fig. 8a). At 95 % RH, until 480 minutes, creep factor curves in each of the three altitude classes showed small differences between each other and from this time onwards, the highest and the lowest curves were observed at the altitude of 800 m and 1100 m, respectively (Fig. 8b).

Figure 9 shows the interactional effect of the three altitude classes and two levels of RH (65 % and 95 %) on creep factor. At 95 % RH, curves of creep factor were placed the same as relative creep for each of the three altitude levels, upper than at 65 % RH. At



(a) (b)

Figure 6 The effect of altitude on creep modulus at 65 % (a) and 95 % RH (b)

Slika 6. Utjecaj nadmorske visine staništa na modul puzanja uzoraka drva kondicioniranih pri: a) 65 % RH i b) 95 % RH

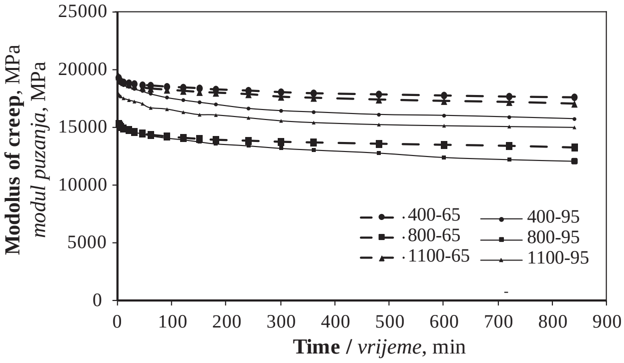


Figure 7 Interaction effects of altitudes and RH on creep modulus in hornbeam wood

Slika 7. Interakcija utjecaja nadmorske visine staništa i relativne vlažnosti zraka pri kondicioniranju uzoraka na modul puzanja drva graba

95 % RH, the highest curve was observed at the altitude of 800 m and at 65 % RH, the lowest curve was observed at the altitude of 400 m.

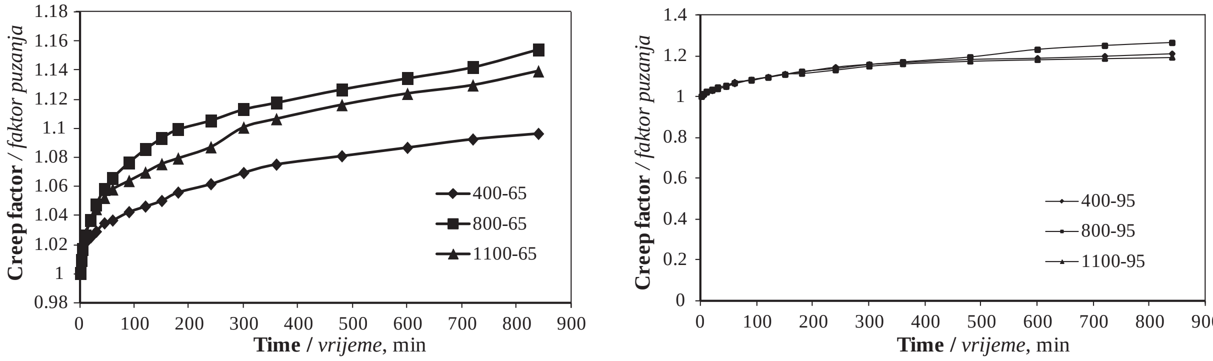
At two levels of RH (65 % and 95 %), the relative creep and creep factor increase at the altitude of 800 m, due to a lower value of MOE at this altitude, because there is an inverse relationship between immediate creep and maximum creep and MOE (Taniquichi and Ando 2010; Table 5). At the two levels of RH (65 % and 95 %), the lack of significance related to MOE at two altitudes, 400 m and 1100 m, (Fig. 1 and 2) caused a little change in the procedure of measuring the relative creep and creep factor, as the least relative creep was observed at the altitude of 400 m and creep factor at the altitude of 1100 m. There is, also, an inverse relationship between creep modulus and relative creep and creep factor, and for this reason maximum creep modulus was observed at the in altitude of 400 m for both levels of RH (65 % and 95 %). Relative creep and creep factor were higher at 95 % RH than at 65 % RH, which is compatible with the results of Van de kuilen research (1999).

Besides moisture, numerous factors affect the creep behavior of wood in the same way as load, microfibril angle (MFA) and temperature. Kojima and Yamamoto (2004) and Dong *et al.*, (2010) reported that the increasing of MFA causes the decreasing of mechanical resistances and increasing of creep in wood.

3.8 Fitting parabolic equations and curves to creep behavior of samples under study
3.8. Prilagođivanje parabolične jednadžbe i krivulje ponašanju analiziranih uzoraka pri puzanju

At the two levels of RH (65 % and 95 %), two samples of empirical behavior compatible with treatments at the altitude of 400 m have been shown (Fig. 10). Having the value of *a* and *m* by plotting the related graphs and based on equation 4, parabolic equations can be obtained for each sample.

Najafi and Kazemi Najafi (2009) reported that strain creep can be predicted for different times of loading and by parabolic equation. Calculated values



(a) (b)

Figure 8 Effect of altitude on creep factor at 65 % (a) and 95 % RH (b)

Slika 8. Utjecaj nadmorske visine staništa na modul puzanja uzoraka drva graba kondicioniranih pri: a) 65 % RH i b) 95 % RH

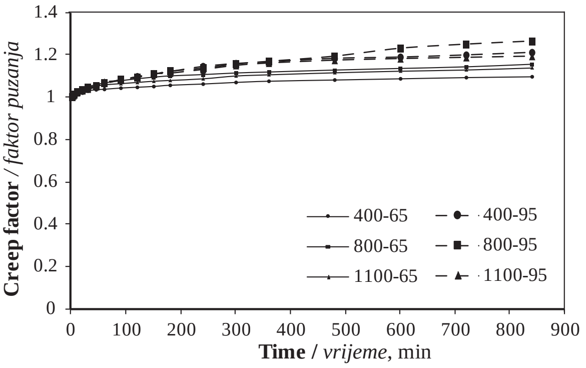


Figure 9 Interaction effects between altitudes and RH on creep factor in hornbeam wood
Slika 9. Interakcija utjecaja nadmorske visine staništa i relativne vlažnosti zraka pri kondicioniranju uzoraka na faktor puzanja drva graba

of *m*, *a* and parabolic equations of all treatments are shown in Table 6. Based on the results it can be concluded that creep behavior of studied samples follows the power law proposed by Findley *et al*. (1989).

4 CONCLUSION
4. ZAKLJUČAK

1. The maximum density and cell wall thickness were present in samples from the altitude of 400 m, the highest fiber length was detected at the altitude of 1100 m and the largest fiber diameter and lumen diameter were observed at the altitude of 800 m.

2. At 65 % and 95 % RH, the maximum and the minimum amounts of MOE and MOR were observed at the altitude of 400 m and 800 m, respectively.

3. At 65 % and 95 % RH, the maximum average immediate displacement, maximum displacement, permanent displacement and creep coefficient were observed at the altitude of 800 m. Also the range of return creep was higher at 95 % RH than at 65 % RH.

4. At 95 % RH, there was no relationship of fiber size, density and bending properties with immediate displacement and maximum displacement, while at 65 % RH, MOE showed a reverse and significant relationship with immediate creep and maximum creep. Also, a negative and significant relationship was observed between oven-dry density and maximum displacement.

5. At 65 % and 95 % RH, the maximum values of relative creep and creep factor were observed at the altitude of 800 m and the maximum and minimum creep modulus at the altitude of 400 m and 800 m, respectively.

6. The results of this research indicate that the use of hornbeam wood harvested at the altitude of 800 m is not recommended in applications under high bending forces, while wood harvested at altitudes of 400 and 1100 m is suitable.

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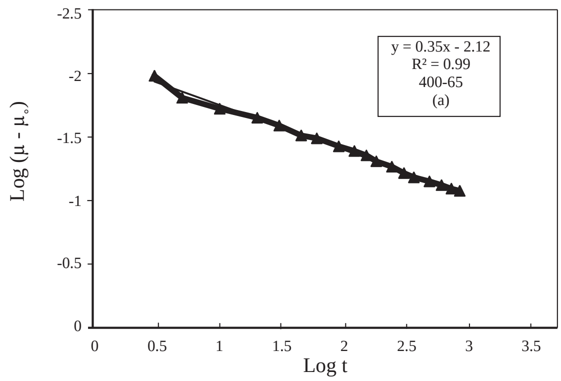
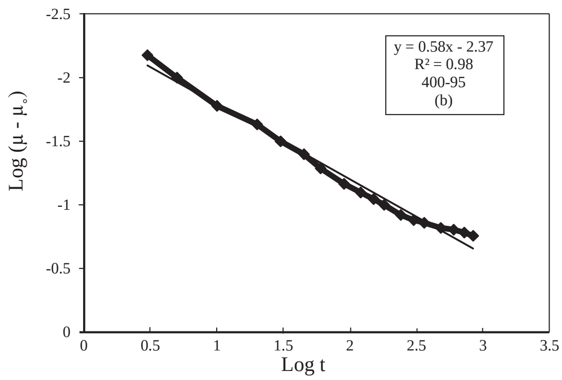
Table 6 Calculated values of *m* and *a* in parabolic equation
Tablica 6. Izračunane vrijednosti *m* i *a* u paraboličnoj jednadžbi

Altitude *Nadmorska visina* m	**RH** %	***m***	***a***	μ_0	$\mu_0 + at^m$	R^2
400	65	0.35	0.007	0.86	$0.86+0.007 \cdot t^{0.35}$	0.99
800		0.45	0.009	1.09	$1.09+0.009 \cdot t^{0.45}$	0.95
1100		0.38	0.009	0.86	$0.86+0.009 \cdot t^{0.38}$	0.98
400	95	0.58	0.004	0.83	$0.83+0.004 \cdot t^{0.58}$	0.98
800		0.59	0.005	1.03	$1.03+0.005 \cdot t^{0.59}$	0.99
1100		0.57	0.004	0.88	$0.88+0.004 \cdot t^{0.57}$	0.97



(a)



(b)

Figure 10 Creep behavior fitting plots for two samples at altitude of 400 m at 65 % (a) and 95 % RH (b)
Slika 10. Prikaz prilagođenih krivulja koje pokazuju puzanje drva za uzorke s nadmorske visine 400 m kondicionirane pri: a) 65 % RH, b) 95 % RH

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Employee Job Satisfaction in Furniture Manufacturing Companies in the Slovak Republic

Zadovoljstvo zaposlenika poslom u tvrtkama za proizvodnju namještaja u Republici Slovačkoj

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ABSTRACT • *The research was focused on the comprehensive understanding of motivation factors that affected empoyee job satisfaction in furniture manufacturing companies in the Slovak Republic in 2015. Questionnaire analysis was selected as the key research method. Questionnaires consisted of 36 most motivating factors organized into 5 sub-cathegories, analyzed on the basis of the degree of satisfaction for respondents. Based on the collected data, top 10 motivation factors, which the employees of Slovak furniture manufacturing companies rated as the most satisfying, were identified. According to respondents, 3 most satisfying factors included physical work demands, "interestingness" of work and the ability to use the qualification. Research outcomes resulted in a series of recommendations for the furniture manufacturing companies to focus on in order to boost employee job satisfaction with regards to the fact that only well-motivated employees can increase the efficiency of the whole enterprise.*

Key words: *motivation factors, employee job satisfaction, furniture manufacturing companies in the Slovak Republic (FM-companies), questionnaire, statistical analysis*

SAŽETAK • *Istraživanje je usmjereno na cjelovito razumijevanje motivacijskih čimbenika koji utječu na zadovoljstvo zaposlenika radom u tvrtkama za proizvodnju namještaja u Republici Slovačkoj u 2015. godini. Kao glavna metoda istraživanja odabrana je analiza putem upitnika. Upitnicima je obuhvaćeno 36 motivacijskih čimbenika organiziranih u pet potkategorija, koji su analizirani na osnovi stupnja zadovoljstva ispitanika. Na temelju prikupljenih podataka, identificirano je deset motivacijskih čimbenika koje su zaposlenici ocijenili zadovoljavajućima u slovačkim tvrtkama za proizvodnju namještaja. Prema mišljenju anketiranih, tri čimbenika koja većina ispitanika smatra zadovoljavajućim jesu fizički zahtjevi posla, „zanimljivosti" u radu i mogućnost da se zaposlenici koriste svojim kvalifikacijama. Ishodi istraživanja rezultirali su nizom preporuka za proizvođače namještaja kako bi se usredotočili na podizanje razine zadovoljstva zaposlenika poslom jer je poznata činjenica da samo dobro motivirani zaposlenici mogu povećati učinkovitost cijelog poduzeća.*

Ključne riječi: *motivacijski čimbenici, zadovoljstvo zaposlenika poslom, tvrtke za proizvodnju namještaja u Slovačkoj (FM poduzeća), upitnik, statističke analize*

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1 INTRODUCTION
1. UVOD

Business cannot be regarded as a closed and isolated system as the world financial crisis has influenced the whole entrepreneur society (Marková and Lesníková, 2015; Vetráková *et al.,* 2013). Turbulent changes influenced by the world business depression have created an absolutely new set of conditions for the operation of various entrepreneurs. To be able to react to the said changes and to ensure their continuous sustainable development, it is necessary to optimize their performance (Čambál and Cagáňová, 2010). Against the background of increasing local and global competitiveness, it is crucial for any organization to ensure that it consistently develops and retains a loyal, committed and able workforce. This presupposes employees who are satisfied with the work that they do and with the culture of the organization that they are employed by and who are consequently motivated to continue their relationship with that organization (Roos *et al.,* 2008). Hitka and Štípalová (2011) take a similar view according to which the existence of the enterprise, its prosperity and dynamic progress are primarily affected by the quality of human resources. Kucharčíková (2014) also considers human resources as significant production input for economies and companies. As performance of employees is significant for organizations, the management should consider improving the performance of workers in their companies by encouraging them to do their tasks and duties as efficiently and effectively as possible. Therefore, motivation in firms is absolutely important and necessary because it could change the behaviour of employees in positive ways. That is why many managers believe that when they establish motivated employees in the workplace, they can observe significant achievements in their organizations (Aarabi *et al.,* 2013).

Human resources management is one of the most important parts of the business. Success of the whole enterprise depends on human resources management (Vaníčková, 2015). One of the most important and at the same time the most difficult task of human resources management is motivation of employees (Hitka *et al.,* 2011). For better understanding the role of motivation, the meaning of motivation should be made clear. Motivation is a Latin word and it means "to move" (Wade & Tavris, 2008). Motivation can be defined in a number of ways. At a fairly straightforward level, it could be described as: "What makes us do what we do" (Bagshawe, 2011). Psychologists believe that motivation is the process that drives an individual towards achieving a goal. Moreover, motivation gives a person a purpose and the drive that he needs to achieve it. It helps people to push or pull from a bad situation, which are negative features in their lives (Aarabi *et al.,* 2013). Halepota (2005) defines motivation as "a person's active participation and commitment to achieve the prescribed results". Without motivation, employees cannot offer their best, meaning that they are less efficient in the company's performance. According to Antomioni (1999), the amount of effort people are willing to put in their work depends on the degree to which they feel their motivational needs will be satisfied. Greenberg and Baron (2003) define motivation as: "The set of processes that arouse, direct, and maintain human behavior towards attaining some goal". Motivation, in general, is more or less basically concerned with factors or events that move, lead, and drive certain human action or inaction over a given period of time under the prevailing conditions (Kachalla, 2014).

Thanks to globalization, the requirements on the quality of human resources are increasing (Kampf *et al.,* 2015). Nowadays, nobody doubts that success of every company on the global market depends, in a great extent, on how fast it can adjust to quick changes of the business environment. This is also one of the reasons why human capital is becoming a crucial and more valuable factor as technology, processes and organizational structure can be copied but the value that competent and dedicated employees can bring to companies cannot be easily taken away (Antošová, 2010; Ahmad *et al.,* 2012). Times, when the main role of a manager or supervisor in the workplace was to assign tasks to employees, are over. Employees want to be familiar with the business process and not only to be paid. To provide higher productivity, they are expected to work with responsibility and to contribute to successful achievement of the company goals (Hitka *et al.,* 2015). For traditional approaches of business performance measurement, the most important objective is the maximization of profit but prosperous enterprises realize that the most profitable capital of the enterprise is its employees and their motivation, through which an enterprise can successfully meet its objectives (Potkány *et al.,* 2014). Moynihan and Pandey (2007) have pointed out that the organizational effectiveness depends on how organizations manage their employees. Motivated employees are needed to ensure the operational health of each organization. This is because motivated employees help businesses to succeed, as they are more productive (Alnıaçık *et al.,* 2012). Hence, motivated employees can contribute to making an organization more valuable and profitable (McKenzie-Mohr & Schultz, 2014). To be effective, managers need to understand what motivates employees within the context of the roles they perform (Noor *et al.,* 2016). Of all the functions a manager performs, motivating employees is arguably the most complex. This is partly due to the fact that what motivates employees changes constantly (Bowen & Radhakrishna, 1991). For example, when an employee's income increases, money becomes less of a motivator (Kovach, 1987). Therefore, it is crucial to understand the factors that may cause the changes in employee motivation. Anitha (2014) identified six factors increasing employee´s motivation such as working environment, management, training and professional development, wages, working place, team work and relationship to co-workers. Imhof, however, as early as in 2003, suggested and analyzed a wider spectrum of motivation factors than Anitha (2014). Imhof´s factors included: healthy working conditions, career opportunity, supportive boss, unambiguous and definite goals, competitive compensation, stable place of work, interesting job, high prestige, good performance evaluation, pleasant working atmosphere, peaceful private life, competent leadership, appreciation, participation in decision-making and fringe benefits. Nevertheless, there are many more factors that influece employee motivation. Therefore, we have extended the overall scope of motivation factors to 36 (Table 1) and these were further divided into five sub-cathegories related to the nature of work, physical conditions of work, economic conditions of work, technical and logistic conditions of work, interpersonal relationships at workplace. The aim of the research was focused on the comprehensive understanding of motivation factors that affected empoyee job satisfaction in furniture manufacturing companies in the Slovak Republic in 2015.

All organizations aim to have workers who will become key employees that the organization will retain over the long term. Therefore, the motivation factors and values that affect the quality of a worker‘s performance must be systematically explored because if a manager does not find the right way to motivate staff, workplace absenteeism and fluctuation will rise and taking breaks in an inappropriate way (surfing the Internet, private phone calls), interruption, intrigues, conflicts, dissatisfaction with management will be more obvious (Urbancová *et al.*, 2015). At the same time interest in work, quality and productivity at work, willingness to become responsible, level of submitting proposals, concentration at work, personal participation of an employee and punctuality are declining (Forsyth, 2003). Early research has reported that unsatisfied employees show lower job performance and leave their jobs more often than satisfied employees (Judge *et al.*, 2001; Hellman, 1997).

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

In order to acquire empirical data, a questionnaire method, with regards to multiple benefits, has been selected as the key research method. Among other positives, questionnaires enable collecting of respondents‘ opinions and attitudes in a short period of time and the follow-up bulk data processing. Additonal relevant information about the respondents (such as age, education and other identification data) can also be collected. Anonymous questionnaires further enhance opennes and sincerity of respondents. Finally, in comparison with a personal debate, questionnaires are less stressful and responses are less affected by the atmosphere and the place. The main part of the questionnaires included closed type questions focused on the level of motivation analyzed through motivation factors in the particular company measured by the level of satisfaction for respondents. Motivation factors were further cathegorized into 5 sub-cathegories according to Table 1.

The total number of 36 motivation factors has been analyzed by the extrapolation method. Respondents were asked to match each motivation factor with 5-point rating scale of satisfaction indexes, 1 = minimum and 5 = maximum (Table 2).

Table 1 Analyzed motivation factors
Tablica 1. Analizirani čimbenici motivacije

The nature of work 1. “Interestingness” of work 2. Variability of work 3. Independence at work 4. Usefulness of one’s qualification 5. Physical work demands 6. Education and personal growth 7. Work content	**Technical and logistic conditions of work** 21. Technical equipment of the workplace 22. Working hours 23. Flow of work 24. Organization of work 25. Work distribution
Physical conditions of work 8. Overall workplace equipment 9. Space 10. Work environment 11. Work safety 12. Anti-dust precautions **Economic conditions of work** 13. Job security 14. Salary 15. Financial benefits and rewards 16. Social services 17. Company reputation 18. Promotion potential 19. Company’s ecological policy 20. Extra-work activities	**Interpersonal relationships at workplace** 26. Working team 27. Workplace atmosphere 28. The manner of decision-making 29. Employer-employee relationship 30. Criticisism by superiors 31. Recognition of one’s performance by superiors 32. The manner of work distribution 33. Information about current affairs in the company 34. Information about work distribution 35. Just system of rewarding 36. Opportunity to express one’s opinion

Table 2 5-point rating scale: the degree of satisfaction
Tablica 2. Rangiranje motivacijskih čimbenika u pet razina: stupnjevi važnosti i zadovoljstva

	1	2	3	4	5
The degree of satisfaction *Stupanj zadovoljstva*	Very dissatisfied *Vrlo nezadovoljan*	Dissatisfied *Nezadovoljan*	Quite satisfied *Relativno zadovoljan*	Satisfied *Zadovoljan*	Very satisfied *Vrlo zadovoljan*

Pre-research and questionnaire pilot-testing to minimize inadequacities was conducted in 3 companies. After innitial error elimination, questionnaires were distributed in FM-companies, specifically, in companies focused on complex furniture manufacturing and shipping and on custom-based interiors. However, according to the Slovak Bureau of Statistics, there were as many as 76 furniture companies registered in Slovakia in 2013 with 9,594 average numbers of registered employees and, therefore, the whole sampling unit could not be analyzed. Generally, the larger the sampling unit is, the more accurate and confident results will be acquired; proportionally, however, expenses and efforts rise. Therefore, it was essential to strike balance between the sampling unit size and desired accuracy, confidence and effectiveness of survey. In order to calculate the minimum sampling unit size (n) the mathematical relation has been used, where n is the function of desired confidence and accuracy at certain estimated variability of analyzed phenomena in the sampling unit. Given the 95 % confidence secured by the tabular value $z_{0.025}$ = 1.96, desired accuracy Δx = 0.05 and average variability of responses according to the satisfacion scale of various motivation factors, given by variance of $\sigma_x^2 = 0.3$, a minimum number of respondents has been set as follows:

$$n = \frac{1.96^2 \cdot 0.3}{0.05^2} = 461 \text{ respondents} \quad (1)$$

The minimum sampling unit size has been set at pre-defined 0.05 accuracy and 95 % confidence criteria. 461 returned questionnaires were thus the necessary minimum to meet the pre-defined accuracy and confidence requirements. In order to collect the necessary set of questionnaries and well aware of the low turnover of e-questionnaires, three times more questionnaires (1,500) were distributed between June 2015 and October 2015. In October 2015, 522 valid questionnaires (sampling unit size of this research) were correctly completed and returned. The overall questionnaire response rate was thus 34.80 %, which meets the minimum sampling unit size criterion.

Structure of sampling unit: 20.69 % women and 79.31 % men participated in the research; a majority of them were manual workers (75.86 %), only 24.14 % were managers. A majority of respondents were 31 – 40 years old (48.28 %). The same percentage, 48.28 % of respondents, had lower secondary education (without a school leaving exam/certificate). 58.62 % respondents have been working in the company for 6 – 8 years. No respondents younger than 20 years and older than 50 years, and no respondents with only primary education or those who have been working for the company for more than 10 years participated in the research.

Table 3 Variance – decomposition into individual items
Tablica 3. Raspadanje komponenata disperzije

Variance *Varijan-ca*	**Sum of square deviations** *Zbroj kvadrata odstupanja*	**Degree of freeom** *Stupanj slobode*	**Variance** *Varijanca*
Inter-group	$s_M = n\sum_{j=1}^{k}(\bar{x}_j - \bar{x})^2$	$\nu_M = k-1$	$s_M^2 = \frac{s_M}{\nu_M}$
Residual (intra-group)	$s_R = \sum_{j=1}^{k}\sum_{i=1}^{n}(x_{ji} - \bar{x}_j)^2$	$\nu_R = k(n-1)$	$s_R^2 = \frac{s_R}{\nu_R}$
Total	$s_C = \sum_{j=1}^{k}\sum_{i=1}^{n}(x_{ji} - \bar{x})^2$	$\nu = k\cdot n\text{-}1$	$s_C^2 = \frac{s_C}{\nu}$

Survey results were processed by mathematical--statistical methods, using the statistical software program STATISTICA 12. Except for the descriptive statistics, inductive statistics method such as specific interval estimates and one-way analysis of variance which, based on testing of hypotheses, enabled generalizing of results, were used to process the data. (Note: in spite of the term "variance analysis", what we really mean is the test of equality of k averages). The null hypothesis H_0: $\mu_1 = \mu_2 = \ldots = \mu_k$, was tested and compared with an alternative hypothesis H_1. In the context of the overall research, H_0 was tested: average results of satisfaction in 10 observed motivation factors are the same when compared with H_1: at least two motivation factors differ in average satisfaction values. By this, the fact can be confirmed that FM-employees view these factors differently in terms of their job satisfaction. The key of research thus lies in the analysis of variance into its individual items.

Testing criterium $F_0 = \frac{s_M^2}{s_R^2}$ is F-devided with ν_M, ν_R degrees of freedom. If $F_0 > F_\alpha(\nu_M, \nu_R)$, then H_0: $\mu_1 = \mu_2 = \ldots = \mu_k$ is rejected in favor of H_1, which means that there are statistically significant differences between k averages. "Post hoc" tests (Duncan test) were used to provide a more detailed evaluation and to identify the groups with significantly different averages. The aim of this testing was to prove which pairs of motivation factors differ in average satisfaction values and which are similar or the same. Duncan's multiple-range test is based on the comparison of the range of a subset of the sample means with a calculated least significant range. If the range of the subset exceeds the least significant range, then the population means can be considered significantly different. It is a sequential test and so the subset with the largest range is compared first, followed by smaller subsets. Once a range is found not to be significant, no further subsets of this group are tested. The least significant range, Rp, for subsets of p sample means is given by:

$$R_p = r_p\sqrt{\frac{s^2}{n}} \quad (2)$$

where r_p is called the least significant studentized range and depends upon the error degrees of freedom and the numbers of means in the subset, n is the sample size, and s^2 is the error mean square from the analysis of variance table (Bewick *et al.*, 2004).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The first part of the questionnaire gathered data on the degree of motivation according to employee job

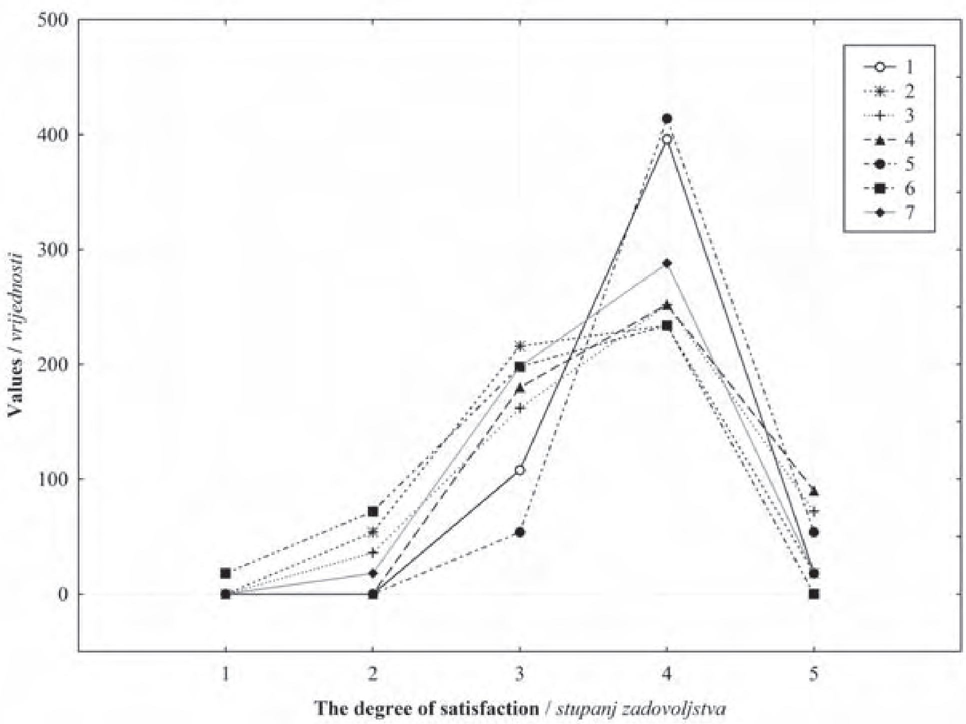


Figure 1 Absolute multiplicity of respondents evaluating motivation factors related to the criteria of nature of work
Slika 1. Apsolutna raznovrsnost ispitanika pri vrednovanju motivacijskih čimbenika koji se odnose na kriterije prirode posla

satisfaction. Respondents responded to the spectrum of motivation factors, ordered according to the degree of their satisfaction. Following figures represent absolute multiplicity of respondents evaluating motivation factors organized into 5 sub-cathegories based on Table 1. Figures match 5-point rating scale where satisfaction indexes represent 1 = very dissatisfied, 2 = dissatisfied, 3 = quite satisfied, 4 = satisfied and 5 = very satisfied (Table 2).

Based on the gathered data, in the area of nature of work, the following conclusion can be drawn: 79.31 % of respondents were "satisfied" with their physical work demands and 75.86 % were "satisfied" with the "interestingness" of work. As many as 41.38 % of em-

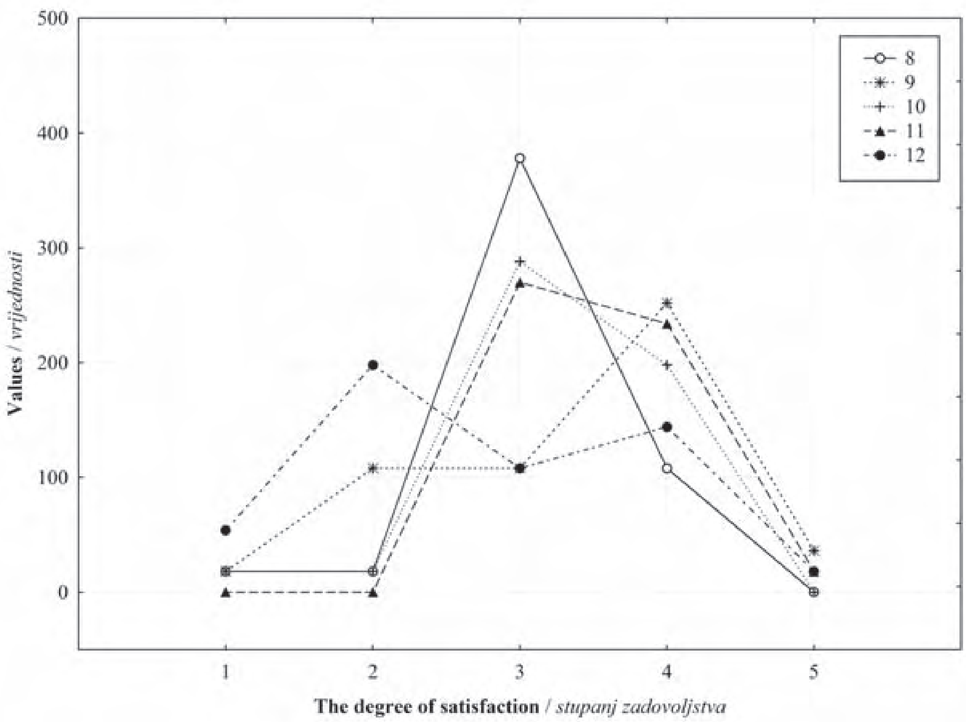


Figure 2 Absolute multiplicity of respondents evaluating motivation factors related to the criteria of physical conditions of work
Slika 2. Apsolutna raznovrsnost ispitanika pri vrednovanju motivacijskih čimbenika koji se odnose na kriterije fizičkih uvjeta rada

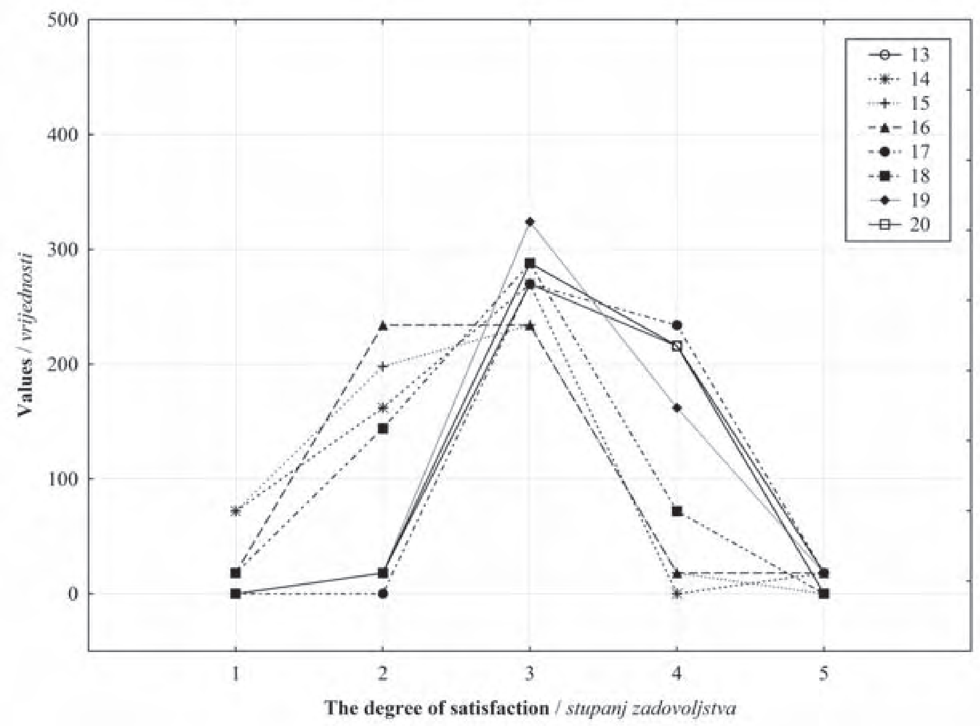


Figure 3 Absolute multiplicity of respondents evaluating motivation factors related to the criteria of economic conditions of work
Slika 3. Apsolutna raznovrsnost ispitanika pri vrednovanju motivacijskih čimbenika koji se odnose na kriterije ekonomskih uvjeta rada
Source: autors

ployees were "quite satisfied" with the varibility of work. In the field of education and personal growth, 13.79 % of respondents were "dissatisfied" and 3.35 % were "very dissatisfied" with the educational and personal growth potential in their company.

In the field of physical conditions of work, very low number of repondents rated the analyzed factors as "very satisfactory". Only 6.90 % of respondents were "very satisfied" with work safety and only 3.45 % with anti-dust precutions. Many respondents rated most criteria with lower ratings, mostly as "quite satisfying". For example, as many as 72.41 % were "quite satisfied" with the workplace equipment, 55.17 % with their workplace equipment and 51.72 % with work safety. Respondents were seriously dissatisfied with anti-dust precautions – 37.93 % of respondents were "dissatisfied" and 10.34 % were "very dissatisfied".

3.35 % of employees expressed their maximum satisfaction with job security, salary, company's reputation and their company's ecological policy. Salary proved to be one of the most crucial motivation factors. Ony 3.35 % of respondents were "very satisfied", 31.03 % were "dissatisfied" and 13.79 % were "very dissatisfied". What needs to be taken into consideration is the fact that as many as 62.07 % of respondents considered salaries to be "the most important factor".

As long as the organization of work is concerned, respondents rated work organization (10.34 %) and the flow of work (6.90 %) as "very satisfactory". 62.07 % of respondents were "quite satisfied" with the technical equipment of their workplace and 55.17 % with work distribution.

Only 3.45 % of respondents were "very satisfied" with interpersonal relationships at their workplaces, including their working team, workplace atmosphere, employer-employee relationships, superior's recognition and with the opportunity to express one's opinion. Interpersonal relationships and related factors were generally rated very low, especially those considering superior's recognition (24.14 %), criticizing by superior and just rewarding system (both factors acquired 20.69 %). These factors proved to be most sensitively perceived by the employees.

Table 4 presents motivation factors, ordered by satisfaction, as rated by respondents. 10 bold-marked motivation factors acquired the highest values of selected averages. Except for selected averages and standard deviations, Table 4 presents 95 % confidence intervals for sampling unit averages. Based on the results, generalizations can be made. For example, when considering the motivation factor "salary", the respondents will evaluate this motivation factor by average value of 2.41 – 2.56 with 95 % confindence.

Based on collected data, the research outcomes can now be generalized and further assumptions made. The research has proved that employees were generally satisfied with physical work demands. Based on the statistical data analysis, it can be assumed, with a 95% confidence, when FM-company employees would rate the factor "physical work demands" by an interval rating from 3.96 to 4.04 in a similar survey. The second and third place among most satisfying motivation factors are "interestedness" of work and usefulness of

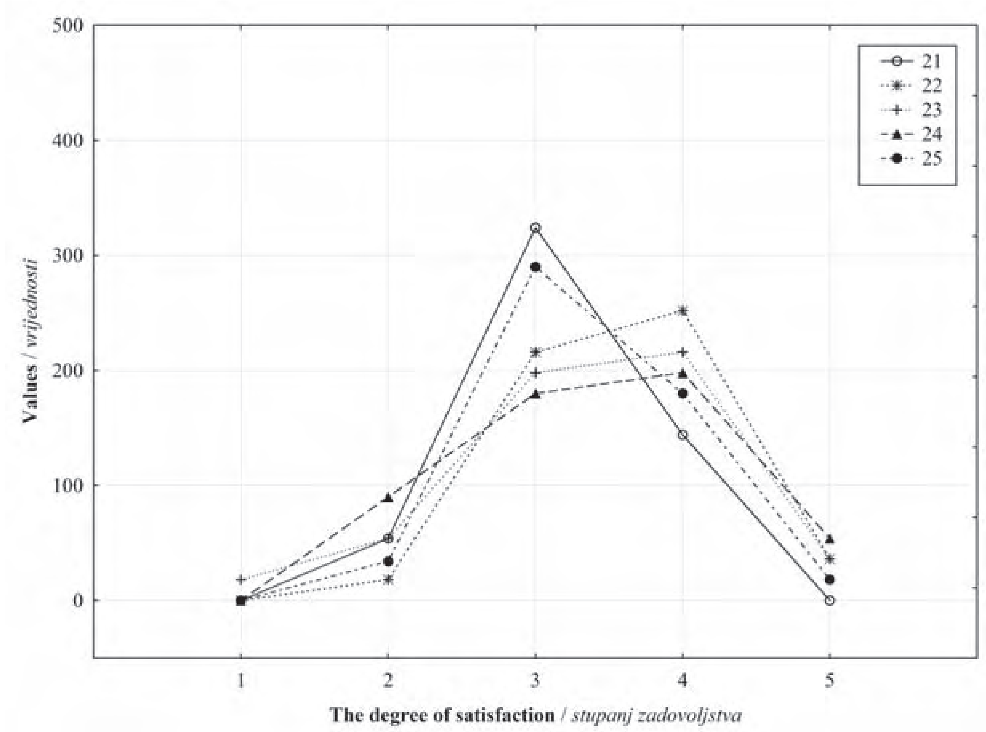


Figure 4 Absolute multiplicity of respondents evaluating motivation factors related to the criteria of technical and logistics conditions of work
Slika 4. Apsolutna raznovrsnost ispitanika pri vrednovanju motivacijskih čimbenika koji se odnose na kriterije tehničkih i logističkih uvjeta rada

one's qualification. Independence and the content of work were also among top 5 most satisfying factors.

Top 10 motivation factors that proved to be most satisfying were subject to a more detailed analysis based on Table 5.

By one-way analysis of variance with a = 5 %, it has been verified that average values of importace of 10 motivation factors are statistically significantly different (p = 0.000). Based on the follow-up post-hoc tests (Duncan test a = 5%), signifiant differences have

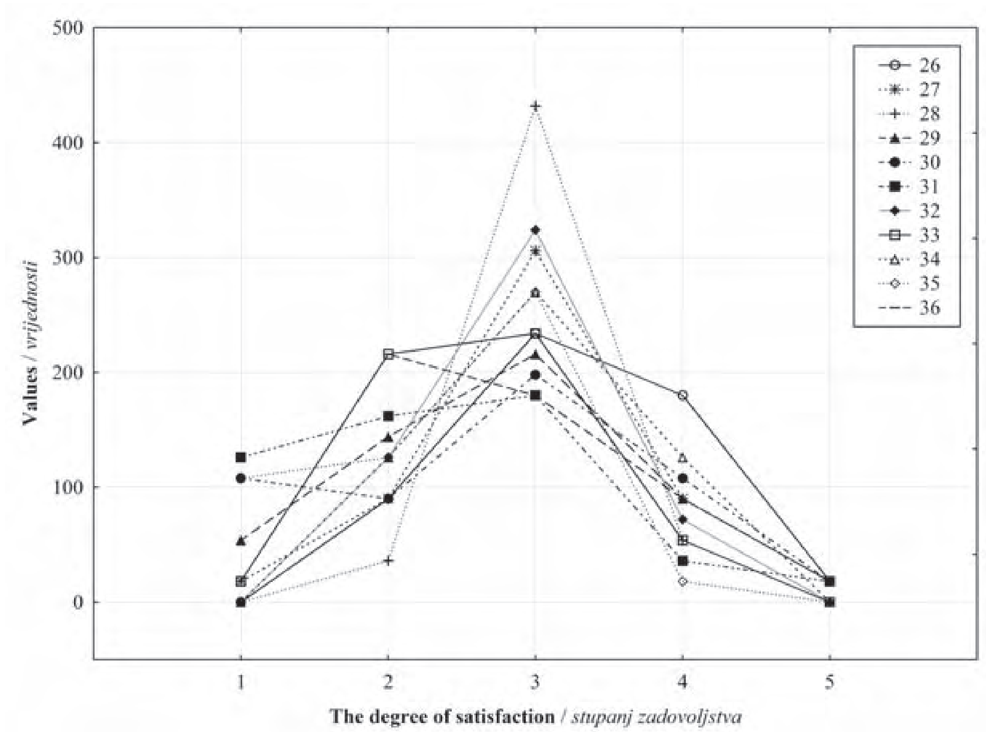


Figure 5 Absolute multiplicity of respondents evaluating motivation factors related to the criteria of interpersonal relationships at workplace
Slika 5. Apsolutna raznovrsnost ispitanika pri vrednovanju motivacijskih čimbenika koji se odnose na kriterije međuljudskih odnosa na radnome mjestu

Table 4 Motivation factors, ordered according to the criterion: the degree of satisfaction
Tablica 4. Motivacijski čimbenici, redoslijed prema kriteriju ***stupanj zadovoljstva***

Motivation factor *Motivacijski čimbenik*	**Average** *Prosječno*	**Standard deviation** *Standardno odstupanje*	**Confidence interval 95 %** *Interval pouzdanosti 95 %*	
			Low limit *Donja granica*	**Top limit** *Gornja granica*
Physical work demands / *zahtjevi za fizičkim radom*	**4.00**	**0.45**	**3.96**	**4.04**
"Interestingness" of work *„zanimljivosti" posla*	**3.83**	**0.46**	**3.79**	**3.87**
Usefulness of one's qualification / *korisnost nečije kvalifikacije*	**3.82**	**0.70**	**3.77**	**3.89**
Work independence / *neovisnost u poslu*	**3.69**	**0.79**	**3.62**	**3.76**
Content of work / *sadržaj rada*	**3.59**	**0.62**	**3.53**	**3.64**
Working hours / *radni sati*	**3.58**	**0.67**	**3.53**	**3.64**
Work safety / *zaštita na radu*	**3.52**	**0.57**	**3.47**	**3.57**
Company's reputation / *ugled tvrtke*	**3.51**	**0.56**	**3.46**	**3.56**
Job security / *sigurnost radnog mjesta*	**3.45**	**0.62**	**3.40**	**3.50**
Variability of work / *varijabilnost rada*	**3.41**	**0.72**	**3.35**	**3.48**
Work organization / *organizacija rada*	3.41	0.89	3.34	3.49
Extra-work activities / *ekstra radne aktivnosti*	3.38	0.55	3.33	3.43
Flow of work / *protok posla*	3.37	0.89	3.30	3.46
Work distribution / *raspodjela posla*	3.36	0.65	3.29	3.41
Company's ecological policy / *ekološka politika tvrtke*	3.35	0.60	3.29	3.40
Space / *prostor*	3.34	0.99	3.26	3.43
Work environment / *radno okružje*	3.28	0.69	3.22	3.34
Working team / *radni tim*	3.25	0.77	3.18	3.31
Education and personal growth / *obrazovanje i osobni razvoj*	3.24	0.82	3.17	3.31
Workplace technical equipment / *tehnička oprema na radnome mjestu*	3.17	0.59	3.12	3.22
Workplace equipment / *radna oprema*	3.10	0.61	3.05	3.16
The manner of decision-making / *način odlučivanja*	3.03	0.41	3.00	3.07
Workplace atmosphere / *atmosfera na radnome mjestu*	3.00	0.79	2.93	3.07
Information about work distribution / *informacije o raspodjeli posla*	2.99	0.70	2.94	3.06
The manner of work assignaments / *način dodjele radnih zadataka*	2.90	0.61	2.84	2.95
Promotion potential / *promotivni potencijal*	2.79	0.71	2.73	2.86
Anti-dust precautions / *mjere zaštite od prašine*	2.77	1.07	2.67	2.85
Employer-employee relationship / *odnos poslodavca i zaposlenika*	2.76	0.97	2.68	2.84
Opportunity to express one's opinion / *mogućnosti izražavanja osobnog mišljenja*	2.75	0.90	2.67	2.83
Criticism of superiors / *kritičnost nadređenih*	2.69	1.12	2.59	2.79
Information about company current affairs / *informacije o trenutačnim aktivnostima tvrtke*	2.62	0.72	2.56	2.68
Social services / *socijalne usluge*	2.59	0.77	2.52	2.65
Salary / *plaća*	2.48	0.86	2.41	2.56
Financial benefits and rewards / *financijske prednosti i nagrade*	2.38	0.76	2.31	2.45
Just rewarding system / *pravedan sustav nagrađivanja*	2.37	0.85	2.31	2.44
Superior's recognition / *priznanje nadređenih*	2.35	1.03	2.26	2.43

also been identified in the rating of importance among motivation factors in individual pairs. In Table 5, under the diagonal line, *p*-level pairs of motivation factors with statistically significant differences in the degree of satisfaction are highlighted. It has been observed that pairs of motivation factors with $p < 0.05$ significantly differ in average satisfaction results, which means that Slovak employees working in furniture company rate these factors differently in terms of their satisfaction.

Top 10 motivation factors that proved to be the most satisfying for FM-company employees can be furhter devided into 5 sub-cathegories according to the degree of satisfaction, which, however, significantly differ. Intra-group motivation factors were, according to the employee satisfaction criterion, rated as equally satisfying.

The first group with the highest degree of satisfaction is represented by the physical work demands factor. "Interestingness" of work and usefulness of one's qualification represent the second group of motivation factors. The third group is only represented by a single factor, work independence. The fourth group includes 4 factors: the content of work, working hours, work safety and company's reputation. The last, fifth

Table 5 Results of tested pairs of motivating factors, ordered according to the criterion: the degree of satisfaction
Tablica 5. Rezultati ispitivanih parova motivirajućih čimbenika: redoslijed prema kriteriju stupanj zadovoljstva

Duncan's test, Marked differences are statistically significant at p < .05000 level *Duncanov tes, označene su razlike statistički značajne uz p <.05000*											
		{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}	{10}
		M=4.000	M=3.828	M=3.828	M=3.690	M=3.586	M=3.586	M=3.517	M=3.517	M=3.448	M=3.414
Physical work demands *zahtjevi za fizičkim radom*	{1}		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
"Interesting-ness" of work *„zanimljivosti" posla*	{2}	**0.000**		1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Usefulness of one's qualification / *korisnost zaposlenikove kvalifikacije*	{3}	**0.000**	1.000		0.001	0.000	0.000	0.000	0.000	0.000	0.000
Work independence *neovisnost u poslu*	{4}	**0.000**	**0.000**	0.001		0.008	0.010	0.000	0.000	0.000	0.000
Content of work *sadržaj rada*	{5}	**0.000**	**0.000**	**0.000**	0.008		1.000	0.092	0.105	0.001	0.000
Working hours *radni sati*	{6}	**0.000**	**0.000**	**0.000**	0.010	1.000		0.075	0.092	0.001	0.000
Work safety *zaštita na radu*	{7}	**0.000**	**0.000**	**0.000**	0.000	0.092	0.075		1.000	0.092	0.013
Company's reputation *ugled tvrtke*	{8}	**0.000**	**0.000**	**0.000**	**0.000**	0.105	0.092	1.000		0.075	0.010
Job security *sigurnost radnog mjesta*	{9}	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	**0.001**	0.092	0.075		0.373
Variability of work *varijabilnost rada*	{10}	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.013**	**0.010**	0.373	

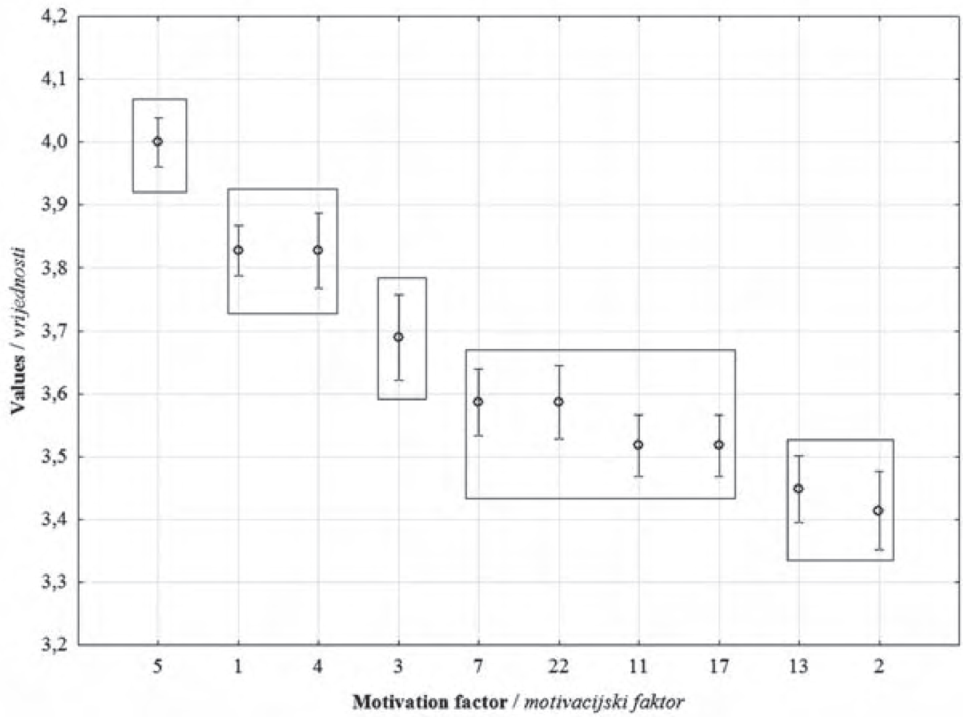
group comprises factors such as job security and variability of work.

Research outcomes proved that FM-company employees were generally satisfied with factors belonging to the the nature of work area. Employees were generally satisfied with physical work demands, given the fact that the work is not physically overly demanding or bound to an assembly line. Each employee was independent in his/her job performance and could set his or her own pace of work. Moreover, many types of work could be done in a comfortable sitting position. As far as the content of work in the field of furniture maufacturing was concerned, the work was not monotonous in any way. The assignments varied and were manifold and interesting, as each product was slightly different or custom-made according to cutomer's needs. Employees were also satisfied with work safety as furniture manufactures pay extra attention to work safety and invariably maintain strict safety regulations.

Finally, FM-company employees were also satisfied with their job security. Their employers often run joint ventures with bigger international enterprises such as IKEA Bratislava s.r.o. and Idea NÁBYTOK Nitra, which usually provide a grounded certainty of long-term working contracts.

4 CONCLUSION
4. ZAKLJUČAK

Each enterprise participating in the market economy is well aware of the fact that in order to survive and compete, they have to acquire better results than their competition. That, however, is impossible without productive, loyal and most importantly well-motivated employees. Managers who know what their employees want from work can design a work environment that promotes excellent service by meeting employees´ needs and desires. At the same time, informed managers can avoid common pitfalls that reduce employee motivation (Simons and Enz, 1995). Therefore, each company that aims at improvement of work attitudes and work habits of its employees should pay special attention to employee motivation. The need for a better motivation also inspired the present research that fo-



Explanation
Objašnjenje:
5 - Physical work demands / *zahtjevi za fizičkim radom*
1 - "Interestingness" of work / *„zanimljivosti" posla*
4 - Usefulness of one's qualification / *korisnost zaposlenikove kvalifikacije*
3 - Work independence *neovisnost u radu*
7 - Content of work *sadržaj rada*
22 – Working hours *radni sati*
11 - Work safety *zaštita na radu*
17 - Company's reputation / *ugled tvrtke*
13 - Job security *sigurnost radnog mjesta*
2 - Variability of work *varijabilnost rada*

Figure 6 Representative averages and 95 % confidence intervals of top 10 motivation factors with the highest values according to the criterion: the degree of satifaction
Slika 6. Reprezentativni prosjeci i 95 %-tni intervali pouzdanosti deset motivacijskih čimbenika s najvišim vrijednostima prema kriteriju stupanj zadovoljstva

cused on the analysis of those motivation factors that most significantly affect employee job satisfaction in furniture manufacturing companies operating in Slovakia in 2015. In order to gather the most precise data, a questionnaire (focused on the degree of satisfation of various motivation factors, as viewed by employees) has been generated. The degree of motivation was rated on the basis of 36 motivation factors (further organized into 5 sub-cathegories according to their relations to the nature and physical conditions of work, economic conditions of work, logistics and technical conditons of work and interpersonal relationships at workplace). Out of 1,500 respondents, 522 valid questionnaires were collected. Questionnaire responses were bulk-data processed by mathematical and statistical methods, using satistical software program STATISTICA 12, descriptive statistics and inductive statistical methods, including interval estimates and one-way analysis of variance.

Some research revealed that motivation contains factors that motivate and direct one's behaviour (Daft *et al.*, 2000). It has shown that human activities are motivated by one or many known and sometimes unknown complex factors (Možina, 2002). There are individual factors that influence human acitivities, and they are very often part of the human social life (Faletar *et al.*, 2015). According to Závadský *et al.* (2015), the most commonly used tools of motivation are various incentives, extra holidays, corporate entertaining and rewards. In our research, motivation factors were ordered according to criteria: the degree of satisfaction. Top 10 motivation factors, rated by the employees of Slovak furniture manufacturing companies as the most satisfying, were identified. On the basis of collected data, it can be concluded that 3 most satifying motivations factors for FM-companies in Slovakia in 2015 included physical work demands, "interestingness" of work and usefulness of one's qualification. Supporting our conclusions with the research outcomes, we would like to recommend to the Slovak funiture manufacturing companies to pay special attention to the aforementioned 3 most satisfying motivation factors as these factors significantly affect motivation as well as the overall job performance of employees. Many renowned scholars (Grladinović *et al.*, 2007) agree that motivating the employees is of key importance to increase their efficiency and quality of work. Kampf *et al.* (2014) point out that the enterprise management should pay dequate attention to motivation programs. Similar positive effects will undoubtedly result not only in enhancement of the overall employee job satisfaction but also in more effective and efficient use of employee work potential, which will eventually lead to more prosperous enterprises. Additional research should be done to gain a continuous view of what motivates people to do their work best. The ability to motivate subordinates is critical to every manager´s job. Demographic changes in the workplace, as well as technological advances and globalization, only accentuate the need to continue to determine what motivates people to perform well (Wiley, 1997). A motivated workforce can make powerful contributions to the profits of a firm.

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Hydrophilic Extractives in Heartwood of European Larch (*Larix decidua* Mill.)

Hidrofilni ekstraktivi u srži europskog ariša (*Larix decidua* Mill.)

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ABSTRACT • *The heartwood of two European larch trees was examined for the content of hydrophilic extractives. Ethanol was used as a solvent for extractions of adequately pretreated samples, while gas chromatography with flame ionisation detection (GC-FID), gas chromatography coupled to mass spectrometry (GC-MS) and high performance size exclusion chromatography (HPLC-SEC) were applied for analyses. Different phenolic compounds, such as flavonoids and lignans were identified and quantitatively evaluated. The most abundant flavonoids were taxifolin and dihydrokaempferol, while the main lignan was secoisolariciresinol. Contents of flavonoids and lignans, measured at different stem heights, varied between 10.6 and 15.7 mg/g. At lower and medium heights flavonoids prevailed, while at upper stem positions the concentrations of lignans significantly increased. In addition, some trimeric and tetrameric phenolic structures were also detected. There was very little variation in the composition of hydrophilics between the two examined trees. The identified flavonoids and lignans are classified as very strong antioxidants.*

Key words: *European larch, heartwood, hydophilic extractives, flavonoids, lignans, chromatographic techniques*

SAŽETAK • *U radu su prikazani rezultati istraživanja hidrofilnih ekstraktivnih tvari u srži dvaju stabala europskog ariša. Kao otapalo za ekstrakciju prethodno adekvatno obrađenih uzoraka upotrijebljen je etanol, a za kemijske analize primijenjene su plinska kromatografija s plameno-ionizacijskim detektorom (GC-FID), plinska kromatografija povezana s masenom spektrometrijom (GC-MS) i tekućinska kromatografija visoke djelotvornosti (HPLC-SEC). U uzorcima su identificirani i kvantitativno procijenjeni različiti fenolni spojevi kao što su flavonoidi i lignani. Taksifolin i dihidrokamferol najzastupljeniji su flavonoidi, a glavni je lignan sekoizolaricirezinol. Cjelokupne koncentracije flavonoida i lignana koje su određivane u srži na različitim visinama stabla variraju između 10,6 i 15,7 mg/g. Na niskim i srednjim visinama prevladavaju flavonoidi, a na visinama bližima vrhu stabla zabilježen je značajan porast koncentracije lignana. Također, u ekstraktima su identificirani trimerni i tetramerni fenolni spojevi. Varijacije u sastavu hidrofilnih ekstraktiva između oba stabla bile su vrlo malene. Identificirani flavonoidi i lignani poznati su kao vrlo jaki antioksidansi.*

Ključne riječi: *europski ariš, srž, hidrofilni ekstraktivi, flavonoidi, lignani, kromatografske tehnike*

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1 INTRODUCTION
1. UVOD

Hydrophilic extractives are nonstructural wood components, which are readily soluble in polar solvents, such as acetone, methanol, ethanol and water. In contrast to lipophilic compounds in resin canals and parenchyma cells of sapwood (Zule *et al.*, 2015), they mainly originate from the transition zone between heartwood and sapwood. Their concentrations are the highest at the boundary, after which they gradually decrease in radial direction towards the pith. Hydrophilics are mostly composed of phenolic compounds. Their synthesis is genetically regulated so each tree species contains specific compounds by which it differs from other species. Phenolic type compounds are comprised of aromatic components from simple phenols to complex phenolic polymers.

The most important are compounds with two phenolic groups, e.g. stilbenes, flavonoids and lignans (Hillis, 1962; Shen *et al.*, 1986; Kolhir *et al.*, 1996; Debell *et al.*, 1997; Celimene *et al.*, 1999; Eaton and Hale, 1999; Kleist and Schmitt, 1999; Stenius, 2000, Willför *et al.*, 2004). Flavonoids have a characteristic diphenylpropane ($C_6C_3C_6$) carbon skeleton. Both aromatic rings in the molecule usually contain hydroxyl groups. The most abundant flavonoids in wood are dihydrokaempferol ($C_{15}H_{12}O_6$, M_w=288), taxifolin ($C_{15}H_{12}O_7$, M_w=304), naringenin ($C_{15}H_{12}O_5$, M_w=272) and catechin ($C_{15}H_{14}O_6$, M_w=290) (Hillis, 1962; Sjöstrom, 1981; Stenius, 2000). In addition to simple flavonoids, there are also flavonoid polymers with 3 to 8 flavonoid units, which are known as condensed tannins.

Lignans are an important group of plant phenols and are widespread in the plant world. Typical for them is oxidative coupling of two phenylpropane (C_6C_3) units via linkage between β-positions on propane side chains. In addition to dimeric lignans, minor quantities of trimers (sesquilignans) and tetramers (dilignans) can also be found in wood. They are generally called oligolignans. Several tens of lignans have been identified so far in wood tissues. However, the predominating are dimeric components, e.g. hydroxyimatairesinol ($C_{20}H_{22}O_7$, M_w=374), pinoresinol ($C_{20}H_{22}O_6$, M_w=358), lariciresinol ($C_{20}H_{24}O_6$, M_w=360), secoisolariciresinol ($C_{20}H_{26}O_6$, M_w=362) and nortrachelogenin ($C_{20}H_{22}O_7$, M_w=374), Lignans appear as free components or linked to carbohydrates via glycoside bonds (Ward, 1997; Bohm, 1998; Stenius, 2000; Willför *et al.*, 2006).

On account of their specific chemical structure and related antioxidative properties, phenolic compounds are toxic for numerous microorganisms, fungi and insects. They function as powerful natural biocides and enable chemical protection of wood against harmful impacts and biological degradation (Rennerfelt and Nacht, 1955; Hart, 1989; Willför, 2002).

Wood of larch (various species of the genus *Larix)* is generally known as durable as well as resistant against weather conditions, acids and water. So far, several authors have studied chemical composition of hydrophilic extractive fraction of the heartwood of different larch species (Gripenberg, 1952; Brewerton, 1956; Nair and von Rudloff, 1960; Gardner and Barton, 1960; Sasaya *et al.*, 1970; Lepteva *et al.*, 1971; Tyukavkina *et al.*, 1973; Giwa and Swan, 1975; Keith and Chauret, 1988; Chui and Mackinnon-Peters, 1995). They found out that the predominating hydrophilics were flavonoids. Their concentrations, measured in radial direction at representative stem height (1.5 m), were highest at the heartwood/sapwood boundary.

Some researchers studied the correlation between the content of hydrophilics and natural durability of larch heartwood (Doi *et al.*, 1998; Ohmura *et al.*, 1999; Windeisen *et al.*, 2002; Windeisen and Wegener, 2003; Gierlinger *et al.*, 2002, 2003, 2004). Strong connection between extractive structure and rotting resistance has been confirmed.

Recently, many studies have also been dedicated to evaluation of larch wood as potential source of technologically important highly bioactive phenolic compounds, such as taxifolin, dihydrokaempferol and secoisolariciresinol (Babkin *et al.*, 1999; Babkin *et al.*, 2001; Aleksandrova *et al.*, 2002; Ivanova *et al.*, 2012; Ostroukhova *et al.*, 2012; Wen-jie *et al.*, 2005, Willför *et al.*, 2003).

Most authors focused on chemical characterization of larch heartwood at the representative stem height (1.5 m), while there is almost no data on the content of extractives at different positions along the stem and in branches.

The aim of the present work was to make a detailed chemical characterization of hydrophilics in the heartwood of European larch (*Larix decidua* Mill.) and to determine their variability in longitudinal direction within a tree and between two trees selected for analyses. This article is the continuation of the previously published work (Zule *et al.*, 2015), where lipophilic extractive compounds of the same samples were characterized.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Samples
2.1. Uzorci

Two larch trees (*Larix decidua* Mill.) were felled at the end of June, 2009 in the Alpine region of Slovenia at the altitude of 1000 m. They originated from a mixed forest where beech (*Fagus sylvatica* L.) and spruce (*Picea abies* Karst.) predominated. Both larch trees were 180 years old and about 30 m high. They were healthy without visual damage.

About 5 cm thick discs were cut from the trunks at the base (50 cm above ground) as well as at the heights of 8, 18 and 28 m. The discs were debarked and representative sections of heartwood (circular sectors from the pith to the heartwood/sapwood boundary) were cut into smaller pieces, which were subsequently frozen at -24°C prior to analysis.

2.2 Drying and grinding
2.2. Sušenje i mljevenje

Frozen samples were first conditioned at room temperature, after which they were cut into short splinters, freeze-dried for 24 hours (Martin Christ Gefriertrocknungsanlagen GmbH) and ground by means of a Wiley laboratory mill (0.150 mm) to wood meal. The latter was freeze-dryed again for 24 hours in order for volatile compounds to be removed.

2.3 Extraction
2.3. Ekstrakcija

Extractions were conducted by means of an accelerated solvent extraction system (ASE) using the instrument Dionex ASE 200. About 5 g of each freeze-dried powdered sample was weighed into a metal extraction cell and sequentially extracted first with hexane (V-50 ml) to remove lipophilic fraction (Zule *et al.*, 2015) and afterwards with 95 % ethanol (V-50 ml) to isolate hydrophilic extractive portion. The temperature of the first extraction step was 90 ºC, pressure 13.8 MPa and extraction time 10 minutes (2 static cycles with static time of 5 minutes). Ethanol extraction was carried out at 100 ºC under the same experimental conditions. Both extractions were performed under the stream of nitrogen.

2.4 Derivatization of extractives
2.4. Derivatizacija ekstraktiva

All ethanol extracts were derivatized prior to chromatographic analyses (GC-FID, GC-MS) by which components with hydroxyl groups, such as flavonoids and lignans, were converted to the corresponding trimethylsilyl (TMS) derivatives, which where less polar and so more convenient for subsequent chromatographic analyses. 2 ml of internal standard solution were added to each extract, containing about 0.5 mg of extractive compounds. Internal standards were heneicosanoic acid (S1), betulinol (S2), cholesteryl heptadecanoate (S3) and 1.3-dipalmitoyl-2-oleyl glycerol (S4), all having concentration of 0.02 mg/ml. The mixture of a sample and standards was dried under the stream of N_2 and in vacuum desiccator at 40 ºC, after which sylilation reagents were added: 80μl BSTFA (bis-trimethylsilyl-trifluoroacetamide) and 20 μl TMCS (trimethyl-chlorosilane) in 20 μl of pyridine. The reaction mixture was heated for 1 hour at 70 ºC, than it was cooled and injected into gas chromatograph (Willfor, 2007).

2.5 Chromatographic analyses of extractives
2.5. Kromatografska analiza ekstraktiva

2.5.1 Identification of extractive compounds by GC-MS
2.5.1. Identifikacija ekstraktivnih spojeva metodom GC-MS

Characteristic components of the representative ethanol extracts were identified by means of gas chromatography coupled to mass spectroscopy (GC-MS). The analyses were performed on the HP 6890-5973 GC-MSD instrument. The separation was carried out on the HP-1 (30 m x 0.25 mm x 0.25 μm) capillary column under the following experimental conditions: temperature program of column heating 80 ºC, 8 ºC/min, 290 ºC; carrier gas He (0.9 ml/min); split injector (1:15) – 260 ºC; MS-EI detector (source temp. 280 ºC, 70 eV, quadrupole temp. 180 ºC). Mass range (m/z) was between 10 and 1050. For positive identification of individual compounds, the mass spectra of their chromatographic peaks were compared with spectra of pure compounds from the Wiley Registry NIST 2008 Mass Spectral Library. On both GC-FID and GC-MS chromatograms there was practically the same sequence of chromatographic peaks of individual compounds as similar long capillary columns were used, by which reliability of identification was ensured and quantitative work facilitated (Willfor, 2007).

2.5.2 GC-FID analysis on long capillary column
2.5.2. GC-FID analiza na dugoj kapilarnoj koloni

The determination of individual flavonoids, lignans and other hydrophilic compounds was accomplished by means of gas chromatography on the Perkin Elmer AutoSystem XL instrument. HP-1 (25 m x 0.20 mm x 0.11 μm) capillary column was used for separation of compounds under the following experimental conditions: temperature program of column heating: 120 ºC, 6 ºC/min, 300 ºC (10 min); carrier gas H_2 (0.8 ml/min); split injector (1:20) – 160 ºC, 8 ºC/min, 260 ºC (15 min); FID detector: 320 ºC; injection volume 1 μl. Betulinol (S2) served as standard in determination of phenolic compounds. The latter were calculated by comparison of the corresponding peak areas using correction factor 1.2. All results are expressed as milligram per gram of dry sample weight, where the limit of quantification was about 0.01 mg/g (Willfor, 2007).

2.5.3 Characterization of phenolic compoudns by HPLC-SEC
2.5.3. Karakterizacija fenolnih spojeva metodom HPLC-SEC

High performance size exclusion chromatography (HPLC-SEC) was used for the determination of molecular mass distribution of phenolic compounds. The presence of dimeric, trimeric and tetrameric phenols in representative ethanol extracts was thus confirmed as higher phenols can not be detected by gas chromatography due to their low volatility. The selected nonderivatized ethanol extracts of heartwood samples were dried under the stream of N_2, after which they were redissolved in THF, so that the concentration was 1 mg/ml. The analyses were carried out on the chromatographic system, composed of the following units: autosampler Spark Holland Marathon-XT, pump Shimadzu LC – 10ATVP, chromatographic columns 2x Jordi Gel DVB 500A (300 mm x 7.8 mm) and detector Sedere SEDEX 85 ELSD, which is a low temperature evaporative light scattering detector. Tetrahydrofuran (THF) was used as eluent with the flow of 0.8 ml/min. The injection volume was 50 μl.

2.6 Gravimetric determination of the content of hydrophilic extractives
2.6. Gravimetrijsko određivanje sadržaja hidrofilnih ekstraktiva

10 ml aliquots of ethanol extracts were dried under the stream of N_2 and in vacuum desiccator at 40 ºC until a constant weight was reached. The gravimetric amount of extractives was calculated as milligram per

gram of dry sample weight. All quantitative determinations of hydrophilic extractives in the samples of heartwood were performed in two parallels. The presented results are average values of individual determinations.

3. RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Gravimetric determination of ethanol extracts
3.1. Gravimetrijsko određivanje etanolnih ekstrakata

Hexane extracted heartwood samples, from which lipophilics (free fatty and resin acids, diterpenoids, triglycerides, steryl esters and sterols) had been removed, were consecutively extracted in the same way by a polar solvent ethanol (95 %) to obtain hydrophilic extractives. Gravimetrically determined content of ethanol extract in the heartwood of both trees is presented in Figure 1. Evidently, the concentrations were slightly higher in the base of the trees (0.5 m), however they remained more or less constant further up the stems. The average values were 28.0 ± 2.8 mg/g for Tree 1 and 30.5 ± 2.7 mg/g for Tree 2, calculated on dry mass of heartwood. Obviously, there was no significant difference between the two trees.

Ethanol proved to be a suitable polar solvent. It is less toxic than methanol and less flammable than acetone. It can be easily recycled. The ASE extraction method has many advantages over commonly used Soxhlet method. It is automated and computer controlled. The whole process is very quick due to the application of elevated temperature and pressure, while solvent consumption is significantly reduced. It is indispensable method for sequential analyses of large numbers of samples. The results are comparable to Soxhlet.

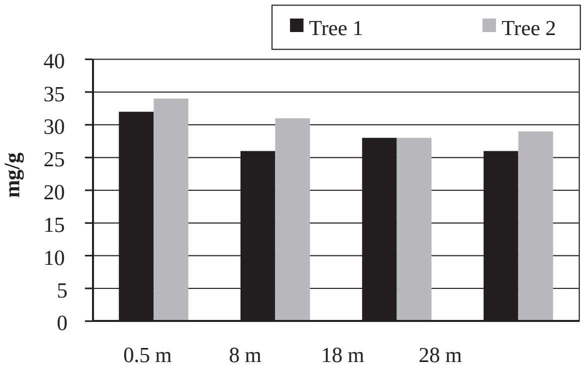

Figure 1 Content of ethanol extract in heartwood of trees 1 and 2 as a function of stem height
Slika 1. Sadržaj etanolnog ekstrakta srži stabla 1. i 2. na različitim visinama

3.2 Identification of individual phenolic compounds (GC-MS)
3.2. Identifikacija pojedinačnih fenolnih spojeva (GC-MS)

Identification was performed by GC-MS analyses of two typical ethanol extracts of the heartwood of tree 1 at 0.5 and 28 m of height. The following flavonoids and lignans were identified: naringenin, taxifolin (2 isomers), dihydrokaempferol, secoisolariciresinol, isoliovil, lariciresinol, todolactol A and nortrachelogenin. In addition, some monomeric and dimeric sugar units were also detected in the extracts.

3.3 Determination of the composition of ethanol extracts related to stem height
3.3. Određivanje sustava etanolnih ekstrakata u odnosu prema visini stabla

The composition of ethanol extracts was established from GC-FID chromatograms, recorded on a 25 m long capillary column. Qualitative composition of phenols was almost the same for all heartwood samples of both trees up to the stem height of 18 m, while it considerably changed at the height of 28 m near the top of the trees. The flavonoids dihydrokaempferol and taxifolin predominated in all samples at lower and middle stem heights, where lignans were present only in trace amounts. On the other hand, the concentrations of lignans significantly increased at the top of both trees at 28 m. Secoisolariciresinol was far the most abundant lignan in the heartwood of both trees.

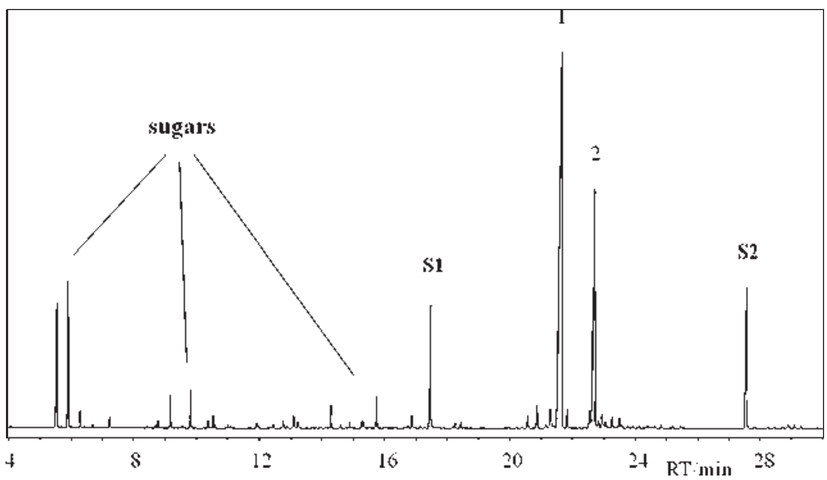

Figure 2 GC-FID chromatogram of ethanol extract of heartwood of tree 1 (8 m)
(1 – dihydrokaempferol, 2 – taxifolin, S1, S2 – internal standards)
Slika 2. GC-FID kromatogram etanolnog ekstrakta srži stabla 1. (8 m)
(1 – dihidrokamferol, 2 – taksifolin, S1, S2 – interni standardi)

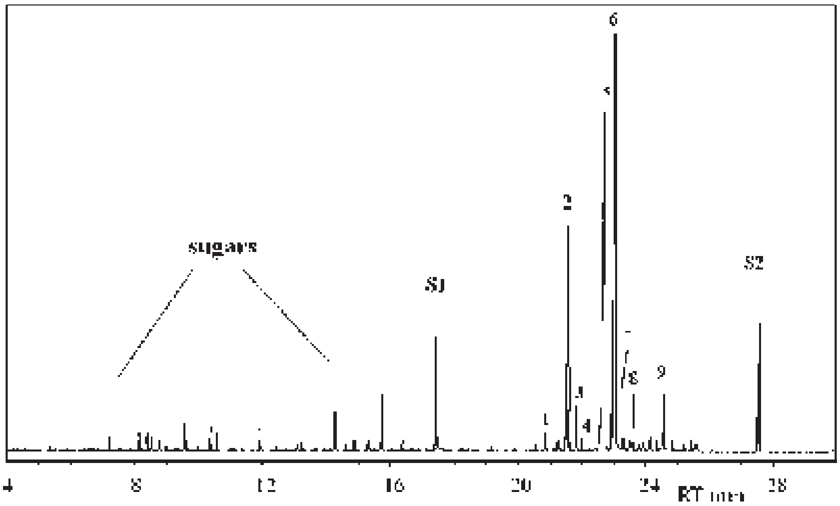

Figure 3 GC-FID chromatogram of ethanol extract of heartwood of tree 1 (28 m)
(1 – naringenin, 2 – dihydrokaempferol, 3 – taxifolin (isomer), 4 – todolactol A, 5 – taxifolin,
6 – secoisolariciresinol, 7 – isoliovil, 8 – nortrachelogenin, 9 – lariciresinol, S1, S2 – internal standards)
Slika 3. GC-FID kromatogram etanolnog ekstrakta srži stabla 1. (28 m)
(1 – naringenin, 2 – dihidrokamferol, 3 – taksifolin (izomer), 4 – todolaktol A, 5 – taksifolin,
6 – sekoizolaricirezinol, 7 – izoliovil, 8 – nortrakelogenin, 9 – laricirezinol, S1, S2 – interni standardi)

GC-FID chromatograms of ethanol extracts of the heartwood of tree 1 at 8 and 28 m are presented in Figures 2 and 3.

Total flavonoid and lignan concentrations, which were calculated from the corresponding GC/FID chromatograms, varied between 10.6 and 12.6 mg/g in tree 1, while the corresponding values in tree 2 were slightly higher – between 12.4 and 15.7 mg/g. Concentrations of dihydrokaemferol were in the range between 1.8 and 7.1 mg/g and those of taxifolin between 3.3 and 8.4 mg/g.

Secoisolariciresinol was the most abundant lignan and it was even the predominant phenolic compound at the top of tree 1 (Figure 4). The concentration of secoisolariciresionol in the heartwood of tree 1 at 28 m was 4.2 mg/g and in the heartwood of tree 2 at the same height it was 3.4 mg/g. It is very interesting that its concentration never exceeded 0.2 mg/g in the lower sections of heartwood.

The content and composition of phenols in the heartwood of trees 1 and 2 in relation to stem height is shown in Figures 4 and 5.

From the comparison of gravimetric and chromatographic results, it was evident that the contents of ethanol extracts were at least twice as high as the chromatographically determined concentrations of flavonoids and lignans in those extracts. This could be partly ascribed to the presence of different sugar units, such as mono- and disaccharides in ethanol extracts, as they are readily soluble in polar solvents. However, some substances, which were simultaneously extracted by ethanol, could not be detected by GC-FID due to their

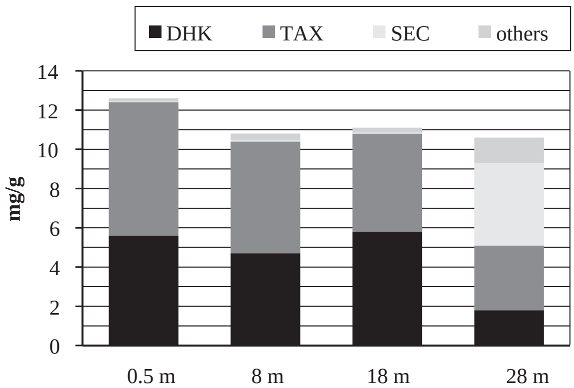

Figure 4 Content and composition of phenolic fraction of heartwood of tree 1 (DHK – dihydrokaempferol, TAX – taxifolin, SEC – secoisolariciresinol, others – naringenin, taxifolin (is), todolactol A, isoliovil, nortrachelogenin, lariciresinol
Slika 4. Sadržaj i sustav fenolne frakcije srži stabla 1. (DHK – dihidrokamferol, TAX – taksifolin, SEC – sekoizolaricirezinol, ostalo – naringenin, taksifolin (iz.), todolaktol A, izoliovil, nortrakelogenin, laricirezinol)

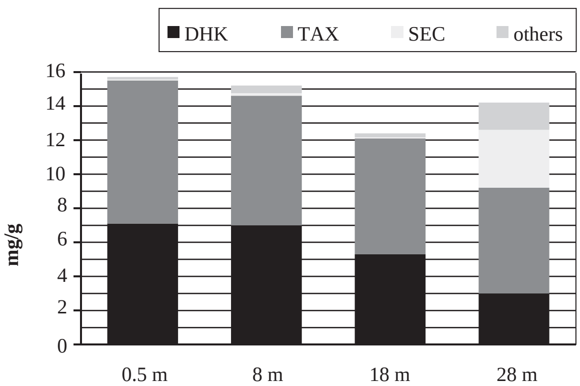

Figure 5 Content and composition of phenolic fraction of heartwood of tree 2 (DHK – dihydrokaempferol, TAX – taxifolin, SEC – secoisolariciresinol, others – naringenin, taxifolin (is), todolactol A, isoliovil, nortrachelogenin, lariciresinol)
Slika 5. Sadržaj i sustav fenolne frakcije srži stabla 2. (DHK – dihidrokamferol, TAX – taksifolin, SEC – sekoizolariciresinol, ostalo – naringenin, taksifolin (iz.), todolaktol A, izoliovil, nortrakelogenin, laricirezinol)

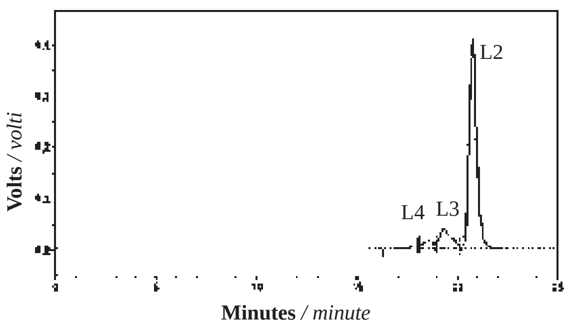

Figure 6 HPLC-SEC chromatogram of ethanol extract of heartwood of tree 1 (8 m)
Slika 6. HPLC-SEC kromatogram etanolnog ekstrakta srži stabla 1. (8 m)

higher molecular mass and thus lower volatility. The presence of higher phenolic structures was unambiguously confirmed by HPLC-SEC (Figure 6).

Figure 6 shows the molecular mass distribution of a THF redissolved typical ethanol extract. The most intensive peak (L2) with the retention time of 21 min represents dimeric phenols, e.g. flavonoids and lignans, while weaker peaks with retention times between 18 and 20 min (L3 and L4) simbolize higher phenols having three and four phenolic groups in their molecular structure. According to the peak area ratio, it could be estimated that typical ethanol extracts of larch heartwood contained averagely about 20 % of higher phenols. Sugar units and other non phenolic components were not detected by HPLC-SEC under specified experimental conditions.

The most abundant phenolic compounds of European larch, e.g. dihydrokaempferol, taxifolin and secoisolariciresinol exhibit, according to available literature data, very strong antioxidative properties, which can be ascribed to their specific molecular structure. The structural formulas of the most typical larch flavonoids and lignans are presented in Figure 7.

The biological activity of taxifolin could be attributed to the relatively high content of phenolic hydroxyl groups in the right ring of its molecular structure, while on the other hand secoisolariciresinol is very efficient antioxidant on account of its butanediol structure (Figure 7). Presence of higher trimeric and tetrameric phenols also positively affects antioxidative properties of extractives and thus biological resistance of wood tissues against rotting (Pietarinen *et al.* 2006; Willför *et al.* 2003; Scalbert, 1991; De Bruyne *et al.* 1999).

The most significant finding in the case of larch heartwood was that chemical structure of hydrophilic extractive fraction changed towards the top of both examined trees, which was not the case with lipophilic fraction of the same tissues (Zule *et al.*, 2015). While the flavonoids taxifolin and dihydrokaempferol predominated in the majority of heartwood, lignans appeared at the top in abundant concentrations with secoisolariciresinol as the main phenolic compound. Such distribution points to the fact that lignans are synthesized during early growth period, while later on, during wood aging, the synthesis proceeds more and more in the direction of flavonoid formation (Willför, 2002).

Larch forest residues, such as tree tops, damaged wood, cuttings, sawdust, knots and branches from wood processing could serve as relevant source for large scale isolation of valuable bioactive compounds. The latter may be applied as "green chemicals" or natural preservatives in farmaceutic, food, chemical and other industries. The remaining extracted wood may be further chemically converted to different platform chemicals and biofuel, which is the main idea of wood biorefineries.

4 CONCLUSIONS
4. ZAKLJUČCI

Nine different phenolic compounds, such as flavonoids and lignans were determined in ethanol ex-

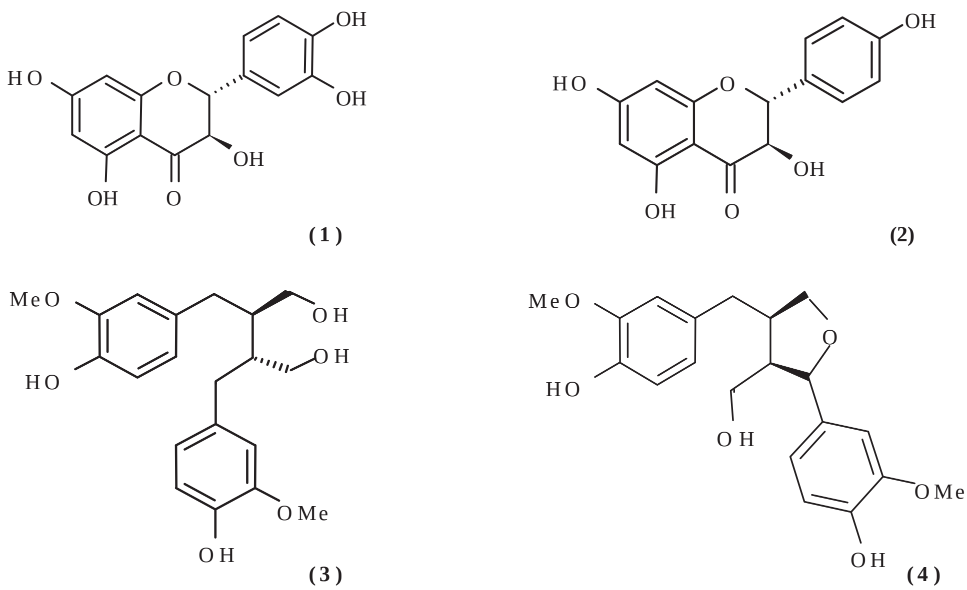

Figure 7 Structural formulas of taxifolin (1), dihydrokaempferol (2), secoisolariciresinol (3) and lariciresinol (4)
Slika 7. Strukturne formule taksifolina (1), dihidrokemferola (2), sekoizolaricirezinola (3) i laricirezinola (4)

tracts of the heartwood of two European larch trees. All substances identified, e.g. naringenin, taxifolin (2 isomers), dihydrokaempferol, secoisolariciresinol, lariciresinol, isoliovil, northrachelogenin and todolactol A, are typical for larch species (European, Siberian, Japanese, Western, Tamarack and others) and are commonly not found in other conifers in any significant amounts. Their average concentrations in the heartwood of the two examined trees were 12 ± 2 mg/g and 15 ± 2 mg/g, and did not change essentially in vertical direction along the stems. Flavonoids predominated at lower and middle positions while lignans were more abundant at the top of both trees. The most important flavonoid taxifolin and lignan secoisolariciresinol are classified as very powerful antioxidants which, in combination with other phenolic substances, most likely provides efficient chemical protection of larch heartwood against rotting and harsh environmental conditions. Our study may contribute to better understanding of the chemistry of wood tissues.

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Design Methodology of New Furniture Joints

Metodologija dizajniranja novih spojeva za namještaj

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ABSTRACT • *Techniques for self-assembly and disassembly of furniture are predominant mainly in the group of cabinet furniture. The lack of new constructions of furniture joints affects the market development of skeletal furniture intended for self-assembly. These connections should have the following characteristics: be easy to assemble and disassemble, have a minimum number of components, meet aesthetic requirements and be externally invisible. The aim of the study was to develop a methodology for formulating the assumptions for designing a new connection of skeletal furniture. At the outset, the distinguished joint features were presented. Then, assessment criteria were formulated for each feature, with adeqate numerical values. On this basis, specific joints and fittings for skeletal furniture were collected and divided into 84 groups. The prepared numerical values were used as the data for statistical analysis. In the first step of the analysis, relationships were characterized between the studied features using the Spearman rank correlation. On the basis of statistical analysis, the correctness of the obtained classification was confirmed. Based on the analysis of the characteristics of the cluster and Spermans correlation coefficient values, there was no reason to highlight any qualities as a component of project assumptions. Cluster analysis pointed to differences between groups, as well as goups having similar features. Against this background, a clear design assumption was built.*

Keywords: *furniture, joints, design, brief, cluster analysis*

SAŽETAK • *U skupini korpusnog namještaja uglavnom prevladavaju tehnička rješenja za samostalnu montažu i demontažu namještaja. Nedostatak novih konstrukcijskih spojeva za namještaj utječe na razvoj tržišta korpusnog namještaja namijenjenoga samostalnoj montaži. Konstrukcijski spojevi korpusnog namještaja trebali bi se moći lako sastaviti i rastaviti, imati minimalan broj komponenata, zadovoljiti estetske uvjete i biti izvana nevidljivi. Cilj istraživanja bio je razviti metodologiju za formuliranje pretpostavki za projektiranje novoga konstrukcijskog spoja za korpusni namještaj. Na početku rada prikazana su istaknuta obilježja pojedinih spojeva. Potom su za svako obilježje formulirani kriteriji vrednovanja, kojima su dodijeljene brojčane vrijednosti. Prikupljeni su i u 84 skupine grupirani različiti spojevi i elementi za spajanje korpusnog namještaja. Tako pripremljene numeričke vrijednosti uvrštene su kao podaci u statističke analize. U prvom koraku analize primjenom Spearmanove korelacije ranga određeni su odnosi između istraživanih obilježja. Na temelju statističke analize potvrđena je ispravnost dobivene klasifikacije. Na temelju klasterske analize obilježja i Spermanova koeficijenta korelacije pokazalo se da nema razloga za naglašavanje bilo kojeg obilježja kao sastavnog dijela projektne pretpostavke. Klasterska analiza*

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označuje različitosti među skupinama, ali i povezuje skupine koje imaju zajednička obilježja. Na temelju dobivenih rezultata formulirane su jasne pretpostavke za dizajn novih spojeva korpusnog namještaja.

Ključne riječi: *namještaj, spojevi, dizajn, uputa, klasterska analiza*

1 INTRODUCTION
1. UVOD

Joints fulfil important strength, technological and operational-aesthetic functions in furniture constructions. This is confirmed by numerous publications analysing the influence of different factors on skeleton furniture joint strength depending on the kind of: joint, composite material and glue, as well as its impact on stress distribution (Smardzewski and Papuga, 2004; Kociszewski, 2005; Tankut and Tankut, 2006). It was demonstrated that joint stiffness increased together with the application of a greater number of connecting links (Liu and Eckelman, 1998), and that stiffness of a construction can be enhanced by increasing thickness of the applied materials (Tankut, 2009). In addition, studies conducted by (Vassiliou and Barboutis, 2009) showed that joint strength changed slightly depending on the manufacturer of the same type of connectors. On the basis of the available literature (Eckelman, 1997; Smardzewski and Prekrat, 2002; Eckelman, 2003), it can be said that, in general, joints are the weakest parts of a given piece of furniture and that furniture durability depends, first and foremost, on their quality.

In the case of skeleton furniture, it can be said that a considerable number of furniture joints consists of a tenon and mortise (Dzięgielewski and Zenkteler, 1975; Akcay *et al.*, 2005; Eckelman and Haviarova, 2008; Smardzewski, 2008, 2015). Such joints are characterised by very good technical properties as well as by the fact that they are invisible outside. Their mechanical properties are commonly evaluated using destructive methods (Atar and Özçifçi, 2008; Altinok *et al.*, 2009; Maleki *et al.*, 2012; Yerlikaya and Aktas, 2012). Continuous efforts are being made to find new joint constructions, which would: ensure their easy assembly and disassembly, consist of a minimum number of components, be characterised by simple construction, look nice and be invisible outside (Smardzewski, 2015a). These requirements are difficult to realise both in terms of technical and technological solutions.

Innovative products usually evolve in the course of the product development process. The complexity of such processes can involve: designing, styling, marketing as well as planning of the product and appropriate production processes (Vajna and Kittel, 2009). The selection of designing assumptions is one of many stages of this proces (Ginalski *et al.*, 1994).

It is worth emphasising that precise determination of designing assumptions is the precondition, to a considerable extent, of the success or failure of the entire project. There is no universal method for choosing such assumptions and each designer employs his/her own individual approach. The most popular methods include: brainstorming technique and its numerous variants (Buzan and Buzan, 2004) and heuristic methods (Daly *et al.*, 2012).

Bearing in mind the above, the authors decided to propose a method of assumption selection to be used in designing new skeleton furniture joints. The method presents a procedure involving a systematic and universal selection of design assumptions for every kind of product. Using this procedure, it is possible to group appropriate, interesting features of a given product, which will be important from the point of view of properties of the new furniture joint.

The undertaken investigations aimed at elaborating methodology of developing assumptions to be used when designing a new skeleton furniture joint. The cognitive objective of the study was to select a group of joints characterised by similar features, whose value provided recommendations for the development of new constructions for skeleton furniture joints.

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

Bearing in mind the solutions discussed in the above Introduction and presented in the study objective, the authors decided to distinguish the following features characterising joints: visibility, separability, assembly force, method of connection, tools, aesthetics, recycling and Coefficient of Assembly (*CoA*). Next, evaluation criteria were formulated for each feature; they were assigned the following numerical values: 1, 0.5 and 0, where 1 – refers to an unfavourable criterion, 0.5 – intermediate and 0 – a favourable criterion.

The value of CoA was calculated from the following formula:

$$CoA=(N_F+N_E)\cdot N_O \qquad (1)$$

N_F in the above formula refers to the number of connecting links, N_E - to the number of elements in the joint and N_O designates the number of operations necessary to assemble the joint. These values were applied to evaluate the ease of assembly of a given joint (Table 1).

In the case of the dowel type of joint, the number of links N_F is 1, the number of elements N_E in the joint amounts to 2 and the number of operations necessary to assemble the joint N_O is 6 (because in order to assemble the joint, the following consecutive operations must be performed: drilling of two seats – 2, glue application to each seat – 2, placing of the link in one seat – 1, pressing down the assembly elements until the adhesive solidifies – 1). The *CoA* for this type of joint equals 18 (Table 2). In the case of the VB 25 T joint, the number of links N_F is 3, the number of elements N_E in the joint amounts to 2 and the number of operations necessary to assemble the joint N_O is 8. The *CoA* for this type of joint equals 40.

Taking into account the established features and the adopted criteria of their evaluation, Table 3 collates 84 characteristic joints and connecting links of skele-

Table 1 Features, criteria and numerical values of skeleton furniture joints evaluation
Tablica 1. Obilježja, kriteriji i numeričke vrijednosti za vrednovanje konstrukcijskih spojeva namještaja

Feature *Obilježje*	**Evaluation criterion** *Kriterij vrednovanja*	**Rank** *Rang*
Visibility *Vidljivost*	completely visible *potpuno vidljiv*	1
	partially visible *djelomično vidljiv*	0.5
	Invisible / *nevidljiv*	0
Separability *Odvojivost*	non-separable *neodvojiv*	1
	separable / *odvojiv*	0
Assembly force *Sila sastavljanja*	external / *vanjska*	1
	internal / *unutarnja*	0
Method of connection *Način sastavljanja*	using glue / *upotrebom ljepila*	1
	based on friction force *na temelju sile trenja*	0
Tools / *Alati*	using tools / *uz primjenu alata*	1
	without using tools *bez primjene alata*	0
Aesthetics *Estetika*	unfavourable *neprikladna*	1
	favourable *prikladna*	0
Recycling *Recikliranje*	metal / *metal*	1
	plastic / *plastika*	0.5
	wood / *drvo*	0
CoA	*CoA* > 36	1
	19 < *oA* ≤ 36	0.5
	19 < *oA* ≤ 36	0

ton furniture. When selecting the joints, the following properties were taken into consideration: functionality, technical-aesthetic and technological quality as well as strength. The selected joints were divided into groups to allow better differentiation of ways of mounting of connecting links: using glue, catch, screw, bolt, wedge, spring and magnet. Table 3 also contains symbols of joints (codes), which were used in the course of analyses carried out later.

Two groups of joints are described below together with their brief characterisations. In the first group, joints, which employ glue, are presented (AAA, AAB, AAC, AAD, AAE, AAF, AAG, AAH, and AAI). They are non-separable and externally invisible. They are frequently employed in combination with other connectors and external force acting on the furniture body is necessary.

The second group comprises catch joints (BAA, BAB, BAC, BAD, BAE, BAF, BAG, BAH, BAI, BAJ, BAK, BAL, BAM, BAN, BAO, BAP, BAQ, BAR, BAS, BAT, BAU). These joints include solutions in which immobilisation of elements and their pressure is achieved by turning an appropriate coupler resulting in a mounting load. Usually, these are separable joints, partially visible externally. They guarantee stable assembly also when repeated assembly and disassembly is necessary.

In order to illustrate differences between evaluation of individual features for selected connectors, three representative joints are presented in Table 4. The collated joints differ with respect to: visibility, separability, assembly force, method of connection, need to use tools, recycling, number of connectors, number of operations necessary to assemble them and *CoA*. This comparison shows significant differences regarding the evaluation of individual features.

Data prepared for statistical analyses constituted a set consisting of 84 kinds of joints collated in rows and their features collated in 8 columns. Appropriate ranks of a given joint, i.e. values 1, 0.5 or 0, can be found on the intersection of a row with a column.

In the first step of the performed analysis, correlations between the examined traits were characterised. Due to qualitative features, Spearman's non-parametric correlation method was applied (Spearman, 1904, 1906). The value of the calculated correlation coefficient is contained in   interval and indicates how strong the correlation between variables is. If the value of this coefficient belongs to (, then it is a positive correlation, which means that a value increase of the first feature is accompanied by a value increase of the second one. In the situation when the value of the correlation derives from the) interval (negative correlation), then a value decrease of the first feature is accompanied by a value decrease of the second one. When the correlation value equals 0, there is no dependence (absence of dependence).

In the next step of investigation of experimental material, cluster analyses were performed. Their objective was to combine objects into clusters in such a way that the similarity of objects belonging to the same cluster was the strongest, whereas it was the weakest with objects from the remaining clusters (Everitt, 1974). This kind of analysis is employed widely in order to organise data into sensible structures or to group analysed data (Romesburg, 1984, Karimizadeh *at al.*, 2012). Data for cluster analyses were prepared in numerical form on the basis of joint assessment values, whose examples are shown in Table 4. Ward's agglomeration method (Ward, 1963) based on the Euclidean metric was applied for the analysis. It consists in combining such objects, which ensure minimum sum of square distances from the centre of gravity of a new cluster they form. As the result of such analysis, a den-

Table 2 Example of *CoA* values
Tablica 2. Primjeri vrijednosti koeficijenta spoja (*CoA*)

Illustration *Ilustracija*	**Name of connector** *Naziv konektora*	N_F	N_E	N_O	**CoA**
	VB 25 T	3	2	8	40
	RASTEX	2	2	7	28
	DOWEL	1	2	6	18

Table 3 List of joints used for statistical analysis
Tablica 3. Popis spojeva korištenih za statističku analizu

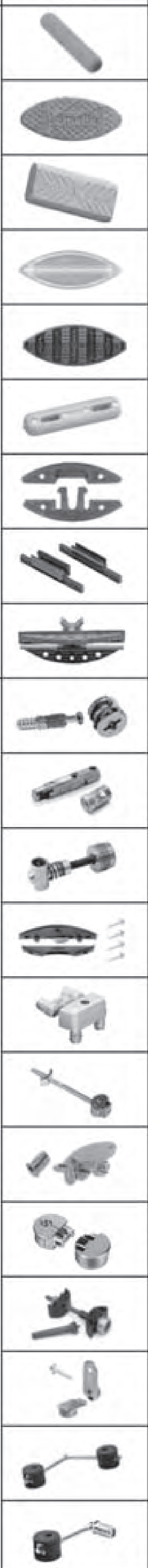
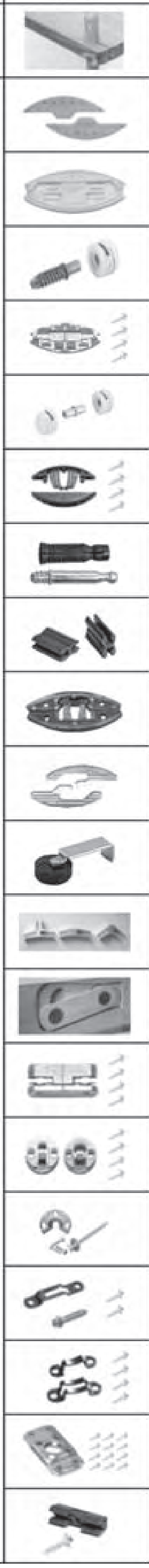
Group *Skupina*	Picture *Slika*	Name *Naziv*	Code *Kod*	Group *Skupina*	Picture *Slika*	Name *Naziv*	Code *Kod*
GLUE APP		FURNITURE DOWEL	AAA			LE BELGE SYSTEM	CAM
		ORIGINAL BISCUIT	AAB	WEDGE		CHAMP	DAA
		DOMINO	AAC			SUNNY	DAB
		C-20	AAD			EVERFIX + MANDREL	DAC
		BISCO P-10	AAE			METAL	DAD
		PLASTIC DOWEL	AAF			EVERFIX + DUPLO	DAE
		FAST(GLUE)	AAG			TENSO P-14	DAF
		MINI CLICK	AAH			QUICK SET SYSTEM	DAG
		CLIPS	AAI			CLICK	DAH
CATCH		RASTEX	BAA			FAST	DAI
		ROSTRO + INSERT NUT	BAB			SIMPLEX	DAJ
		EASY CON	BAC			VB 160	DAK
		CLAMEX P-15	BAD			MODOS	DAL
		BLUM COUPLING	BAE			TEAM 7	DAM
		ZIPBOLT MINI	BAF			CHICO	DAN
		K-D 512 + INSERT NUT	BAG			DUO 35	DAO
		STABILOFIX	BAH			UNO 30	DAP
		ZIPBOLT NEW	BAI			M. S. + PIN	DAQ
		SOLO 32 + SCREW	BAJ			M. S. ANTI TORSION	DAR
		VB 90-180 T	BAK			DUO-SYSTEM	DAS
		VB 45-90 T	BAL			SCLICK	DAT

Table 3 Continuation
Tablica 3. Nastavak tablice

		VB 25 T	BAM
		ELEFANT	BAN
		ELICA	BAO
		MANDREL M6 + SLEEVE	BAP
		SLIMFIX	BAQ
		OFON SYSTEM	BAR
		ZIPBOLT FAST FIT	BAS
		ROBO + INSERT NUT	BAT
		TOFIX RTA	BAU
SCREW AND BOLT		PUSHFIX	CAA
		VB 16	CAB
		TZ 321	CAC
		CORNERFIX	CAD
		VALKOMP	CAE
		VHS 32	CAF
		CONFIRMAT	CAG
		RV	CAH
		PLY 90	CAI
		CROSS	CAJ
		MIEKE MAIJER	CAK
		A-JOINTS	CAL
		RAFIX TAB 20	DAU
		RAFIX 30	DAW
		TOOLEX VB 54	DAX
		CLICK PRO	DAY
		MULTI-CLIP	DAZ
		BALL	DBA
		NOMADIC	DBB
		WHY THE FRIDAY	DBC
		DOWEL PLASTIC	DBD
		DOUBLE DOVETAIL M/D	DBE
		MILLER DOWEL SYSTEM	DBF
		JOIN NAILS	DBG
		E-20	DBH
		HOFFMAN SYSTEM	DBI
		CHAIR COUPLING	DBJ
		TUCK SYSTEM	DBK
		TOFIX RTA + MANDREL	DBL
SPRING		63 DEGREES	EAA
		STICK LETS	EAB
		SPRING-BOLT SYSTEM	EAC
MAGNET		INVIS	FAA

Table 4 Examples of furniture joints evaluation
Tablica 4. Primjeri vrednovanja spojeva za namještaj

Joint / *Spoj*	**Feature** / *Obilježje*	**Evaluation criterion** *Kriterij vrednovanja*	**Rank** / *Rang*
VB 25 T	visibility *vidljivost*	partially visible / *djelomično vidljiv*	0.5
	separability *odvojivost*	separable / *odvojiv*	0
	assembly force *sila za sastavljanje*	external / *vanjska*	0
	method of assembly *način sastavljanja*	based on friction forces *na temelju sila trenja*	0
	tools / *alati*	using tools / uz *primjenu alata*	1
	aesthetics / *estetika*	favourable / *prikladna*	0
	recycling / *recikliranje*	metal / *metal*	1
	number of connectors *broj konektora*		3
	number of joints *broj spojeva*		2
	number of operations *broj operacija*		8
	CoA	$CoA > 36$ / $CoA=(N_F+N_E)N_O$	1 / 40
 **RASTEX**	visibility *vidljivost*	partially visible / *djelomično vidljiv*	0.5
	separability *odvojivost*	separable / *odvojiv*	0
	assembly force *sila za sastavljanje*	external / *vanjska*	0
	method of assembly *način sastavljanja*	based on friction forces *na temelju sila trenja*	0
	tools / *alati*	using tools / uz *primjenu alata*	1
	aesthetics / *estetika*	favourable / *prikladna*	0
	recycling / *recikliranje*	metal / *metal*	1
	number of connectors *broj konektora*		2
	number of joints *broj spojeva*		2
	number of operations *broj operacija*		7
	CoA	$19 < CoA < 36$ / $CoA=(N_F+N_E)N_O$	0.5 / 28
 **DOWEL**	visibility *vidljivost*	invisible / *nevidljiv*	0
	separability *odvojivost*	non-separable / *neodvojiv*	1
	assembly force *sila za sastavljanje*	external / *vanjska*	1
	method of assembly *način sastavljanja*	using glue / *upotrebom ljepila*	1
	tools / *alati*	without use of tools / *bez uporabe alata*	0
	aesthetics / *estetika*	favourable / *prikladna*	0
	recycling / *recikliranje*	wood / *drvo*	0
	number of connectors *broj konektora*		1
	number of joints *broj spojeva*		2
	number of operations *broj operacija*		6
	CoA	$CoA < 19$ / $CoA=(N_F+N_E)N_O$	0 / 18

drogram is obtained, which presents a graphic interpretation of the obtained clusters.

Cluster analyses were performed for individual eight features as well as for 84 considered joints. On the basis of the obtained results, it will be possible to select joints and features, which constitute fundamental design assumptions for joint construction of skeleton furniture.

3 RESULTS
3. REZULTATI

First, the authors analysed features and then joints. Table 5 presents values of Spearman's correlation coefficients, which provide non-parametrical measure of statistical dependences between two variables.

In the case of the examined group of features, the value of Spearman's correlation coefficients in the second column confirms a significant (*) statistical dependence between "aesthetics" and "visibility" features. This correlation amounts to 0.47*, which means that the statistical dependence between these features is proportional. Therefore, if the probability of occurrence of aesthetic joints increases for "aesthetics", then for "visibility" – the probability of occurrence of externally invisible joints also increases. On the other hand, the value of the correlation coefficient between "assembly force" and "visibility" is significant and negative (0.52*), which indicates that the statistical correlation between them is inversely proportional. If for "assembly force" the probability of occurrence of joints with internal assembly force decreases, then for "visibility", the probability of occurrence of externally invisible joints increases. The correlation between "*CoA*" and 'separability" amounts to -0.46*, therefore the statistical dependence is significant and inversely proportional. If for "*CoA*" the probability of occurrence of joints with easy assembly decreases, then the probability of occurrence of separable joints increases for "separability". The value of correlation coefficient between "*CoA*" and "tools" is 0.45, where statistical dependence is significant and proportional. If the probability of occurrence of joints with easy assembly increases for "*CoA*", then for "separability", the probability of occurrence of joints which do not require the use of tools increases. The highest value of the correlation coefficient in Table 5 occurs between "recycling" and "tools" (0.56*). This means that if the probability of occurrence of wooden connecting links decreases for "recycling", then for "tools" – the probability of occurrence of joints, which do not require the application of tools, declines. Table 5 shows the value of the correlation coefficient between individual features ranging between -0.58 and 0.56.

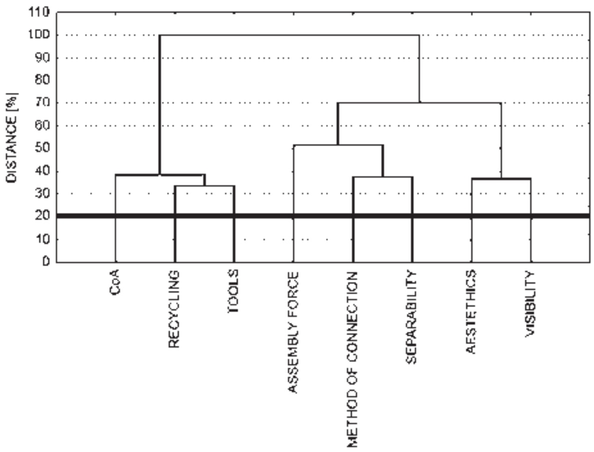


Figure 1 Cluster analysis for features
Slika 1. Klasterska analiza obilježja konstrukcijskih spojeva

Next, cluster analysis aggregating individual features and joints was carried out. Fig. 1 presents clusters for the analysed features.

Figure 1 clearly shows that "recycling" and "tools" features form a cluster, which is characterised by the shortest agglomeration distance (34 %). This is also confirmed by the value of the correlation coefficient (0.56*) (Table 5). The remaining features such as: "*CoA*", "assembly force" - "method of connection" - "separability" and "aesthetics" – "visibility" exhibit similar binding distances – from 36 % to 52 %. Statistical dependences between these features are also corroborated by the results of correlation calculations found in Table 5, ranging from 0.3 to 0.5. Differences and similarities between agglomerations found in individual clusters are so conspicuous that it is difficult to indicate unequivocally where the expected boundary of aggregation distances should occur. Nevertheless, adopting the assumption that variability between elements inside individual clusters should not exceed 20 %, the dendrogram arms were cut off at this value and this yielded eight autonomic sets. The "*CoA*" feature does not specify the ease of assembly of a given joint and the number of connectors. The "recycling" feature fails to indicate the type of appropriate material, while the "tools" feature does not specify whether tools should be employed during the assembly process. The

Table 5 Values of Spearman's correlation coefficients
Tablica 5. Vrijednosti Spearmanova koeficijenta korelacije

Variable *Varijabla*	**Visibility** *Vidljivost*	**Separability** *Odvojivost*	**Assembly force** *Sila za sastavljanje*	**Method of assembly** *Način sastavljanja*	**Tools** *Alati*	**Aesthetics** *Estetika*	**Recycling** *Recikliranje*	
Visibility / *Vidljivost*	1.00							
Separability / *Odvojivost*	-0.50*	1.00						
Assembly force *Sila za sastavljanje*	-0.52*	0.54*	1.00					
Method of assembly *Način sastavljanja*	-0.27*	0.35*	0.29*	1.00				
Tools / *Alati*	0.07*	-0.28*	-0.33*	-0.48*	1.00			
Aesthetics / *Estetika*	0.47*	-0.09*	-0.12	-0.05	0.19	1.00		
Recycling / *Recikliranje*	0.30*	-0.51*	-0.39*	-0.58*	0.56*	0.08	1.00	
CoA	0.13	-0.46*	-0.18	-0.34*	0.45*	0.01	0.49*	1.00

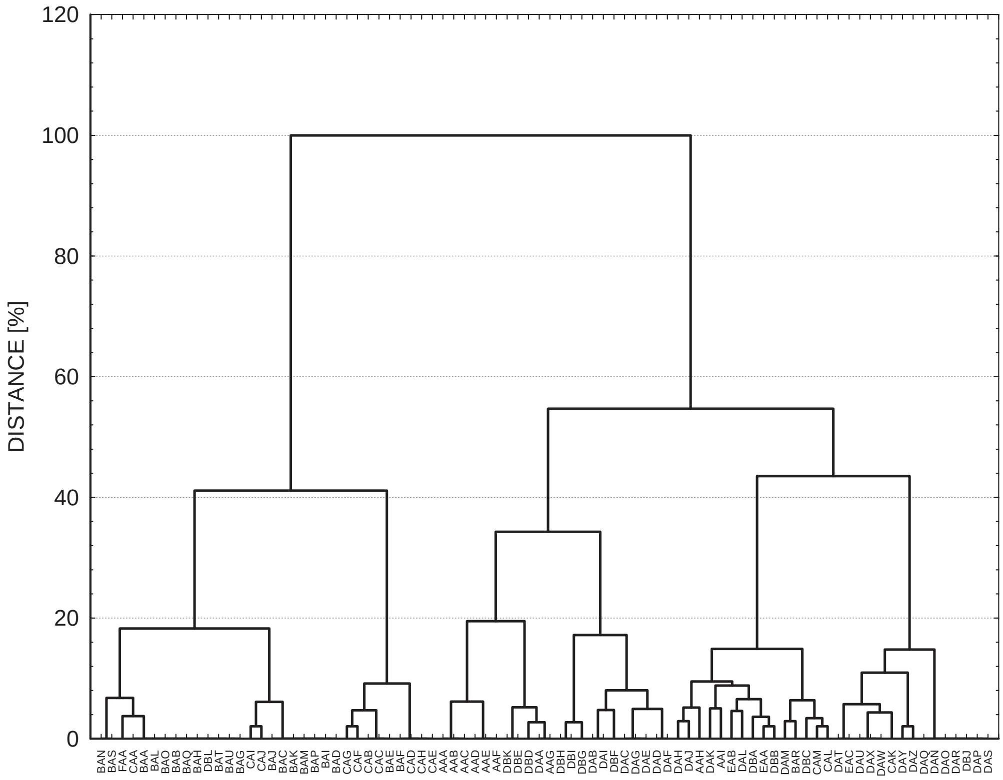


Figure 2 Cluster analysis for joints
Slika 2. Klasterska analiza spojeva

"separability" feature does not indicate whether a permanent or dismountable joint would be desirable. The feature "method of connection" fails to indicate whether glue should be used in the joint or if it should employ the principle of friction forces. The feature "assembly force" does not specify what force should be used. The "aesthetic" feature does not say anything about its importance and the trait "visibility" fails to indicate the degree of visibility.

Both Spearman's correlation analysis of features and cluster analysis emphasise the necessity to take all features into consideration in further design assumptions.

Fig. 2 presents clusters of joints characterised by similar properties. By cutting off dendrogram arms at the boundary of 20 %, six autonomous subsets were obtained. This indicates that element variability inside individual subsets cannot exceed 20 %.

The first cluster comprises the following 23 joints: BAN, BAS, CAA, BAA, BAL, BAO, BAT, BAU, BAG, BAB, BAQ, BAH, DBL, FAA, BAJ, BAC, BAK, BAM, BAP, BAI, BAD, CAI, CAJ and BAC. These are dismountable joints using internal assembly forces associated with the construction of wedges causing friction between connectors. They require the application of additional tools for assembly. They also exert a favourable effect on aesthetics of joints. They vary among one another with respect to: visibility and *CoA* ranging from 15 to 112.

The second cluster consists of nine joints: CAB, CAC, BAE, CAG, CAF, BAF, CAD, CAH and CAE. They comprise separable joints, which - similarly to those mentioned above - use internal friction forces and require the application of additional tools for their assembly. They have an unfavourable influence on joint aesthetics. They vary among one another with respect to: visibility and *CoA* ranging from 12 to 108.

The third cluster is made up of eleven joints: AAA, AAB, AAC, AAD, AAE, AAF, DBK, DBD, DBE, DAA and AAG. These are joints with externally invisible and non-separable connections, which require additional outside force in the assembly process. However, these connectors do not require the use of additional tools during the process of assembly and have an advantageous effect on joints aesthetics. They vary among one another with respect to: the method of assembly, recycling and *CoA* ranging from 12 to 28.

The fourth cluster comprises eleven joints: DAB, DAI, DBF, DAC, DAG, DAE, DAD, DAF, DBH, DBI and DBG. All of them are non-separable and the buyer must apply an additional external force to assemble them. These joints use internal friction forces and require the use of additional tools during the process of assembly. Within the group, they differ among one another with respect to: visibility, aesthetics, recycling and *CoA* ranging from 12 to 104.

The fifth cluster consists of fifteen joints: DAH, DAJ, AAH, DAK, EAB, DAL, AAI, EAA, DBB, DBA, DAM, BAR, DBC, CAM, CAL and they require from the user the application of additional tools in the course of assembly. They differ among one another with regard to: visibility, separability, assembly force, method of connection, aesthetics, recycling and *CoA* ranging from 6 to 49.

The sixth cluster includes fifteen joints: DAT, EAC, DAU, DAX, DAW, CAK, DAY, DAZ, DAQ, DAN, DAO, DAR, DBJ, DAP, DAS. These are dismountable joints, which require additional external

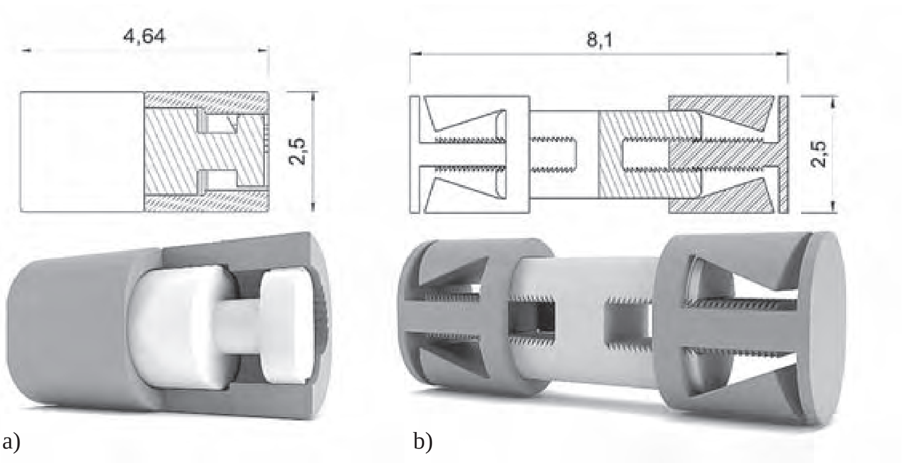


Figure 3 Examples of new joints corresponding to: a) agglomeration one, b) agglomeration three
Slika 3. Primjeri novih spojeva koji odgovaraju: a) aglomeraciji jedan, b) aglomeraciji tri

force in the course of assembly. They use internal friction forces and need additional tools. They differ with respect to: visibility, aesthetics and *CoA* ranging from 20 to 320.

From among the above-mentioned six groups of clusters, the first and third groups appear most advantageous from the point of view of their functionality and construction. The first set is advantageous because it comprises dismountable joints of complex constructions using internal assembly forces, which exert a favourable influence on joint aesthetics. Such joints can be employed in furniture constructions intended for individual assembly and are characterised by good mechanical properties, in particular long-term use. The third set contains connectors and connecting links ensuring easy furniture assembly with no necessity to apply additional tools. These joints are characterised by simple construction, they are non-separable and non-visible, which contributes to their attractive appearance. In addition, they are characterised by considerable strength and durable utilisation.

On the basis of the performed experiments and analyses, detailed recommendations for designing joints for skeleton furniture were elaborated. A new joint should be characterised by:
- lack of visibility,
- separability,
- necessity to employ additional external force in the course of assembly,
- method of assembly based on the action of internal friction forces,
- no necessity for the user to apply additional tools during the assembly process,
- favourable appearance,
- easy for recycling,
- *CoA*, not exceeding 36.

4 CONCLUSIONS
4. ZAKLJUČAK

On the basis of the performed statistical analyses, a number of assumptions were developed to be used when designing a new joint for skeleton furniture. First, the applied joints were divided into groups in accordance with widely applied engineering practice (Table 3). Statistical correctness of the elaborated classifications was corroborated following careful examination of Spearman's correlation coefficient values and cluster analysis using Ward's method. The performed cluster analyses (Fig. 1) and values of Spearman's correlation coefficients failed to provide a basis allowing identification of a trait to be used as a constituent of design assumptions. In the cluster analysis (Fig. 2), the authors identified sets of joints which, although differing among one another, were intrinsically consistent and which characterised individual features. On this basis, unequivocal design assumptions were developed. Values of features in the obtained clusters were frequently repeated and they included, among others: separability, need of an additional force during the assembly process, utilisation of internal friction forces as well as the necessity to employ additional tools during assembly. Traits referring to: external visibility and aesthetics occurred in the clusters most rarely. The developed method made it possible to elaborate an objective classification of the examined joints with respect to their functionality and construction. Properties of joints agglomerated in cluster one and three turned out to be most advantageous. They were found to contain the best premises, which can be used to elaborate design assumptions of a new joint. Examples of new joint constructions corresponding to the developed assumptions are presented in Fig. 3.

According to Table 1, the new joints are characterised by: lack of visibility, separability, necessity to employ additional external force in the course of assembly, method of assembly based on the action of internal friction forces, no necessity for the user to apply additional tools during the assembly process, favourable appearance, easy for recycling, *CoA* equal to 25.

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Modeling and Energy Consumption of Unilateral Heating Process of Flat Wood Details

Modeliranje i potrošnja energije u procesu jednostranog zagrijavanja ravnih drvenih elemenata

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ABSTRACT • *A methodology has been suggested for mathematical modeling and research of two mutually connected problems: the temperature distribution along the thickness of flat wood details subjected to unilateral heating and the energy consumption of this process. For the realization of the methodology, a 1-dimensional mathematical model has been created and solved for the transient linear heat conduction in flat wood details during their unilateral heating at arbitrary initial and boundary conditions encountered in the practice. Based on the integration of the model's solutions, a numerical approach has been suggested for the computation of the specific energy consumption (for 1 m^2) and the specific heat flux needed for the heating of the details and for the covering of their heat emission in the surrounding environment during unilateral heating aimed at wood plasticizing and bending. This paper presents solutions of the model concerning the non-stationary temperature distribution along the thickness of spruce details with thicknesses of 6, 8 and 10 mm and the non-stationary change in the specific energy consumption and in the specific heat flux during unilateral heating at temperatures of the electrically heated metal band equal to 100, 120, and 140 ºC aimed at plasticizing and bending of the details in the production of outside curved parts of the body of string musical instruments. The obtained results can be used for technological and energy calculations and for analysis of processes of unilateral heating of wood details at different boundary conditions, as well as in software for systems for model based automatic control of such processes aimed at bending of the heated and plasticized details.*

Key words: *unilateral heating, modeling, wood details, plasticizing, bending, specific energy consumption*

SAŽETAK • *Autori u radu daju prijedlog metodologije za matematičko modeliranje i istraživanje dvaju međusobno povezanih problema: raspodjele temperature u smjeru debljine ravnih drvenih elemenata izloženih jednostranom zagrijavanju i potrošnje energije tog procesa. Za realizaciju metodologije izrađen je jednodimenzionalni matematički model i riješen za linearni tok topline pri provođenju topline u ravnim drvenim elementima za vrijeme njihova proizvoljnoga jednostranog zagrijavanja, s početnim i rubnim uvjetima koji se mogu susresti u praksi. Na temelju integracije rješenja modela, predložena je numerička metoda za izračunavanje specifične potrošnje energije (za 1 m^2) i specifičnoga toplinskog toka potrebnoga za zagrijavanje elemenata i za nadoknađivanje emisije topline u okolinu za vrijeme jednostranoga grijanja radi plasticiranja i lakšeg savijanja drva.*

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U radu su prikazana rješenja modela koja se odnose na nestacionarnu raspodjelu temperature smrekovih elemenata debljine 6, 8 i 10 mm po debljini i na nestacionarnu promjenu specifične potrošnje energije i specifičnoga toplinskog toka za vrijeme jednostranog zagrijavanja na temperature električno grijane metalne trake koje su iznosile 100, 120 i 140 °C. Elementi su zagrijavani radi plasticiranja i savijanja drvenih elemenata u proizvodnji vanjskih zakrivljenih dijelova korpusa žičanih glazbenih instrumenata. Dobiveni se rezultati mogu koristiti za tehnološke i energetske izračune i za analizu procesa jednostranog zagrijavanja drvenih elemenata u različitim rubnim uvjetima, kao i za softver za modeliranje sustava koji se temelji na automatskom upravljanju procesima usmjerenima na savijanje zagrijanih i plastificiranih drvenih elemenata.

Ključne riječi: *jednostrano grijanje, modeliranje, drveni elementi, plastificiranje, savijanje, specifična potrošnja energije*

1 INTRODUCTION
1. UVOD

An important mandatory component of technologies for the production of curved wood details in furniture industry and others is their plasticizing up to the stage that allows for their faultless bending (Angelski, 2010). The current applications of such technologies differ mainly by the method selected for plasticizing wood (by heating using water steam, hot water, heated metal curved surfaces, or high frequency electric current).

The method for plasticizing wood details before their bending is chosen primarily based on economic reasons and according to the values of the relationship *R*/*h*, where *R* is the radius of bending curvature of the concave side of the details, and *h* is the size of the cross section of details in the direction coinciding with the bending plane.

During the bending of details with large radii of curvature at *R*/*h* > 20, the wood need not have a large degree of plasticity. In this case, from technological and economical standpoints, it is most advantageous to plasticize the wood using unilateral heating at relatively low wood moisture content in the range from 12 % to 20 % (Rowell and Konkol, 1987; Rice and Lucas, 2003). Plasticizing with such, relatively low, wood moisture content ensures considerable decreasing of the duration of the drying of the bent details aimed at providing lasting stabilization of their form.

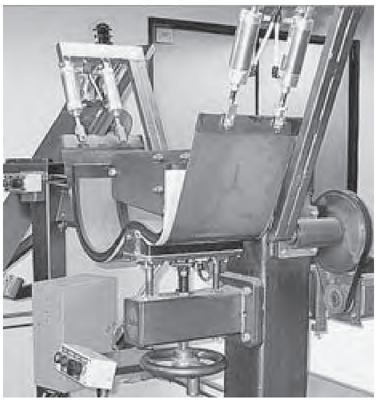

Figure 1 Equipment with electrically heated band for unilateral heating and bending of flat wood details in the production of outside curved parts for bodies of string musical instruments
Slika 1. Oprema s električno grijanom trakom za jednostrano zagrijavanje i savijanje ravnih drvenih elemenata u proizvodnji vanjskih zakrivljenih dijelova korpusa gudaćih instrumenata

Unilateral heating of wood details is most often carried out in the specific equipment used for bending. For such heating of details with thicknesses between 10 and 25 mm, hot hydraulic presses with appropriately bent surfaces are usually used. Curved details for the back parts of chairs are produced, for example, by this method of plasticizing. These details have a relatively small thickness, a large radius of curvature and *R*/*h ratio* = 20 - 25.

In the production of curved outside parts for the bodies of string musical instruments (violins, guitars, mandolins, violoncellos), details with thickness between 5 mm and 10 mm and with a 15 % moisture content are subjected to bending. The technology for plasticizing of such details usually uses equipment with metal band, electrically heated up to the temperature in the range from 100 ºC to 150 ºC (Figure 1).

It is known that the degree of plasticizing and deformability of the wood depends considerably on the temperature distribution in the details' volume at the moment of bending. The non-stationary temperature distribution in the details and the specific energy consumption during their unilateral heating, aimed at the details' plasticizing before bending, depends on many factors: wood species, thickness and moisture content of the details, temperatures of the heating medium (body) and of the surrounding air, desired degree of plasticizing, radius of the bending, etc. (Chudinov, 1968; Shubin, 1990; Požgaj *et al*., 1997; Taylor, 2001; Trebula and Klement, 2002; Deliiski, 2003, 2013b; Videlov, 2003; Pervan, 2009; Angelski, 2010; Deliiski and Dzurenda, 2010; Gaff and Prokein, 2011).

In the specialized literature, there is little data available about the temperature distribution in wood details subjected to multilateral heating with water steam before bending (Angelski, 2010) and there is no information at all about the temperature distribution in details during their unilateral heating. Information about the energy consumption needed for the heating of wood details during their unilateral heating was provided only by the authors (Deliiski *et al*., 2014). In the cited publication, an approach for the calculation of the specific energy consumption needed only for the wood heating in $kWh \cdot m^{-3}$ was presented and there is no information about the energy needed for the covering of the heat emission from the non-heated side of wood details.

That is why the modeling and energy consumption of the processes of unilateral heating of wood details, as well as the multiparameter study of these processes, are of considerable scientific and practical interest. For the practical needs, it is more convenient to determine the total energy consumption during unilateral heating of flat details in kWh·m^{-2} instead in kWh·m^{-3}.

The aim of the present paper is to suggest a methodology for mathematical modeling and research of two mutually connected problems: the temperature distribution in flat wood details subjected to unilateral heating and the energy consumption of this process.

The paper presents the development and solution of 1-dimentional mathematical model of the transient linear heat conduction in flat wood details during their unilateral heating at arbitrary initial and boundary conditions encountered in the practice. Based on the integration of the model's solutions, for the first time a numerical approach will be suggested for the computation of the specific (for 1 m^2) energy consumption and the specific heat flux needed for the heating of the details and for the covering of their heat emission during unilateral heating aimed at wood plasticizing and bending.

The paper also presents the results of simulation research of the non-stationary temperature distribution along the thickness of spruce details with h = 6, 8 and 10 mm and the non-stationary change in the specific energy consumption and in the heat flux during unilateral heating at temperatures of the electrically heated metal band t_m = 100, 120, and 140 ºC aimed at plasticizing and bending of the details in the production of outside curved parts for the bodies of string musical instruments.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Modeling of heat distribution in flat wood details during their unilateral heating
2.1. Modeliranje raspodjele topline u ravnim drvenim elementima tijekom jednostranog zagrijavanja

When the width and length of wood details exceed their thickness by at least 3 and 5 times, respectively, then the change in the temperature only along the thickness of the details in the center of their flat side during unilateral heating (i.e. along the coordinate x, which coincides with the details thickness h) can be calculated with the help of the following linear 1D mathematical model (Deliiski, 2003, 2011, 2013b):

$$\frac{\partial T(x,\tau)}{\partial \tau} = a_w(T,u,u_{fsp},\rho_b,S_v)\cdot\frac{\partial^2 T(x,\tau)}{\partial x^2} \qquad (1)$$

with an initial condition

$$T(x, 0) = T_0 \qquad (2)$$

and following boundary conditions:

- from the side of the details heating – at prescribed surface temperature, which is equal to the temperature of the metal heating band T_m:

$$T(0, \tau) = T_m(\tau). \qquad (3)$$

- from the opposite non-heated side of the details – at convective heat exchange between the details surface and the surrounding air environment

$$\frac{\partial T(X,\tau)}{\partial x} = -\frac{\alpha}{\lambda_{ws}(T,u,\rho_b)}\cdot\left[T_{ws}(\tau)-T_a(\tau)\right] \qquad (4)$$

For practical use of eqs. (1) and (4), it is necessary to have mathematical descriptions of wood temperature conductivity, a_w, of wood thermal conductivity, λ_w, and of the heat transfer coefficient between the details surface at their non-heated side and the surrounding air, α. For this purpose, the mathematical description of a_w and λ_w of non-frozen wood given in (Deliiski, 2003, 2013a; Deliiski *et al*., 2015) can be used.

The heat transfer coefficient, α can be calculated with the help of the following equation, which is valid for the cases of cooling or heating of horizontally situated rectangular surfaces in atmospheric conditions of free convection (Chudinov, 1968; Telegin *et al*., 2002):

$$\alpha = 3.256\cdot\left[T_{ws}(\tau)-T_a(\tau)\right]^{0.25} \qquad (5)$$

According to eq. (3), the temperature at the details surface, which is in contact with the heating metal band, is accepted to be equal to its temperature T_m due to the extremely high coefficient of heat transfer between the band and the wood during their very close contact.

2.2 Modeling of the total specific energy consumption for unilateral heating of wood details
2.2. Modeliranje ukupne specifične potrošnje energije za jednostrano zagrijavanje drvenih elemenata

The total specific energy consumption for unilateral heating of wood details, q_{total}, consists of two components:

- energy needed for heating of the wood itself, q_w;
- energy needed for the covering of the heat emission from the non-heated side of wood details, q_e.

This means that the energy q_{total} can be calculated according to the following equation:

$$q_{total} = q_w + q_e. \qquad (6)$$

Analogously, the total heat flux needed for unilateral heating of wood details, dq_{total}/dτ, can be calculated according to the equation

$$\frac{dq_{total}}{d\tau} = \frac{dq_w}{d\tau} + \frac{dq_e}{d\tau}. \qquad (7)$$

2.2.1 Modeling of the specific energy consumption for heating of the wood itself
2.2.1. Modeliranje specifične potrošnje energije samo za zagrijavanje drva

It is known that the specific energy consumption for heating 1 m^3 of solid wood with an initial mass temperature T_0 to a given average mass temperature T_{avg} is determined using the equation (Deliiski, 2013b; Deliiski *et al*., 2014)

$$q = \frac{c_w(T,u)\cdot\rho_w(\rho_b,u,u_{fsp})}{3.6\cdot 10^6}\cdot\left(T_{avg}-T_0\right). \qquad (8)$$

After multiplying the right part of eq. (8) by the detail thickness h, the following equation is obtained for the determination of the specific mass energy consumption needed for heating 1 m^2 of wood details subjected to unilateral heating, q_w:

$$q_{\mathrm{w}} = \frac{c_{\mathrm{w}}(T,u)\cdot\rho_{\mathrm{w}}(\rho_{\mathrm{b}},u,u_{\mathrm{fsp}})\cdot h}{3.6\cdot 10^6}\cdot\left(T_{\mathrm{avg}} - T_0\right), \tag{9}$$

where

$$T_{\mathrm{avg}} = \frac{1}{h}\int_{(h)} T(x,\tau)\mathrm{d}x \tag{10}$$

and according to Chudinov (1968) and Deliiski (2013b)

$$\rho_{\mathrm{w}} = \rho_{\mathrm{b}}\cdot\frac{1+u}{1-\frac{S_{\mathrm{v}}}{100}\cdot\left(u_{\mathrm{fsp}}^{293.15} - u\right)} \quad @ \quad u \le u_{\mathrm{fsp}}. \tag{11}$$

The multiplier 3.6·10^6 in the denominator of eq. (9) ensures that the values of q_w are obtained in kWh·m^{-2}, instead of in J·m^{-2}.

The change in q_w during the time Δτ, i.e. the heat flux needed for heating 1 m^2 of wood details subjected to unilateral heating, dq_w/dτ (in kW·m^{-2}), can be calculated according to equation

$$\frac{\mathrm{d}q_{\mathrm{w}}}{\mathrm{d}\tau} \approx \frac{3600\cdot\Delta q_{\mathrm{w}}}{\Delta\tau}. \tag{12}$$

For practical use of eqs. (9) and (12), it is necessary to have a mathematical descriptions of the specific heat capacity of the non-frozen wood, c_w. Such descriptions are given in (Deliiski, 2003, 2011, 2013b; Deliiski *et al.*, 2015; Radmanović *et al.*, 2014; Deliiski and Dzurenda, 2010).

2.2.2 Modeling of specific energy consumption for covering of the heat emission from the non-heated side of wood details
2.2.2. Modeliranje specifične potrošnje energije za nadoknađivanje emisije topline nezagrijavane strane drvenih elemenata

The change in the specific energy consumption q_e (for 1 m^2 of the details surface), which is required for the covering of the heat emission from the non-heated side of wood details into the surrounding air environment during the time Δτ, can be calculated according to the following equation (Deliiski, 2003; Deliiski *et. al*. 2014a):

$$\Delta q_{\mathrm{e}} = \frac{\alpha(\tau)\Delta\tau}{3.6\cdot 10^6}\cdot\left[T_{\mathrm{ws}}(\tau) - T_{\mathrm{a}}(\tau)\right]. \tag{13}$$

The specific energy consumption required for the covering of the heat emission from 1 m^2 surface of the details during their unilateral heating with duration τ_p = N. Δτ is equal to

$$q_{\mathrm{e}} = \sum_{i=1}^{N}\Delta q_{ei}. \tag{14}$$

The change in q_e during the time Δτ, i.e. the heat flux required for the covering of the heat emission from the non-heated side of 1 m^2 of wood details subjected to unilateral heating, dq_e/dτ (in kW·m^{-2}), can be calculated according to equation (Deliiski *et al.*, 2016b)

$$\frac{\mathrm{d}q_{\mathrm{e}}}{\mathrm{d}\tau} \approx \frac{3600\Delta q_{\mathrm{e}}}{\Delta\tau}. \tag{15}$$

2.3 Transformation of the model to a form suitable for programming
2.3. Transformacija modela u oblik pogodan za programiranje

The following system of equations was derived by passing to final increases in equations (1) to (5) with the use of the same approach, as well as by the explicit form of the finite-difference method described in Deliiski (2003, 2011, 2013b; Deliiski and Dzurenda, 2010):

$$T_i^{n+1} = T_i^n + \frac{a_{\mathrm{w}}\Delta\tau}{\Delta x^2}\cdot\left(T_{i-1}^n + T_{i+1}^n - 2T_i^n\right), \tag{16}$$

$$T_i^0 = T_0 \;@\; 1 \le i \le \mathrm{M} = 9, \tag{17}$$

$$T_1^{n+1} = T_{\mathrm{m}}^{n+1}, \tag{18}$$

$$T_9^{n+1} = \frac{T_8^n + \frac{\alpha^n\cdot\Delta x\cdot T_{\mathrm{a}}^n}{\lambda_{\mathrm{ws}}}}{1 + \frac{\alpha^n\cdot\Delta x}{\lambda_{\mathrm{ws}}}}, \tag{19}$$

$$\alpha^n = 3.256\cdot\left[T_9^n - T_{\mathrm{a}}^n\right]^{0.25}, \tag{20}$$

where

$$\Delta x = \frac{h}{M-1}, \tag{21}$$

$$M = \frac{h}{\Delta x} + 1, \tag{22}$$

$$\Delta\tau \le \frac{\Delta x^2}{a}. \tag{23}$$

The equations (9) and (10) for the computation of the specific energy consumption needed for unilateral heating of wood details results in the following form suitable for programming:

$$q_{\mathrm{w}}^{n+1} = \frac{\rho_{\mathrm{w}}\cdot c_{\mathrm{w}}\cdot h}{3.6\cdot 10^6}\cdot\left(T_{\mathrm{avg}}^{n+1} - T_0\right), \tag{24}$$

where

$$T_{\mathrm{avg}}^{n+1} = \frac{1}{h}\int_{(h)} T[x,(n+1)\Delta\tau]\mathrm{d}x. \tag{25}$$

The highest precision for the solution of eq. (25) is ensured by the use of the Simpson's method instead of the well- known but less accurate trapezoidal method and the method of Gregori's (Deliiski, 2003). According to this method, eq. (25) obtains the following discrete analogue (Dorn and McCracken, 1972):

$$T_{\mathrm{avg}}^{n+1} = \frac{\Delta x}{3}\begin{pmatrix} T_1^{n+1} + 4T_2^{n+1} + 2T_3^{n+1} + 4T_4^{n+1} + \\ 2T_5^{n+1} + 4T_6^{n+1} + 2T_7^{n+1} + 4T_8^{n+1} + T_9^{n+1}\end{pmatrix}. \tag{26}$$

Equation (12) for the computation of the specific heat flux needed for unilateral heating of wood details obtains the following form suitable for programming:

$$\frac{\mathrm{d}q_{\mathrm{w}}^{n+1}}{\mathrm{d}\tau} \approx \frac{3600\Delta q_{\mathrm{w}}^{n+1}}{\Delta\tau}, \tag{27}$$

where

$$\Delta q_{\mathrm{w}}^{n+1} = q_{\mathrm{w}}^{n+1} - q_{\mathrm{w}}^n, \tag{28}$$

$$q_{\mathrm{w}}^n = \frac{\rho_{\mathrm{w}}\cdot c_{\mathrm{w}}\cdot h}{3.6\cdot 10^6}\cdot\left(T_{\mathrm{avg}}^n - T_0\right), \tag{29}$$

$$T_{\mathrm{avg}}^n = \frac{\Delta x}{3}\begin{pmatrix} T_1^n + 4T_2^n + 2T_3^n + 4T_4^n + \\ 2T_5^n + 4T_6^n + 2T_7^n + 4T_8^n + T_9^n\end{pmatrix}. \tag{30}$$

The change in the specific energy consumption q_e (for 1 m^2 of the details surface), required for the covering of the heat emission from the non-heated side of wood details into the surrounding air environment during the time $\Delta\tau$, can be calculated according to the following equation (Deliiski 2003, Deliiski *et al.*, 2016b):

$$\Delta q_e^{n+1} = \frac{\alpha^n(\tau)\Delta\tau}{3.6\cdot 10^6}\cdot\left[T_9^n(\tau) - T_a^n(\tau)\right]. \qquad (31)$$

Equation (15) for the computation of the specific heat flux needed for the covering of the heat emission from the non-heated side of wood details obtains the following form suitable for programming:

$$\frac{dq_e^{n+1}}{d\tau} \approx \frac{3600\cdot\Delta q_e^{n+1}}{\Delta\tau}. \qquad (32)$$

The step on the time coordinate $\Delta\tau$ is determined by keeping the condition for stability of the solution of 1D models by using the explicit form of the finite difference method (Deliiski, 2003, 2011):

$$\Delta\tau \le \frac{\Delta x^2}{a_w}. \qquad (33)$$

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

For the numerical solution of the above presented mathematical model, a software program was prepared in FORTRAN in the calculation environment of Visual Fortran Professional.

With the help of the program, as examples, computations were made for the determination of the 1D non-stationary change of t, t_{avg}, q_w, q_e, q_{total}, $dq_w/d\tau$, $dq_e/d\tau$, and $dq_{total}/d\tau$ for non-frozen spruce (*Picea Abies Karst*) details with h = 6 mm, h = 8 mm, h = 10 mm, t_0 = 20 ºC, u = 0.15 kg·kg^{-1}, ρ_b = 380 kg·m^{-3}, and S_v = 11.4 % during their 10 min unilateral heating at t_m = 100 ºC, t_m = 120 ºC, t_m = 140 ºC, and at t_a = 20 ºC.

The computations were carried out with average values of the spruce temperature conductivity cross-sectional to the fibers, a_w, and values of the spruce thermal conductivity cross-sectional to the fibers, $\lambda_w = \lambda_{ws}$, which have been obtained using the mathematical descriptions of a_w and λ_w depending on t, u, and u_{fsp} of the wood species (Deliiski, 2003, 2013a, Deliiski *et. al.*, 2015). The calculated values of a_w and λ_w with the help of these mathematical descriptions for spruce wood with u = 0.15 kg·kg^{-1} and $u_{fsp}^{293.15} = 0.32\ \text{kg}\cdot\text{kg}^{-1}$ (Nikolov and Videlov, 1987; Deliiski and Dzurenda, 2010) in the temperature ranges from 20 ºC to 100 ºC, from 20 ºC to 120 ºC, and from 20 ºC to 140 ºC, are shown in Table 1.

The linear dependences of a_w and of $\lambda_{ws} = \lambda_w$ on t (Deliiski, 2003, 2013a, 2013b; Deliiski *et al.*, 2015) allow for the solution of the mathematical model using the average arithmetic values of a_w and $\lambda_{ws} = \lambda_w$ in respective temperature ranges (Table 1) for the determination of the temperature distribution along the details thickness during unilateral heating of the details.

Simultaneously with the computation of the non-stationary distribution of t along the details thickness, calculations of t_{avg}, t_{ws}, α, q_w, q_e, q_{total}, $dq_w/d\tau$, $dq_e/d\tau$, and $dq_{total}/d\tau$ were carried out, using the value of the density ρ_w = 445.6 kg·m^{-3} and average arithmetic values of the specific heat capacity c_w given in the last row of Table 1 in respective temperature ranges. This value of ρ_w is calculated according to eq. (11) for spruce wood with u = 0.15 kg·kg^{-1}, $u_{fsp}^{293.15} = 0.32\ \text{kg}\cdot\text{kg}^{-1}$, ρ_b = 380 kg·m^{-3}, and S_v = 11.4 % (Nikolov and Videlov, 1987). The values of c_w were calculated according to the mathematical description of the specific heat capacity of the non-frozen wood in the hygroscopic range given in (Deliiski, 2003, 2011, 2013b). Because of the almost linear dependence of c_w on t, the average arithmetic values of c_w for the respective temperature ranges were used during the solution of eqs. (24) and (29).

The left part of Figure 2 presents the temperature change calculated by the model in 4 characteristic points, equidistant from one another, along the thickness of the detail with h = 8 mm during its unilateral heating at t_m = 140 ºC. The coordinates of these points are shown in the legend of the figure. The right part of this figure shows the change in t_{avg} of the details during their heating at t_m = 140 ºC, depending on h.

Figure 3 presents the change in the surface temperature at the non-heated side of the details, t_{ws}, and in the heat transfer coefficient, α, during unilateral heating at t_m = 140 ºC, depending on h.

Figures 4, 5, and 6 present the calculated change of q_w, q_e, and q_{total} during unilateral heating at t_m = 100 ºC and at t_m = 140 ºC of the spruce details with studied thicknesses.

Figures 7, 8, and 9 present the calculated change of $dq_w/d\tau$, $dq_e/d\tau$, and $dq_{total}/d\tau$ during unilateral heating at t_m = 100 ºC and at t_m = 140 ºC of the spruce details with studied thicknesses.

Table 1 Change in a_w, $\lambda_w = \lambda_{ws}$, and c_w of spruce wood with u = 0.15 kg.kg^{-1}, depending on t
Tablica 1. Promjena vrijednosti a_w, $\lambda_w = \lambda_{ws}$, i c_w za smrekovinu sa sadržajem vode u = 0,15 kg·kg^{-1}, ovisno o temperaturi t

Wood parameter *Svojstvo drva*	**Temperature t, ºC** *Temperatura t, ºC*				**Average arithmetic values of λ_w, a_w, and c_w for temperature ranges:** *Prosječne vrijednosti λ_w, a_w, i c_w za raspon temperatura*		
	20	60	100	140	t =20÷100 ºC	t =20÷120 ºC	t=20÷140 ºC
$\lambda_{ws} = \lambda_w$, W·m^{-1}·K^{-1}	0.2341	0.2664	0.2987	0.3311	0.2664	0.2745	0.2826
$a_w\cdot 10^7$, m^2·s^{-1}	2.5799	2.7412	2.8818	3.0052	2.7309	2.7627	2.7926
c_w, J·kg^{-1}·K^{-1}	2036	2181	2326	2472	2181	2218	2254

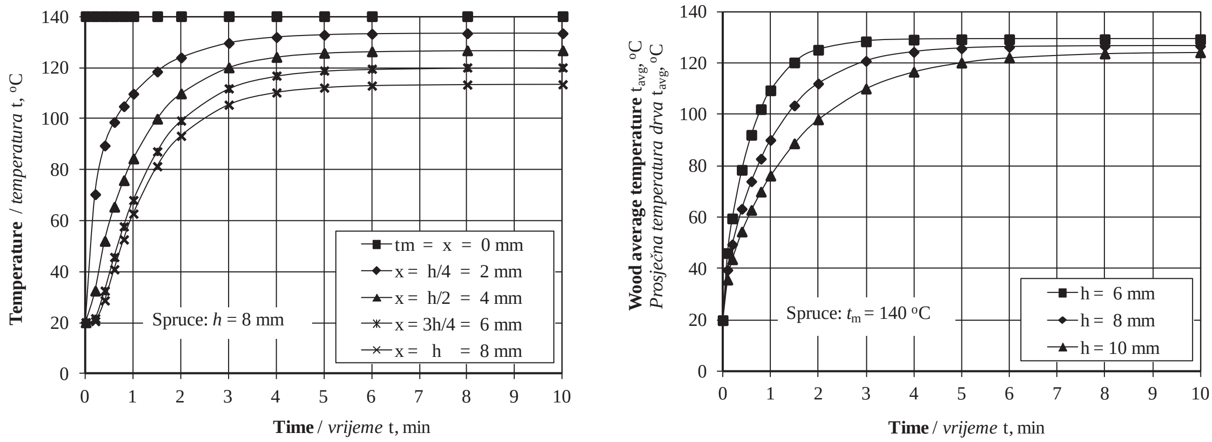

Figure 2 Change in t along the detail thickness of h = 8 mm (left) and in t_{avg} (right) of spruce details with t_0 = 20 ºC, u = 0.15 kg·kg^{-1}, h = 6 mm, h = 8 mm, and h = 10 mm during their unilateral heating at t_m = 140 ºC and at t_a = 20 ºC
Slika 2. Promjena temperature t u smjeru debljine elementa h = 8 mm (lijevo) i prosječne temperature drva t_{avg} (desno) smrekovih elemenata pri t_0 = 20 ºC, u = 0,15 kg·kg^{-1}, h = 6 mm, h = 8 mm i h = 10 mm tijekom njihova jednostranog zagrijavanja pri t_m = 140 ºC i t_a = 20 ºC

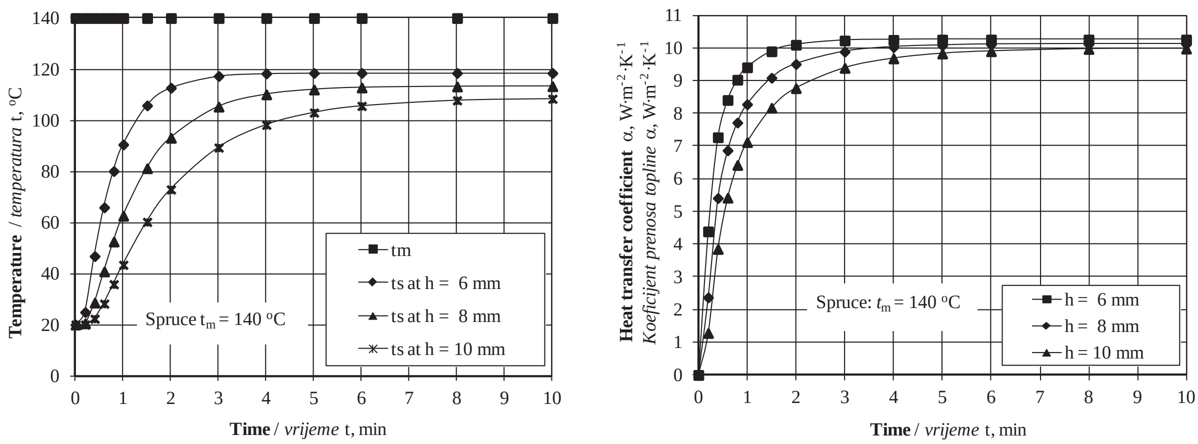

Figure 3 Change in t_{ws} (left) and in α (right) of spruce details with t_0 = 20 ºC, u = 0.15 kg·kg^{-1} during their unilateral heating at t_m = 140 ºC and at t_a = 20 ºC, depending on h
Slika 3. Promjena temperature t_{ws} (lijevo) i koeficijenta prijenosa topline α (desno) smrekovih elemenata pri t_0 = 20 ºC, u = 0,15 kg·kg^{-1} tijekom njihova jednostranog zagrijavanja pri t_m = 140 ºC i t_a = 20 ºC, ovisno o debljini elemenata h

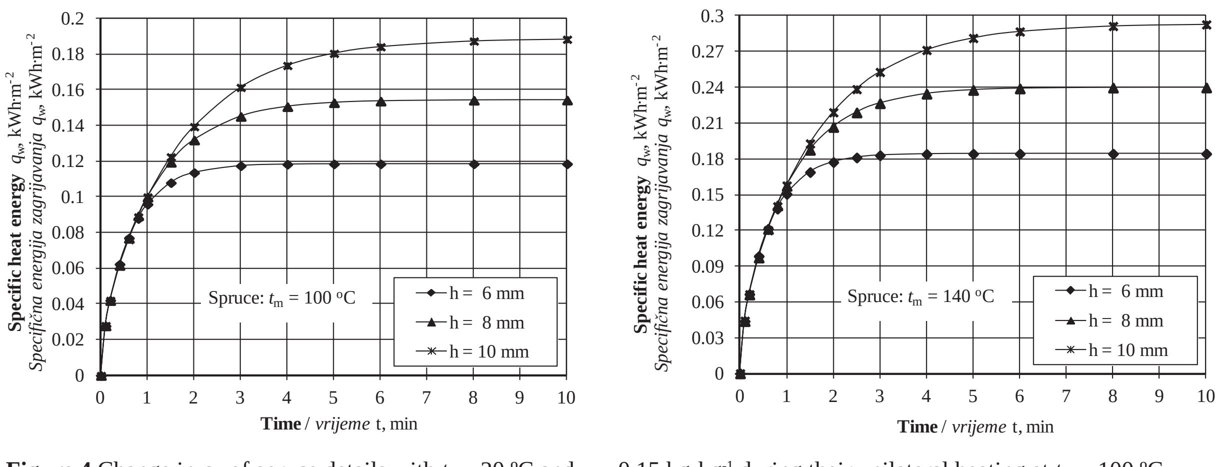

Figure 4 Change in q_w of spruce details with t_0 = 20 ºC and u = 0.15 kg·kg^{-1} during their unilateral heating at t_m = 100 ºC (left) and t_m = 140 ºC (right), depending on h
Slika 4. Promjena specifične energije zagrijavanja q_w smrekovih elemenata pri t_0 = 20 ºC i u = 0,15 kg·kg^{-1} tijekom njihova zagrijavanja pri t_m = 100 ºC (lijevo) i t_m = 140 ºC (desno), ovisno o debljini elemenata h

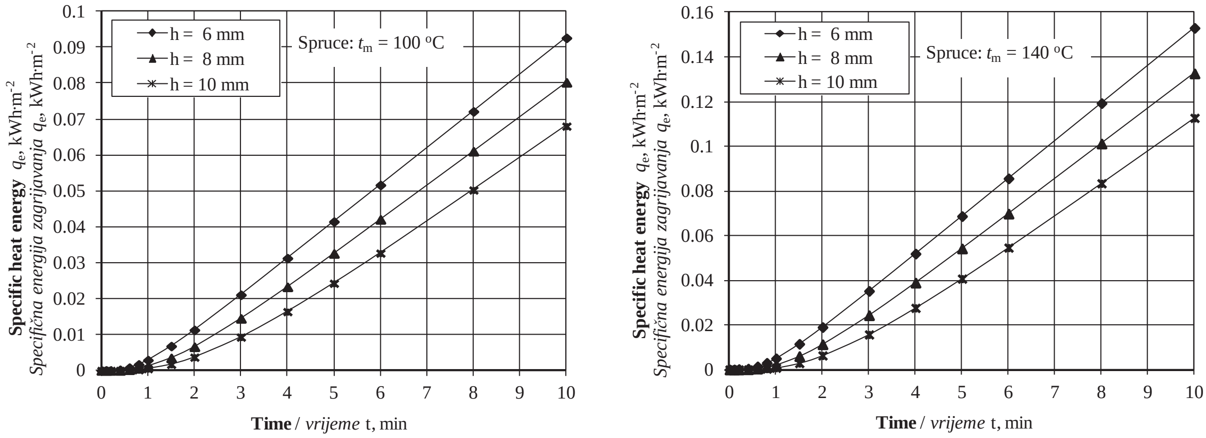

Figure 5 Change in q_e of spruce details with t_0 = 20 ºC and u = 0.15 kg·kg^{-1} during their unilateral heating at t_m = 100 ºC (left) and t_m = 140 ºC (right), depending on h
Slika 5. Promjena specifične energije zagrijavanja q_e smrekovih elemenata pri t_0 = 20 ºC i u = 0,15 kg·kg^{-1} tijekom njihova jednostranog zagrijavanja pri t_m = 100 ºC (lijevo) i t_m = 140 ºC (desno), ovisno o debljini elemenata h

The obtained results show that during unilateral heating of the details, the change of all studied parameters of the process takes place according to complex curves.

By increasing the heating time, the curves of t gradually approach asymptotically their largest values, decreasingly dependent on the remoteness of the characteristic points from the heated surface of the details. Analogously, the curves of the change in t_{avg}, α, q_w, and dq_e/dτ approach asymptotically their largest values, increasingly dependent on t_m and decreasingly dependent on h. The largest values of t, t_{avg}, α,q_w,and dq_e/dτ are achieved when a stationary temperature distribution occurs along the details thickness.

The stationary temperature distribution along the thickness of the studied spruce details (with precision of up to –0.2 ºC) occurs upon reaching the following temperature at their non-heated side:

- for details with h = 6 mm: 86.0 ºC after heating duration of 3.5 min at t_m = 100 ºC, 102.7 ºC after heating duration of 3.8 min at t_m = 120 ºC, 118.5 ºC after heating duration of 3.9 min at t_m = 140 ºC;
- for details with h = 8 mm: 82.7 ºC after heating duration of 6.4 min at t_m = 100 ºC, 98.0 ºC after heating duration of 6.7 min at t_m = 120 ºC, 113.3 ºC after heating duration of 6.8 min at t_m = 140 ºC;
- for details with h = 10 mm: 79.7 ºC after heating duration of 9.7 min at t_m = 100 ºC, 94.2 ºC after heating duration of 10.2 min at t_m = 120 ºC, 108.7 ºC after heating duration of 10.4 min at t_m = 140 ºC.

At t_m = 100 ºC, the most slowly changing temperature of the details surface, t_{ws}, which is in contact with the outside air environment reaches temperatures of 50 ºC, 60 ºC, 70 ºC and 80 ºC, which are necessary for the start of the bending of the details with different radii R after a duration of unilateral heating, equal, respectively, to: 0.6 min, 0.8 min, 1.0 min and 1.8 min at h = 6 mm; 1.1 min, 1.5 min, 2.1 min and 3.9 min at h = 8 mm; 1.7 min, 2.4 min, 3.6 min and ≈10.0 min at h = 10 mm.

At t_m = 120 ºC, the temperature t_{ws} reaches temperatures of 50 ºC , 60 ºC , 70 ºC 80 ºC and 90 ºC, after a duration of one sided heating, equal, respectively, to: 0.5 min, 0.6 min, 0.8 min, 1.0 min and 1.min at h = 6

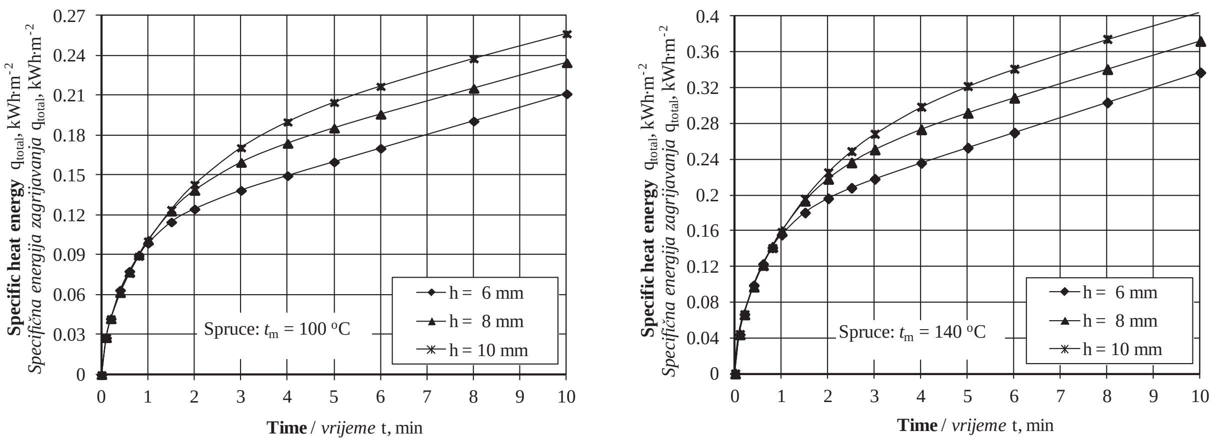

Figure 6 Change in q_{total} of spruce details with t_0 = 20 ºC and u = 0.15 kg·kg^{-1} during their unilateral heating at t_m = 100 ºC (left) and t_m = 140 ºC (right), depending on h
Slika 6. Promjena specifične energije zagrijavanja q_{total} smrekovih elemenata pri t_0 = 20 ºC i u = 0,15 kg·kg^{-1} tijekom njihova jednostranog zagrijavanja pri t_m = 100 ºC (lijevo) i t_m = 140 ºC (desno), ovisno o debljini elemenata h

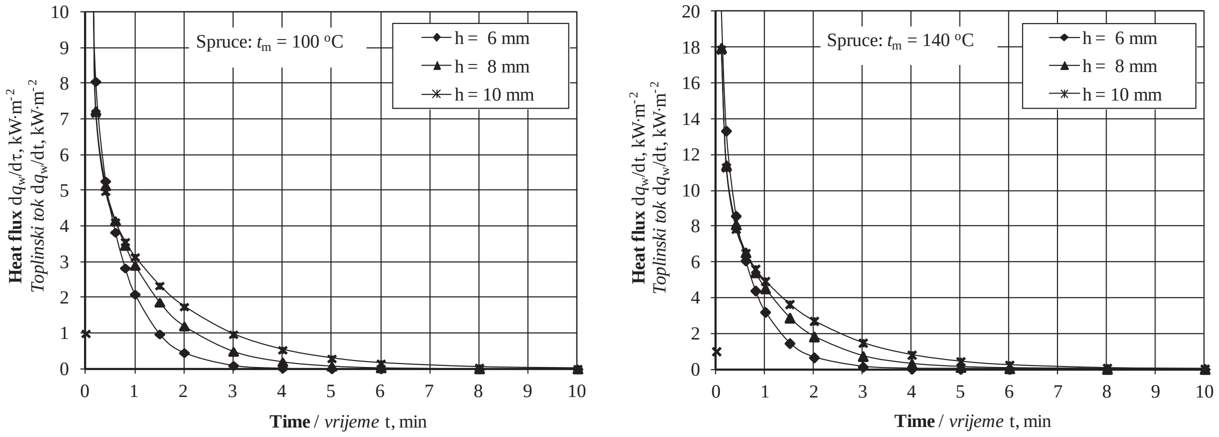

Figure 7 Change in dq_w/dτ of spruce details with t_0 = 20 ºC and u = 0.15 kg·kg^{-1} during their unilateral heating at t_m = 100 ºC (left) and t_m = 140 ºC (right), depending on h

Slika 7. Promjena toplinskog toka dq_w/dτ smrekovih elemenata pri t_0 = 20 ºC i u = 0,15 kg·kg^{-1} tijekom njihova jednostranog zagrijavanja pri t_m = 100 ºC (lijevo) i t_m = 140 ºC (desno), ovisno o debljini elemenata h

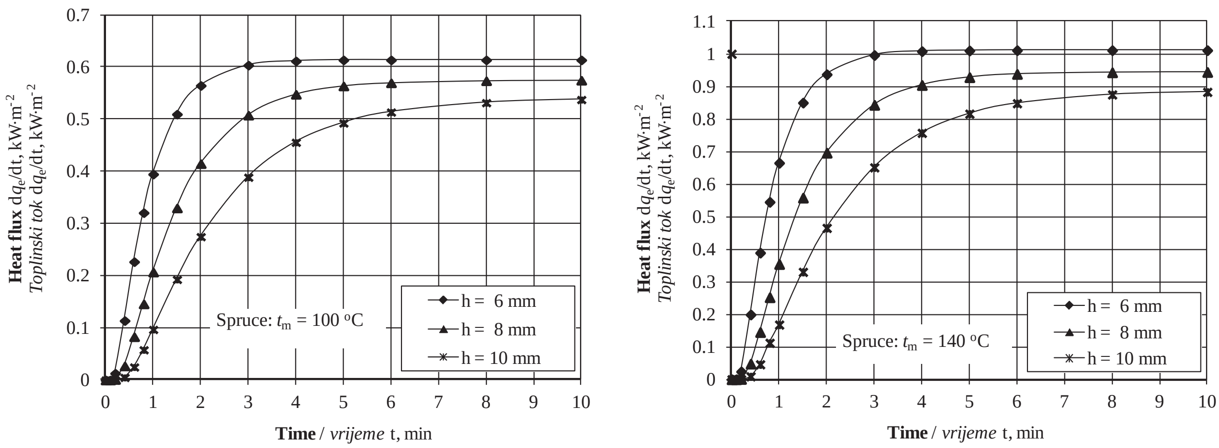

Figure 8 Change in dq_e/dτ of spruce details with t_0 = 20 ºC and u = 0.15 kg·kg^{-1} during their unilateral heating at t_m = 100 ºC (left) and t_m = 140 ºC (right), depending on h

Slika 8. Promjena toplinskog toka dq_e/dτ smrekovih elemenata pri t_0 = 20 ºC i u = 0,15 kg·kg^{-1} tijekom njihova jednostranog zagrijavanja pri t_m = 100 ºC (lijevo) i t_m = 140 ºC (desno), ovisno o debljini elemenata h

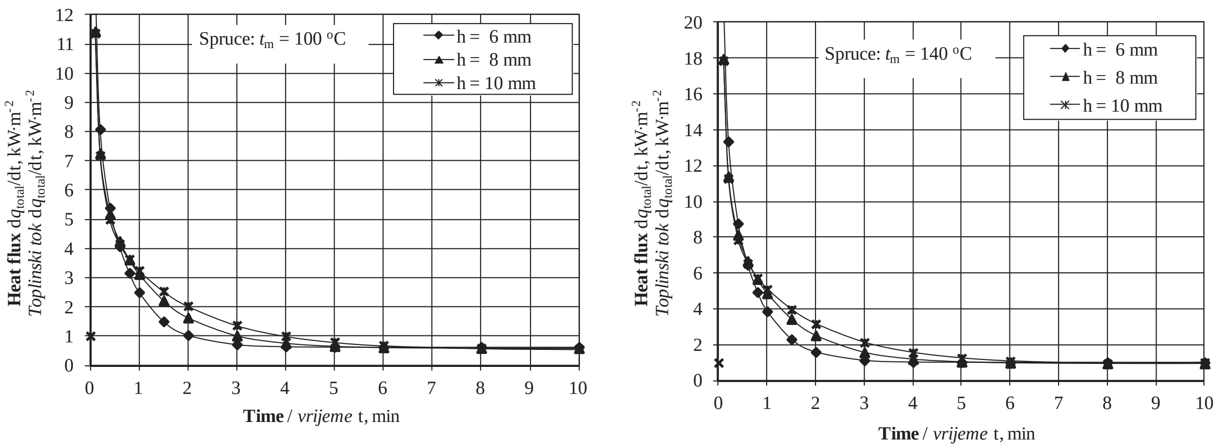

Figure 9 Change in dq_{total}/dτ of spruce details with t_0 = 20 ºC and u = 0.15 kg·kg^{-1} during their unilateral heating at t_m = 100 ºC (left) and t_m = 140 ºC (right), depending on h

Slika 9. Promjena toplinskog toka dq_{total}/dτ smrekovih elemenata pri t_0 = 20 ºC i u = 0,15 kg·kg^{-1} tijekom njihova jednostranog zagrijavanja pri t_m = 100 ºC (lijevo) i t_m = 140 ºC (desno), ovisno o debljini elemenata h

mm; 0.9 min, 1.2 min, 1.5 min, 2.0 min and 2.9 min at h = 8 mm; 1.4 min, 1.8 min, 2.4 min, 3.3 min and 5.3 min at h = 10 mm.

At t_m = 140 ºC, the temperature t_{ws} reaches temperatures of 50 ºC , 60 ºC , 70 ºC 80 ºC, 90 ºC and 100 ºC, after a duration of heating, equal, respectively, to: 0.4 min, 0.5 min, 0.6 min, 0.8 min, 1.0 min and 1.3 min at h = 6 mm; 0.8 min, 1.0 min, 1.2 min, 1.5 min, 1.9 min and 2.5 min at h = 8 mm; 1.2 min, 1.5 min, 1.9 min, 2.5 min, 3.1 min and 4.3 min at h = 10 mm.

By increasing the heating time, q_e and q_{total} increase according to curvilinear dependences, which change into linear after the reaching of stationary distribution of t along the details thickness. The slopes of the linear sections of dependences $q_e = f(\tau)$ and $q_{total} = f(\tau)$ are proportional to t_m.

The values of q_{total} are increasingly dependent on t_m and decreasingly dependent on h. For example, after 10 min duration of unilateral heating, q_{total} reaches the following values:

– for details with h = 6 mm: q_{total} = 0.2115 kWh·m^{-2} at t_m = 100 ºC, q_{total} = 0.2730 kWh·m^{-2} at t_m = 120 ºC, and q_{total} = 0.3372 kWh·m^{-2} at t_m = 140 ºC;
– for details with h = 8 mm: q_{total} = 0.2350 kWh·m^{-2} at t_m = 100 ºC, q_{total} = 0.3022 kWh·m^{-2} at t_m = 120 ºC, and q_{total} = 0.3723 kWh·m^{-2} at t_m = 140 ºC;
– for details with h = 10 mm: q_{total} = 0.2569 kWh·m^{-2} at t_m = 100 ºC, q_{total} = 0.3260 kWh·m^{-2} at t_m = 120 ºC, and q_{total} = 0.4053 kWh·m^{-2} at t_m = 140 ºC.

The change of dq_w/dτ and dq_{total}/dτ during the heating time also takes place according to complex curves. In the beginning of heating, these parameters increase rapidly to values, which are beyond the grading of the Y-axis in Fig. 7 and Fig. 9. This rapid increase of dq_w/dτ and dq_{total}/dτ corresponds to the steep initial sections of dependencies $q_w = f(\tau)$ and $q_{total} = f(\tau)$. After reaching their maximum values, the heat fluxes dq_w/dτ and dq_{total}/dτ begin to decrease – initially very sharply and then more smoothly. When a stationary distribution of t along the details thickness occurs, dq_w/dτ becomes equal to 0. Then dq_{total}/dτ approaches asymptotically its lowest values, increasingly dependent on t_m and decreasingly dependent on h. For example, these lowest values of dq_{total}/dτ for h = 10 mm are equal to 0.552 kW·m^{-2} at t_m = 100 ºC, to 0.726 kW·m^{-2} at t_m = 120 ºC, and to 0.905 kW·m^{-2} at t_m = 140 ºC.

Using the values of q_{total} and dq_{total}/dτ, the minimum necessary power of the heating metal band (refer to Fig. 1) can be determined depending on the desired duration of unilateral heating of details at given values for t_m, h and R/h.

4 CONCLUSIONS
4. ZAKLJUČAK

This paper presents a methodology for mathematical modeling and research of two mutually connected problems: the temperature distribution in flat wood details subjected to unilateral heating and the energy consumption of this process.

The paper describes the development and solution of a 1-dimensional mathematical model of the transient linear heat conduction in flat wood details during their unilateral heating at arbitrary initial and boundary conditions encountered in the practice. Heat distribution along the thickness of wood details from any wood species subjected to such heating is described by the 1D partial differential equation of heat conduction. For the solution of the model, an explicit form of the finite-difference method is used.

Based on the integration of the model's solutions, for the first time a numerical approach is suggested for the computation of the specific energy consumption (for 1 m^2) and the specific heat flux needed for the heating of the details and for the covering of their heat emission during unilateral heating aimed at wood plasticizing and bending.

For the numerical solution of the mathematical model, a software program was prepared in FORTRAN in the calculation environment of Visual Fortran Professional.

The paper shows and analyzes diagrams of a 1D non-stationary and stationary distribution of the temperature along the thickness of flat spruce details subjected to unilateral heating in order to be plasticized before their bending for the production of outside parts for the bodies of string musical instruments. It also shows and analyzes the change of the total specific energy consumption, q_{total}, and its components, and of the total specific heat flux, dq_{total}/dτ, and its components needed for unilateral heating of details. All diagrams are drawn using the results calculated by the model.

The 1D distribution of the temperature and the change of q_{total}, dq_{total}/dτ and of their components for flat spruce details with thickness of 6 mm, 8 mm and 10 mm, initial wood temperature of 20 ºC, and moisture content of 0.15 kg.kg^{-1} during their unilateral heating of 10 min at temperatures of the heating metal body of t_m = 100 ºC, t_m = 120 ºC, t_m = 140 ºC, and temperature of the air near the non-heated side of the details of t_a = 20 ºC have been calculated, visualized and analyzed using the model.

The suggested methodology and algorithm for its realization, as well as the results obtained from the computer solutions of the model could be used for the following purposes:

– Visualization and technological analysis of the temperature change along the thickness of details from different wood species with different thickness and moisture content during their unilateral heating before bending accomplished by a heating body with different temperatures;
– Determination of the time of details heating, which is necessary for achieving the minimum required plasticity of the details before their bending with a specified radius and R/h ratio;
– Computation of the energy consumption of the details at each moment of their unilateral heating;
– Determination of the necessary power of the heating metal body depending on the desired duration of unilateral heating of details at given values for t_m, h и R/h;
– Creation of a scientifically derived model-based automatic control of the unilateral heating process.

The mathematical model could be input into the software of programmable controllers for model predictive automatic control (Deliiski, 2004; Hadjiski, 2013; Hadjiski and Deliiski, 2015) of unilateral heating of wood details used for different purposes after the bending of the details.

The methodology for the development and solution of the model could be further applied in the creation of analogous models, for example, for the calculation of the change of the temperature and energy consumption in flat details during their heating before lacquering (Deliiski *et al*., 2016a) or in equipment walls made of various materials.

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Symbols – Simboli

a = temperature conductivity, $m^2 \cdot s^{-1}$
c = specific heat capacity, $J \cdot kg^{-1} \cdot K^{-1}$
h = thickness, m
M = number of steps on the *x*-coordinate used for solving the model
N = number of steps on the τ-coordinate used for solving the model
q = specific energy consumption, $kWh \cdot m^{-2}$
$dq/d\tau$ = specific heat flux, $kW \cdot m^{-2}$
R = radius, m
S = wood shrinkage, %
t = temperature, ºC: $t = T - 273.15$
T = temperature, K: $T = t + 273.15$
u = moisture content, $kg \cdot kg^{-1}$: $u = W/100$
W = moisture content, %: $W = 100u$
x = coordinate along the thickness of details: $0 \le x \le X = h$
α = heat transfer coefficient, $W \cdot m^{-2} \cdot K^{-1}$
λ = thermal conductivity, $W \cdot m^{-1} \cdot K^{-1}$
ρ = density, $kg \cdot m^{-3}$
τ = time, s
Δx = step on the *x*-coordinate of the model, which coincides with the thickness of wood detail subjected to heating, m
$\Delta\tau$ = step on the τ-coordinate for solution of the model, i.e. interval between time levels, s
Δq = change of *q* for time equal to $\Delta\tau$, $kWh \cdot m^{-2}$
@ = at

Subscripts / indeksi:

a = air (air temperature near the non-heated side of wood details)
avg = average (the average mass temperature of details at a given moment of their unilateral heating or the average arithmetic values of thermo physical characteristics of wood)
b = basic (density, based on dry mass divided by green volume)
e = emission (energy of heat flux needed for covering of the heat emission from the details)
fsp = fiber saturation point of wood
i = nodal point of the calculation mesh along detail thickness: *i* = 1, 2, 3, 4, 5, 6, 7, 8, 9
m = medium (temperature of the heating metal band used for unilateral heating)
p = process (duration of the whole process of unilateral heating)
total = total (energy or heat flux needed both for heating of wood and for covering of the heat emission from the details)
v = volume (wood shrinkage)
w = wood (energy or heat flux needed for heating of wood)
ws = wood surface (non-heated surface of wood details)
0 = initial (the average mass temperature of the details in the beginning of the heating or the time level in the beginning of the model's solution)

Superscripts / eksponenti:

n = time level: *n* = 0, 1, 2, 3, ……., *N*
293.15= at 293.15 K, i.e. at 20 ºC (for the standard values of the wood fiber saturation point)

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The Effect of Altitude Difference on Physical and Mechanical Properties of Scots Pine Wood Grown in Turkey - Sinop Province

Utjecaj nadmorske visine staništa na fizikalna i mehanička svojstva drva običnog bora u turskoj pokrajini Sinop

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ABSTRACT • *In this study, the effect of altitude difference on the physical and mechanical properties of Scots pine (Pinus sylvestris L.) wood was investigated. For this purpose, nine Scots pine trees were selected from three altitudes: 250 m (low altitude), 700 m (intermediate altitude), and 1200 m (high altitude) located in the forestry of Sinop province (Black Sea Region in Turkey). For the physical properties of wood: air and oven dry specific gravity were determined, and for the mechanical properties of wood: compression strength parallel to the grain, static bending strength and modulus of elasticity in static bending were determined. Moreover, the variation of all wood properties was determined related to the altitude difference. The results of statistical analyses showed that the altitude difference was an important factor influencing the physical and mechanical properties of Scots pine wood. The air and oven dry density, compression strength parallel to the grain, static bending strength and modulus of elasticity in static bending were higher at intermediate altitude than at other altitudes.*

Keywords: *Scots pine (Pinus sylvestris L.), altitude difference, site, physical properties of wood, mechanical properties of wood*

SAŽETAK • *U radu su prikazani rezultati istraživanja utjecaja nadmorske visine staništa na fizikalno-mehanička svojstva drva običnog bora (Pinus sylvestris L.). Za istraživanje je odabrano devet stabala običnog bora u šamama pokrajine Sinop (u crnomorskoj regiji Turske) s lokacija različite nadmorske visine: 250 m (mala nadmorska visina), 700 m (srednja nadmorska visina) i 1200 m (velika nadmorska visina). Od fizikalnih svojstava u istraživanju je određena gustoća drva u zrakosuhom i apsolutno suhom stanju, a od mehaničkih svojstava određene su tlačna čvrstoća paralelno s vlakancima, statička čvrstoća na savijanje i modul elastičnosti pri statičkom savijanju. Varijacije svih spomenutih svojstava drva određene su s obzirom na visinske razlike lokacija s kojih su uzorci uzeti. Rezultati statističke analize pokazali su da je nadmorska visina staništa važan čimbenik koji utječe na fizikalno-mehanička svojstva drva običnog bora. Vrijednosti gustoće drva u prosušenom i apsolutno suhom stanju, tlačne čvrstoće paralelno s vlakancima, statičke čvrstoće na savijanje i modul elastičnosti u statičkom savijanju bili su najveći za uzorke uzete s lokacije na srednjoj nadmorskoj visini.*

Ključne riječi: *obični bor (Pinus sylvestris L.), visinska razlika, lokacija, fizikalna svojstva drva, mehanička svojstva drva*

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1 INTRODUCTION
1. UVOD

Scots pine, which has the largest geographical distribution among pine species, covers a rather large natural area of approximately 3700 km in width and 14700 km in length in Europe and Asia (EUFOGEN, 2016). Scots pine has the largest distribution area after Calabrian pine and Black pine in Turkey. It is one of the most used Pine species in silvicultural works. It starts from the east of Eskisehir, encompasses the upper parts of the North Anatolian Mountains eastward and passes to Caucasus in Turkey (GDF, 2007).

Environmental factors can be classified as physiographic factors (altitude, aspect, slope, and side slope), climatic factors (light intensity, temperature, air humidity, precipitation, and wind), edaphic factors (soil characteristics), and biotic factors (humans, animals, plants, and microorganisms) (Cepel 1995). The effects of altitude difference on forest plants have been discussed in many studies (Brazier 1977, Kiaei and Samariha, 2011; Hosseini 2006; Kiaei, 2012; Schweingruber, 2007). The physical and mechanical properties of the Scots pine were studied according to several factors (resonance frequency and ultrasonic techniques, main and normal cutting forces, industrial sawing, heat-treatment, finishing, photodegradation, thermal blending with plastics, etc.) in various studies (Yörür, 2016, Zborowska *et al.* 2015; Budakçı and Karamanoğlu, 2014; Pelit *et al.* 2014; Lehto *et al.* 2014; Wang *et al.* 2014; Hassan *et al.* 2013; Ulker *et al.* 2012; Porankiewicz *et al.* 2011; Ghosh *et al.* 2009). However, there are no studies on the effect of altitude difference on the physical and mechanical properties of the Scots pine.

The aim of this study is primarily to compare some physical and mechanical properties of the Scots pine wood obtained from different altitudes. Afterwards, if gained findings show a statistically significant difference, the aim will be to determine which altitudes are the most suitable in terms of these properties. Finally, the aim of this study is to investigate the effects of altitude on the quality of wood. The outcome expected at the end of the study is to contribute to the research on the use of timber with minimum loss and optimum yield, considering the fact that misused timber leads to great economic losses based on the increasing importance of wooden material.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Wood formation is affected by many factors, such as climate, site, environment, stand conditions, management, genetics and age (Zobel and van Buijtenen, 1989). Therefore, trees were selected in homogenous conditions such as soil (sandy), age (35), directions (North), tree height (15-17 m), diameter (26-28 cm), and the same macroscopic properties such as latewood, annual ring/fiber orientation, and non-defects. All the trees in the stand were dominant. One disk, 5 cm thick, was collected from each tree at breast height for evaluation of physical properties. Test samples from mature wood with 15–30 rings were prepared according to the standard ISO 3129 (1975).

Study material originates from nine trees of *Pinus sylvestris* L. sampled from three different altitude classes of the Sinop province in the north of Turkey. These altitude classes are 250 meter (low altitude), 700 meter (intermediate altitude), and 1200 meter (high altitude). Disks and logs were taken from the trunk 1-2 m in height to determine various wood properties.

Test samples obtained from the lumber were prepared at a sawmill located at the Forestry Faculty of Bartin University, in Turkey. Sampling methods and general requirements for the physical and mechanical tests of the lumber were carried out based on ISO 3129 (1975). The lumber was planed with a knife angle of 45°, and then small clear specimens were cut with the dimensions 20 x 20 x 30 mm (L x W x H) for density measurements; these were taken according to the ISO 3130 (1975) and ISO 3131 (1975). Bending strength was conducted on the samples with the dimensions 20 x 20 x 360 mm according to the ISO 3133 (1975), and elasticity modulus in bending was done on the samples with the dimensions 20 x 20 x 360 mm according to ISO 3349 (1975). The compression strength was done on the samples with the dimensions 20 x 20 x 30 mm according to the ISO 3787 (1976). After the samples were prepared, physical (oven-dry and air-dry density), mechanical tests (bending strength and elasticity in bending and brittleness) were conducted.

All parameters were analyzed using multiple comparisons and analysis of variance (ANOVA). Significant differences between the mean values of samples were evaluated using Duncan's Multiple Range Test. Measurements obtained from the ANOVA tests, mean, standard deviation, variance, minimum, and maximum values were calculated using the SPSS 10.1 computer software program (IBM, USA). Significance was accepted at $P < 0.05$.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

This research examined the effect of altitude variation on physical and mechanical properties of Scots pine wood in Sinop province (Black Sea Region in Turkey). The results of research showed that altitude index had a significant influence on physical and mechanical properties of wood. In order to determine the relationship between the experimental variable (altitude parameters) and physical properties of wood, all the data measured were subjected to an analysis of variance and Duncan's mean separation test. Table 1 shows the results of variance analysis and Duncan's mean separation test for the physical properties of wood. ANOVA and Duncan's Multiple Range Tests showed that there were significant differences between physical and mechanical results according to various altitudes. According to the density results, the mean value of air-dry density in low altitude is 0.504 g/cm^3, in intermediate altitude 0.683 g/cm^3, and in high alti-

Table 1 Results of variance analysis and Duncan's mean separation test for physical properties of wood
Tablica 1. Rezultati analize varijance i Duncanova testa odvajanjem srednjih vrijednosti za fizikalna svojstva drva običnog bora

Altitude, m *Nadmorska visina*, m	**Statistical values** *Statističke vrijednosti*	**Density, g/cm³ /** *Gustoća, g/cm³*	
		Air-dry / *Zrakosuho stanje*	Oven-dry / *Apsolutno suho stanje*
250 (low/*nisko*)	*x*	0.504 (±0.04)	0.479 (±0.04)
	min.	0.416	0.401
	max.	0.640	0.619
	Cov.	8.4	8.7
700 (intermediate/*srednje*)	*x*	0.683* (±0.07)	0.634* (±0.07)
	min.	0.600	0.570
	max.	0.962	0.733
	Cov.	10.6	10.9
1200 (high/*visoko*)	*x*	0.491 (±0.02)	0.443 (±0.02)
	min.	0.436	0.391
	max.	0.537	0.483
	Cov.	3.7	3.6

X – Mean / *srednja vrijednost*; ±s – Standard Deviation / *standardna devijacija*; Min. – Minimum values / *minimalne vrijednosti*; Max. – Maximum values / *maksimalne vrijednosti*; Cov (%) – Coefficient of variation / *koeficijent varijacije*; N – number of samples used in each test / *broj uzoraka upotrijebljen u svakom testu*; * significantly difference at 95 % confidence level (*p*<0.05) / *značajna razlika pri razini pouzdanosti 95 % (p<0,05)*.

tude 0.436 g/cm³. The oven-dry density results in low altitude were 0.479 g/cm³, in intermediate altitude 0.634 g/cm³, and in high altitude 0.443 g/cm³. Both the oven-dry and air-dry density value in intermediate altitude was determined to be higher than other altitudes.

In a study, Krzysik (1978) notified that spruce wood density increases with increasing altitude. However, in another study, Kiaei and Samariha (2011) investigated the effects of altitudes on density of *Pinus Eldarica* Medw, and the results showed that the density for the intermediate altitude was higher than for other altitudes. They explained that the reason for these changes could be ascribed to the tracheid cell wall thickness measured for each altitude index. The results obtained by Kiaei and Samariha (2011) were seen to be similar with the values of density in this study.

Relationship between air-dry density and oven-dry density is shown in Figure 4 for each altitude class. There are positive correlations between air-dry and oven-dry density. However, correlation coefficients between these properties in intermediate altitude are higher than in other altitudes. Table 2 shows the results of variance analysis and Duncan's mean separation test for the mechanical properties. ANOVA and Duncan's Multiple Range Tests showed that there were significant differences between the values. According to Table 2, the mean value of compression strength in low altitude is 47.14 N/mm², in intermediate altitude 64.81 N/mm², and in high altitude 44.16 N/mm², respectively. As seen, the compression strength value in intermediate altitude is higher than in other altitudes. According to the values of bending strength results, it was 79.533 N/mm² in low altitude, 134.210 N/mm² in intermediate altitude and 77.868 N/mm² in high altitude. Obviously, the bending strength value in intermediate altitude is higher than in other altitudes.

Mean value of modulus of elasticity in static bending is 8515 N/mm² in low altitude, 17383 N/mm²

Table 2 Results of variance analysis and Duncan's mean separation test for mechanical properties of wood
Tablica 2. Rezultati analize varijance i Duncanova testa odvajanjem srednjih vrijednosti za mehanička svojstva drva običnog bora

Altitude, m *Nadmorska visina*, m	**Statistical values** *Statističke vrijednosti*	**Compression strength** *Tlačna čvrstoća* N/mm²	**Bending strength** *Čvrstoća na savijanje* N/mm²	**Modulus of elasticity** *Modul elastičnosti* N/mm²
250 (low/*nisko*)	*x*	47.14* (±8.85)	79.53* (±12.22)	8515* (±2562)
	min.	39.14	49.08	3114
	max.	62.71	91.16	10913
	cov	18.79	15	30.08
700 (intermediate/ *srednje*)	*x*	64.81* (±4.29)	134.21* (±21.82)	17383* (±2944)
	min.	58.11	85.73	11651
	max.	70.06	155.58	20315
	cov	6.62	25	16.94
1200 (high/*visoko*)	*x*	44.16* (±3.55)	77.87* (±13.95)	10389* (±1580)
	min.	39.31	53.28	8561
	max.	49.88	99.80	12645
	cov	8.04	17	15.20

X – Mean / *srednja vrijednost*; ±s– Standard Deviation / *standardna devijacija*; Min. – Minimum values / *minimalne vrijednosti*; Max. – Maximum values / *maksimalne vrijednosti*; Cov (%) – Coefficient of variation / *koeficijent varijacije*; N – number of samples used in each test / *broj uzoraka upotrijebljen u svakom testu*; * significantly difference at 95 % confidence level (*p*<0.05) / *značajna razlika pri razini pouzdanosti 95 % (p<0,05)*.

in intermediate altitude, and 10389 N/mm^2 in high altitude. Similarly, bending strength value in intermediate altitude is higher than in other altitudes (low and high altitude). The results of statistical analyses showed that the altitude difference was an important factor influencing the mechanical properties of Scots pine. These differences in wood properties have been reported by Bektas *et al*. (2003) and Keiaei and Samariha (2011).

4 CONCLUSIONS
4. ZAKLJUČAK

The results indicate that there is an important relationship between the physical and mechanical properties of Scots Pine wood and the altitude.

1. According to the properties of density, which is considered an important indicator of wood quality, middle altitude (700 m) can be suggested as the most suitable height for plantations of Scots Pine in future silviculture plans to be realized in the in the region.
2. Compression strength, static bending strength and modulus of elasticity in static bending are higher in intermediate altitude than in other altitude classes.
3. According to this result, when making wooden constructions, bridges, boats and furniture supporting parts, optimum benefit will be gained by using timber obtained from the middle altitude, instead of low (250 m) and high (1200 m) altitudes. In this way, potential economic losses will be prevented. This study has been made for one tree species and one region and provides a base for further studies of other tree species and their growing areas in Turkey and worldwide. As a result, it can be said that the quality of timber provided from low and high altitude will be lower than the quality of timber from middle altitude. Timber from the middle altitude can be recommended.

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Feasibility of Using Foamed Styrene Maleic Anhydride (SMA) Co-polymer in Wood Based Composites

Mogućnosti primjene upjenjenog kopolimera stiren anhidrida maleinske kiseline (SMA) u kompozitima na bazi drva

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ABSTRACT • *Wood plastic composites (WPCs) have often been used in consumer applications, automotive industry and exterior construction. WPCs consist mostly of wood and thermoplastic polymer. WPCs can have superior outdoor durability and much lower maintenance costs than regular wood. WPCs can be used instead of wood. Styrene maleic anhydride (SMA) is used in plastic composites for the automotive industry and also in engineering applications. SMA wood composites, as one of the WPCs using wood fibers as reinforcing fillers, produces composites with mechanical properties that are stiffer and stronger than the neat polymer. This paper evaluates the feasibility of using foamed SMA copolymer composites in wood applications. Although it is currently used in the automotive industry and construction industry, this copolymer presents interesting opportunities for wood applications.*

Key words: *Wood Polymer Composite, Foaming, Styrene Maleic Anhydride (SMA), Physical and Mechanical Properties*

SAŽETAK • *Drvo-plastični kompoziti (WPCs) imaju vrlo široku primjenu, a uglavnom se sastoje od drva i termoplastičnog polimera. Mogu imati vrhunsku trajnost na otvorenome i mnogo niže troškove održavanja od običnog drva te se mogu upotrebljavati svugdje gdje se obično upotrebljava drvo. Stiren anhidrid maleinske kiseline (SMA) primjenjuje se u plastičnim kompozitima za automobilsku industriju, ali i u tehnici. SMA drvni kompoziti jedan su od WPCs-a u kojima su drvna vlakanca punilo za ojačavanje kompozita i imaju bolja mehanička svojstva od čistog polimera. U ovom se radu procjenjuje isplativost upotrebe upjenjenih SMA kopolimera kao zamjene za drvo. Iako se zasad rabi u automobilskoj industriji i graditeljstvu, taj kopolimer ima višestruke mogućnosti primjene kao zamjena za drvo.*

Ključne riječi: *drvo-polimerni kompoziti, pjena, stiren anhidrid maleinske kiseline (SMA), fizikalna i mehanička svojstva*

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1 INTRODUCTION TO WOOD PLASTIC COMPOSITE TECHNOLOGY
1. UVOD U TEHNOLOGIJU DRVO-PLASTIČNIH KOMPOZITA

Wood plastic composite (WPC) is a general term related to wood-based elements like lumber, veneer and fibers, where they are combined with polymers to produce a composite material. Wood plastic composites are thought of interchangeably and are categorized as different material types when produced from either thermoplastic or thermosetting polymers (Forest Products Laboratory, 2010). Examples of wood plastic composites made from different polymer types and wood elements are listed in Table 1.

Approximately one hundred years ago, a composite material combining phenol-formaldehyde resin with wood flour was used for making automobile gearshift knobs (Gordon, 1988). Around 60 years ago, there are references to combining wood with thermoplastic resin via extrusion processing (Oksman and Sain, 2008; Klyosov, 2007). Extrusion, injection and compression molding are the preferred production processes for WPCs (Figure 1).

WPC has gained the interest of material engineers because of its structural properties (El-Haggar and Kamel, 2011). Some of its main properties are high durability, low maintenance, strength and stiffness, lower prices and decrease in bio-degradation, which makes the composites suitable for outdoor applications. Some of the applications of these composites are: decking, sheathing, roof tiles, window trim and automobile parts. WPCs perform like conventional wood; however they are not stiff and may require special fasteners or design changes. WPCs are still stiffer than plastics (Clemons and Caufield, 2005). A developing class of materials, including WPC has favorable attributes – they are cost effective and have good performance (Marutzky, 2004; Bledzki *et al.*, 2002; Sperber, 2002; Riedel and Nickel,2003; Aydemir *et al.*, 2014a; Aydemir *et al.*, 2014b; Aydemir et *al.*, 2015a; Aydemir *et al.*, 2015b).

2 FOAMING PROCESSING OF NATURAL FIBER-FILLED COMPOSITES
2. PROCES PJENJENJA KOMPOZITA ISPUNJENIH PRIRODNIM VLAKNIMA

Blowing agents, nucleating agents and other necessary additives are responsible for creating foams in a polymer (Baker, 2000). Both physical and chemical blowing agents contribute to a foamed polymer. Volatile chemicals like chlorofluorocarbons, hydrocarbons/alcohols, and inert gases (CO_2, N_2, Argon, and Water) are considered physical blowing agents, with CO_2 being the most commonly used (Han *et al.*, 1976; Punnathannam, 2002) (Figure 2).

Figure 1 Wood fiber filled thermoplastic composites (WPCs) and their applications (Anonymous, 2016a)
Slika 1. Termoplastični kompoziti punjeni drvnim vlaknima i njihova primjena (Anonymous, 2016a)

The esterification reaction between the hydroxyl groups of wood and the anhydride groups of SMA generates water, which is used as a foaming agent. The density of neat SMA is 1.08 g/cm^3 and of the foamed SMA/wood composites 0.60 g/cm^3 (Han and Gardner, 2010).

The water by-product of the esterification reaction between SMA and wood is strategically created during the carboxylic acid and alcohol reaction process (Figure 3.). A contaminant from hemicelluloses degradation can be removed after the acids react with alcohols, which produces one mol of ester and another mol of water as a by-product. A hydroxyl group breaks the furan anhydride structure as an electron donator and esterifies with the hydroxyls of wood, which produces water as a by-product (Han and Gardner, 2010) (Figure 4).

Under extrusion processing, a large, soluble amount of a blowing gas into a polymer may be completely dissolved under a high pressure. How-

Table 1 Wood-plastic composites (WPCs) are materials comprising polymers and wood elements (Gardner *et al.*, 2015)
Tablica 1. Drvo-plastični kompoziti (WPCs) – materijali koji sadržavaju polimere i drvne elemente (Gardner *et al.*, 2015.)

Polymer type *Vrsta polimera*	**Wood elements** *Drvni materijal*	**WPC types** *Vrsta drvo-plastičnog kompozita*
Thermoplastic polymer *termoplastični polimer*	Lumber, veneer, fibers, particles, flour, etc. *piljenice, furnir, vlakanca, iverje, drvno brašno i dr.*	Extruded lumber, injection-molded automotive components *ekstrudirana građa, injekcijski prešani automobilski dijelovi*
Thermosetting polymer *termostabilni polimer*	Lumber, veneer *piljenice, furnir*	Polymer impregnated wood (impreg, compreg) *polimerom impregnirano drvo (impreg, compreg)*

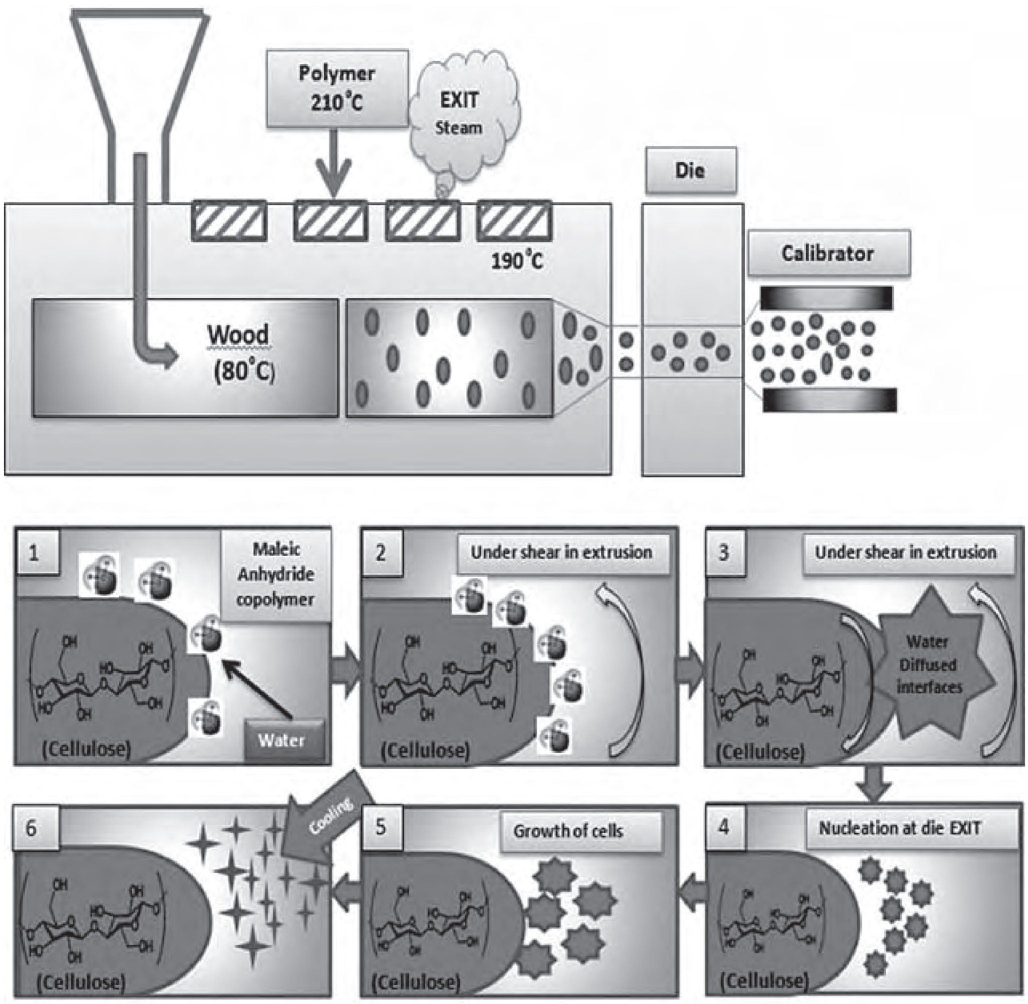

Figure 2 Foaming mechanism with natural fiber-filled composite
Slika 2. Mehanizam pjenjenja kompozita ispunjenih prirodnim vlaknima

ever, to reach appropriate conditions in the microcellular foaming system, there must be a mechanism for regulating the growth of bubbles and additionally preventing them from coalescing and collapsing (Park *et al.*, 1994; Park and Suh, 1996; Baldwin et *al.*, 1996; Park *et al.*, 1998).

The generation of high cell density for foaming may be possible when thermodynamic instability happens in a polymer gas solution. These newly formed cells should be preserved through a stabilization process that controls the growth of the cells and re-equates the gas bubbles (Park and Suh, 1996; Park *et al.*, 1994). During initial testing, a batch process was used to create micro cellulose foams. Now, these foams are produced in continuous extrusion, injection and compression molding systems (Martini *et al.*, 1982).

Extrusion is one of the most commonly used plastic technologies. In extrusion, there are several ways to transform a plastic resin including heated, melted, compressed and conveyed downstream by rotating screw/screws in a barrel. In terms of cost effectiveness, extrusion based technologies are leading in the commercial production of plastics. As compression molding gently shapes thermoplastic prepregs, it successfully retains different layer orientations (Faruk *et al.*, 2007). Wood fiber reinforced plastic composites are converted by extrusion processes to get structural building profiles including, sheathing, decking, roof tiles, and window trim,

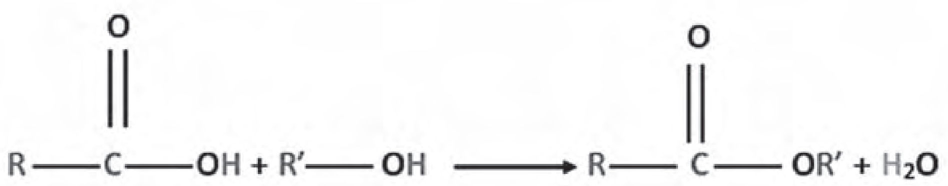

Figure 3 Typical chemical reactions between carboxyl acids and alcohols with acid catalyst (Anonymous, 2016b)
Slika 3. Tipične kemijske reakcije između karboksilne kiseline i alkohola s kiselim katalizatorom (Anonymous, 2016b)

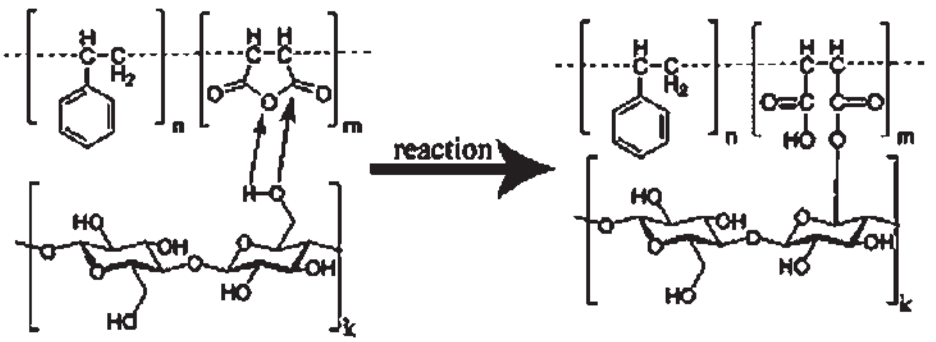

Figure 4 Schematic representation of the interfacial reaction between SMA copolymer and cellulose (Kiziltas *et al.*, 2016)
Slika 4. Shematski prikaz interfacijalne reakcije između SMA kopolimera i celuloze (Kiziltas *et al*., 2016.)

with enhanced thermal and creep performance compared with unfilled plastics (English and Falk, 1996; Verhey and Laks, 2002).

Usually, the production of foamed polymers comes from blowing agents such as a gas, a liquid or solid (Klempner and Frisch, 1991; Tavasoli *et al.*, 2011). There are limitations of using blowing agents because they have a negative impact on the ozone layer. On the other hand, common aliphatic hydrocarbons are highly flammable. The blowing agents have a high price and low gas concentration during their decomposition (Rizvi *et al.*, 2000). The government continues to promulgate regulations aimed at enhancing environmental protection and worker safety. Developing environmentally friendly blowing agents should help in addressing regulations and save on chemicals (Seo *et al.*, 2011). Since water is available, non-toxic and environmentally friendly, it can be used as a blowing agent in the production of foams in the extrusion process when transformed into a gaseous state at temperatures above 100°C.

Several studies have been published on thermal analysis of fillers that can be employed as both nucleating agents and reinforcing components. To enhance performance aesthetics, processability and productivity, many additives in foamed composites are necessary (Klempner and Frisch, 1991). When it comes to the use of natural fillers, such as cellulose particles, it appears to have advantages over inorganic fillers and properties of the fillers that can be changed by either surface treatment or the use of coupling agents (Maldas and Kokta, 1991; Wang *et al.*, 2003; Mishra and Patil, 2003). Fiber properties (orientation of fibers and natural properties of fiber), combined with the use of coupling agents, may enhance the properties of the composite manufactured (Andrepoulus and Trantili, 1988). Natural fibers are much preferred for use in commodity plastics because of their easy processability (Raj *et al.*, 1992). After all, natural fiber-filled polymer composites commonly have high densities. Therefore, the composites can be foamed to lessen their density using chemical or physical blowing agents (Rizvi *et al.*, 2000). Natural filler reinforced composites have shown excellent performance regarding physical, mechanical and thermal properties (Ozen *et al.*, 2013; Kiziltas *et al.*, 2014).

Even though, lignocelluloses and wood fiber reinforced composite are used in automotive and decking application, their use is limited because of lower impact resistance and higher density in comparison to neat plastics (Matuana and Heiden, 2004).

The likely innovative applications of these materials could be increased if these advantages were improved. The reduced weight of foamed plastic makes it stronger than non-foamed analogs, and also makes it achieve outstanding cost to performance ratios, as well as favorable strength to weight ratios. Foamed wood fiber reinforced composites enhance their capability to withstand constant nailing and screwing operations in comparison to un-foamed products of the same composition. In the end, the results are better surface definition and sharper contours and corners. Plasticizing effects of gas and foamed composites reduce the cost of the foaming process (Schut, 2001). The specifics of mechanical properties are significantly improved when microcellular wood fiber reinforced composite generate a finer microcellular structure. Microcellular foamed structures are created to enhance the performance in the composites (Matuana *et al.*, 1996).

3 CHARACTERISTIC PROPERTIES OF FOAMED SMA
3. KARAKTERISTIČNA SVOJSTVA UPJENJENOG SMA KOPOLIMERA

Foamed styrene-wood plastic composites (FSWPC) have been produced at the Advanced Structures and Composites Center at the University of Maine using reactive extrusion (Han *et al.*, 2013). To prevent loss of blowing agents through venting, they are created by chemical reaction during the extrusion process and dissolved into the polymer melt, where the dissolution occurs in the mixing zone of the barrel next to the venting zone. Supercritical water is formed under the high pressure and high temperature enabling foaming cells to locally initiate and grow to a certain size level. For the creation and maintenance of supercritical water, the extrusion system should be developed for appropriate pressure levels with a foaming die.

The industrial manufacturing arena has paid significant attention to the use of wood as reinforc-

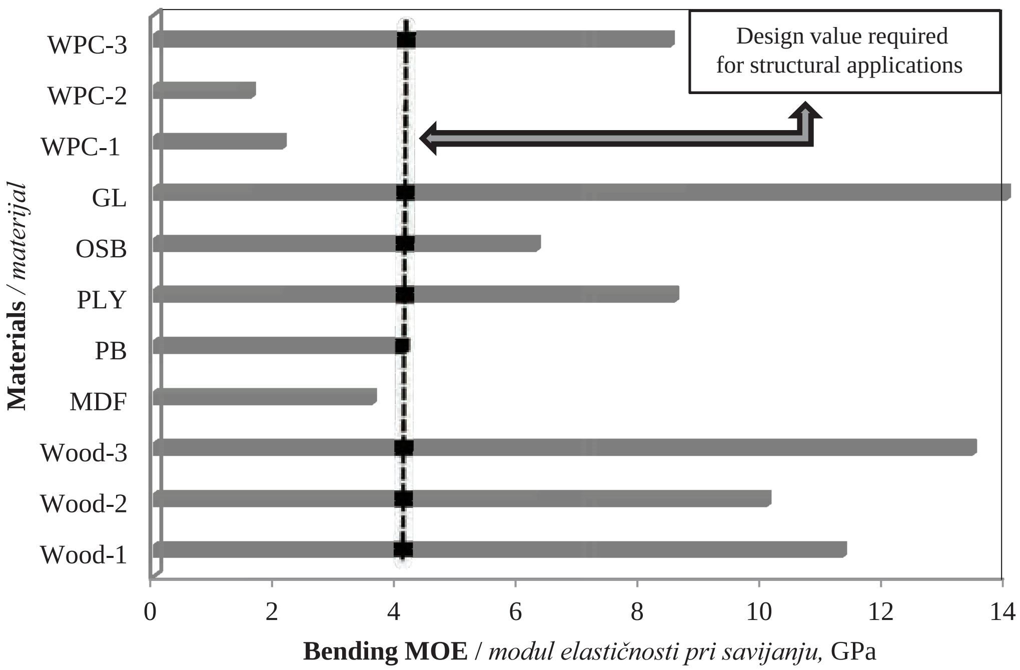

Figure 5 Comparison of flexural modulus of various wooden materials for structural applications (Wood-1 - Red Maple; Wood-2 - White Oak; Wood-3 - Douglas Fir = South; GL - Glued laminated timber; PLY - Plywood; OSB - Oriented Strand Board; PB - Particleboard; MDF - Medium Particleboard (Wood Handbook, 2010); WPC-1 - PP-based 60 % wood (Wechsler *et al.*, 2008); WPC-2 - Recycled PE-based 40 % wood (Najafi and Khademi-Eslam, 2011); WPC-3 - SMA-based wood plastic composite, a pilot product of sheet pile by University of Maine) (Han and Gardner, 2010) (Maximum values are shown)

Slika 5. Usporedba modula elastičnosti različitih drvenih materijala za građevinske konstrukcije (Wood-1 - javor; Wood-2 - bijeli hrast; Wood-3 - duglazija; GL - lijepljena drvna građa; PLY - furnirska ploča; OSB - OSB ploča (ploča s orijentiranim iverjem); PB - ploča iverica; MDF - MDF ploča (ploča vlaknatica srednje gustoće) (Wood Handbook, 2010.); WPC-1 - ploče na bazi PP-a s udjelom drva od 60 % (Wechsler *et al.*, 2008.); WPC-2 - reciklirane ploče na bazi PE-a s udjelom drva od 40 % (Najafi i Khademi-Eslam, 2011.); WPC-3 - drvo-plastični kompoziti na bazi SMA-a, pilot-proizvod Sveučilišta u Maineu) (Han i Gardner, 2010.) (prikazane su maksimalne vrijednosti)

ing filler for thermoplastics (Kishi *et al.*, 1988; Maidas *et al.*, 1988; Woodhams *et al.*, 1984; Yam *et al.*, 1990). The injection molding process and thermoforming of interior parts is used along with styrene maleic anhydride (SMA) copolymer in the automotive industry (ARCO Chemical Company, 1990). The main reason for the choice of maleic anhydride is to improve the properties of the copolymer. The importance of using SMA lies in the fact that it shows a similar behavior to maleic anhydride polypropylene (MAPP) (Takase and Shiraishi, 1989). The other advantages of using SMA plastics in automobiles include the fact that SMA can be recycled and combined with other materials in order to improve the strength properties. Filler effect, reinforcement of polymer, and superior mechanical properties can be improved by using glass fillers. These fillers have shortcomings with regard to environmental safety. Natural fillers can improve the environmental effects. Using natural fillers will enhance mechanical and thermal properties; low density, high aspect ratio and no abrasiveness are beneficial properties (Bledzki *et al.*, 2002; Sperber, 2002; Riedel and Nickel, 2003).

Over the past several decades, it has been established that foamed composites provide high cost savings (30-40 %), lower density and rapid manufacturability attributable to its properties (Faruk *et al.*, 2007; Bledzki and Faruk, 2005; Bledzki and Faruk, 2006).

Micro-fibrillated cellulose, using water as a foaming for PLA matrix composites, was investigated by Boissard *et al.*, (2011). It was found that density and morphological properties of the foams were related to processing temperatures and to water contents ranging from 3.7 to 98 wt.%. To obtain lower densities, a low processing temperature and MFC water content of 9 wt.% were required.

Polystyrene/wood foamed composites were studied by Rizvi *et al.*, (2000), who used hydrocerol compounds and wood particle water (moisture content of 8 %) at 130 °C and 140 °C. These results have shown that expansion ratio was 9 to 20 %.

During the last decade, bigger profiles and density reductions (5-50 %) have been achieved in foamed wood composites including ABS, ASA, SAN, PVC, PP, and monolayer, coextruded and even tri-extruded profiles (Bledzki and Faruk, 2006).

Figure 5 shows the difference in mechanical properties when compared to other wood composites when designing structures. The flexural modulus of elasticity or stiffness is not the only mechanical properties that needs to be considered.

4 ADHESIVE BONDED JOINTS OF WOOD PLASTIC COMPOSITES
4. LIJEPLJENI SPOJEVI DRVO-PLASTIČNIH KOMPOZITA

Many articles have studied the characteristics of WPC bonding (Gramlich *et al.*, 2006; Oporto *et al.*, 2007; Gupta and Laborie, 2007; Laborie and Gupta, 2008; Wolkenhauer *et al.*, 2008; Oporto *et al.*, 2009), specifically polyolefins (Kharitonov and Kharitonova, (2009); Lee *et al.*, (2009); Pandiyaraj KN, *et al.*, (2009); Wang *et al.*, (2009); Farris *et al.*, (2010); Jacobs *et al.*, 2010; Kirk et al., (2010)) and wood treatments (Custodio, *et al.*, 2008; Wolkenhaure *et al.*, 2009; Custodio *et al.*, 2009).Various methods of surface treatments on wood plastic composites have been reported by Gramlich *et al.*, (2006); Oporto et al., (2007); Gupta and Laborie, (2007); Laborie and Gupta, (2008); Wolkenhauer *et al.*, (2008); Oporto *et al.*, (2009) to improve adhesive bonding. These surface treatments resulted in the increase of joint strength.

More research should be made on load carrying capacity of WPC joints as they are used in structural applications. So, this research will help identify the most effective design and cost considerations (Vinson, 1989). Some research has been conducted on bolted joints of WPC panels; however, further research is required (Thoppul *et al.*, 2009). There is no current evidence of the effect of geometrical configuration of screws, pilot hole diameter and penetration depth on withdrawal resistance of related joints of WPC composites.

WPC is used commercially in automotive interiors, furniture, packaging and housing. There are

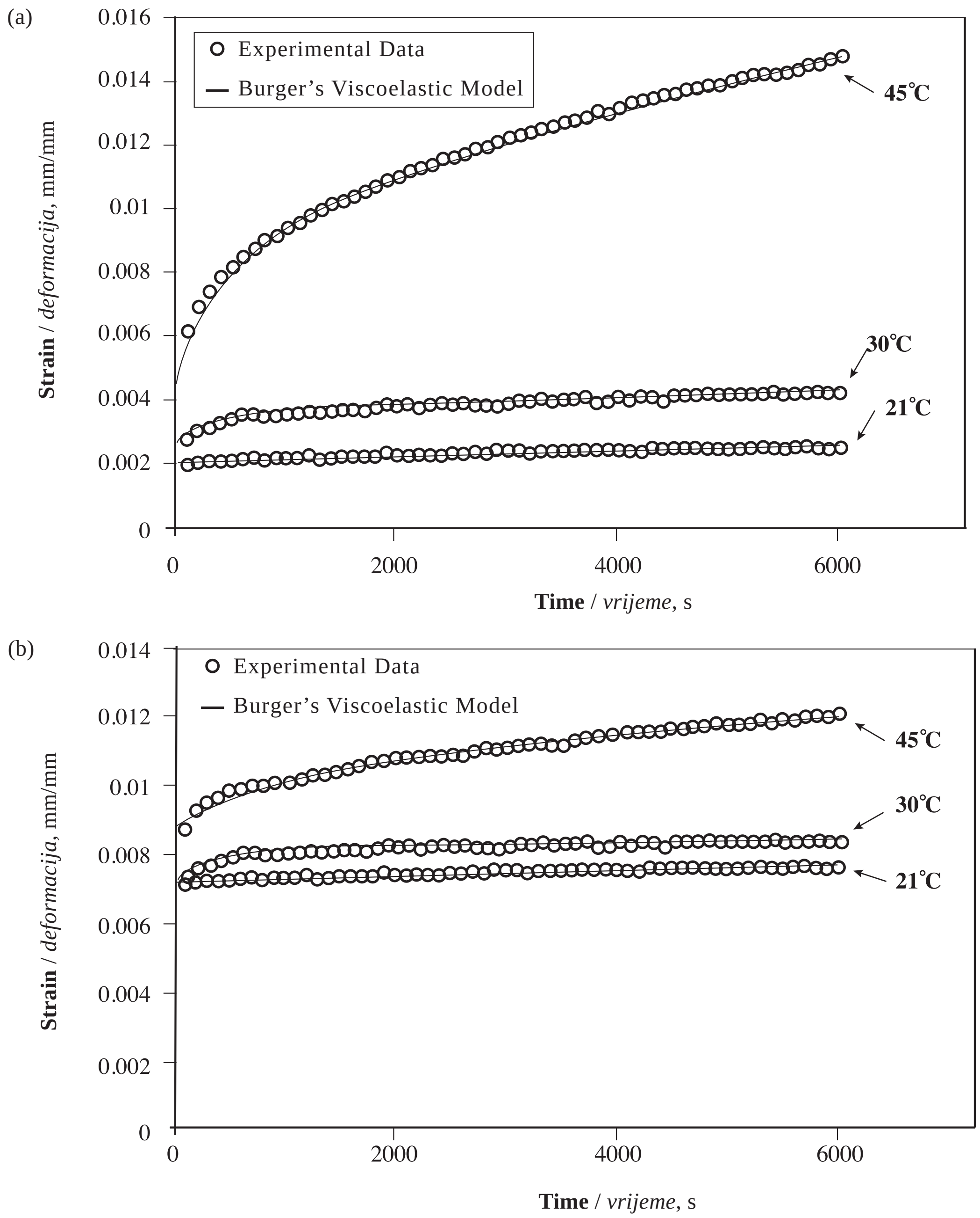

Figure 6 Short-term creep response of (a) WPC and (b) PVC (Tamrakar *et al.*, 2011)
Slika 6. Kratkoročni odgovor puzanja materijala (a) WPC-a i (b) PVC-a (Tamrakar i sur., 2011.)

some critical factors that affect the application of wood plastic composites (English and Falk, 1996). These are:

Cost

There are many variables affecting costs, including cost of compounding fillers, wood and paper fibers or inorganic fillers. Fillers are often less expensive than the polymer on a price per weight basis.

Hygroscopicity

Wood fiber is hygroscopic and when used in the plastic process at normal processing temperatures, the plastics will foam attributable to steam. Water is occasionally used for a foaming agent in plastic lumber profiles.

Fiber loading limits

A continuous thermoplastic matrix is required to process WPC. Upper fiber loading limit is about 70 wt.%. To maintain ideal melt viscosity, the fiber loading limit is around 50 wt.% (Charrier, 1991).

Water absorption

There is little water absorption when wood component is surrounded by the plastics. Even when immersed for several days, the water absorption values are typically less than 2 %. Humidity variation has shown little effect on dimensional changes (Kokta and Danueault, 1986).

Engineering properties

An engineering property is the capability of WPC to safely resist the expected loads. Another property is the short and long term serviceability limits when functioning within the design load.

Creep

Creep is related to the wood's ability to sustain shape during time dependent mechanical loading. Research shows that WPC has lower resistance to creep deflection, which reduces its structural applications (Felby, 1992).

Figure 6 shows the short term creep response of WPC and polyvinyl chloride (PVC) at three different temperatures (21 °C, 30 °C and 45 °C). According to Tamrakar *et al.* (2011), creep deformation of WPC was lower and more stable at 21 °C and 30 °C than that of PVC.

5 CONCLUSION
5. ZAKLJUČAK

Natural fiber-filled plastic profiles are used as a non-structural wood-replacement in specific applications such as decking. Processors are evaluating foamed composites, which weigh less, accept screws and nails and more closely resemble real wood. Foaming gives better surface definition and sharper contours and corners because of internal pressures created by foaming. Heavier foamed profiles can be joined like conventional wood with no caps or hiding edges. Most wood foamed profiles are combined with un-foamed cap layers to provide color, decoration or UV stability, which provides important structure engineering applications.

In recent years, an increasing number of attempts have been made to combine wood with plastics to create interiors (window or door frames, staircase railings, screens and even decorative items), garden furniture and other outdoor applications (terrace decking, weatherboarding and fencing panels).

Industry and academia are now evaluating foam-like structure in WPCs to decrease their density and cost, improve mechanical properties (impact strength and toughness), nailing and screwing properties.

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Projekt *Izgradnja hrvatskoga drvnotehnološkog nazivlja (DRVNA)*

Development of Croatian Terminology in Wood Technology

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SAŽETAK • *Nastavnici Drvnotehnološkog odsjeka Šumarskoga fakulteta Sveučilišta u Zagrebu započeli su rad na projektu Izgradnja hrvatskoga drvnotehnološkog nazivlja (DRVNA), koji je prihvaćen na natječaju Hrvatske zaklade za znanost Izgradnja hrvatskoga strukovnog nazivlja (STRUNA-05-2016), raspisanome u travnju 2016. Projekt je prihvaćen za razdoblje od 1. listopada 2016. do 30. rujna 2017. Dva su osnovna cilja projekta: sustavna izgradnja nazivlja drvnotehnološke struke i njegova popularizacija. Osnovni je zadatak projekta DRVNA izraditi bazu podataka u kojoj će biti objedinjeni pojmovi drvnotehnološke struke, njihove definicije i nazivi na hrvatskom jeziku, zajedno s istovrijednicama na engleskome i njemačkom jeziku. Nazivi će se u elektroničkoj bazi e-Struna dodatno klasificirati na preporučene, dopuštene i nepreporučene nazive te na žargonizme i arhaizme. Na projektu radi tim od 29 profesora, izvanrednih profesora, docenata i asistenata Šumarskoga fakulteta Sveučilišta u Zagrebu, zajedno sa suradnicima iz Instituta za hrvatski jezik i jezikoslovlje koji osiguravaju kroatističku i terminološku provjeru i potvrdu predloženih naziva.*

Ključne riječi: *strukovno nazivlje, hrvatski jezik, drvna tehnologija, biotehničke znanosti*

ABSTRACT • *Experts from Wood Technology Division at the University of Zagreb, Faculty of Forestry have started work on the project "Development of Croatian Terminology in Wood Technology", which has been accepted for the call "Development of Croatian Special Field Terminology (STRUNA)" published by Croatian Science Foundation in April 2016. The project is approved for support from October 1, 2016 to September 30, 2017. The two main goals of the project are to build a Croatian terminology in woodworking profession and to promote its popularization. The main task of the project DRVNA is to create a database with assembled woodworking terms, their definitions and equivalents in English and German. The terms stored in the electronic database STRUNA will be further classified as recommended, admitted, deprecated, obsolete, colloquial and proposed terms. The project has a team of 29 professors, associate professors, assistant professors and assistants from the Wood Technology Department of Faculty of Forestry, University of Zagreb, together with colleagues from the Institute of Croatian Language and Linguistics, who provide the linguistic and terminographic verification of the terminological work in progress.*

Key words: *special field terminology, Croatian language, wood technology, biotechnical sciences*

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1. UVOD
1 INTRODUCTION

Drvnotehnološki odsjek Šumarskog fakulteta jedina je visokoškolska ustanova u Hrvatskoj koja se bavi znanstvenoistraživačkim i nastavnim radom u znanstvenom polju Drvna tehnologija. Iako je na Drvnotehnološkom odsjeku objavljen znatan broj znanstvenih i stručnih publikacija o problematici prerade i obrade drva, na polju drvne tehnologije još uvijek nedostaje izgrađeno i usklađeno strukovno nazivlje. Često se u drvnotehnološkoj struci kao prijevodi pojedinih stručnih pojmova iz njemačkoga ili engleskog jeziku mogu pronaći različiti hrvatski nazivi koji nisu jasni ni jednoznačni, kao i jezične konstrukcije koje nisu u duhu hrvatskog jezika. U stručnim i znanstvenim tekstovima katkad se zbog nedostatka/nepostojanja hrvatskoga nazivlja za pojedine stručne pojmove rabe strani nazivi. Nedostatak hrvatskih istovrijednica za stručne pojmove i nedefinirani hrvatski pojmovi u drvnotehnološkoj struci pojavljuju se i pri radu tehničkih odbora u Hrvatskom zavodu za norme, kao i pri radu Ureda za javnu nabavu. To se posebno očituje pri prevođenju naslova normi i pri sastavljanju natječajne dokumentacije za opremanje prostora proizvodima od drva. Na razvoj hrvatskoga strukovnog jezika u polju drvne tehnologije nepovoljno utječe i trend poticanja znanstvenika da svoje radove objavljuju u prestižnim inozemnim časopisima i na engleskom jeziku kako bi zadovoljili kriterije znanstvenog napredovanja, kao i činjenica da je najveći dio stručne i znanstvene literature na području drvne tehnologije objavljen na njemačkome i engleskom jeziku. Budući da je izgradnja nazivlja preduvjet uspješnoga stručnoga i znanstvenog sporazumijevanja unutar i izvan drvnotehnološke struke, navedena je problematika bila snažan poticaj za prijavljivanje projekta *Izgradnja hrvatskoga drvnotehnološkog nazivlja (DRVNA).* Cilj je ovoga rada stručnoj i široj javnosti predstaviti projekt *DRVNA* koji financira Hrvatska zaklada za znanost i program STRUNA, unutar kojega se ovaj projekt i provodi.

2. STRUNA – HRVATSKO STRUKOVNO NAZIVLJE
2 CROATIAN SPECIAL FIELD TERMINOLOGY

STRUNA je terminološka baza hrvatskoga strukovnog nazivlja u kojoj se sustavno prikuplja, stvara, obrađuje i tumači nazivlje različitih struka radi izrade, usklađivanja i normiranja nazivlja u hrvatskome jeziku (www.struna.hr).

Nazivlje je iznimno važan dio standardnoga jezika i jedan od preduvjeta za jednoznačno stručno i znanstveno sporazumijevanje. Izgradnja terminološke infrastrukture zahtjevan je i složen posao koji podrazumijeva interdisciplinarni pristup, tj. suradnju stručnjaka pojedinih struka s jedne te jezikoslovaca (terminologa, standardologa) s druge strane. STRUNA je jedini program u sklopu kojega se aktivno i sustavno provodi terminološko planiranje u Republici Hrvatskoj. Program je pokrenut na inicijativu Vijeća za normu hrvatskoga standardnog jezika pri Ministarstvu znanosti, obrazovanja i športa, koje je nakon iscrpnih rasprava o stranim riječima u hrvatskom jeziku zaključilo da se uputi pismo Nacionalnoj zakladni za znanost (danas Hrvatska zaklada za znanost) s pozivom da pokrene projekte izrade hrvatskoga nazivlja, i to suradnjom stručnjaka za različita područja i jezikoslovaca. Hrvatska je zaklada za znanost 2007. raspisala natječaj za izbor nacionalnog koordinatora izrade hrvatskoga strukovnog nazivlja na kojemu je izabran Institut za hrvatski jezik i jezikoslovlje. Institut je 2008. započeo projekt *Hrvatsko strukovno nazivlje (STRUNA)* s ciljem izgradnje ujednačenoga i verificiranoga hrvatskog nazivlja usklađenoga s normom hrvatskoga standardnog jezika.

Hrvatska zaklada za znanost financijski je podupirala program *STRUNA* od 2008. do 2013. godine te ponovno od rujna 2016. Do sada su u javno dostupnu e-bazu *STRUNA-e* uneseni rezultati osamnaest projekata. *Anatomija i fiziologija*, *Antropologija*, *Brodostrojarstvo*, *Fizika*, *Pravo EU-a*, *Vojno nazivlje* – samo su neki od njih.

U radu na izgradnji hrvatskoga strukovnog nazivlja primjenjuje se prilagođena inačica tradicionalnoga terminografskog opisa koja se temelji na načelima razrađenima u normama ISO-a (u sklopu Tehničkoga odbora 37) i u drugoj terminološkoj literaturi. Znanstvena i umjetnička područja raspoređena su prema razredbi iz Pravilnika Nacionalnoga vijeća za znanost objavljenoga 2009. godine.

STRUNA je osmišljena kao program koji će omogućivati i olakšavati stručnu i znanstvenu komunikaciju stručnjacima pojedinih struka, rad stručnih prevoditelja te poboljšavati kakvoću i učinkovitost visokoga obrazovanja.

Spomenuli smo da je za uspješan terminološki rad nužan interdisciplinarni pristup, tj. suradnja stručnjaka pojedinih područja i jezikoslovaca. Dok stručnjaci odabiru korpus koji se unosi u *STRUNA-u*, razrađuju ontološki sustav svoje struke, definiraju odabrane pojmove prema jasno definiranim načelima i donose istovrijednice na stranim jezicima, terminolozi i terminografi iz Instituta za hrvatski jezik i jezikoslovlje brinu se za uspostavu i odabir odgovarajućih naziva i njihovu harmonizaciju te daju savjete pri oblikovanju definicija (Bergovec, Runjaić, 2012.).

Kako je cilj terminološkog opisa normiranje naziva, u bazi se preporučuje uporaba jezično najprihvatljivijeg naziva za određeni pojam. Zadaća je Instituta za hrvatski jezik i jezikoslovlje predložiti jezično najprihvatljiviji naziv koji se najbolje uklapa u sustav hrvatskoga standardnog jezika, ali i u sustav nazivlja struke o kojoj je riječ.

Međutim, u bazu se unose i drugi supostojeći nazivi za isti pojam, no ti se nazivi normativno jasno stratificiraju. Tako se u bazi razlikuju naziv i njegove istoznačnice koje mogu biti označene kao *dopušteni naziv*, *predloženi naziv*, *nepreporučeni naziv*, *zastarjeli naziv* i žargonizam.

Dopušteni naziv onaj je koji se rabi u struci kao istoznačnica preporučenog naziva, ali je normativno manje prihvatljiv od preporučenoga.

Kako je pri terminološkom normiranju bitan konsenzus stručnjaka i jezikoslovaca, ako stručnjaci ne prihvate naziv što su ga predložili stručnjaci Instituta, taj se naziv navodi u posebnoj rubrici kao *predloženi naziv*.

Nepreporučenim nazivima smatraju se nazivi koji nisu prihvatljivi za uporabu u strukovnom jeziku jer su jezično neprihvatljivi odnosno pogrešno ili nepotpuno izražavaju pojam na koji se odnose.

Zastarjeli su nazivi oni koji se više ne upotrebljavaju, a žargonizmi izrazi koji se rabe u neslužbenoj komunikaciji među stručnjacima.

Unijevši u bazu bilo koji od tih naziva (npr. žargonizam ili nepreporučeni naziv), korisnik može doći do preporučenoga naziva, što bazu čini korisnom stručnjacima, studentima, prevoditeljima, pa i široj zainteresiranoj javnosti.

O svim se unosima u bazu (definicijama, nazivima, stranojezičnim istovrijednicama) raspravlja na projektnim radionicama, a problemi se redovito rješavaju suradnjom i praćenjem rada u terminološkoj bazi.

3. O PROJEKTU *IZGRADNJA HRVATSKOGA DRVNOTEHNOLOŠKOG NAZIVLJA (DRVNA)*
3 ABOUT PROJECT „DEVELOPMENT OF CROATIAN TERMINOLOGY IN WOOD TECHNOLOGY“

Hrvatska zaklada za znanost raspisala je u travnju 2016. natječaj *Izgradnja hrvatskoga strukovnog nazivlja (STRUNA)* čiji je cilj izrada baze podataka hrvatskoga strukovnog nazivlja pojedinih struka uz prijevodne istovrijednice na drugim jezicima. Na natječaj je zaprimljeno 20 projektnih prijava, a projekt *Izgradnja hrvatskoga drvnotehnološkog nazivlja (DRVNA)* jedan je od šest projekata prihvaćenih za financiranje u ovom krugu natječaja (www.hrzz.hr) i jedini projekt s područja biotehničkih znanosti. Osnovni su ciljevi predloženog projekta izrada nazivlja drvnotehnološke struke i njegova popularizacija. Na projektu radi tim od 29 profesora, izvanrednih profesora, docenata i asistenata Drvnotehnološkog odsjeka Šumarskoga fakulteta Sveučilišta u Zagrebu, zajedno s dvoje suradnika iz Instituta za hrvatski jezik i jezikoslovlje, koji osiguravaju kroatističku i terminografsku provjeru i potvrdu predloženih naziva. Interdisciplinarnom suradnjom stručnjaka za pojedina područja drvne tehnologije i jezikoslovaca koji će provoditi terminološku i jezičnu verifikaciju nazivlja izradit će se terminološka zbirka drvnotehnološke struke.

Projekt je započeo održavanjem prvih dviju radionica u suradnji s Institutom za hrvatski jezik i jezikoslovlje. Na radionicama je predstavljen cijeli projekt *STRUNA* i projektni je tim upoznat s osnovnim jezičnim i terminološkim načelima pri odabiru i obradi naziva te s tehnikom rada u bazi. Nakon edukacije i definiranja referentne literature predviđeno je da projektni tim odabere pojmove koje će obrađivati u sklopu projekta. Nakon izrađenog popisa literature i okvirnog popisa pojmova po granama i disciplinama, predviđena je treća radionica na kojoj će nastavnici biti upoznati s načelima tvorbe hrvatskih naziva, razlikama između preporučenih, dopuštenih i predloženih naziva te s pripremom korpusa i harmonizacijom podataka. Nakon toga slijedi unošenje podataka u bazu, u skladu s preporukama terminologa i jezičnih savjetnika iz Instituta za hrvatski jezik i jezikoslovlje. Pri kraju četvrtog mjeseca provođenja projekta predviđena je terminološko-jezična (četvrta) radionica na kojoj bi terminolog i jezikoslovac na temelju analize podataka unesenih u bazu upozorili stručnjake na najčešće pogreške (jezične, pogreške u oblikovanju definicija itd.). Cilj je radionice zajednička analiza pogrešaka i rasprava o njima.

Osim izrade drvnotehnološkog nazivlja, cilj predloženoga projekta jest i popularizacija tog nazivlja. Već u prvome mjesecu provođenja projekta izrađena je mrežna stranica s osnovnim informacijama o projektu i s mogućnošću davanja prijedloga i sugestija vezanih za nazivlje (http://drvna.weebly.com/).

Nakon polugodišnjeg izvješća predviđena je prva diseminacijska radionica na kojoj će se projekt i prvi rezultati predstaviti strukovnim udruženjima s područja drvne tehnologije (Komora inženjera šumarstva i drvne tehnologije, Udruga inženjera drvne tehnologije, Hrvatski drvni klaster, Udruženje drvne industrije pri HGK), Ministarstvu poljoprivrede i Ministarstvu gospodarstva, Uredu za javnu nabavu te predstavnicima drvodjeljskih škola i drugih ustanova koje bi izrada drvnotehnološkoga nazivlja mogla zanimati. U posljednjem mjesecu projekta predviđena je završna diseminacijska radionica, na kojoj će rezultati projekta biti predstavljeni svim zainteresiranima za drvnotehnološko nazivlje. Pri izradi hrvatskoga drvnotehnološkog nazivlja u sklopu projekta *DRVNA* primjenjivat će se metodologija i načela terminološkog rada koja preporučuje nacionalni koordinator za izgradnju hrvatskoga strukovnog nazivlja.

4. ZAKLJUČAK
4 CONCLUSION

Nazivlje je iznimno važan dio standardnog jezika i jedan od preduvjeta za jednoznačno stručno i znanstveno sporazumijevanje. Zadatak znanstvenika na svim znanstvenim područjima, pa tako i na području drvne tehnologije, jest praćenje razvoja struke i stvaranje strukovnog nazivlja. U sklopu projekta *DRVNA*, u suradnji s Institutom za hrvatski jezik i jezikoslovlje, izgradit će se baza podataka hrvatskog nazivlja drvnotehnološke struke, uz prijevodne istovrijednice na engleskome i njemačkom jeziku. Na taj će se način obogatiti hrvatsko strukovno nazivlje općenito, olakšati studentima praćenje literature i mobilnost u sklopu programa ERASMUS te olakšati komunikacija stručnjacima unutar i izvan struke. Hrvatska terminološka baza s unesenim prijevodnim istovrijednicama znatno će pridonijeti kvaliteti prevođenja normi i ostalih dokumenata s područja drvne tehnologije te omogućiti široj javnosti i stručnjacima ostalih struka pravilnu uporabu termina iz područja drvne tehnologije.

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Oxystigma oxyphyllum J. Léonhard

UDK: 674.031.738.36

NAZIVI

Oxystigma oxyphyllum J. Léonhard naziv je drva botaničke vrste iz porodice *Leguminosae*, potporodice *Caesalpinioideae*. Trgovački su nazivi drva te vrste tchitola (Njemačka, Francuska, Kongo); rotes tola (Njemačka); tola chinfuta, tola mafuta (Angola); m'babou (Gabon); lolagbola (Gana, Nigerija); kitola, tuba (Kongo).

NALAZIŠTE

Stabla *Oxystigma oxyphyllum* J. Léonhard rastu u zapadnoj i srednjoj Africi. Areal im se proteže od Nigerije preko cijeloga Gvinejskog zaljeva sve do Angole. Ne rastu u čistoj sastojini, već u zajednici s vrstama tola i faro.

STABLO

Naraste 20 do 45 metara, duljina debla mu je od 15 do 20 metara, a prsni promjer od 0,6 do 1,8 metara. Stabla su cilindričnog oblika. Kora mladog drva je glatka, a na zrelom je drvu raspucana, zelenkastosiva. Debljina kore kreće se od 1,0 do 3,0 centimetra.

DRVO

Makroskopska obilježja

Bjeljika i srž međusobno se razlikuju. Bjeljika je bljedoružičasta do crvenkastosiva, vrlo smolasta, izrazito široka (katkad i do 12 centimetara), u ekstremnim primjerima čini i dvije trećine poprečnog presjeka. Srž je crvenkastosmeđa, s manje smole od bjeljike. Često je vidljiva diskoloracija s crnim ili svjetložutim uzdužnim linijama. Tekstura drva je fina do gruba, jednolična, mramorastog izgleda, izbrazdana, matirana do dekorativna. Svježe posječeno drvo ugodnog je mirisa. Na poprečnom su presjeku uočljive granice godova, pore i uzdužni parenhim. Na radijalnom presjeku drvni traci zrcalno sjaje.

Mikroskopska obilježja

Traheje su pretežito pojedinačno raspoređene, a pojavljuju se i u paru ili u skupinama. Promjer traheja je 80...160...200 mikrometara, a gustoća 2...4...10 na 1 mm^2 poprečnog presjeka. Volumni udio traheja iznosi oko 11 %.

Aksijalni parenhim je apotrahealno marginalan, paratrahealno vazicentričan, paratrahealno aliforman, konfluentan i uniltateralan. Volumni je udio aksijalnog parenhima oko 11 %.

Drvni su traci heterogeni, visine 450...1000...2000 mikrometara, odnosno 10...50...90 stanica, širine 20...31...46 mikrometara, odnosno 1...2...3 stanice. Gustoća drvnih trakova je 4...6...8 na 1 mm poprečnog presjeka. Volumni udio drvnih trakova iznosi oko 18 %. Drvna su vlakanca libriformska. Dugačka su 750...1550...2300 mikrometara. Debljina staničnih stijenki vlakanaca iznosi 2,4...3,9...4,8 mikrometara, a promjer lumena 3,7...7,5...12,3 mikrometara. Volumni je udio vlakanaca oko 60 %.

Fizička svojstva

Gustoća standardno suhog drva, ρ_o	550...600 kg/m^3
Gustoća prosušenog drva, ρ_{12-15}	580...630...670 kg/m^3
Gustoća sirovog drva, ρ_s	800...850...900 kg/m^3
Poroznost	oko 64 %
Radijalno utezanje, β_r	oko 3,9 %
Tangentno utezanje, β_t	7,5 %
Volumno utezanje, β_v	8,3···9,5 %

Mehanička svojstva

Čvrstoća na tlak	oko 57 MPa
Čvrstoća na savijanje	oko 105 MPa
Čvrstoća na vlak, okomito na vlakanca	oko 2,5 MPa
Modul elastičnosti	14 960 MPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Drvo se dobro i bez teškoća ručno i strojno obrađuje. Zbog povećanog sadržaja smole brže zatupljuje alate. Dobro se ljušti, reže i blanja. Obrađene površine imaju lijep taman sjaj. Smola u drvu otežava lakiranje. Drvo se lako čavla i dobro drži vijke. Obrađeno je drvo postojano.

Sušenje

Pri sušenju je potrebno obratiti pozornost na smolu u drvu, koja može prouzročiti mrlje. Drvo se dobro suši prirodnim postupkom i u sušionicama. Treba izbjegavati visoke temperature sušenja.

Trajnost i zaštita

Prema normi HRN 350-2, 2005, srž drva srednje je otporna na gljive uzročnice truleži (razred otpornosti 3) i srednje otporna na termite (razred otpornosti M). Srž je slabo do slabo permeabilna (razred 3 – 4). Po trajnosti pripada razredu 2 i stoga se može upotrebljavati u unutarnjim i u natkrivenim prostorima. Drvo koje je povremeno izloženo vanjskim utjecajima treba na odgovarajući način zaštiti, dok se trajno izlaganje vanjskim utjecajima ne preporučuje ni uz zaštitu.

Uporaba

Drvo se upotrebljava u industriji furnira i furnira za izradu šperploča, za izradu unutarnje stolarije, kutija i sanduka te dijelova namještaja.

Sirovina

Drvo se isporučuje u obliku trupaca dužine 4,0 metra, najčešće srednjeg promjera od 80 do 130 centimetara.

Napomena

Nije na popisu ugroženih vrsta međunarodne organizacije CITES ni na popisu međunarodne organizacije IUCN Red list. Manje smolasto drvo može se iskorištavati kao zamjena za orahovinu (*Juglans* spp.). Drvo sličnih svojstava imaju i ove vrste drveća: *Oxystigma manii* Harms, *Oxystigma* spp., *Daniellia ogea* Rolfe, *Daniellia* spp., *Gossweilerodendron balsamiferum* Harms, *Prioria copaifera* Gris.

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

Upute autorima

Opće odredbe

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

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

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

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

Upute

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

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

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

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

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

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

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

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

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

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

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

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

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

Primjeri navođenja literature

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

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).

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

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