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Piotr Beer, Sylwia Olenska, Izabela Podobas, Marcin Zbiec[1]

Design for AAL Integrated Furniture for the Care and Support of Elderly and Disabled People

Dizajn za AAL integrirani namještaj za brigu i pomoć starijim osobama i osobama s invaliditetom

Original scientific paper • Izvorni znanstveni rad
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ABSTRACT • *The European furniture sector is a key driver of sustainable growth, with a significant contribution to Europe's overall economic health, competitiveness, creativity, innovation, employment and exports. It provides 1.08 million jobs to the European economy, and the needs of the European population in the future are one of the key factors of its improvement. By 2050, the number of people in the EU aged 65 and above is expected to grow by 70 % and the number of people aged over 80 by 170 %! Ambient Assisted Living (AAL) allows people to live at home for longer, despite cognitive or physical impediments. AAL is the answer for the growing elderly population in most European economies, and is a growing sector creating jobs. Furniture for elderly and disabled people needs to be special because of the requirements of its users. Its functionality depends on a good combination of: design and ergonomics, basic electronics, psychology, and AAL.*

Keywords: *furniture, AAL, ergonomic, design, elderly, disabled people*

SAŽETAK • *Europski sektor proizvodnje namještaja ključni je pokretač održivog razvoja koji znatno pridonosi i zdravlju ukupnoga europskoga gospodarstva, konkurentnosti, kreativnosti, inovativnosti, zapošljavanju i izvozu. Sektor proizvodnje namještaja osigurava europskom gospodarstvu 1,08 milijuna radnih mjesta, a jedan od ključnih čimbenika poboljšanja stanja u sektoru jesu buduće potrebe europskog stanovništva. Do 2050. godine u EU-u se očekuje porast broja stanovnika u dobi od 65 i više godina za 70 %, a stanovnika starijih od 80 godina za 170 %. Život potpomognut okolinom (Ambient Assisted Living – AAL) omogućuje ljudima da dulje žive kod kuće unatoč njihovim kognitivnim ili fizičkim poteškoćama. AAL je odgovor na sve veći broj starijih osoba u većini europskih gospodarstava te je riječ o sektoru koji stvara nova radna mjesta. Namještaj za starije osobe i osobe s invaliditetom mora biti poseban zbog specifičnih potreba njegovih korisnika. Funkcionalnost tog namještaja ovisi o dobroj kombinaciji dizajna i ergonomije, osnovne elektronike, psihologije i AAL-a.*

Ključne riječi: *namještaj, Ambient Assisted Living, ergonomija, dizajn, starije osobe, osobe s invaliditetom*

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1 INTRODUCTION
1. UVOD

Because of the growing average age of the population, the aspects of Ambient Assisted Living (AAL) are becoming more important. Many companies across Europe are trying to prepare their production system for the possibility of producing AAL integrated furniture. One of the most problematic aspects related to the implementation of AAL integrated furniture concerns the qualifications of employees (f.e. Estaco, Granberg, IKEA, Pegasus Peka, BLUM). This problem has led to the analysis of the need for a Vocational Education Trainings (VET) system in the furniture sector.

The main objective of the study is to address the challenges of the vocational skill mismatch that the new demand for AAL integrated habitats has produced, by the development and validation of a harmonised European Curriculum based on the principles of ECVET in the area of design and manufacture of Smart Support Furniture for Ambient Assisted Living. One of the most important specific objectives of the study is the definition of skills needs in the field of AAL, and requirements for manufacturing Smart Support Furniture for Ambient Assisted Living. The manufacturing covers almost all aspects of technological production, logistics, specific equipment (electronics, functional equipment, etc.), and is especially connected with ergonomic requirements. A VET of manufacturing "ergonomic" furniture for the care and support of elderly and disabled people is especially difficult because furniture is produced by people who do not understand AAL [540016-LLP-1-2013-1-ES-LEONARDO-LMP]. They are just fit, which is why it is necessary to prepare a very detailed handbook for the teaching programme.

1.1 Universal design philosophy
1.1. Univerzalna filozofija dizajna

The idea of universal design was born in the 1980s, in the environment of American architects, who decided that buildings should be designed so as to be available to all potential users, including the elderly and disabled. Since then, the concept of universal design has spread worldwide and has influenced and combined related concepts such as Design for AAL, Life Span Design, and Inclusive Design (Duncan, 2015).

The architect Ronald Lawrence Mace was the first to define the concept of universal design; it was he who assumed that "the design of products and environment should be made in such a way that it is usable by all the people, to the greatest possible extent, without the need for adaptation or special design" (Mace, 1988). Nowadays, this concept has become the philosophy and strategy of democratic states, and it is increasingly present in our daily lives.

Universal design applies to both the design of public spaces and industrial facilities. It should be emphasised that universal design is not a set of strictly defined rules and standards, but a concept that assumes that the goal is the largest possible usefulness and flexibility of the achieved results. It should be added that universal design reduces the need for individual facilities, but allows them if necessary. The philosophy of universal design – regardless of the field of design – is based on seven key principles (Duncan, 2015):

1) equitable use – it is assumed that the design results will be used by people with very different potential uses;
2) flexibility in use – as far as possible, the design should take into account the preferences of different user groups, e.g. the ability to choose the method of use and adjustment to the different speeds of use of individual users;
3) simple and intuitive – the use of this product should not pose great difficulties, i.e., the principles of use of the product should be understandable regardless of the experience and skillset of the user;
4) perceptible information – ensuring the effective flow of information to the user, regardless of its perceptive abilities;
5) tolerance of error – minimizing the effects of accidental and abnormal activities (such as warning against errors, security in case of failure);
6) low physical effort – reducing the physical effort required to use the design results, such as reducing the number of repetitive activities;
7) size and space for approach and use – it is assumed that the designed product will have the right size, and that space required will be guaranteed in order to get closer to it and handle it, regardless of the posture and mobility of the user.

The aim of applying the rules of universal design is to obtain better solutions in terms of servicing the needs of the user and to ensure its availability to satisfy the user's needs, regardless of physical fitness, skills or knowledge.

Accordingly, universal design is something more than adapting public space to the needs of people with various disabilities – it is a practical implementation of human rights, which prevents discrimination, marginalisation and stigmatisation of people with reduced functionality.

The philosophy of universal design also fits into the design of AAL , which is based on the assumption that the Design for AAL means a design for human diversity, social inclusion and equality. Its essence is to support designs that produce innovative devices for the elderly and disabled (Lusher and Mace, 1989). It also assumes that innovative technological solutions need to be flexible, functional and tailored to individual and changing needs of the elderly and dysfunctional people. These solutions have to be smart to enable living assisted by the environment. This holistic and innovative approach constitutes a creative and ethical challenge for all planners, designers, and entrepreneurs of the furniture industry. The design of AAL furniture can be based on some studies and experiences (BLUM; Jabłoński, 2006; Openshaw and Taylor, 2006; Ramsey, 1999; PMI, 2009).

1.2 Design for AAL – a challenge for furniture designers of the XXI century
1.2. Dizajn za AAL – izazov dizajnerima namještaja 21. stoljeća

In the twenty-first century, increasing competitiveness in the market of furniture manufacturers determines the need to seek new market niches allowing for demographic changes, and thus the need to introduce a design for AAL philosophy. This is primarily related to the aging population in Europe, and the increase in the average length of human life. In Poland, for example, demographic forecasts predict that the proportion of the elderly in the population structure will reach 22.3 % in 2030, and as many as 35.6 % in 2050 (***GUS; ***NSP, 2011; St.gov.). Secondly, the number of people with disabilities is increasing year by year.

It is currently estimated that there are about 500 million disabled people in the world. In Poland alone, there are about four million (including two million disabled people over 65 years old). It is, therefore, worth considering the situation of these people and trying to determine what problems and difficulties they face every day, and in what way custom-designed furniture can help them in everyday life.

Unfortunately, in Poland there is still no real long-term approach or focusing on the production of furniture for older consumers, or people with disabilities. Furniture manufacturers have limited knowledge of the needs of the elderly and disabled, and very often they do not understand these people's relationship with furniture. Designing for this group is too often based on generalisations that do not meet their needs and desires. Moreover, as research shows – it is a mistake to consider the elderly and disabled as a homogeneous group and to define their needs in advance, because among them there is a large diversity in relation to the expectations, needs and wishes regarding furniture. The needs expressed by older people themselves are different from the existing recommendations for furniture designed for the elderly. The latter are based primarily on the effects of physiological changes of the elderly and disabled. They provide support also for psychological and social changes. According to the idea of design for AAL, one should merely assume that the furniture should provide comfort, pleasure and independence. Designers should be closely involved in researching the needs and expectations of older people and take a holistic view of people and their different needs that match their individual identity (Jonsson, 2013; Charytonowicz, 1998).

In Poland, most furniture manufacturers do not have skilled workers to design and manufacture products taking into account the needs of the elderly and disabled. It is, therefore, necessary to develop a coherent curriculum in this area that would allow adequate knowledge, personal and professional competencies, to be achieved, and thus introduce the AAL philosophy in the furniture industry. First and foremost, they should be familiar with the concept of universal design and AAL, as well as with the needs and disabilities of the elderly and disabled. They must be able to classify types and degrees of disability, and to know the basics of formal and legal rules for persons with disabilities (system solutions) – in order to be able to determine both the design and the price or distribution. For example, in Poland, subsidies for the elimination of barriers have been envisaged by the State Fund for the Rehabilitation of the Disabled (***PFRON) or by the District Family Assistance Center (***PCPR).

The concept covers the adaptation of kitchen furniture, bathroom customisation and renovation or replacement of old windows, adaptation, building ramps and handrails, etc. Subsidies can reach up to 80 % of investment costs, but not more than fifteen times the average salary (***MOPS).

The knowledge is also critical of the requirements of designing the environment for persons with disabilities, ergonomic design criteria and familiarity with matters relating to the anthropometric rules shaping the work and life environment of the elderly and disabled. Designs must take into account both the needs and functionality, but also the legal requirements and safety standards laid down for the European and international markets (CE mark, ISO standards, etc).

In designing the environment of persons with disabilities and elderly people, it is also important to develop in oneself the ability of practical application of the above-mentioned requirements and master the principles of interior organization, as well as focus on the user.

1.3 Design adapted to needs – the AAL psychology
1.3. Dizajn prilagođen potrebama – psihologija AAL-a

Psychology, being connected to investigating mechanisms and rules governing psychological and human behaviour, constitutes a part of necessary competencies of people with professional interests in design, furniture manufacturing and creating space for the elderly and disabled. Furniture manufacturers who understand the needs of older and disabled people can, while using the current knowledge and technology, excellently fit into the market and, thanks to their products, make everyday life of the elderly and disabled easier – all of this makes AAL psychology. Therefore, taking account the knowledge in this field is an important element in training the design and production of specialised furniture for the elderly and disabled. Building on this knowledge, training participants are open to the needs and expectations of older and disabled people, and when involved in design, they will do their best to improve the life-quality of the elderly and people with disabilities in accordance with the AAL psychology. It could be said that AAL psychology means an informed analysis of the needs of the elderly and disabled; in design, it sets comfort, safety and flexibility as a priority, and it requires the involvement of end-users at every stage of the design process. This type of psychology also provides information as regards users' needs, motivations and tastes, as well as behaviours, and it answers questions, such as: how do consumers accept technology and use it? Or: how to prepare an appropriate offer and appeal to the elderly and disabled with advertising.

It is worth keeping in mind that the need to have a place to live, be it a flat or a house, is one of the crucial needs. While aging, people want to be self-reliant for as long as possible, and are reluctant to change the environment, and in particular their place of residence. Fully agile adults need no special adaptation of the surrounding space, whereas the elderly – most often those with reduced mobility – need a special adaptation of their residence place to their needs. The disability of the motor system is a reason for requiring more space for moving and manoeuvring. In addition, older users also require a completely different approach to design. What they primarily expect is: functionality, safety and comfort in moving. For people moving with difficulty, the appropriate selection and set-up of furniture is pivotal. It is also important to make it easy to open cabinets, store and search for things that should be at arm's reach, equipping a flat with specialized beds, mattresses, bedside tables, walking frames, lifters, wheelchairs or chairs (Nowakowski and Charytonowicz, 2001). For the elderly, the furniture's material is also important; materials should have high durability and long-term usefulness. Furthermore, while aging, people tend to focus more on aesthetics and quality than on current fashion trends.

The constantly increasing number of people with limited ability has made integration aspects in creating flats become a requirement throughout society, and ensuring optimum conditions for satisfying qualitative housing needs relates to a specific flat standard. Therefore, furniture for the disabled should be equipped with special handholds and cavities that make it easy for a disabled person to use the furniture, while adapting to the person's needs and the level of motor ability. Primarily, it must be much lower than standard furniture. Such furniture could be aesthetic, nice-looking and modern, while at the same time it should be well thought out and ergonomic (Sawczuk, 2014; Ślusarczyk, 2015). For instance, modular furniture is a good solution. Enterprises that produce furniture for the disabled in order to address the needs of those with disabilities may design cabinets on wheels, for instance, to make them more easily movable; corner cupboards with revolving shelves to make windows easily accessible; cargo-cabinets that can be ejected on guide rails and thus make their contents easily accessible without the need to bend to get to what is inside. A very useful and comfortable convenience is that of telescope hanger systems with hangers that can easily be pulled to one another, upper cabinets on vertical guide rails or kitchen tables with seats that can be ejected. In addition, special railings and strips securing tables and preventing objects from falling are applied (for more information on this topic, the authors recommend further references, such as: Kmiecik and Tytyk, 2001).

Older consumers will begin to increasingly matter on the market – and it should be remembered that they will also become increasingly demanding. According to the AAL philosophy, older people deserve better designs for living, whereas the industrial designs intended for them have to date been dull, with grim design prevailing, and quite little product range (Burke, 2012).

So there is a great potential for innovation in this field. It is an issue being dealt with not only by entrepreneurs, but also by scientists, since it involves looking for appropriate forms and materials that are more user-friendly for the elderly. The Blum Company, for instance, currently the most advanced innovative company in the field of kitchen furniture – makes use of special suits stimulating the movements of an older person in addressing the needs of the elderly while designing kitchen rooms (BLUM). One of the five key areas of the international StarDust project, in turn, is focused on designing products for the elderly. Advanced research related to designing multi-functional kitchens for older people is being conducted (STARDUST) as part of the "Comfort in Living" concept. Then there is IKEA, which – as early as in 2010 – created a visualisation entitled SKARP, showing a kitchen of the future in 2040. The visualisation was created on the basis of answers by two thousand respondents, who were to write how they imagined a kitchen would look like in thirty years, with solutions proposed excellently fitting in the universal design and the AAL philosophy.

In general, every piece of furniture, equipment, etc. surrounding people has already been designed. It is the manner in which the process has developed that determines the comfort of people's lives, and in many cases also the fact whether they will be able to make active use of it.

1.4 Anthropometrics and ergonomics
1.4. Antropometrija i ergonomija

Anthropometry data for design – the sitting position is presented in Figure 1. The body dimensions in the sitting position of the working age population in Poland, useful in designing office furniture (in mm), are shown in Table 1, together with explanations of symbols. Data on the dimensions of society are defined by lower percentile values (C5), the value of the median (average) percentile (C50) and the upper percentile (C95). This means that the values determined by C5 do not reach 5 % of the population of a given society, and that a majority of the population

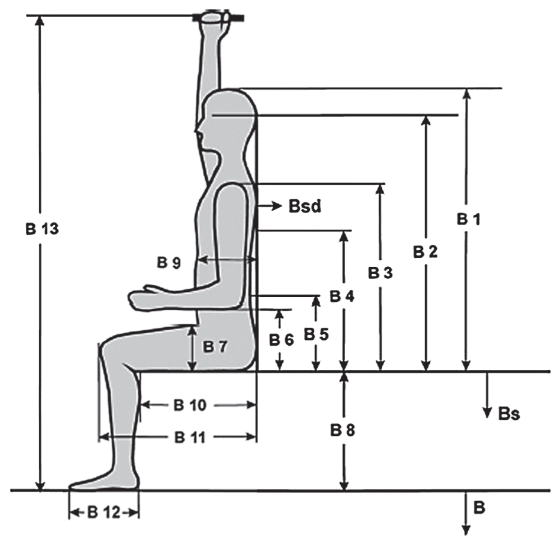

Figure 1 Anthropometry data for design – sitting position (***IWP; ***CIOP)
Slika 1. Antropometrijski podatci za dizajn – sjedeći položaj (*** IWP; *** CIOP)

Table 1 Body dimensions in sitting position (***IWP; ***CIOP)
Tablica 1. Dimenzije tijela u sjedećem položaju (***IWP; ***CIOP)

Feature symbol *Oznaka obilježja*	**Feature** *Obilježje*	**Male** / *Muškarci*		**Female** / *Žene*	
		C5	C95	C5	C95
B1	Sitting height / *visina sjedenja*	833	980	792	916
B2	Eye height / *visina očiju*	711	840	691	781
B3	Midshoulder height / *visina sredine ramena*	547	668	515	625
B4	Subscapular height / *visina podlopatice*	364	531	350	489
B5	Lumbar height / *visina lumbalnog područja*	115	171	115	169
B6	Elbow rest height / *visina lakta*	194	301	198	292
B7	Thigh clearance / *visina bedra*	115	171	115	169
B8	Popliteal height / *visina poplitealne udubine*	388	488	361	448
B9	Body depth / *dubina tijela*	230	344	197	343
B10	Popliteal length (seat depth) / *poplitealna duljina (dubina sjedala)*	480	588	441	552
B11	Knee length / *duljina koljena*	554	646	532	624
B12	Foot dimension / *dimenzija stopala*	250	284	221	257
B13	Vertical reach height / *visina vertikalnog dosega*	1181	1382	1097	1278

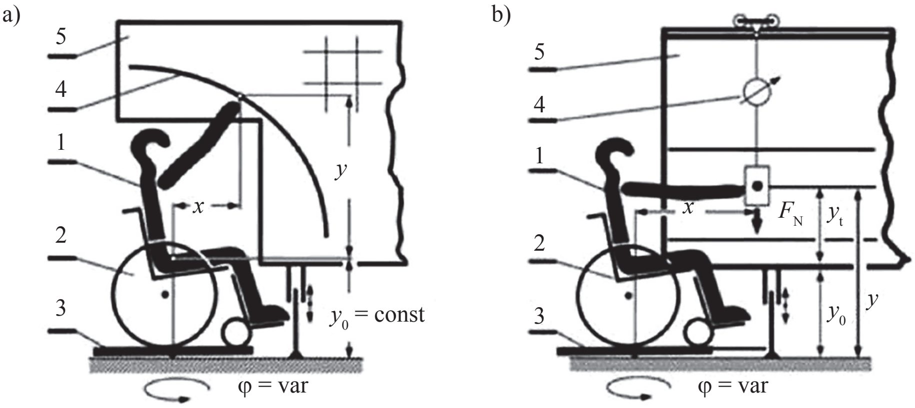

Figure 2 Block diagram of a measurement stand and method of arm reaches (a) and arm forces (b) of a disabled person sitting in a wheelchair in a 3D space of geometrical dimensions *x*, *y*, *z*: (1) – handicapped person; (2) – active wheelchair; (3) – measuring protractor, (4) – reach curve (a) or measuring dynamometer (b); (5) – table (***what-when-how.com)
Slika 2. Blok-dijagram mjernog stalka, (a) metode dosega ruke i (b) ručne sile osobe s invaliditetom koja sjedi u invalidskim kolicima u 3D prostoru geometrijskih dimenzija *x*, *y*, *z*: 1 – osoba s invaliditetom; 2 – aktivna invalidska kolica; 3 – mjerač kuta, 4 – krivulja dosega (a) ili mjerni dinamometar (b); 5 – tablica (***what-when-how.com)

(90 %) is below the value specified by C95. For this reason, furniture and items intended for an anonymous client are designed for people falling in the interval between C5 and C95.

Analogously, there are studies of anthropometry data of design for people in wheelchairs (Figure 2). This data contains block diagrams of a measurement stand and the method of arm reaches.

For people in wheelchairs, there are facilities that enable them to reach all furniture. Figures 3 and 4 show proposals of design and functional solutions.

The goal of the studies was to analyse the needs of vocational education in the furniture sector, which will be adapted to the production of AAL furniture. This paper focuses on the vocational education of workers of various degrees of responsibility in the company's furniture design. In the project, they were divided into four groups: blue collar worker, designer/engineer, freshman, manager. Since all of these groups have other duties in the manufacturing process, it was

Figure 3 Facility to reach upper cabinets 1 (***GRANBERG)
Slika 3. Instalacija za dosezanje gornjih ormara 1 (***GRANBERG)

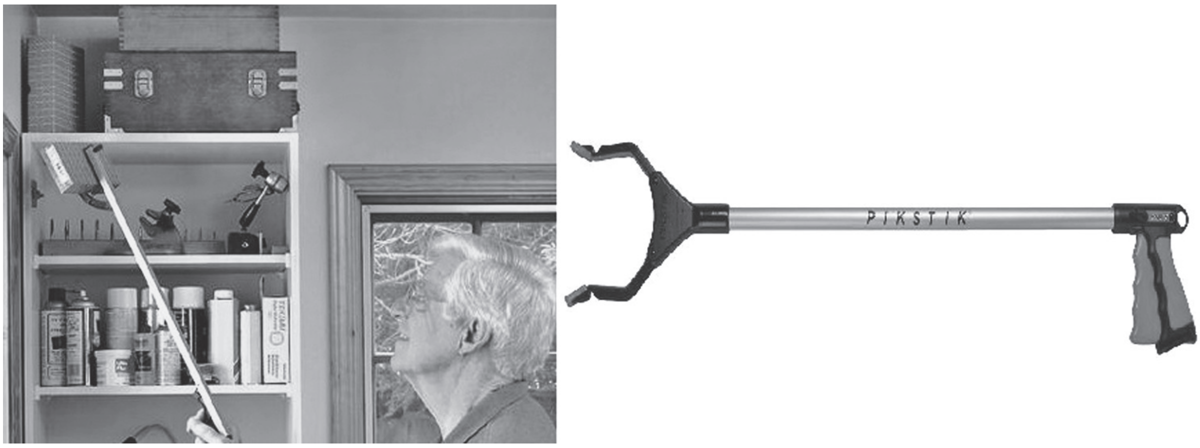

Figure 4 Facility to reach upper cabinets 2 (***AZZURRO DESIGNE)
Slika 4. Naprava za dosezanje gornjih ormara (***AZZURRO DESIGNE)

necessary to define various methods of Vocational Education Trainings (VET).

2 MATERIALS AND METHODS
2. MATERIJAL I METODE

The first task in the analysed project was to determine the Skills, Knowledge and Competences (SKC) of producers, who manufacture furniture for the elderly and disabled people. For this purpose, a questionnaire was created for all pillars: the Basic concepts of electronics, Psychology, Design and Ergonomics, Ambient Assisted Living. The questions were directed to groups of furniture employers working in different positions: blue collar, designer and manager.

Each part of the questionnaire consisted of five yes/no questions and two open questions. The main aim of the questionnaire was to obtain information about the experience of workers in various fields: Design and Ergonomics, Basic Electronics, Psychology and the needs of the elderly and disabled, Ambient Assisted Living and its integration in furniture.

The questions about Design and Ergonomics were drawn up by Polish partners and then corrected by partners from five European countries. The questionnaire was then carried out and analysed in the countries of the main partners: Spain, Slovenia and Poland. The questions asked, and then analysed, were those presented in Table 2.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

After receiving the answer from all the partners (respondents from 25 Polish companies, 19 Spanish companies and 8 Slovenian companies), the national qualification profiles developed were analysed and the desk research was conducted. The analysis was done by counting the percentage of people who correctly answered the questions, which means the answers YES to each question. The results are presented in Figure 5. The questionnaire was also the basis for creating the first draft of an e-learning platform for furniture workers.

The results of the studies presented in Figure 5 show that most furniture companies in Poland, Spain and Slovenia agree that their knowledge about furniture production for the elderly and disabled is insufficient to be competitive on this market. They also agree

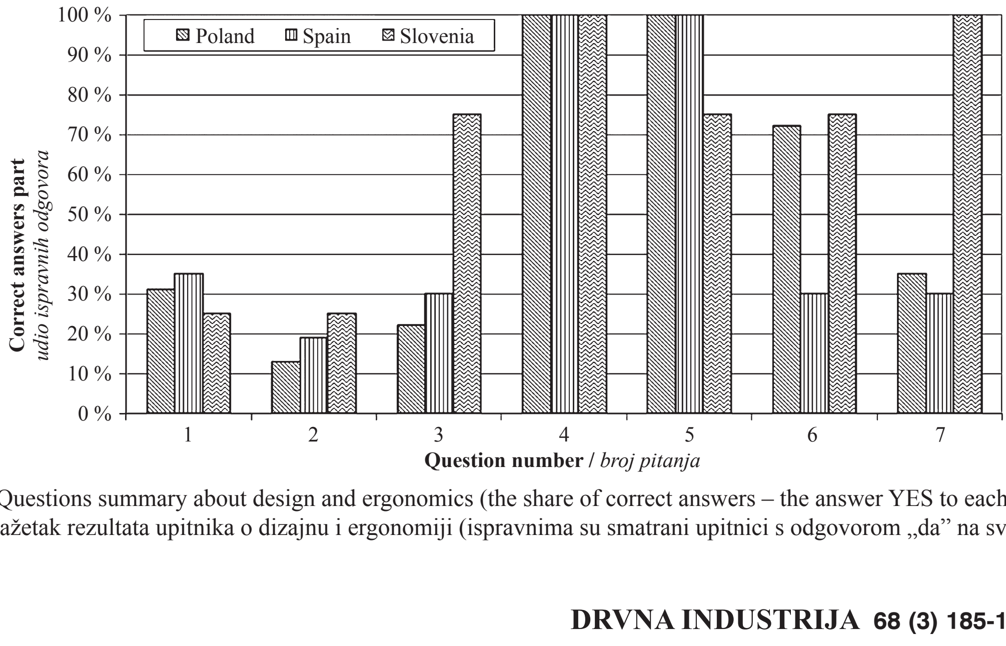

Figure 5 Questions summary about design and ergonomics (the share of correct answers – the answer YES to each question)
Slika 5. Sažetak rezultata upitnika o dizajnu i ergonomiji (ispravnima su smatrani upitnici s odgovorom „da" na svako pitanje)

Table 2 Questions about design and ergonomics
Tablica 2. Pitanja o dizajnu i ergonomiji

No	**Question** / *Pitanje*	**Type of answer** *Odgovor*
1.	Is your company (or you) familiar with design and ergonomics for alder and disabled people to become competitive on this market? *Je li vaša tvrtka (ili vi) upoznata s dizajnom i ergonomijom za starije osobe i osobe s invaliditetom kako bi postala konkurentnija na tržištu?*	yes/no *da/ne*
2.	Do your company's designers and/or constructors already deal with furniture designated for elderly and disabled people? *Bave li se već sad dizajneri i/ili projektanti vaše tvrtke namještajem namijenjenim starijim osobama i osobama s invaliditetom?*	yes/no *da/ne*
3.	Do you plan to educate your workers responsible for design and construction for elderly and disabled people? *Planirate li dodatno obrazovati svoje radnike zadužene za dizajn i projektiranje namještaja za starije osobe i osobe s invaliditetom?*	yes/no *da/ne*
4.	Do you think that a competent institution should undertake the task of collecting anthropometric data on statistically representative group of elders in your country (males and females, aged 65 and above)? Could such data be used in design of a variety of products, furniture and utilities? *Mislite li da bi relevantna institucija trebala provesti projekt prikupljanja antropometrijskih podataka na statistički reprezentativnoj skupini starijih osoba u vašoj zemlji (muškaraca i žena u dobi od 65 i više godina)? Mogu li se takvi podatci koristiti pri dizajniranju različitih proizvoda, namještaja i komunalnih usluga?*	yes/no *da/ne*
5.	Do you think that designers of elderly-oriented furniture should be aware of other implications of their tasks, such as flooring, lighting, signs, etc. with the aim of creating older user-friendly interior environment? *Mislite li da bi dizajneri namještaja za starije osobe trebali biti upoznati s drugim činiteljima koji utječu na okolinu starijih osoba kao što su podovi, rasvjeta, znakovi itd. radi stvaranja interijera prilagođenih starijim korisnicima?*	yes/no *da/ne*
6.	Is it reasonable to reconsider ageing process in contemporary society, which changed a lot through recent years due to new communication possibilities (internet) and other social changes? *Je li razumno ponovo razmotriti proces starenja u suvremenom društvu jer se on tijekom posljednjih godina mijenja zbog novih komunikacijskih mogućnosti (interneta) i drugih društvenih promjena?*	yes/no *da/ne*
7.	If you consider education of workers on the above topics, what would be your preferred teaching type: short courses, periodical meetings and workshops, lifelong learning centers, or maybe some other ideas? *Ako smatrate potrebnim obrazovati radnike o navedenim temama, koju biste vrstu poučavanja izabrali: kratke tečajeve, periodične sastanke i radionice, centre za cjeloživotno učenje? Ili možda imate neke druge ideje?*	Open *otvoreno*

that most of their constructors and designers have no experience in designing furniture with the elderly and disabled in mind.

Answering the question 3, most furniture companies in Poland (22 %) and Spain (30 %) admitted that they did not plan to educate their workers in analysing the manufacturing sector. Only Slovenian companies (75 %) believed that furniture for elderly and disabled was a sector that they wanted to develop in their production companies, and they saw a need for additional education training for workers.

In any case, all the companies in the analysed countries see the need to collect anthropometric data about people over 65. The answers to this question prove that all furniture companies are in fact thinking about the concerned market as one that will develop and can be an interesting sector in their future production. Furthermore, most of the companies in the analysed countries believe that well-designed furniture for the elderly should be accompanied with implications such as flooring, lighting, signs, etc. with the aim of creating user-friendly interior environments for the elderly. So, most of the companies think that these aspects do have an influence on well-designed furniture for this group of people.

In Poland and Slovenia, companies think that it is a reasonable process to reconsider the process due to new communication possibilities and other social changes. Only according to the Spanish industry, reconsidering this issue is not relevant to the needs of furniture manufacturing.

According to the responses to the last question, all of the furniture companies in Spain think that their workers should take training in designing furniture for the elderly and disabled. Most of the companies in Poland and Slovenia do not see any such need for their workers. In any case, all the companies that are interested in such education answered that they would prefer short-term courses or periodical meetings with workshops. This can be interpreted as follows: if a company decided to invest in additional education of workers, it would like to see the effects as soon as possible.

4 CONCLUSIONS
4. ZAKLJUČAK

Demographic changes in this century, in combination with a growing number of people with disabilities and legal requirements on design, are changing design requirements, creating new challenges for furniture designers. On the one hand, their products should be primarily useful, so that they can be enjoyed to the greatest possible extent by everyone, regardless of age, ability, or status in life. On the other hand, the transformation of thinking about old age and disability should contribute to improve the quality of life of these consumers, by implementing Ambient Assisted Living (AAL) design philosophy – namely, designing individual and smart solutions for ambient assisted living. Therefore, training and specialisations, taking into account universal design issues and AAL in their programmes and curricula, are necessary. When designing, designers must be familiar with the guidelines for adapting architectural objects and furniture to the needs of people with various types of disabilities and the needs of the elderly. This requires interdisciplinary knowledge that includes, on the one hand, ergonomic issues, anthropometric research and computer aided design, and issues related to gerontology and social policy, on the other hand.

Analyses show that furniture designed with the elderly and disabled in mind is becoming a market that will develop over the next few years. Companies are aware of this trend and they see the need for changes in their production systems, so they can be adaptable to the needs of elderly people.

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The Effects of Lignocellulosic Fillers on Mechanical, Morphological and Thermal Properties of Wood Polymer Composites

Učinci lignoceluloznih punila na mehanička, morfološka i toplinska svojstva drvno-plastičnih kompozita

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ABSTRACT • *The aim of this study was to investigate some of the physical, mechanical, thermal and morphological properties of wood flour and cellulose fiber filled polypropylene composites. Polypropylene as a polymer matrix and wood flour and cellulose fibers were used as reinforcing fillers to prepare the composites by using a single screw extruder. Physical properties such as density, mechanical properties such as flexure strength and flexure modulus, tensile strength and tensile modulus, and impact strength, thermal behavior with thermogravimetric analysis (TGA/DTA), and morphological characterization with scanning electron microscopy (SEM) of the composites were determined. The density of the composites was found to increase with the addition of fillers. The mechanical properties of the composites showed that the flexure and tensile strength for the composites with wood flour was higher than the composites with cellulose fibers, whereas flexure and tensile modulus, and impact strength for the composites with cellulose fibers was found to have higher values as compared to the composites with wood flour. SEM pictures showed that particles and fibers dispersed to different locations in polypropylene matrix. According to the TGA results, thermal degradation of all the composites was found to be lower compared to neat polymer.*

Keywords: *wood polymer composites, natural fillers, filler rate, mechanical properties, morphological characterization, thermal stability.*

SAŽETAK • *Cilj istraživanja bio je ispitati neka fizikalna, mehanička, toplinska i morfološka svojstva polipropilenskih kompozita s drvnim brašnom ili celuloznim vlaknima kao punilom. Polipropilen kao polimerna matrica te drvno brašno ili celulozna vlakna kao punilo za ojačanje upotrijebljeni su za izradu kompozita uz pomoć jednostrukoga vijčastog ekstrudera. Istraživanjem su određena fizikalna svojstva kompozita, npr. gustoća, te mehanička svojstva kao što su čvrstoća pri savijanju i modul savitljivosti, vlačna čvrstoća i modul elastičnosti te savojna žilavost. Usto je termogravimetrijskom analizom (TGA/DTA) ispitano toplinsko ponašanje kompozita, a skeniranjem elektronskim mikroskopom (SEM) napravljena je morfološka karakterizacija uzorka. Utvrđeno je da se dodatkom*

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punila gustoća kompozita povećava. Rezultati ispitivanja mehaničkih svojstava pokazali su da su čvrstoća pri savijanju i vlačna čvrstoća kompozita s drvnim brašnom veće od čvrstoće kompozita s celuloznim vlaknima, dok su vrijednosti modula savitljivosti, modula elastičnosti i savojne žilavosti veće za kompozite s celuloznim vlaknima nego za kompozite s drvnim brašnom kao punilom. SEM slike pokazuju da se čestice drvnog brašna i celulozna vlakna raspršuju na različite lokacije u polipropilenskoj matrici. Prema rezultatima TGA analize, utvrđeno je da je toplinska degradacija kompozita s drvnim brašnom ili celuloznim vlaknima kao punilom manja od degradacije kompozita s čistim polimerom.

Ključne riječi: *drvno-plastični kompoziti, prirodna punila, udjel punila, mehanička svojstva, morfološka karakterizacija, termička stabilnost*

1 INTRODUCTION
1. UVOD

In the past, wood flour (WF) represented a sawmill waste that needed to be disposed of. Many waste utilization strategies have been introduced over the last century including bedding, composting, combustion, gas generation and use as feedstock for chemical industry. The use of WF as raw material for making new solids is the most positive use of the waste, because of versatility in application and its low energy costs (Ashori, 2008; Okamoto, 2008; Wechsler and Hiziroglu, 2007). Thermoplastic polymers are loaded as matrices in composite materials with the WF filler to save costs, as the WF is a by-product of timber processing (Najafi 2013; Aydemir *et al*., 2015, Yang and Nelson, 2006).

Wood-derived fillers have made significant contributions to the thermoplastic industry, which has led to the emergence of wood–plastic composites (WPCs) in the construction industry. Products such as decking, fencing, siding, window framing, and roof tiles are being introduced into the market. WPCs are also beginning to be used in the fields of construction, transportation, industrial, and consumer industries. Growing interest of renewable resources-based products is due to social and environmental concerns. Commercial thermoplastics such as polyethylene, polypropylene (PP), polyvinyl chloride, and polystyrene are commonly used in the manufacture of plastic/wood fiber composites (Sobczak *et al*., 2013; Bledzki and Gassan, 1999; Rowell *et al*., 1997; Oksman and Sain, 2008). Polymers are used in many areas, such as automotive, electronics, and different construction equipment (Aydemir *et al*., 2016; Kruenate *et al*., 2004). The use of technical and standard plastics has encouraged the application of natural fibers thanks to their low prices and steadily rising performance (Witting, 1994; Zor *et al*., 2016).

In wood industry, a large amount of wood waste is generated at different stages of wood processing and these by-products are mainly intended for landfill (Falk and McKeever 2004). The use of waste wood in wood plastic composites (WPCs) helps to offset these disposal costs. It was well established that waste wood in the form of wood flour, fibers or pulp is suitable as filler for polyolefin (Woodhams *et al*., 1984; Maiti and Singh, 1986; Valles-Rosales *et al*., 2016). In general, wood flour is used as filler for plastic, which tends to increase the stiffness of the composite but does not improve its strength. Natural fibers can be used to reinforce rather than fill a plastic, which increases the strength as well as stiffness. Wood and other lignocellulosic fibers typically have higher particle sizes than those of wood flour. Furthermore, the aspect ratio of the fiber can be increased. At a critical fiber length, stress is transferred from the matrix to the fiber, resulting in a stronger composite. Stress is efficiently transferred only if the bond between the matrix and fiber is good (Oswald and Menges, 1995).

The aim of this study was to determine the usability of waste wood flour and fibers from particleboard and fiberboard in the manufacturing process of wood plastic composites. Also, some physical, mechanical and morphological properties of wood plastic composites were examined.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Wood flours (WF) and cellulose fibers (CF) were supplied by particleboard and medium density fiberboard from a firm in Turkey. For testing in this study, beech was used for wood flours and scots pine was selected for cellulose fibers. All WF samples were made the same size in 0.5 mm sieve. CFs, between 1 and 3 mm in length, were used in study. Polypropylene (EH241) was supplied by PETKIM Inc, in Turkey. The properties of the PP – EH241 are listed in Table 1.

Table 1 Properties of polypropylene (EH241)
Tablica 1. Svojstva polipropilena (EH241)

Properties / *Svojstvo*	**Values** *Vrijednost*
Melt flow index, g/10 min (at 230 °C/2.16 kg) *Indeks protoka taljenjem,* g/10 min *(pri 230 °C/2.16 kg)*	5 to 20
Density, g/cm³ / *Gustoća,* g/cm³	0.92
Water absorption, % / *Upijanje vode,* %	0.1
Processing temperature, °C *Temperatura procesa,* °C	160-170
Tensile strength, MPa / *Vlačna* čvrstoća, MPa	35
Flexure modulus, GPa *Modul savitljivosti,* GPa	1.5
Izod impact, notched, kJ/m² *Otpornost na udarce,* kJ/m²	2

2.2 Preparation of composites
2.2. Izrada kompozita

WF and CFs were oven dried at 103±2 °C to obtain a moisture content less than 1 %. PP was used as matrix polymer, while WF and CFs were used as fillers. Loading ratios of WF and CFs were 10, 20, 30 and 40 % wt. The formulations of the production are given in Table 2.

Table 2 Formulation of samples
Tablica 2. Sastav uzoraka

Samples *Uzorci*	Formulation, % / *Udjel, %*		
	PP	WF	CF
PP	100	-	-
WF10%	90	10	-
WF20%	80	20	-
WF30%	70	30	-
WF40%	60	40	-
CF10%	90	-	10
CF20%	80	-	20
CF30%	70	-	30
CF40%	60	-	40

Legend / *Legenda*: PP – neat polypropylene / čisti polipropilenski uzorci; WF – wood flours as a filler / *drvno brašno kao punilo*; CF – cellulose fibers as a filler / *celulozna vlakna kao punilo*

The materials used in the compounding were first mixed to achieve better dispersion by a mechanical mixer for 15 minute. The obtained samples were extruded at 50 rpm by a single screw extruder. During the extrusion, the zone temperatures ranged between 160 and 170 °C, the melting pressure of the extruder varied between 5 and 10 bars depending on material blends, the screw speed was 50 rpm, and the material output was 1 kg/h. After exiting the extrusion, the obtained compounds, which were in a melt state, were cooled and solidified directly in a water-cooling system, while being pulled with end drive conveyors. Then the solidified materials were pelletized through a pelletizer. Next, the pellets obtained were injection molded to obtain the test samples.

All samples were conditioned at 20 °C and 65 % relative humidity prior to testing. First, the weights of samples were measured in air by a precision scale to the nearest 0.001 gr and immersed in distilled water. Then, the density of the samples was measured by a water displacement technique according to ASTM D792-98.

Flexure strength (MOR), flexure modulus (MOE), tensile strength and tensile modulus (TM) were carried out according to ASTM D 790-03 Test Method 1 and ASTM D 638-03 Type I, respectively. These tests were conducted using a Zwick tester with a 10-kN load cell capacity. Test speed rate of 0.2 in/min was used for all tests. The izod impact tests (IIS) were conducted according to ASTM D 256-06. The notches were provided with a NotchVIS machine (Ceast trademark) and tests were carried out with a Resil 50 B impact tester. The morphological properties of the samples were observed with a scanning electron microscope (SEM) (Phillips Electroscan 2020) with an accelerating voltage of 5 kV under nitrogen. The fracture parts of all samples were sputter-coated with gold using a Denton sputter coater for enhanced conductivity.

The thermal stability of all the composites was investigated using a TGA/DTA and DSC (Perkin Elmer, TA Instruments, USA). In TGA/DTA, the samples were heated from 25 ºC to 600 ºC with a heating rate of 10 ºC/min and a nitrogen flow of 100 mL/min. The samples weighing about 10 mg were used for the tests. Degradation temperatures at 10 % weight loss ($T_{\%10}$) and 50 % weight loss ($T_{\%50}$), maximum degradation temperature in the derivative thermogravimetric peaks (DTG_{max}), and mass loss of the samples in the TGA cures were measured and compared with the results obtained. The differential scanning calorimeter (DSC) tests were performed on a DSC 2920 (Perkin Elmer, TA Instruments, USA) at a heating rate of 5 °C/min under a nitrogen atmosphere. The samples weighed about 10 mg. To determine the crystallinity, 191.3 J/g was used to pure PP enthalpy (Myers *et al*., 1991).

One-way analysis of variance (ANOVA) was performed to identify significant differences at the 99 % confidence level. The Duncan test was used to determine the difference between groups. The important differences between formulations were shown with letters A, B, C, and D.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 Physical and mechanical properties
3.1. Fizikalna i mehanička svojstva

In this study, WF and CFs were used as fillers to different density ratio such as 10 %, 20 %, 30 % and 40 %. Density of pure PP was determined as 0.89 g/cm^3. Addition of fillers increased the density of composites. The maximum densities for both the WF and CFs were found as 0.99 g/cm^3 and 0.98 g/cm^3 (Fig. 1). The difference between the density of the composites with WF and CFs was not statistically important. However, it was determined that the effect of WF on the composite density was higher than that of CFs. In another study, although the density of wood was 0.689 – 0.755 g/cm^3 and polymer matrix was 0.95 g/cm^3, the density of WF filled polymer composites was found to increase to 1.108 g/cm^3 (Ichazo *et al*., 2001).

Fig. 2 shows the tensile strength and TM values. According to Fig. 2, the addition of the fillers reduced tensile strength, while increasing the TM of the composites. Tensile strength of pure PP was 29.68 MPa, and tensile strength was found to decrease to 22.32 MPa for WF and 23.54 MPa for CFs, respectively, with the addition of the fillers. Tensile strength decreased by about 24.8 % and 20.7 % for the composites with 40 % WF and 40 % CFs. Similar results were observed by Meyers *et al*. (1991) and Ichazo *et al*. (2001). The effect of cellulose fibers on the tensile strength of composites is lower than that of wood flour. This can be explained by fiber direction in the composites. The effect of fibers, which are perpendicular to the pulling direction, on the tensile strength

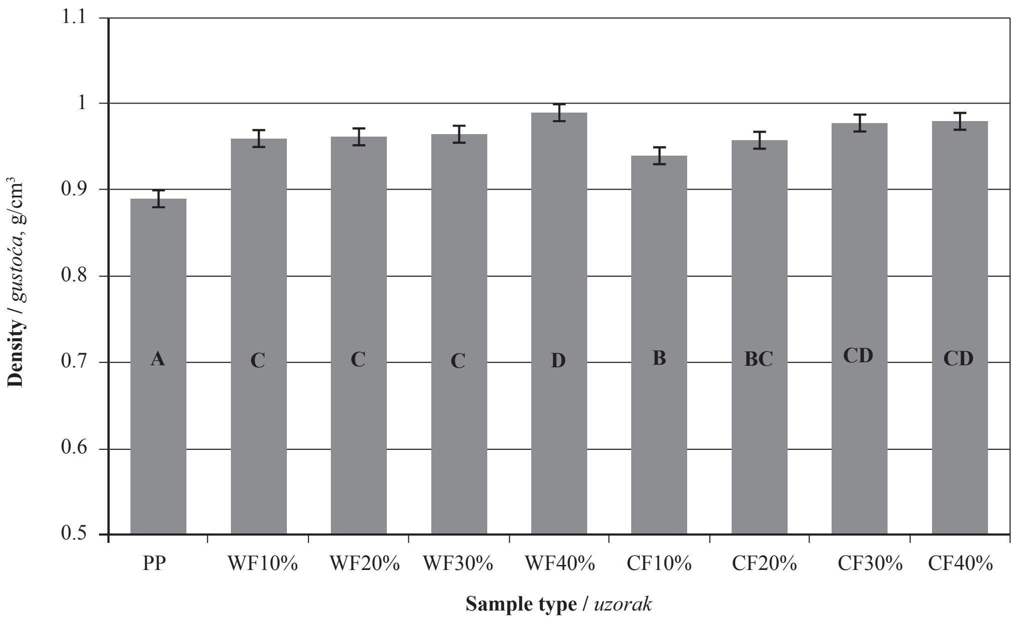

Figure 1 Densities of composites
Slika 1. Gustoća kompozita

is limited. Similar results were also reported by Raghu H (2006); Ismail H (2004). They investigated the effect of filler loading in some composites. They found that the lower tensile strength at 40 % filler content could be referred to as ineffective stress between the particle-matrix interfaces due to weak interface adhesion.

According to Fig. 3, the addition of the fillers generally increased the MOR and MOE. The highest value of MOR and MOE was found as 47.32 MPa, 2.44 GPa for the composites with 30 % CFs. 10 % WF showed the lowest MOE with 1.4 GPa after control samples, the lowest MOR value was obtained from 40 % CF samples as 42.29 MPa. This can be explained by fragile structure of cellulose fibers and rate of cellulose fiber. Since 40 % CF rates in the PP mixing made difficult the performance of the extruder, CFs in the total mixing take up space as volume. For this reason, in the CF samples, MOE and MOR increased until rates of 30 % and decreasing began after 40 % CF rates. Bouafif *et al*. (2009) reported that MOE of the wood polymer composites showed a steady increase with increasing filler content.

As shown in Fig. 4, the izod impact strength (IIS) of all composites was found to be higher than that of the pure PP. The highest values for the IIS were found as 106 % and 35.32 % for 40 % CF and 40 % WF, respectively, as compared to the PP samples.

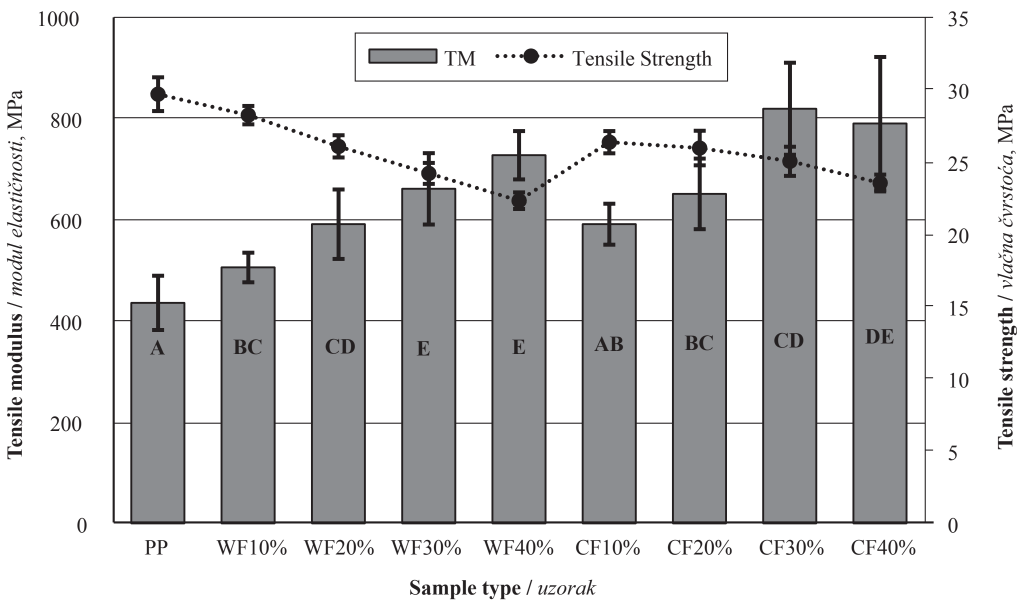

Figure 2 Tensile modulus (TM) and tensile strength values of composites
Slika 2. Modul elastičnosti i vlačna čvrstoća kompozita

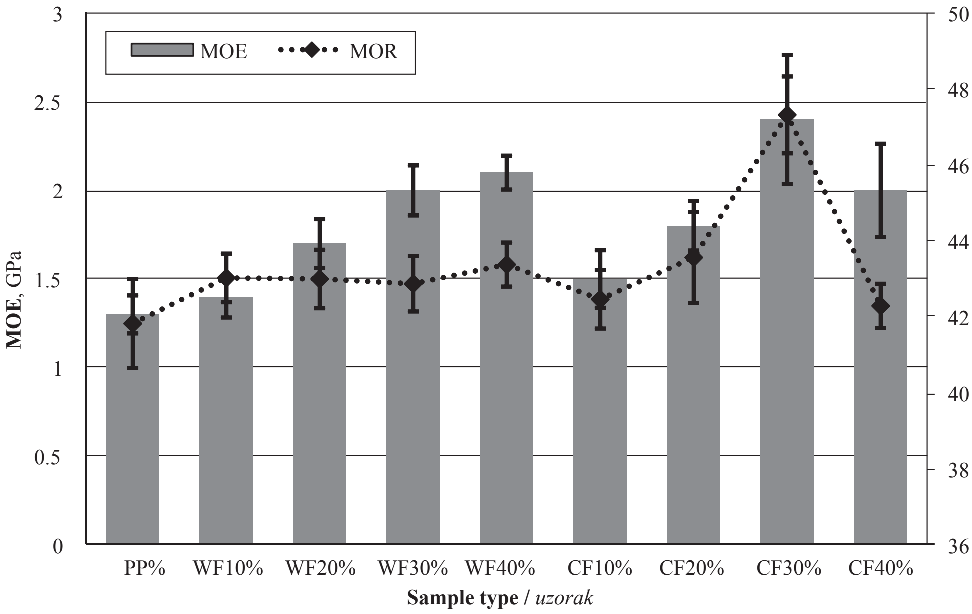

Figure 3 Flexure modulus (MOE) and flexure strength (MOR) values of composites
Slika 3. Vrijednosti modula savitljivosti (MOE) i čvrstoće kompozita pri savijanju (MOR)

3.2 Morphological characterization
3.2. Morfološka karakterizacija

The morphological characterization of the composites was investigated with SEM inside the samples. Fig. 5 presents a SEM micrograph of WF and CFs. It shows adhesion between WF and matrix. Although the amount of WF is increasing (10 % Fig. 5-a, 20 % Fig. 5-b, 30 % Fig. 5-c, and 40 % Fig. 5-d), it can be said that a homogeneous mixture is obtained. This statement is also supported by the increase in mechanical properties (MOR, and izod impact strength) of WF composites.

The SEM micrograph of the interactions between matrix and fillers is shown in Fig. 6. When comparing the interactions between WF and CFs with PP, WFs provided better compliance than CFs. Wood flour used in the study was milled by 0.5 mesh sieve. So, all of the wood flour is almost the same size. This case showed linear increase in mechanical properties of WF composites. On the other hand, the sizes of cellulose fibers varied between 3 mm and 7 mm. CF 10 % and CF 20 % demonstrated a homogeneous dispersion (Fig 6 a-b), in CF 30 % and CF 40 % clustering in composites was observed (Fig 6 c-d). It is thought that using single-cylinder extruder in the study and the increase of CF content (from 10 % to 40 %) led to this status. Khonsari *et al*. (2015) stated that wood flour geometry affected physical and mechanical properties of WPC.

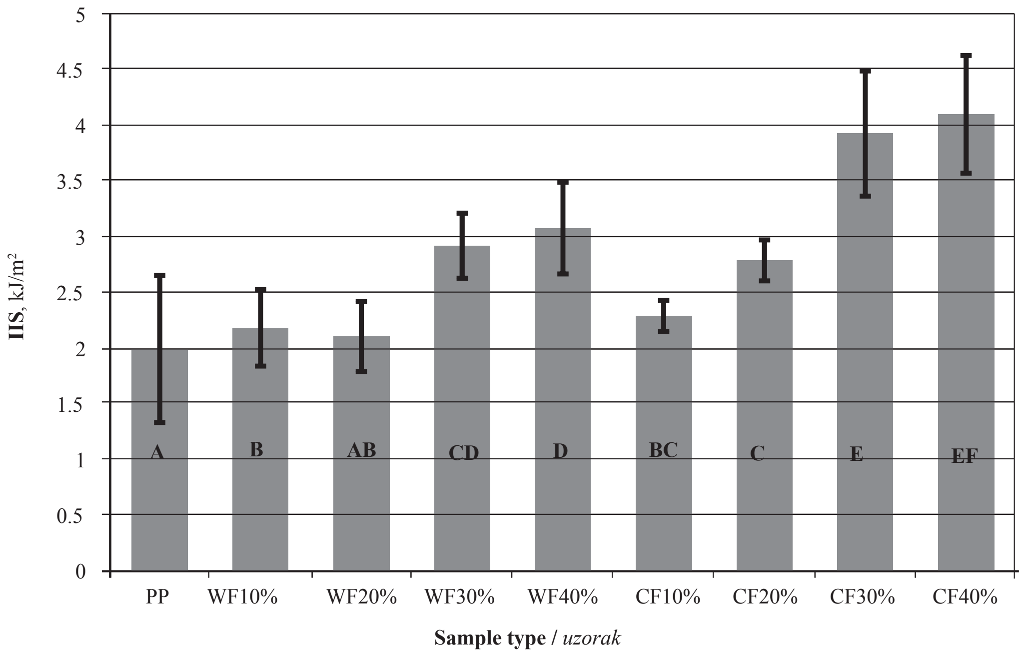

Figure 4 Izod impact strength (IIS) values of composites
Slika 4. *Izod* vrijednosti savojne žilavosti (IIS) kompozita

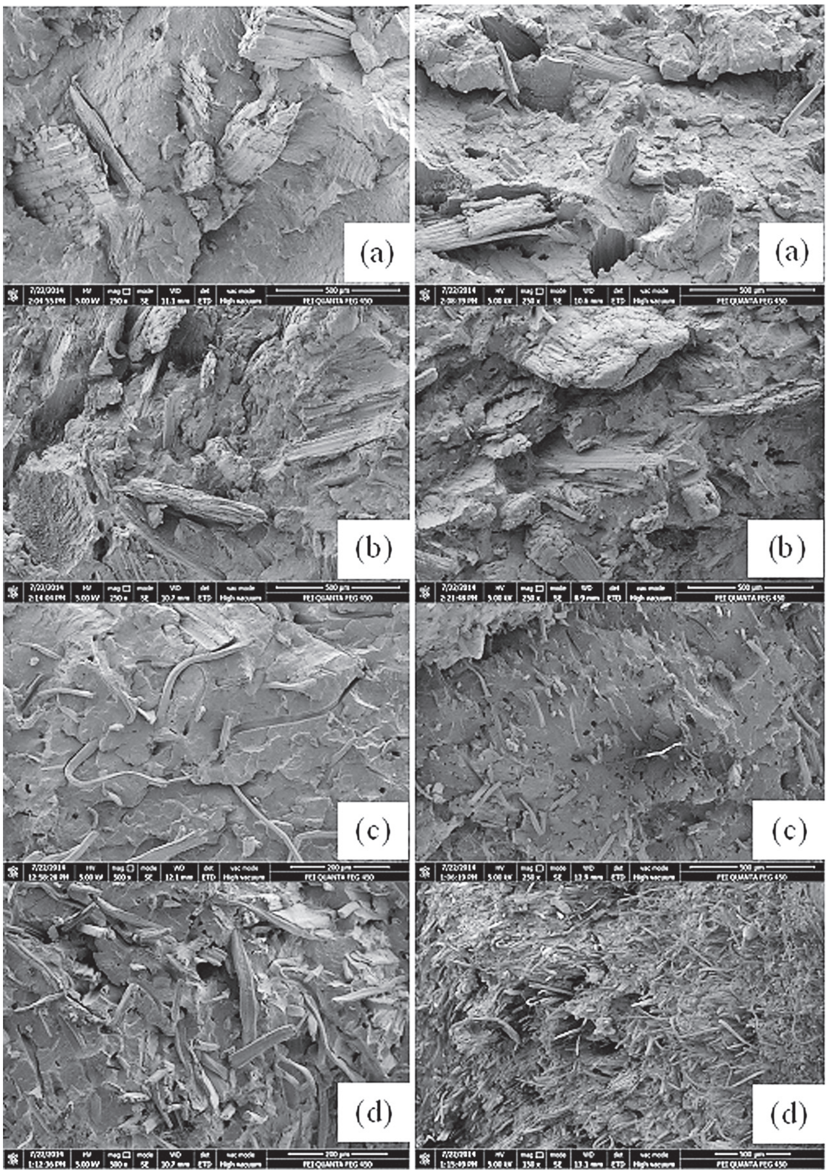

Figure 5 SEM pictures of WF composites (left side) and CF (right side) (a) 10 %, (b) 20 %, (c) 30 % and (d) 40 %
Slika 5. SEM slike kompozita s drvnim brašnom (lijeva strana) i celuloznim vlaknima (desna strana): (a) 10 %, (b) 20 %, (c) 30 % i (d) 40 %

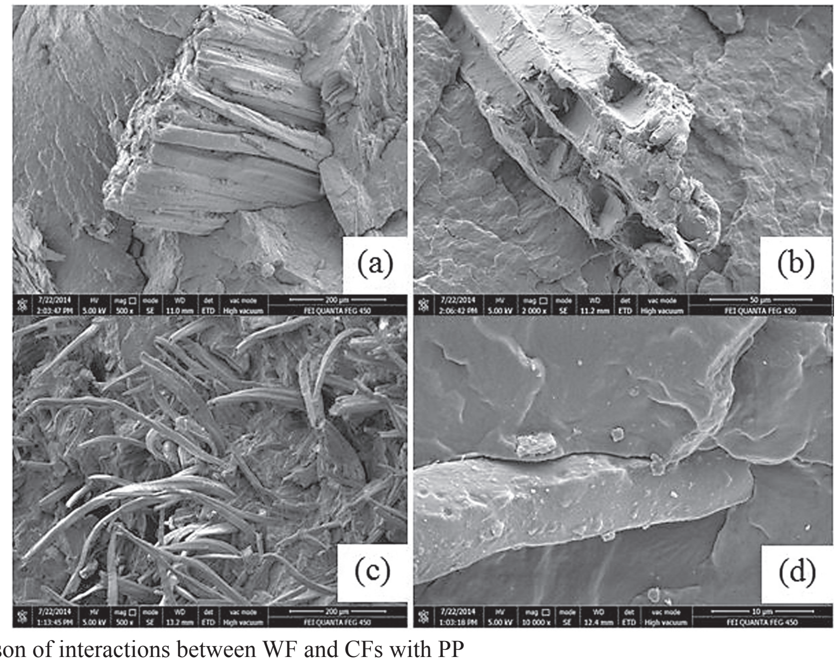

Figure 6 Comparison of interactions between WF and CFs with PP
Slika 6. Usporedba interakcije WF-a i PP-a s interakcijom CF-a i PP-a

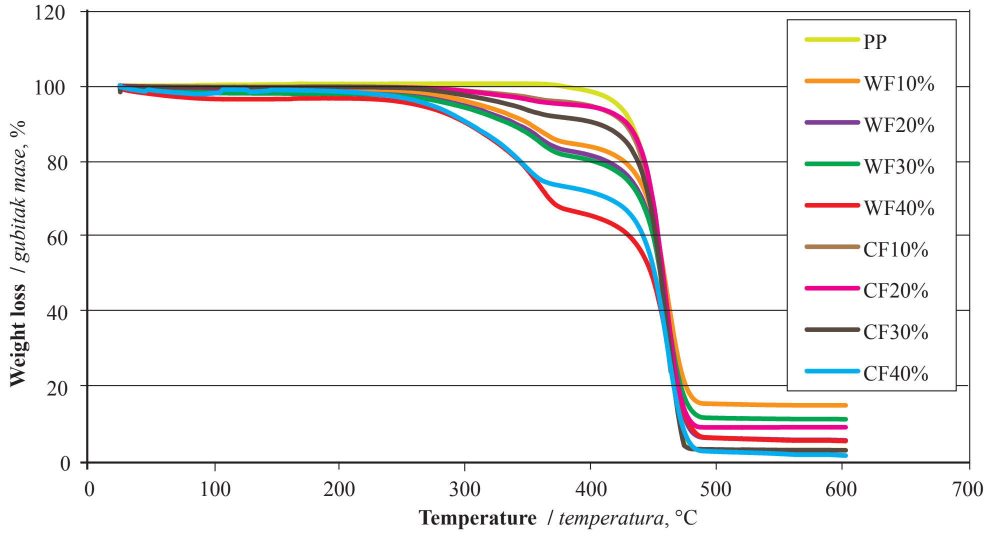

Figure 7 TGA curves of WPC
Slika 7. TGA krivulje drvno-plastičnih kompozita

3.3 Thermal stability
3.3. Toplinska stabilnost

Thermal stability of the composites is an important property for some application areas. For this reason, the thermal property of the composites obtained was investigated by using DSC, TGA and DTA. Fig. 7 shows TGA curves of the composites. It is well known that wood flour decomposes in the order of hemicellulose (200–300°C), cellulose (300–400 °C), and lignin (200–900 °C) (Joseph *et al.*, 2003; Verbicky *et al.*, 1988). According to Fig. 7, the fastest mass losses have been observed in WF 40 % and CF 40 % composites. On the other hand, CF 10 % has the nearest curve to pure PP. Generally, the increasing amount of WF and/or CF brings about decreasing levels of WPC weight loss at the high temperature.

Fig. 8 shows DTA curves, which present the degradation point of pure PP and WF/CF composites. There are two important points: melting point and degradation point. Endothermic peaks are at 165 °C (melting point) and 460 °C (degradation point) in DTA curves. Interfacial interaction also plays a very important role in the degradation of polymeric nanocomposites. Better interfacial interaction allows particles to act as restriction sites for the movement of a polymer chain. This makes the scission of a polymer chain harder at lower temperature, and hence moves the degradation temperature of the material to a higher temperature. Moreover, improved interfacial interaction between additives and polymer chain, introduced by deeper penetration of smaller particles in the polymer matrix, will also limit the movement of the polymer chain (Khan *et al.*, 2010).

DTG curves are shown in Fig. 9. The peaks of the composites were found to be between 370 °C and 470 °C at the value of 2800 mg/min. This peak corresponds

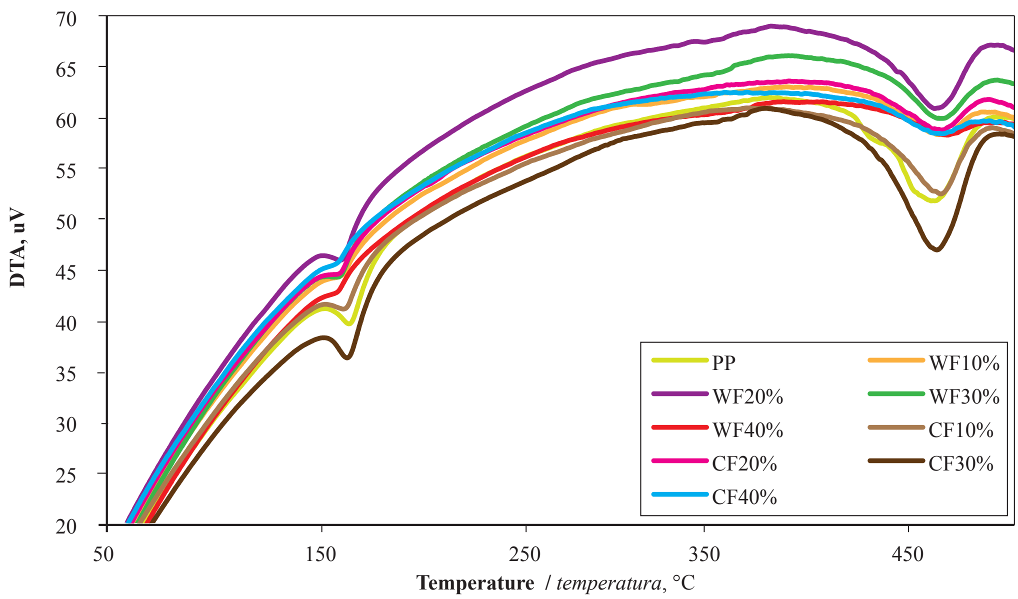

Figure 8 DTA curves of WPC
Slika 8. DTA krivulje drvno-plastičnih kompozita

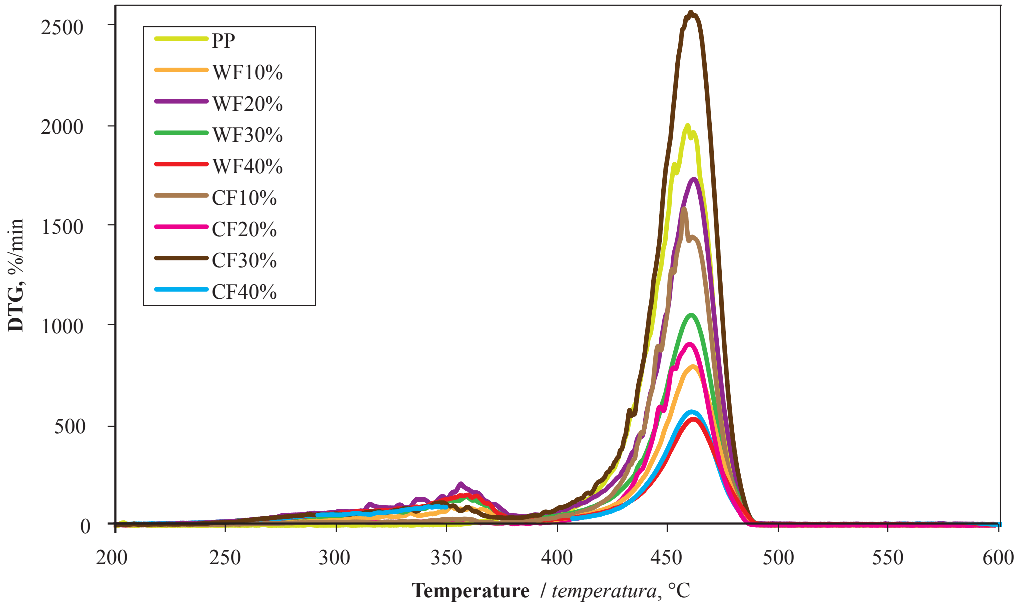

Figure 9 DTG curves of composites
Slika 9. DTG krivulje drvno-plastičnih kompozita

to the rupture of C-C chain bonds along with H-abstraction at the site of rupture (Pandey, 1999; Roger, 2005). PP is strongly hygroscopic in nature and completely depleted at 426 °C without the formation of any char residue (Baeza and Freer, 2001).

The results also show that, as the filler loading increased, the thermal stability of the composites slightly decreased, as the WF/CF content increased because of the lower thermal stability of WF/CF compared to the pure PP. The summary of the thermogravimetric analysis is presented in Table 3.

Table 4 shows DSC curves and summary DSC data of the composites with WF and CFs. The T_m and T_c values of the composites changed a little bit with the addition of WF and CFs and the composites have different T_m and T_c values. The melting enthalpy (ΔH_m), the crystallization enthalpy (ΔH_c) and the degree of crystallinity decreased with the addition of WF and CFs. Similar results were also reported by other researchers for MCC filled composites. The DSC results also indicated that the crystallinity (X_c) decreased with increasing MCC level because of the inability of polymer chains to be fully incorporated into the growing crystalline lamellae (Kızıltaş, 2009). The glass transition temperature provides important evidence for blend miscibility (Liang, 2007). All composites showed only one Tg value and the T_g values of composites are between 110 °C and 120 °C as WF/CF loading increased. Fig. 10 shows dual melting peaks in all composites.

4 CONCLUSIONS
4. ZAKLJUČAK

Wood flour (WF) and cellulose fiber (CF) composites were produced by melt compounding and these composites were investigated for four different loadings based on the properties of polypropylene composites. The results indicated that there were increases in the density and mechanical properties, such as TM, MOE and IIS. However, both the tensile strength and MOR characteristics were decreased. It was found that the thermal stability of the composites decreased with both WF and CFs. The SEM pictures showed that there were some agglomerations in morphological structure

Table 3 Summary of thermogravimetric analysis
Tablica 3. Kratki pregled termogravimetrijske analize kompozita

Samples *Uzorci*	TGA Analysis / *TGA analiza*			DTA Analysis / *DTA analiza*		DTG
	$T_{10\%}$ °C	$T_{50\%}$ °C	$T_{85\%}$ °C	Melting point *Točka taljenja* °C	Degradation point *Točka degradacije* °C	T_{dmax}, °C
PP	431.7	455.6	468.6	169.9	460.6	459.3
WF10	350.1	457.6	464.9	169.5	466.2	462.8
WF20	338.9	454.8	471.3	166.5	463.4	462.3
WF30	334.1	455.1	476.9	164.4	465.5	461.5
WF40	300.8	447.6	471.6	164.1	466.2	461.9
CF10	426.2	454.7	465.9	167.9	464.9	457.7
CF20	428.2	456.8	472.6	165.4	466.4	460.8
CF30	403.1	455.1	467.9	168.8	465.9	460.9
CF40	302.2	450.3	468.3	163.5	466.2	461.9

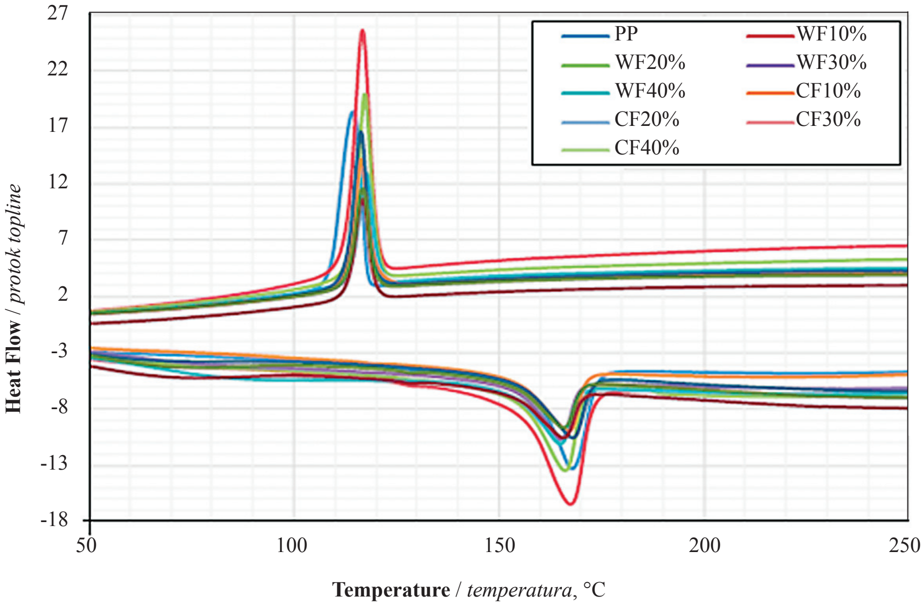

Figure 10 DSC curves of composites
Slika 10. DSC krivulje drvno-plastičnih kompozita

Table 4 Summary of differential scanning calorimetry
Tablica 4. Kratki pregled rezultata diferencijalne skenirajuće kalorimetrije

Samples *Uzorci*	Cooling / *Hlađenje*			Heating / *Zagrijavanje*			X_c, %
	T_{Conset}	T_c	ΔH_c	T_{monset}	T_m	ΔH_m	
	°C	°C	J/g	°C	°C	J/g	
PP	117.4	113.9	99.8	157.3	168.2	88.8	46.4
WF10%	120.7	116.8	84.9	154.6	167.5	82.5	43.1
WF20%	120.4	116.9	75.9	154.3	166.1	73.1	38.2
WF30%	120.9	116.9	68.9	153.9	165.4	66.4	34.7
WF40%	121.4	117.1	61.8	153.3	165.1	64.3	33.6
CF10%	119.6	115.6	90.7	153.2	167.1	82.9	43.3
CF20%	118.8	115.7	70.2	154.4	168.2	64.1	33.5
CF30%	118.5	115.9	78.5	153.1	167.2	73.8	38.6
CF40%	119.7	116.1	62.5	152.9	166.1	60.5	31.8

of the composites. In summary, 40 % filler content had the best properties. As a result, the composites obtained from PP and lignocellulosic fillers have a better performance compared to PP, and the composites can be used as alternative materials in areas such as outdoor furniture, flowerpots, etc.

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Influence of Lyophilisation and Oven-Drying on Extraction Yield of Oregonin from European Black Alder (*Alnus glutinosa* (L.) Gaertn.) Bark

Utjecaj liofilizacije i sušenja u sušioniku na prinos ekstrahiranog oregonina iz kore crne johe (*Alnus glutinosa* (L.) Gaertn.)

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ABSTRACT • *Oregonin ((5S)-1,7-bis(3,4-dihydroxyphenyl)-5-(β-D-xylopyranosyloxy)-heptan-3-one) is the first discovered and reported naturally occurring diarylheptanoid glycoside. It exhibits high biological activity, but it is also the compound of interest because of its ability to form reddish-orange and reddish-brown colours. In this research, European black alder (Alnus glutinosa (L.) Gaertn.) bark was separately subjected to lyophilisation and oven-drying before oregonin extraction with two different solvents. According to the results, methanol has proven to be more suitable as solvent compared to deionised water for oregonin extraction by maceration from black alder bark matrix regardless of the dehydration method. Accordingly, in the case of methanol, much higher yields of oregonin were obtained after lyophilisation, than after oven-drying. Furthermore, extraction by deionised water produced slightly higher yield of oregonin after oven-drying than after lyophilisation, as opposed to methanol. However, in much lower oregonin concentrations. Among other things, oregonin propensity to degradation at elevated temperature could probably be applied for improving and facilitating alder wood hydrothermal processing by minimizing uneven discolouration.*

Keywords: *European black alder, bark, oregonin, hydrothermal treatment, lyophilisation (freeze-drying), oven-drying, extraction yield, methanol, deionised water*

SAŽETAK • *Oregonin ((5S)-1,7-bis(3,4-dihidroksifenil)-5-(β-D-ksilopiranosiloksi)-heptan-3-on) prvi je otkriveni i objavljeni prirodni diarilheptanoid glikozid. Pokazuje visoku biološku aktivnost, a važan je i zbog svoje sposobnosti da stvara crvenonarančaste i crvenosmeđe boje. U ovom je istraživanju kora europske crne johe (Alnus*

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glutinosa (L.) Gaertn.) zasebno podvrgnuta liofilizaciji i sušenju u sušioniku prije ekstrakcije oregonina dvama različitim otapalima. Prema dobivenim rezultatima, pokazalo se da je za ekstrakciju oregonina maceracijom iz matrice kore crne johe prikladnije otapalo metanol nego deionizirana voda, bez obzira na primijenjenu dehidracijsku metodu. U skladu s navedenim, upotrebom metanola ostvareni su mnogo viši prinosi oregonina nakon liofilizacije nego nakon sušenja u sušioniku. Za razliku od metanola, pri ekstrakciji deioniziranom vodom prinosi oregonina nešto su veći nakon sušenja u sušioniku nego poslije liofilizacije, ali su njegove koncentracije znatno niže. Među ostalim, sklonost oregonina degradaciji pri povišenoj temperaturi vjerojatno bi se mogla iskoristiti za poboljšanje i olakšanje hidrotermičke obrade crne johe minimalizacijom neravnomjerne promjene boje.

Ključne riječi: *europska crna joha, kora, oregonin, hidrotermička obrada, liofilizacija, sušenje u sušioniku, prinos ekstrakcije, metanol, deionizirana voda*

1 INTRODUCTION
1. UVOD

Oregonin ((5*S*)-1,7-bis(3,4-dihydroxyphenyl)-5-(*β*-D-xylopyranosyloxy)-heptan-3-one) is the first discovered and reported naturally occurring diarylheptanoid glycoside (Karchesy *et al.,* 1974), and afterwards its "S" absolute configuration was determined combining ^{13}C NMR spectroscopy and the X-ray crystallography (Suga *et al.,* 1982). Considering its structure, oregonin belongs to a class of linear 1,7-diarylheptanoids, natural phenolic compounds, which constitute a separate small group of plant metabolites characterized by two aromatic rings connected with seven carbon chain (C_6–C_7–C_6).

In the previous papers of other researchers, oregonin has been isolated and reported from the bark of several alder species (*Alnus* spp.) (Table 1). Its biological activity was reported together with its anti-oxidant, anti-inflammatory, anti-microbial, anti-atopic dermatitis, and anti-cancer properties (Kuo *et al.,* 2008; Choi *et al.,* 2010; Tung *et al.,* 2010; Sati *et al.,* 2011; Telysheva *et al.,* 2011). Therefore, black alder bark could be used as a resource of bioactive compounds, and not only as fuel in wood processing companies as currently used. Besides exhibiting high biological activity, oregonin is also the compound of interest because of its ability to form reddish-orange and reddish-brown colours, which particularly affects alder wood hydrothermal processing.

Among other factors, heat can have negative influence on bioactive compounds during their acquisition and chemical analysis. On the other hand, however, heat could be used for inactivation of chemical compounds (if prone to thermal degradation) that impede hydrothermal wood processing. As for the lyophilisation process, there is an unwarranted and unexamined assumption that it properly and optimally preserves the plant constituents, but these assumptions may be erroneous in some cases (Abascal *et al.,* 2005). In this research, the influence of heat and dehydration procedure on oregonin extraction yield from black alder bark was investigated and reported. Bark was used instead of wood because it contains larger quantities of oregonin than wood (Klarić, 2015). The stated research results will help understanding the influence of lyophilisation on oregonin extraction yield as compared to oven-drying. Furthermore, methanol and deionised water were compared as solvents for the oregonin extraction.

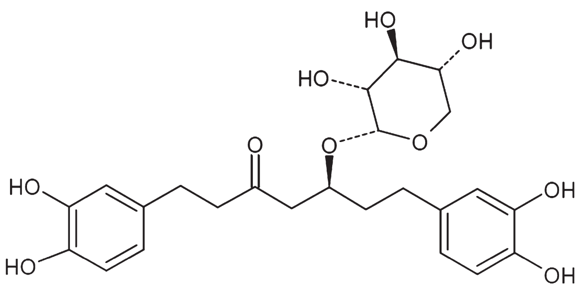

Figure 1 Chemical structure of Oregonin
Slika 1. Kemijska struktura oregonina

Table 1 Alder species (*Alnus* spp.) in which oregonin presence in bark was reported
Tablica 1. Vrste johe (*Alnus* spp.) u kojima je utvrđeno postojanje oregonina u kori

Species / *Vrsta*	**Source** / *Izvor*
Alnus glutinosa (L.) Gaertn.	Guz *et al.,* 2002; Roze *et al.,* 2011; Novaković *et al.*, 2013
Alnus incana (L.) Moench	Guz *et al.,* 2002; Roze *et al.,* 2011; Telysheva *et al.,* 2011
Alnus rubra Bong.	Karchesy *et al.,* 1974
Alnus viridis (Chaix) D.C.	Guz *et al.,* 2002
Alnus cordata (Loisel.) Duby	Guz *et al.,* 2002
Alnus hirsuita var. *sibirica*	Lee *et al.,* 2000
Alnus japonica (Thunb.) Steud.	Baek *et al.,* 2011
Alnus pendula Matsum.	Choi, 2013
Alnus tinctoria Sarg.	Ko *et al.,* 2015

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

2.1 Chemicals
2.1. Kemikalije

High purity (≥95 %) analytical standard of oregonin was obtained from Sigma-Aldrich (Germany). For the extraction process, methanol (MeOH) of HPLC grade was supplied by J. T. Baker (USA), while deionized water (dH_2O) (ASTM Type II) was prepared on TKA/Thermo Scientific MicroMed Pure system (Thermo Fisher Scientific, USA). Formic acid of analytical grade (Orka Lab, Croatia) and deionised water (ASTM Type I, (MiliQ)) prepared on Millipore Simplicity Purification system (Millipore Corporation, USA) were used for mobile phase in high performance liquid chromatography (HPLC) analysis.

2.2 Bark acquisition and preparation
2.2. Dobivanje i priprema kore

Bark (inner & outer bark included) was collected from five-centimetre thick cross-section segment (disk) sawn at the height of 1.5 meters (from the ground) from black alder tree (30 cm breast height diameter). The tree was sampled during July 2014 in thirty-year old forest department "98" section "b" within the management unit "Đurđevačke nizinske šume" owned and governed by the Croatian state forest enterprise Hrvatske šume Ltd. The bark sample was milled and homogenized according to the previously described procedure (Klarić *et al.,* 2016). A certain amount of frozen homogenized raw bark was oven-dried at 103 ± 2 °C till constant mass has been reached. Another amount of frozen homogenized raw bark was lyophilised (Christ alpha 1-2 LD, Germany) by the main drying phase (-55 °C, 0.021 bar, 24 hours) and final drying phase (-50 °C, 0.040 bar, 4 hours).

2.3 Extraction procedure
2.3. Ekstrakcija

Extraction by maceration was conducted on magnetic stirrer (IKA C-MAG HS 7, Germany) for 24 hours (mot 1.5) at 20 ± 1 °C. Two grams of oven-dried and lyophilized bark were separately extracted in 250 mL of MeOH and dH_2O, in triplicates with regard to solvent type and dehydration procedure. The obtained extracts were filtered through grade 388 quantitative ashless filter paper (Munktell, Sweden), and stored in amber glass jars and kept in refrigerator till further analysis. Before HPLC analysis, extracts were additionally filtered through syringe nylon filters (0.22 μm) in amber glass vials with rubber/FEP sept. The amount of extracted oregonin from bark was determined by HPLC-DAD method.

2.4 Liquid chromatography
2.4. Tekućinska kromatografija

The liquid chromatography analysis was conducted using a Varian ProStar 500 (USA) HPLC system consisting of a ProStar 330 diode array detector (DAD), ProStar 410 autosampler, ProStar 230 tertiary pump system and column compartment. Instrument control, data acquisition and evaluation were done with Star Chromatography Work station v5.5 (Varian ProStar 360). Separation was performed on Nucleosil-C18 column 150 × 4.6 mm, particle size 5 μm (Supelco Analytical, USA). The analysis was performed using 0.1 % formic acid in MeOH as eluent A and 0.1 % formic acid in MiliQ water as eluent B in gradient elution mode. The elution started with 90 % of eluent B for 25 min, following 25 min gradient to 0 % of B and then back to initial conditions within 5 min. Flow rate was 0.5 $mL \cdot min^{-1}$ and injection volume was 10 μL. The separation was monitored at absorbance wavelength of 280 nm. Stock standard solution of oregonin was prepared by dissolving accurate quantity of the standard in MeOH and stored in the dark at 4 °C. The working standard solutions of different concentrations were prepared by appropriate dilution of the stock solution. Calibration curve for oregonin was prepared using six working standard solutions in the range 5-100 $mg \cdot L^{-1}$ (5, 20, 40, 60, 80 and 100 $mg \cdot L^{-1}$). The calibration curve was plotted from chromatograms as peak area *vs*. concentration of the standard. For each extract, three separate vials were prepared.

2.5 Statistical analysis
2.5. Statistička analiza

Along with descriptive statistics, Welch's ANOVA compared means test was conducted at the 0.05 significance level. STATISTICA 12 Dell Inc., and MS Excel software were used.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

In this research, the effect of lyophilisation and oven-drying on maceration extraction yield of oregonin with MeOH and dH_2O was investigated. The amount of extracted oregonin was determined by HPLC-DAD analysis. To confirm the presence of the target compound in bark samples, retention time of peak obtained by analysing extracts of bark were compared with retention time of standard compound. Further, confirmation of peak identity was provided by comparison of UV spectra obtained by DAD. Strong agreement of retention time (t_R = 16.50 min) and UV spectra (λ_{max} = 280 nm) from oregonin standard and peak from bark extracts were obtained, thus confirming the identity of target analyte. The chromatogram of oregonin is shown in Figure 2. The quantification of oregonin was carried out on the basis of the calibration curve ($y = 5.8621 \cdot x - 2.322$). Coefficient of determination (R^2) was 0.9993 confirming high degree of correlation and good linearity of the method. Acceptable RSD values were obtained, 0.4 % for repeatability and

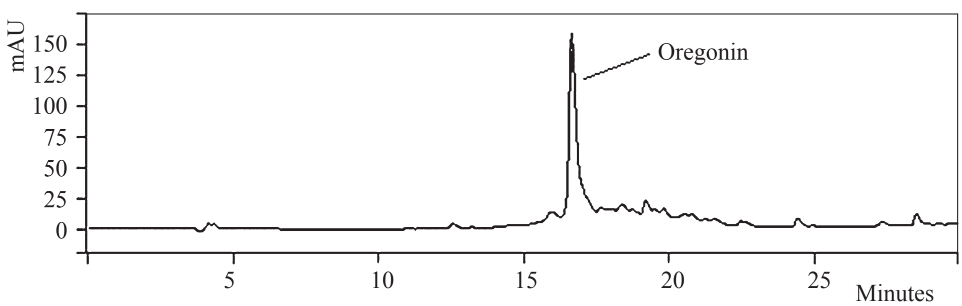

Figure 2 Chromatogram of oregonin obtained with MeOH after lyophilisation
Slika 2. Kromatogram oregonina dobiven uz pomoć MeOH nakon liofilizacije

Table 2 Average content of oregonin, descriptive statistic, $mg \cdot g_{dm}^{-1}$
Tablica 2. Prosječni sadržaj oregonina, deskriptivna statistika, $mg \cdot g_{dm}^{-1}$

S	*D*	*E*	*N*	*Mean*	*SD*	*95 CI*	*Med*	*IQR*	*MIN*	*MAX*
MeOH	Lyo.	I	3	60.63	0.20	60.144 – 61.121	60.53	0.35	60.51	60.86
		II	3	58.21	0.34	57.380 – 59.047	58.03	0.59	58.01	58.60
		III	3	60.25	0.58	58.818 – 61.688	60.42	1.12	59.61	60.73
	O.D.	I	3	7.71	0.09	7.489 – 7.929	7.69	0.18	7.63	7.80
		II	3	7.72	0.10	7.479 – 7.954	7.67	0.18	7.65	7.83
		III	3	7.53	0.17	7.122 – 7.946	7.61	0.31	7.34	7.65
dH_2O	Lyo.	I	3	1.26	0.04	1.163 – 1.364	1.26	0.08	1.22	1.30
		II	3	1.25	0.08	1.058 – 1.434	1.28	0.14	1.16	1.30
		III	3	1.21	0.04	1.110 – 1.300	1.22	0.07	1.16	1.23
	O.D.	I	3	4.12	0.04	4.012 – 4.230	4.12	0.09	4.08	4.17
		II	3	4.22	0.06	4.079 – 4.353	4.21	0.11	4.17	4.27
		III	3	4.10	0.04	3.991 – 4.208	4.10	0.09	4.06	4.14

Note: *S* – type of solvent / *vrsta otapala*; *D* – type of dehydration / *vrsta dehidracije*; *Lyo.* – lyophilisation / *liofilizacija*; *O.D.* – oven-drying at 103 ± 2 °C / *sušenje u sušioniku pri 103 ± 2 °C*; *E* – extraction process / *proces ekstrakcije*; *N* – number of measurements / *broj mjerenja*; *Mean* – arithmetic mean / *aritmetička sredina; SD* – standard deviation / *standardna devijacija*; *95 CI* – 95 % confidence interval of the mean / *95 %-tni interval pouzdanosti*; *Med* – median / *medijan*; *IQR* – interquartile range / *interkvartilni raspon*; *MIN* – minimum value / *minimalna vrijednost*; *MAX* – maximum value / *maksimalna vrijednost*

1.4 % for reproducibility. Extracts of oregonin from bark were analysed and expressed as mg of oregonin per g of dry bark mass. The descriptive results of the research are shown in Table 2.

As it is evident from the presented results (Table 2), statistically significant difference for oregonin yields was established between dehydration methods for MeOH (F(1, 8.220 = 17297.271, $p < 0.001$), and for dH_2O (F(1, 15.191) = 10136.376, $p < 0.001$). A statistically significant difference was also observed in oregonin yields between MeOH and dH_2O after lyophilisation (F(1, 8.033) = 22078.953, $p < 0.001$), and after oven-drying (F(1, 11.646) = 4657.159, $p < 0.001$), as determined by Welch's ANOVA. With methanol, much higher yields of oregonin from black alder bark were obtained after lyophilisation than after oven-drying at 103 ± 2 °C. However, in case of dH_2O, this trend is reversed. This reversed trend in the case of dH_2O was unexpected, but regardless of dehydration method applied, much higher oregonin yield was obtained with MeOH than with dH_2O as a solvent. During the dehydration process, changes that take place within wood are dependent on time-temperature-moisture-oxygen interrelationship (Navi and Sandberg, 2012). Consequently, in specific cases, the degradation of compounds present in wood and/or formation of newly formed compounds is possible, due to a wide range of chemical reactions, such as oxidation, hydrolysis, deacetylation, depolymerisation, *etc.* (Hon and Minemura, 2001; Fengel and Wegener, 2003; Hill, 2006; Navi and Sandberg, 2012; Németh *et al.,* 2013). Although it is generally considered that the lyophilisation is a preferable dehydration method, which retains higher levels of phenols *i.e.* bioactive compounds in the sample, it may not always be the case (Abascal *et al.,* 2005; Dai and Mumper, 2010; Jiang *et al.,* 2016). As regards VOCs (volatile organic compounds), they are probably lost to a greater extent during lyophilisation, as opposed to other dehydration methods at lower temperatures during which no vacuum is applied, or if fresh plant material is used (Abascal *et al.,* 2005). In addition to low temperatures, another important advantage of lyophilisation during the acquisition of natural bioactive compounds is that the sample oxidation is prevented during dehydration process due to the lack of oxygen, considering bark and wood great internal structural voids and hygroscopicity of structural components of the matrix. On the other hand, if an elevated temperature near 100 °C is applied, catechol oxidases will most likely be inactivated, *i.e.* subjected to denaturation causing the loss of activity. This inactivation of the enzymes can then facilitate the successful implementation of wood hydrothermal processing. As regards methanol, it is often a solvent of choice for ex-

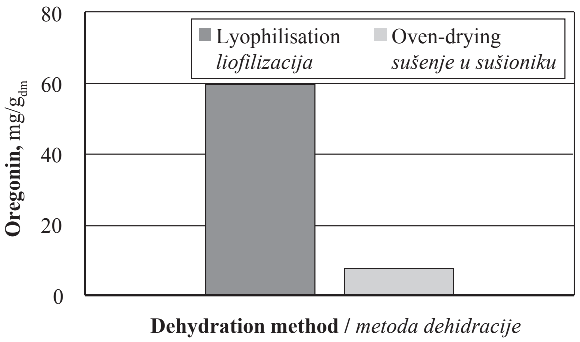

Figure 3 Oregonin average content – MeOH
Slika 3. Prosječni sadržaj oregonina – MeOH

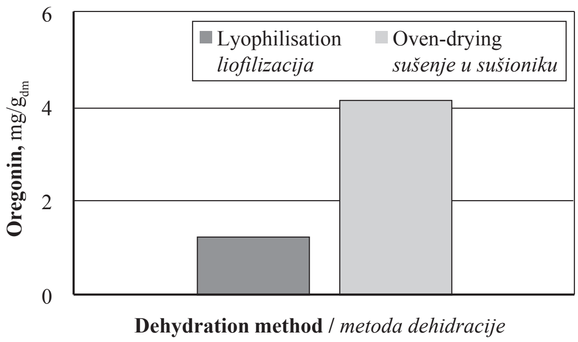

Figure 4 Oregonin average content – dH_2O
Slika 4. Prosječni sadržaj oregonina – dH_2O

traction of phenols from plant material. Comparing several organic solvents and deionised water, Klarić *et al.* (2016) established that MeOH produce highest yields of total soluble extractives (TSEs), phenols (TSPs) and flavonoids (TSFs) from black alder bark and wood. Presumably, additional improvements of oregonin extraction yields with MeOH could most likely be achieved by mixing MeOH with smaller portions of dH_2O (Fang *et al.,* 2013). Also, if slightly higher extraction temperature was employed, the oregonin yield with dH_2O would probably be somewhat higher, due to surface tension and viscosity reduction, thus facilitating dH_2O penetration into the bark matrix (Dai and Mumper, 2010; Fang *et al.,* 2013). Additional advantage of MeOH, compared to dH_2O, is that enzymes (in this case catechol oxidase) present in the plant will be deactivated (Jones and Kinghorn, 2006), and that fungi development will be prevented. Figure 3 and Figure 4 show the combined MeOH and dH_2O oregonin average yields after lyophilisation and oven-drying.

Further research regarding oregonin will be focused on its presence, concentration and influence on black alder wood discolouration during hydrothermal processing.

4 CONCLUSION
4. ZAKLJUČAK

It is more preferable to use MeOH as a solvent for oregonin extraction by maceration from black alder bark than dH_2O, regardless of the applied dehydration method. According to the obtained results, the highest yields of oregonin were achieved by conducting extraction with MeOH after lyophilisation, while significantly lower yields were achieved after oven-drying at 103 ± 2 °C. On the basis of the above mentioned findings, it could be concluded that, among others, oregonin is presumably prone to degradation at elevated temperature (103 ± 2 °C). This finding could probably be implemented in hydrothermal wood processing to minimize the uneven discolouration of wood by conducting pre-steaming or similar high temperature procedures immediately after sawing and before kiln drying. If oregonin is the compound of interest because of its high biological activity, lyophilisation should be a preferred method of dehydration, accompanied by a suitable extraction solvent.

In the case of dH_2O, yields of oregonin obtained after lyophilisation and oven-drying were reversed compared to MeOH as can be seen in Figure 3 and Figure 4. This reversed trend in the case of dH_2O is an interesting and unexpected phenomenon that should be further researched.

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Impregnability of Paulownia and Populus Wood with Copper Based Preservatives

Učinci impregnacije drva paulovnije i topole zaštitnim sredstvima na bazi bakra

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ABSTRACT • *The importance of fast growing wood species such as Paulownia and Populus wood is increasing. Unfortunately, these wood species do not have durable wood, so they have to be protected for use in outdoor applications. One of the most important groups of wood preservatives for heavy duty applications is the copper based one. Paulownia and Populus wood samples were thus treated with copper-ethanolamine (Cu/MEA) and acid copper chromate (ACC) according to various treatment processes: Bethell, Rüping and dipping. The dipping treatment was performed with various submersion times, ranging from 1 min to 10 days. The uptake of preservative solution, penetration and colour of the specimens were then determined. The results clearly indicate that the permeability of Paulownia is not as good as that of Populus wood. The permeability of Paulownia can be improved with the proper selection of impregnation procedure and wood preservatives. Cu/MEA was found to be more suitable for treatment of Paulownia wood than classical ACC.*

Keywords: *impregnation, dipping, Paulownia, Populus***,** *penetration, uptake of preservative solution*

SAŽETAK • *Važnost brzorastućih vrsta drveća kao što su paulovnija (Paulownia) i topola (Populus) svakim danom postaje sve veća. Nažalost, drvo tih vrsta nije baš trajno, stoga se prije uporabe u vanjskim uvjetima mora zaštititi. Jedna od najvažnijih skupina sredstava za zaštitu drva za uporabu u nepovoljnim uvjetima jesu ona na bazi bakra. Uzorci drva paulovnije i topole tretirani su bakar-etanolaminom (Cu/MEA) i acetatnim bakrenim kromatom (ACC) različitim postupcima obrade: Bethellovim, Rüpingovim i potapanjem. Postupak je proveden uz različita vremena uranjanja, u rasponu od 1 min do 10 dana. Tijekom eksperimenta određivana je količina upijene otopine zaštitnog sredstva, dubina njezine penetracija i boja uzoraka. Rezultati jasno pokazuju da permeabilnost paulovnije nije baš dobra kao permeabilnost drva topole. Permeabilnost paulovnije može se poboljšati pravilnim izborom postupka impregnacije i zaštitnog sredstva. Istraživanje je potvrdilo da je Cu/MEA prikladniji za zaštitu drva paulovnije od klasičnoga ACC-a.*

Ključne riječi: *impregnacija, potapanje, paulovnija, topola, penetracija, upijanje otopine zaštitnog sredstva*

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1 INTRODUCTION
1. UVOD

Wood is one of the most commonly used raw materials in a wide variety of applications. However, when wood is used in outdoor applications, it is exposed to a variety of degradation factors (Brischke and Rapp, 2008). Among them, fungi are the most important in the majority of exposure conditions (Despot, 1998). Some very durable (durability class 1) wood species are available on the global market, such as teak, makoré, padouk, opepe and doussié (EN 350) (CEN, 2016). However, the majority of wood species and, consequently, the majority of wood on the market is not durable, so it has to be protected for use in outdoor applications (Brischke *et al*., 2013).

However, wood, as a regenerating and thus renewable resource, is not available indefinitely in terms of volumes and regional availability. In recent years, increasing competition for wood, intensified by rising prices for fossil fuels, has been observed. Shortages of wood are expected due to increased consumption of wood by developing countries, climate changes, etc. (Schwarzbauer and Stern, 2010). Industry will, therefore, have to focus on fast-growing species, such as *Paulownia* and *Populus*, as raw material. *Paulownia* is a fast-growing tree and can be used in a variety of applications, such as furniture, construction, aircraft and packaging (Flynn and Holder, 2001). It is commercialized as a wood species, with a good ratio between density and mechanical properties. However, its low permeability due to tylosis formation (Ghorbani *et al*., 2012) causes problems in penetration of wood preservatives on the one hand but, on the other hand, improves water resistance, which has been identified as the second most important factor contributing to the performance of wood in above ground applications (Žlahtič *et al*., 2015).

The selection of the wood preservative is one of the key steps to determine the use of treated wood (Willeitner, 2001; Melcher and Müller, 2016). The only active ingredients suitable for heavy duty applications worldwide are the copper based ones (Humar *et al.,* 2001; Humar and Lesar, 2013). The majority of the alternatives have been removed from the market or banned since December 2003 after the implementation of the Biocidal Products Directive (BPD 98/8/EC 1998) and Regulation (EU) No. 528/2012 (2012). At the moment, there are three leading groups of copper based wood preservatives on the world market: classical copper-chromium based preservatives, copper amine based solutions and micronized copper. Three different types of Alkaline copper quat (ACQ) formulations for the treatment of wood have been developed over time (Type B, C and D). Type D is manufactured using a monoethanolamine copper formulation (Cu-MEA) (AWPA, 2014). Waterborne copper-monoethanolamine (Mea) has completely replaced chromated copper arsenate (CCA) in the EU, although copper-chromium based solutions are still the key preservatives in the rest of the world. In addition, in the US, copper-amine solutions have been replaced by preservative solutions based on micronized copper, particularly for residential applications. Unfortunately, micronized copper is not suitable for refractory wood species. The particles in the suspension are too big to penetrate through the pit voids. In some countries, acid copper chromate (ACC) is used as an alternative. ACC is a leach-resistant preservative recommended for use above ground and for non-structural items in ground contact and it has been used in Europe and the United States since the 1920s (Preston, 2000; Humar *et al.,* 2006; Civardi *et al.,* 2015).

The aim of the present study was to elucidate whether two fast growing species, *Populus* and *Paulownia*, are suitable for impregnation with the currently most important copper based wood preservatives (acid copper chromate and copper-monoethanolamine). The prime objectives of the present study were hence to determine the influence of wood preservatives, retention and treatment methods on the permeability of *Paulownia fortunie* and *Populus deltoids*.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Three trees of both *Paulownia fortunei* and *Populous deltoids* were harvested from Gorgan Province, located in north-eastern Iran extending from 36° 46' to 36° 46'40″ N and 54° 22′ to 54° 22'50″ E with elevation ranging between 270 to 350 m above sea level. For this study, specimens of *Paulownia fortunie* and *Populus deltoids* of the following dimensions were prepared: 15 mm (T) × 15 mm (R) × 50 mm (L). All specimens were free from defects (knots, checks, rots or blue stain). They were prepared from the adult part of the tree. The experiments were performed with 4 parallel specimens. In total, 88 specimens were used.

The following wood preservative solutions were used for impregnation: Cu/MEA consisted of $CuCO_3$ (Merck) and C_2H_7NO), while ACC was a mixture of $CuSO_4 \times 5H_2O$ (Merck) and $K_2Cr_2O_7$ (Merck). The copper concentration was the same in both solutions (c_{Cu} = 0.5 %). The samples were air dried in laboratory conditions (23 °C; 60 % RH) for four weeks. The first week in the closed chambers, then in half opened, and the last week in completely opened chambers.

Before the treatment process, samples were divided into series. One series of samples was sealed with an epoxy resin (Epikote 828, USA) so that penetration and retention values would specify radial/or tangential pathways, while series of samples were taken without end sealing to give an indication of the absorption/penetration of the preservative from all sides.

In order to fully elucidate the impregnability of the investigated materials, various treatment procedures were applied: Bethell (full cell), Rüping (empty cell) and dipping treatment (various dipping times). These treatment procedures were applied to both preservative solutions used. The specimens were dried and the dry weight was recorded before impregnation. Specimens were weighed before and after impregnation. The uptakes of preservative solutions were determined gravimetrically from the mass difference and the volume of the specimens.

Prior to treatment, specimens were placed in glass jars and submerged in the preservative. Glass bars were used to prevent their floating. During the modified Bethell process, wood specimens were placed in a pilot plant tank and subjected to a vacuum of (-0.8 bar) for 15 min, followed by pressure at 8 bar for 60 min. In the Rüping treatment, all procedures were performed with similar parameters. However, the initial pressure of 2 bar for 15 min was followed by a pressure of 8 bar for 60 min. During the dipping treatment, specimens were dipped into Cu monoethanolamine and ACC solutions for 1, 10, 1440, 2880, 4320, 8640, 11520 and 14400 minutes to establish the influence of different dipping times. Impregnation was performed at room temperature. The specimens were then wiped lightly to remove the preservative solution from the surface and immediately weighed to the nearest 0.01 g.

Impregnated specimens were air dried for four weeks. Thereafter, the specimens were dried in an oven at 103±3 for 24 h and weighed to the nearest 0.01 g. The penetration of preservatives in longitudinal and transverse directions was determined by spraying with Chrome Azurol S solution to indicate the presence of copper. The wood turned blue where the CCA and Cu/Mea had penetrated, whereas untreated zones were coloured red. The area of the treated zone and its percentage of the total cross section were calculated visually by measuring the penetration of preservative in each specimen.

The lightness of samples was measured using a TES-135 (Taiwan) based on the ASTM 2244 standard specification, where the lightness value ranged from 100 (white) to zero (dark). The measurement of lightness in $L^*a^*b^*$ coordinates was repeated at six locations on each sample. Colour measurements were performed, as the colour is the first indication of copper absorption. With copper based preservatives, the selective absorption of copper commonly appears. Hence, the surface uptakes more copper than assumed from the uptake of preservative solution (Humar and Lesar, 2009). CIELAB system characterized colours by three parameters: L^*, a^* and b^*. L axis represents the lightness whereas, a^* and b^* are the chromaticity coordinates. In the CIELAB coordinates, $+a^*$ stands for red, $-a^*$ for green, $+b^*$ for yellow, $-b^*$ for blue, and L^* varies from 100 (white) to zero (black). The total colour change was calculated using the following equation (1).

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Experiments were performed on *Paulownia fortunie* and *Populus deltoids* specimens with a dry density of the respective specimens between 0.28 and 0.42 g/cm^{-3}. The density of *Paulownia* is considerably lower than that of *Populus*. This must be taken into account when interpreting the results. However, these densities are slightly lower than the ones reported for Spruce (300...430...640 kg/m^3) (Wagenführ, 1996).

The uptake of preservative solution is the first essential information that indicates the quality of the treatment. Additionally, this parameter is the only one that can be monitored during the process of impregnation. If the uptake of preservative solution is not sufficient, neither penetration nor retention, (retention is the uptake of active ingredients in wood after impregnation, usually prescribed by specifiers), can meet the specified requirements (Humar and Lesar, 2009).

Uptake of preservative solutions data are presented in Table 1. The uptake of preservatives increased with increasing immersion times. After one minute of dipping, wood samples retained approximately 10 kg/m^3 of wood preservatives, while after 14400 min, they retained 196 kg/m^3 (Cu/MEA) and 65 kg/m^3 (AAC) of wood preservatives in *Populus* wood samples. The uptake of preservative solutions in *Paulownia* wood was slightly lower. Literature data revealed that with spruce wood comparable uptakes can be achieved, namely after 1 min, samples uptake 12 kg/m^3 of Cu/MEA based preservatives. In addition, seven days of immersion resulted in an average uptake of 152 kg/m^3 (Humar and Lesar, 2009). However, these values are difficult to compare, as different methodologies were applied. In addition, respective study on spruce wood clearly indicates that the uptake of preservative solution is considerably influenced by concentration. The Cu/MEA solution of higher concentration penetrates better than the ones of lower concentration (Humar and Lesar, 2009). It is believed that the prime reason for lower penetration of wood preservatives to *Paulownia* wood is that there are more tyloses in *Paulownia* wood than in *Populus*. However, similar ratios between the uptake of AAC and Cu/MEA wood preservatives can also be determined with *Paulownia* wood. It can be assumed that the primary reason for better uptake of Cu/MEA is that the solvent in Cu/MEA, ethanolamine, is a chemical that increases wood swelling (Mantanis *et al.*, 1994). As the cellulose armature swells, the wood enlarges, which enables better penetration of copper/ethanolamine based wood preservative. This phenomenon was more evident with specimens that were dipped for a longer period, since the wood has more time to swell and uptake more wood preservative. This phenomenon has already been elucidated and discussed (Humar *et al.,* 2012).

The highest uptake of wood preservatives was determined with specimens treated according to the Bethell full cell process. This is understandable and was expected (Humar and Lesar, 2009), since the full cell process is an impregnation procedure that fills the lumina of the cells with wood preservatives. Since this process is fairly severe and the wood specimens were fairly small, almost no difference was observed between the wood preservatives applied and the wood species used. On the other hand, these data indicate that even refractory wood of *Paulownia* can be successfully impregnated if the proper procedure is applied. The specifiers usually prescribe the amount of the active ingredients that have to penetrate wood. Hence, it is up to the impregnation facility how this requirement will be achieved. In Europe, wood preservation is based on several standards. The essential standard is EN 351-1 (CEN, 2007). This standard prescribes the penetration classes and the treated zone. There are six penetration classes ranging from NP1 (there are no requirements) to NP6 (full sapwood penetration and 6 mm penetration to exposed heartwood). Spruce wood is usually required to meet penetration class NP3 (penetration of 6 mm), while penetration class NP5 (full sapwood penetration) is required for Scots pine wood. Contrary to penetration, end users and specifiers usually prescribe retention. Retention requirement is to uptake the formulation/active ingredients expressed in kg per m3 of wood in the treated zone. This information is usually based on the extensive field testing based on the standard EN 599-1 (CEN, 2009) that prescribes which tests needs to be performed for the use in the respective use class. The list provided by the Nordic Wood Preservation Council (2008, 2015) is the most frequently used reference by end users who specify the orders of impregnated wood. If wood is not treated correctly, premature failures appear (Humar and Thaler, 2017), which leads to bad reputation of wood preservation in general.

Penetration is another important parameter that indicates the quality of the impregnation process. The specifiers usually prescribe penetration related to specific use class and wood species, as sometimes it is difficult to achieve target penetration to refractory wood species. For use class 3.2 and use class 4, full sapwood penetration is required for pine wood, and 8 mm for spruce wood. Due to the refractory nature of spruce wood, this wood is not recommended for applications in in-ground applications, even if treated (Humar *et al.,* 2017). In contrast to the uptake of preservative solution, this parameter cannot be controlled during the impregnation process. However, good uptake of preservative solution does not ensure a sufficient service life if the active ingredients remain on the surface layer. This is known as the chromatographic effect. As can be seen in Table 1, the time of immersion and impregnation process has a considerable effect on copper penetration (Figure 1). Penetration in the longitudinal direction is five to ten times better than in the radial direction. For example, with *Paulownia* Bethell treated with Cu/MEA, the copper penetrated 40 mm in the longitudinal, 5 mm in the tangential and 6 mm in the radial direction. Penetration during the Rüping process was lower, as was expected. However, both data indicate that *Paulownia* is a refractory wood species. During commercial impregnation, penetration classes with penetration more than 10 mm in radial and tangential directions are usually required. This indicates that after pressure impregnation, the so called shell treatment has been achieved, whereby only the outer layers are protected and the interior is left untreated. However, penetration can be improved with prolongation of the impregnation time, increased pressure or incising.

An alternative treatment suitable for less exposed wood applications is dipping. This process is predominantly suitable for impregnation plants with small capacities, since this technology does not require as much investment as a proper impregnation plant (Humar and Lesar, 2009). As can be seen in Figure 1, penetration of copper increased with immersion time in all directions. The highest increase was recorded after the first day of immersion in all directions. After ten days of dipping, the specimens sometimes reached the same values as recorded after the full cell process (Figure 1D). For example, radial penetration of Cu/MEA into *Paulownia* reached 9 mm, which is better than reported after Bethell or Rüping treatments. It is interesting that penetration in the longitudinal direction was better with *Populus* than with *Paulownia* wood, probably due to the presence of tyloses in *Paulownia* wood. However, in tangential and radial directions, better penetration

Table 1 Influence of wood species and impregnation method on the uptake of preservative solutions into unsealed samples. Standard deviations are presented in parentheses
Tablica 1. Utjecaj vrste drva i metode impregnacije na upijanje zaštitnog sredstva (standardna odstupanja prikazana su u zagradama)

Wood species *Vrsta drva*		***Populus*** *Topola*		***Paulowni*** *Paulovnija*	
Preservative solution *Otopina zaštitnog sredstva*		Cu/MEA	ACC	Cu/MEA	ACC
Treatment method *Metoda tretiranja*	**Time of immersion** *Vrijeme potapanja,* min	**Uptake of preservative solution, kg/m³** *Upijanje otopine zaštitnog sredstva,* kg/m³			
Dipping *potapanje*	1	10.5 (04)	9.0 (01)	8.0 (02)	4.2 (01)
	10	10.6 (07)	10.5 (02)	12.1 (09)	7.0 (06)
	60	24.9 (03)	13.9 (08)	14.3 (09)	9.7 (05)
	1440	75.0 (05)	26.2 (05)	43.1 (01)	18.7 (04)
	2880	86.1 (10)	29.4 (05)	57.5 (03)	21.5 (08)
	4320	118.9 (07)	37.2 (11)	67.7 (01)	25.5 (22)
	8640	150.0 (16)	46.4 (09)	90.7 (07)	35.5 (03)
	11520	155.8 (22)	52.7 (13)	99.0 (05)	37.0 (08)
	14400	196.2 (23)	64.7 (04)	117.0 (12)	40.0 (15)
Rueping process /*Ruepingov postupak*		288.0 (03)	275.5 (25)	155.0 (06)	175.0 (43)
Bethell process / *Bethellov postupak*		365.0 (13)	329.0 (42)	330.0 (57)	320.0 (44)

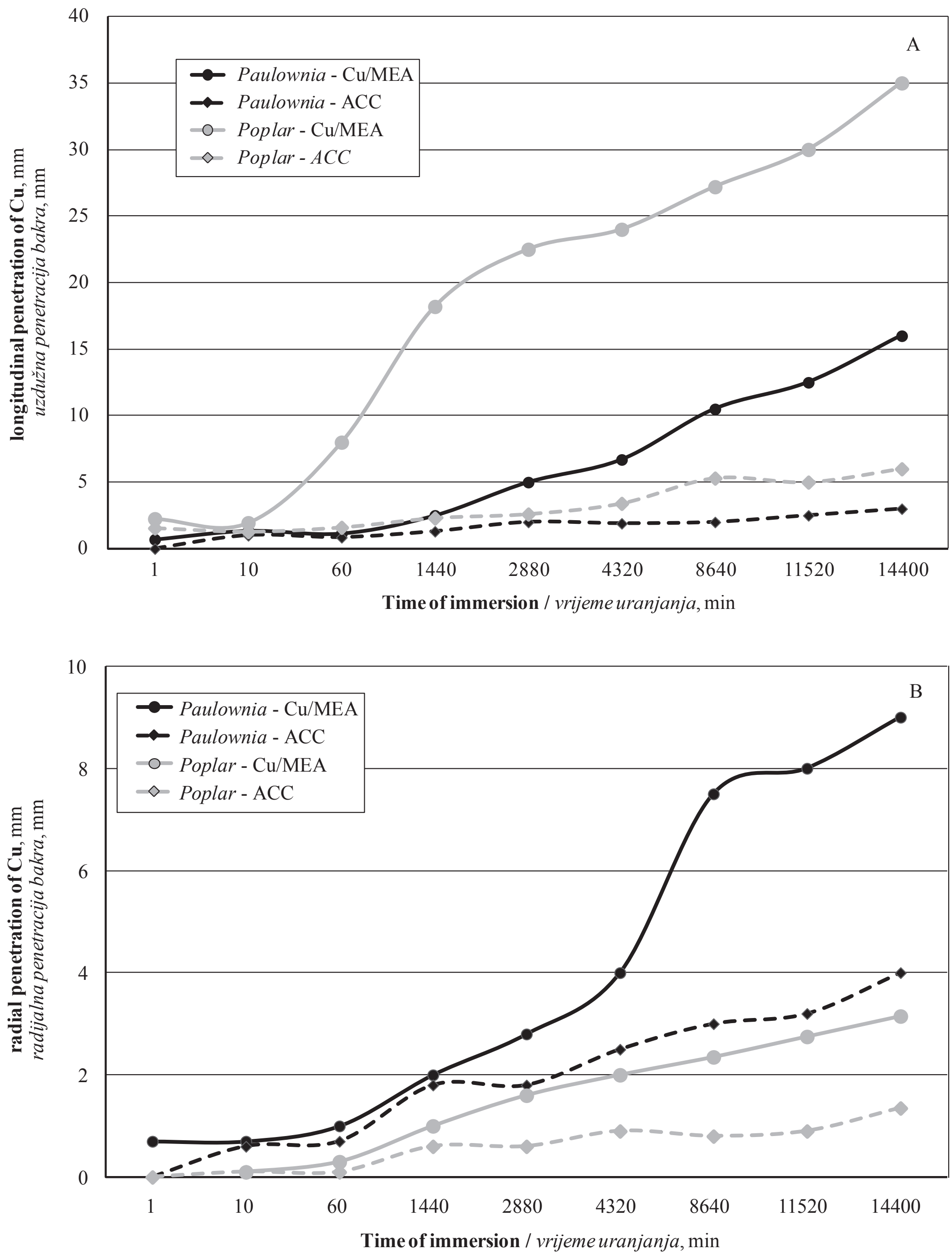

Figure 1 Influence of preservative solution and immersion time on penetration of preservative solutions in longitudinal (A), radial (B) and tangential (C) directions. Penetration after Bethell and Rueping process is presented in plot D.
Slika 1 Utjecaj otopine zaštitnog sredstva i vremena potapanja uzoraka na penetraciju otopine zaštitnog sredstva u uzdužnome (A), radijalnome (B) i tangencijalnome (C) smjeru; penetracija nakon Bethellova i Ruepingova postupka tretiranja prikazana je grafom D

was achieved with *Paulownia* than with *Populus* wood. This phenomenon was noted with both preservative solutions applied. In addition, it was noted that Cu/MEA penetrated much better than ACC, presumably due to the already explained phenomenon of wood swelling caused by ethanolamine.

However, it should be noted that, during long term dipping, selective absorption of copper can occur on wood constituents (Humar and Lesar, 2009). This is reflected in the fact that the outer layer contains more copper than indicated by the uptake of preservative solution. Additionally, users should also be aware that the strength of the solution decreases with the number of impregnation cycles. This phenomenon is also reflected in the colour (Figure 2) (Humar and Lesar, 2009).

Total colour changes increased with increasing dipping time and correlate with the retention. The most prominent change appeared during the first minute of immersion. This indicates that the reaction between active ingredients and wood is fairly fast. However, total changes were more prominent with Cu/MEA treated wood than with ACC. This can be linked to the uptake of wood preservatives, since it has already been reported that Cu/MEA penetrates wood better. Colour is one

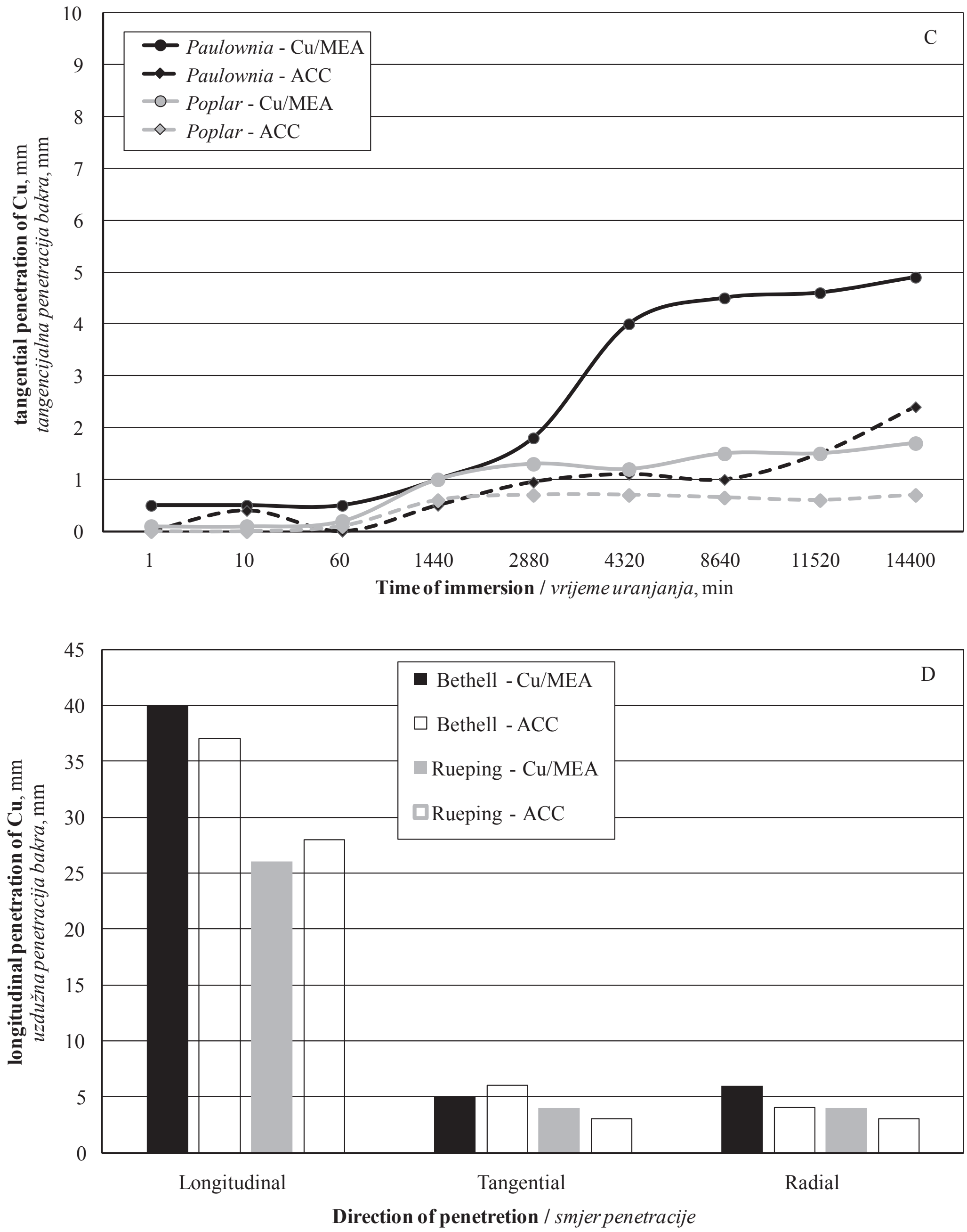

Figure 1. Continued
Slika 1. Nastavak

of the issues related to user expectations. The darker tones of Cu/MEA treated wood were considered negative in the initial period of introduction of these wood preservatives. Nowadays, this colour is generally expected.

4 CONCLUSIONS
4. ZAKLJUČAK

The treatability of *Paulownia* wood is not as good as that reported for *Populus* wood. However, if the proper procedure is applied, *Paulownia* wood can be expected to meet the specified requirements. However, Cu/MEA based wood preservatives were found more suitable for *Paulownia* wood than classical ACC, due to better penetration. *Paulownia* was found to be particularly suitable for long term dipping treatments, in which it performed better than *Populus*. Colour changes of *Paulownia* after treatment were comparable or even less prominent than those reported for *Populus* wood.

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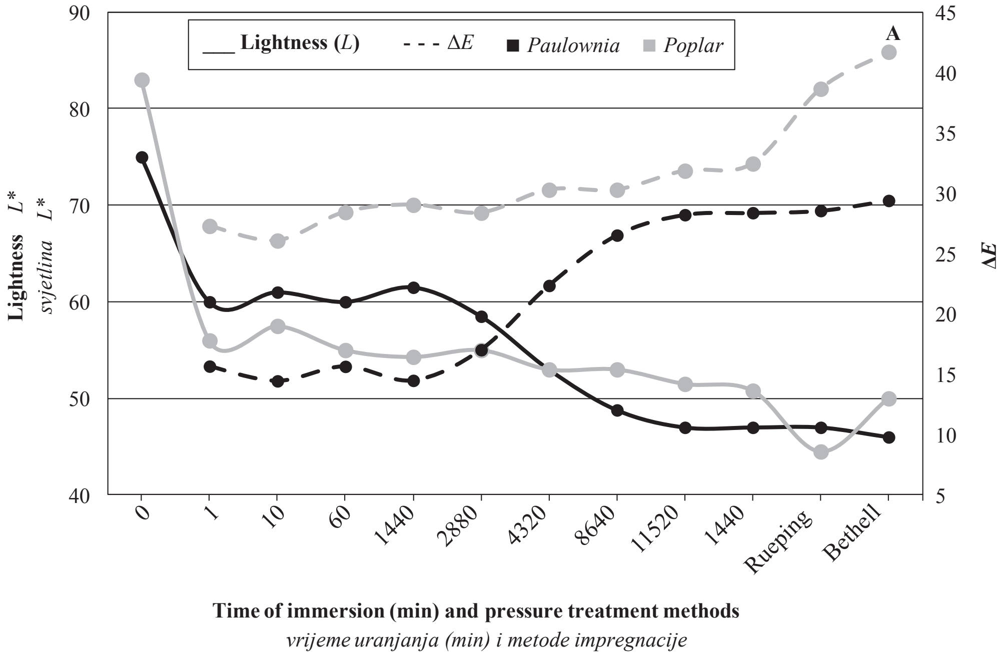

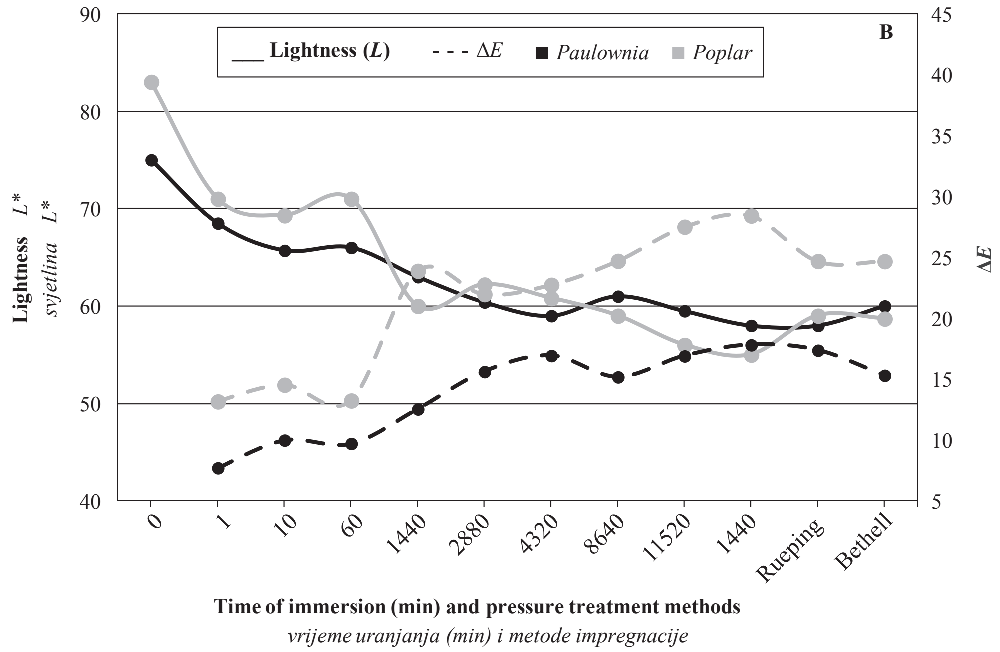

Figure 2 Influence of wood species and impregnation method on lightness (L^*) and total colour change (ΔE) of treated wood. Plot A shows the changes after impregnation with Cu/MEA, while plot B reflects changes of ACC treated wood.
Slika 2 Utjecaj vrste drva i metode impregnacije na svjetlinu (L^*) i ukupnu promjenu boje (ΔE) tretiranog drva; graf A predočuje promjene nakon impregnacije Cu/MEA-om, a graf B prikazuje promjene drva tretiranoga ACC-om

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Application of Artificial Neural Networks Using Bayesian Training Rule in Sales Forecasting for Furniture Industry

Primjena umjetnih neuronskih mreža uz pomoć Bayesova pravila učenja u predviđanju prodaje za industriju namještaja

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ABSTRACT • *Most organizations in manufacturing environments aim to increase their profits and reduce costs against competitive and rapidly changing market conditions. Accuracy of sales forecasting is undoubtedly a successful way to reach the aforementioned goals. At the same time, this enables executives to improve customer satisfaction, reduce lost sales and plan production efficiently. As a growing industry in Turkey, furniture manufacturing has an increased product demand in relation to the recent growth in construction and related industries, increase in urban population and increase in person-level income. Therefore, accurate sales forecasting systems in this industry are more focused on the special and calendar factors, such as consumer confidence index, producer price index, time of the year and number of vacation days. In this paper, an artificial neural network (ANN) based forecasting model is proposed by using MATLAB for processing total monthly sales data of a corporate furniture manufacturer located in the Black Sea region of Turkey. The method is a component of ANN, namely Bayesian regularization. The proposed model is applied to monthly sales figures of a corporate furniture manufacturing company. In conclusion, the results of performance measures show that using the ANN model based on Bayesian rules training is an applicable choice for forecasting of monthly sales of the observed furniture factory.*

Keywords: *artificial neural networks; Bayesian rules training; sales forecasting; furniture manufacturing*

SAŽETAK • *Cilj većine proizvodnih organizacija jest povećanje dobiti i smanjenje troškova u skladu s konkurentnim i promjenjivim tržišnim uvjetima. Točnost predviđanja prodaje nesumnjivo je uspješan način postizanja navedenih ciljeva. Istodobno, to povećava zadovoljstvo korisnika, učinkovito smanjuje izgubljenu prodaju i omogućuje bolje planiranje proizvodnje. U proizvodnji namještaja, industriji koja se u Turskoj sve jače razvija, bilježi se povećana potražnju proizvoda, u skladu s nedavnim rastom građevinskih i srodnih industrija, s povećanjem broja urbanog stanovništva i s rastom osobnih prihoda. Stoga precizni sustavi predviđanja prodaje u industriji namještaja više pozornosti usmjeravaju na posebne i kalendarske čimbenike poput indeksa povjerenja potrošača, indeksa proizvođačkih cijena, doba godine i broja dana odmora u godini. U ovom je radu predložen model predviđanja*

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na temelju umjetne neuronske mreže (ANN) uz pomoć MATLAB-a za obradu podataka ukupne mjesečne prodaje proizvođača uredskog namještaja koji se nalazi u Crnomorskoj regiji u Turskoj. Metoda je komponenta ANN-a, tj. Bayesova regulacija. Predloženi se model primjenjuje na podatke o mjesečnoj prodaji tvrtke za proizvodnju uredskog namještaja. Zaključno, rezultati mjerenja uspješnosti pokazuju da je primjena ANN modela utemeljenoga na Bayesovim pravilima dobar izbor za prognoziranje mjesečne prodaje promatrane tvornice namještaja.

Ključne riječi: *umjetne neuronske mreže, Bayesova pravila učenja, predviđanje prodaje, proizvodnja namještaja*

1 INTRODUCTION
1. UVOD

Forecasting is a methodology for estimating future characteristics of a business or operation (Gahirwal and Vijayalakshmi, 2013). Forecasts gain importance for short-term, mid-term and long-term decisions. In the literature, forecasting is applied to several business areas such as demand forecasting and sales forecasting (Yip *et al.*, 1997; Alon *et al.*, 2001; Kuo *et al.*, 2002; Mahbub *et al.*, 2013). Sales forecasting of a business is described as a prediction depending on past sales performance and an analysis of expected market conditions (Gahirwal and Vijayalakshmi, 2013), and it is considered the starting point for the elaboration of business plans (Fabianová, 2016). Many management decisions are often influenced by the current market situation (Gahirwal and Vijayalakshmi, 2013). Since the firms face dynamic complexities of internal and external factors, many apply qualitative forecasting techniques (Luxhøj *et al.*, 1996). However, these techniques are mostly inadequate compared to quantitative forecasting models with their structure and extrapolation capability, and forecasting inaccuracies typically negatively affect the mechanism of production planning. Accuracy of forecasting affects readiness of the business to be flexible in responding to market demand, its future costs and benefits (Fabianová, 2016). Mahbub *et al.*, (2013) highlight some inaccuracies and errors in demand forecasting as follows: difficulty in identifying the real factors that are actually influencing the demand, uncertainty in the demand of the products, non-availability of the actual demand data of the earlier demand periods. To this end, this study presents the application of a quantitative forecasting tool *Bayesian rules training algorithm in Artificial Neural Networks (ANNs)* for forecasting total monthly sales of a corporate furniture manufacturing company located in the Black Sea region of Turkey.

Recently, demand for furniture products have rapidly increased in Turkey in relation to the recent growth in construction and related industries, increase in urban population and increase in person-level income (Hazır *et al.*, 2015; Internet 1). Strengths of the industry, such as geographic location, trend of development in the sector, performance of the sector in the recent years, high labor potential, increasing technology transfer in the sector, increase in the number of firms producing modern and technological production, furniture production network/potential, increase in export activities for target markets, broad distribution network, material and product variety, prompt manufacturers to efficiently control and determine sales and demand (Turkey Furniture Products Council Industry Report, 2013). In order to do this, many firms prefer more sophisticated statistical models and accurate forecasting tools. ANNs are such tools that are successfully applied for forecasting sales, demand and predicting situations in a number of fields. Therefore, sales data of a corporate furniture manufacturer in Trabzon, Turkey from January 2009 to December 2015 were studied.

The rest of the paper is organized as follows: Section 2 gives a brief summary of ANNs used in this research; Section 3 provides the application, which includes data used, accuracy results of developed models and discussion. Finally, the conclusions are given in Section 4.

2 ARTIFICIAL NEURAL NETWORKS (ANNs)
2. UMJETNE NEURONSKE MREŽE (ANNs)

ANNs are machine learning algorithms, which aim to solve the computational processes in specific areas by using a large number of interconnected processing elements (Gul and Guneri, 2015; Akkoyunlu *et al.*, 2015; Gul and Guneri, 2016a; 2016b; Yapıcı *et al.*, 2015). They are mainly used for prediction, clustering, classification, and alerting to abnormal patterns (Efendigil *et al.*, 2009; Pusat *et al.*, 2016). An ANN model, which is formed of *n* layers, presents a different number of computational elements that function like biological neurons and intensive connections between these computational elements among layers. The computational elements used in various ANN models are called artificial neurons (Guneri and Gumus, 2008; 2009). In Efendigil *et al.* (2009), the model flow of an artificial neuron is presented as in Figure 1.

In Figure 1, $x_1, x_2, \ldots, x_p$ are the input signals; $w_{k1}, w_{k2}, \ldots, w_{kp}$ are the weights of neuron *k*, and, u_k is the linear combiner output, while θ_k denotes the threshold. Furthermore, Φ *()* is the activation function; and y_k is the output of the neuron. The first layer, called the "input" layer, and the last layer, called the "output" layer, are used to get information from inside and outside the network, respectively. The middle layers, generally called "hidden" layers, are essential to the network as they enable converting certain input patterns into appropriate output patterns (Akkoyunlu *et al.*, 2015; Somoza and Somoza, 1993). The flow of information is passed through the network by linear connections and linear or nonlinear transformations. Learning of the ANNs can be categorized into two distinct groups: supervised learning and unsupervised learning. The error between the actual output value and the pre-

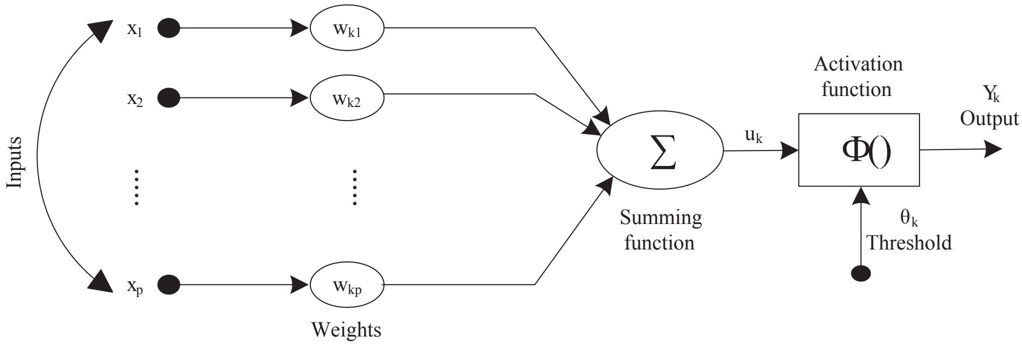

Figure 1 Flow chart of an artificial neuron (Adapted from Efendigil *et al.*, 2009)
Slika 1. Dijagram toka jednoga umjetnog neurona (adaptirano iz Efendigil *et al.*, 2009.)

dicted output value is computed. Then a minimization procedure is used to adjust the weights between two connection layers, i.e. for back propagation model starting backwards from the output layer to input layer. There are many minimization procedures based on different optimization algorithms, such as Quasi-Newton, and Levenberg–Marquardt, gradient descent and conjugate gradient methods. ANN models have a practical problem in network architecture (number of hidden layers and units in each layer) and network properties (error and activation functions). The design of hidden layers is dependent on the selected learning algorithm (Kröse *et al.*, 1993). The more layers and neurons, the more complex dependencies the network can model. According to the study of Efendigil *et al.* (2009), the number of hidden layer nodes can be up to (1) $2n + 1$ (where n is the number of nodes in the input layer), (2) 75 % of the quantity of input parameters, or (3) 50 % of the quantity of input and output parameters. Another important property of an ANN model is the activation function of the hidden layer. The software used in the current research has the following functions:

- Linear: This function produces its input as its output or, in other words, it passes the activation level directly as the output. Its output range is $(-\infty,\infty)$.
- Logistic: This function has a sigmoid curve and is calculated as in Eq. (1):

$$F(x) = 1 / (1 + e^{-x}) \tag{1}$$

Its output range is [0..1]. This function is used most often in various practical applications.

- Hyperbolic tangent: This function also has a sigmoid curve and is calculated as in Eq. (2):

$$F(x) = (e^{x} - e^{-x}) / (e^{x} + e^{-x}) \tag{2}$$

Its output range is [-1..1]. Empirically, it is often found that this function performs better than the Logistic function.

In ANNs, some controllable factors are available in order to aid the learning of the selected algorithm such as *Learning Rate* and *Momentum*. They are control parameters used by several learning algorithms, which affect the changing of weights. The higher learning rates cause higher weight changes during each iteration. The greater the momentum, the more the current weight change is affected by the weight change that took place during the previous iteration.

To measure the performance of ANN models, mean squared error (*MSE*), network error (average train error and average test error), absolute relative error (*ARE*), mean absolute percentage error (*MAPE*) and R-squared (R^2) can be used. R^2, *MSE* and *MAPE* are defined as in Eqs. (3)-(5).

$$R^2 = 1 - \frac{SS_{residuals}}{SS_{total}} \tag{3}$$

where SS_{total} refers to the total sum of squares (proportional to the variance of data), and $SS_{residuals}$ indicate the sum of squares of residuals, also called the residual sum of squares.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(f_i - y_i)^2 \tag{4}$$

$$MAPE = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{y_i - f_i}{y_i}\right| \tag{5}$$

Where f_i is the vector of n forecasting, and y_i is the vector of actual values.

2.1 Bayesian rules training in ANN
2.1. Bayesovo pravilo učenja u ANN-u

Bayesian networks are robust approach for making inferences and drawing conclusions based on available information (Jensen, 1996; Doğan and Aydin, 2011). The gradient descent method is used in the back propagation neural network as supervised learning to reduce a chosen error function. The weights of input are changed in the supervised learning algorithm to decrease the chosen error function to optimize the network for use with unknown samples. A major problem for these techniques is the potential for overfitting an overtraining, which leads to a fitting of the noise and a loss of network generalization ability (Ticknor, 2013). Bayesian regularization is developed to convert nonlinear systems into “well posed” problems to reduce the potential for overfitting (Burden and Winkler, 2008; MacKay, 1992). In general, the training step is aimed at reducing the error function of the model output and target value. Bayesian regularization adds an additional term to Eq. (6):

$$F = \beta E_D + \alpha E_W \tag{6}$$

Where F is the objective function, E_D is the sum of squared errors, E_w is the sum of squared network weights, and α and β are objective function parameters

(MacKay, 1992; Ticknor, 2013). The random variables are taken as weights and hence their density function is presented with respect to the Bayes rules (Foresee and Hagan, 1997) as in Eq. (7):

$$P = \left(D \middle| w, \alpha, \beta, M\right) = \frac{P\left(D \middle| w, \beta, M\right) P\left(D \middle| w, \alpha, M\right)}{P = \left(D \middle| \alpha, \beta, M\right)} \quad (7)$$

Where w is the vector of network weights, D represents the data vector, and M is the neural network model used. In Bayesian regularized networks, very complex models are penalized as redundant relation, where weights are effectively driven to zero. The network will be used with constant weights as the network grows (Burden and Winkler, 2008).

3 APPLICATION
3. PRIMJENA

3.1 Data
3.1. Podatci

The data used in this paper were derived from one of the biggest furniture factory in the Black Sea region of Turkey. The factory in Trabzon Organized industry, located in a closed area of 120,000 m^2, produces bedrooms, dining rooms, sitting groups, teen rooms and armchairs. The data set contains monthly sales figures of these products in the period 2009 to 2015. The time series plot is given in Figure 2, showing monthly sales figures of products.

The company's product range consists of different models for dining rooms, sitting groups, teen rooms, bedrooms and armchairs. There are 14 models of dining rooms, 14 models of bedrooms, 14 models of sitting rooms and 6 models of teen rooms. Every model consists of different parts. For example, the teen room consists of a bookcase, desk, laundry, nightstand, bedstead and wardrobe and these parts must be equal in every model. In other words, when one model of teen room is sold, one bookcase, one desk, one laundry, one nightstand, one bedstead and one wardrobe of the same model will also be sold (Eq. 8). There is no a special model type for the armchair. It is sold as single.

$$\forall \left(X_{i,j} = X_{i+1,j} = X_{i+2,j} = X_{i+3,j} = X_{i+4,j} = X_{i+5,j} \right) \quad (8)$$

Where
X_i – size of parts
j – number of produced models (j = 1 to 48)

In order to forecast sales value of the furniture company, four parameters were used as input parameters of ANN model. One of them is consumer confidence index (CCI). CCI is an aggregate of four sub-indices. Two of them are based on expectations regarding household finances, while the other two are based on expectations about economy-wide developments (Jansen and Niek, 2003). The second input parameter is the producer price index (PPI). PPI is an aggregate of over 1,500 components. Each component is a monthly index of the national average price for a producer good. The price pertains to the first transaction after production. This is a transaction between firms rather than between businesses and consumers (Peltzman, 2000). Other input parameters are the number of vacation days in Turkey and time of the year. The number of vacation days in our data set is shown in Table 1.

The output parameters are monthly sales of teen rooms, bedrooms, dining rooms, sitting groups and armchairs. Inputs and outputs for proposed ANN model are shown in Figure 3.

Parameters of the inputs and outputs were collected for 84 months from January 2009 to December 2015 from the furniture company. Descriptive statistics of variables are presented in Table 2. The values of CCI and PPI are ratios that have a mean of 72.85 and 209.2, respectively. The mean number of vacation days in the studied data set is 9.45 per month. The reason of considering this input variable in our proposed ANN

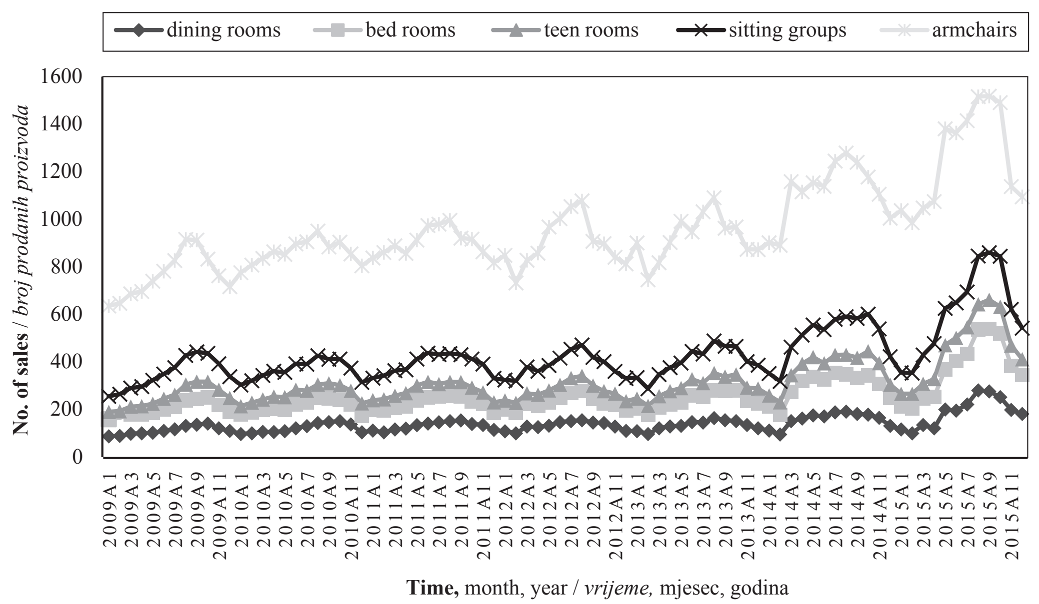

Figure 2 Sales figures of products
Slika 2. Podatci o prodaji proizvoda

Table 1 Number of vacation days
Tablica 1. Broj dana odmora

Month *Mjesec*	Year / *Godina*						
	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
1	10	11	10	9	9	9	10
2	8	8	8	8	8	8	8
3	9	8	8	9	10	10	9
4	9	9	9	10	9	9	9
5	12	11	10	9	9	11	12
6	8	8	8	9	10	9	8
7	8	9	10	9	8	11	9
8	10	10	10	11	12	10	10
9	10	10	9	10	9	8	10
10	10	11	10	11	13	11	10
11	11	12	11	8	9	10	9
12	8	8	9	10	9	8	8

Table 2 Descriptive statistics of variables
Tablica 2. Deskriptivna statistika varijabli

Parameters / *Parametri*	**Unit** *Jedinica*	**Type** *Vrsta*	**Mean** *Srednja vrijednost*	**Variance** *Varijanca*	**Max** *Maksimum*	**Min** *Minimum*
CCI	Ratio / *omjer*	Input /*ulaz*	72.85	32.4	83.19	58.33
PPI	Ratio / *omjer*	Input /*ulaz*	209.2	1052.13	269.5	160.4
Number of vacation days *broj dana godišnjeg odmora*	Numerical *numerički*	Input /*ulaz*	9.45	1.41	13	8
Teen room sales *prodaja tinejdžerskih soba*	Numerical *numerički*	Output / *izlaz*	60.44	362.48	122	29
Bedroom sales *prodaja spavaćih soba*	Numerical *numerički*	Output / *izlaz*	114.2	1706.66	268	70
Dining room sales *prodaja blagovaonica*	Numerical *numerički*	Output / *izlaz*	140.4	1440.45	281	88
Sitting groups sales *prodaja namještaja za sjedenje*	Numerical *numerički*	Output / *izlaz*	115.2	747.96	212	65
Armchair sales *prodaja naslonjača*	Numerical *numerički*	Output / *izlaz*	531	7330.78	755	370

model stems from the fact that, according to decision makers in furniture industry, the number of sales increases in vacation days. The mean number of teen room sales, bedroom sales, dining room sales, sitting group sales and armchair sales vary from 60.44 to 531.

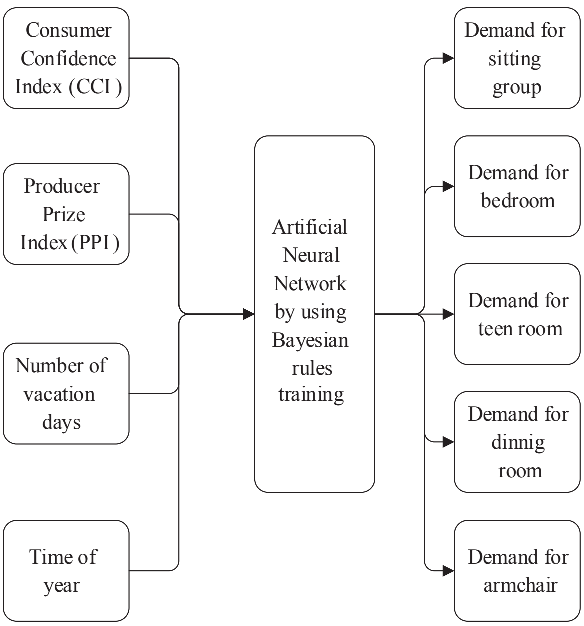

Figure 3 Proposed ANN model
Slika 3. Predloženi model ANN-a

4 RESULTS AND DISCUSSION
4. REZULTATI I RASPRAVA

The main aim of this study was to forecast the monthly sales of a corporate furniture manufacturing company located in the Black Sea region of Turkey. To achieve this aim, an ANN-based approach was proposed. First, the data detailed above were put together. The model included 84 data points for each output variable. This process was followed by data partition and normalization by min-max normalization method. A training and testing model based on ANN was then employed, after determining the design architecture and network properties. A tangent sigmoid (tansig) transfer function and linear (purelin) transfer function were applied in hidden and output layer, respectively. Three layers, including input, hidden and output layers, were formed in the model as presented in Figure 4. While "15" represents the number of inputs in the input layer, "11" shows the number of neurons with the best accuracy value in the hidden layer. "5" shows the number of outputs in the output layer. The accurateness of the model is directly re-

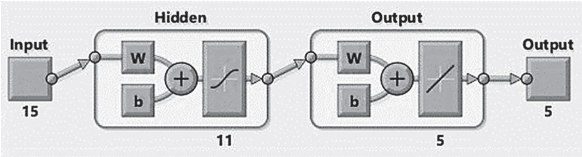

Figure 4 Structure of applied ANN network
Slika 4. Struktura primijenjene mreže ANN-a

lated to the number of neurons in the hidden layer. The performance indicators of R^2 and MSE were used to evaluate the accurateness of the method. Finally, the best network was applied reflecting the variability.

Commercial software, MATLAB, was used throughout the study. The proposed model was run for a different number of hidden layer neurons. The system matrix to be tested was selected as 4x84 input matrix with 1x84 output matrix. The number of hidden neurons varied from 1 to 30 for evaluating the performance of the model with different neuron numbers. The performance results of 30 experiments with a different number of neurons are presented in Table 3. After the data were loaded into the software, it randomly selected 70:15:15 ratios for training, validation and testing. The experiments were run with Bayesian rules training. The best networks and their performance measure are indicated in bold in Table 3. While R^2 value is obtained as 0.982961154 and 0.724966567 for training and testing, the MSE is obtained as 0.000644576 and 0.0101874 for training and testing, respectively.

The validation performance and regression plot of the best network are presented in Figure 5. The validation performance plot demonstrates that MSE becomes minimum at epoch 426 and no significant over fitting occurs when the best validation performance is obtained. The regression plot shows network output and targets for training, testing and they are all almost close because the coefficient of determination is almost equal to 1 (Figure 6).

The plots related to the comparison of the actual and forecasted values for the model are made by the software as shown in Figures 7-11. The results show that using the ANN model based on Bayesian rules training is an applicable choice for forecasting monthly sales of the observed furniture factory. The MAPE value of the sitting product group is calculated as 5.223 %, which means that a reasonable result is obtained (Çelik *et al.*, 2016). On the other hand, MAPE values are also calculated for the sales forecasting of bedroom, teen room, dining room, and armchair as 5.951 %, 5.954 %, 3.588 %, and 3.057 %, respectively.

Table 3 Experiments with a different number of neurons
Tablica 3. Eksperimenti s različitim brojem neurona

Number of Neurons *Broj neurona*	***R*²**		***MSE***	
	Training *Učenje*	**Testing** *Provjera*	**Training** *Učenje*	**Testing** *Provjera*
1	0.752129501	0.792244187	0.009006000	0.019161000
2	0.875669236	0.636392299	0.005788060	0.015446200
3	0.890656513	0.808130880	0.004532460	0.015282300
4	0.915598283	0.826439174	0.000107210	0.024810950
5	0.922485333	0.815716049	0.003227050	0.013012000
6	0.949157217	0.529062753	0.002550710	0.011339400
7	0.961754837	0.680398969	0.001806460	0.016721700
8	0.970745150	0.637928080	0.001386840	0.016071000
9	0.977169813	0.516630313	0.001006140	0.031910500
10	0.971436928	0.710347238	0.001001700	0.029709000
11	0.982961154	0.724966567	0.000644576	0.010187400
12	0.985080070	0.590827434	0.000570310	0.041409100
13	0.914146332	0.660912091	0.000411074	0.016425200
14	0.991603699	0.465867677	0.000414008	0.051115500
15	0.991964209	0.595196820	0.000389077	0.015593300
16	0.995724580	0.593357468	0.000201961	0.017802300
17	0.974326926	0.547964141	0.000125438	0.015422800
18	0.998504560	0.382565753	0.000074672	0.019955900
19	0.999558049	0.497965915	0.000022625	0.031717900
20	0.999998000	0.531887242	0.000000010	0.283021000
21	0.999998000	0.660001884	0.000000000	0.019164000
22	0.999998000	0.269372418	0.000000000	0.018399500
23	0.999998000	0.515697771	0.000000000	0.042244500
24	0.999998000	0.317472522	0.000000000	0.062623300
25	0.999998000	0.673871885	0.000000000	0.037031500
26	0.999998000	0.594982365	0.000000000	0.029209500
27	0.986247610	0.591359462	0.000056606	0.032884600
28	0.999998000	0.481624896	0.000000002	0.025859000
29	0.999998000	0.660609703	0.000000000	0.025427500
30	0.999998000	0.277704759	0.000000000	0.037270000

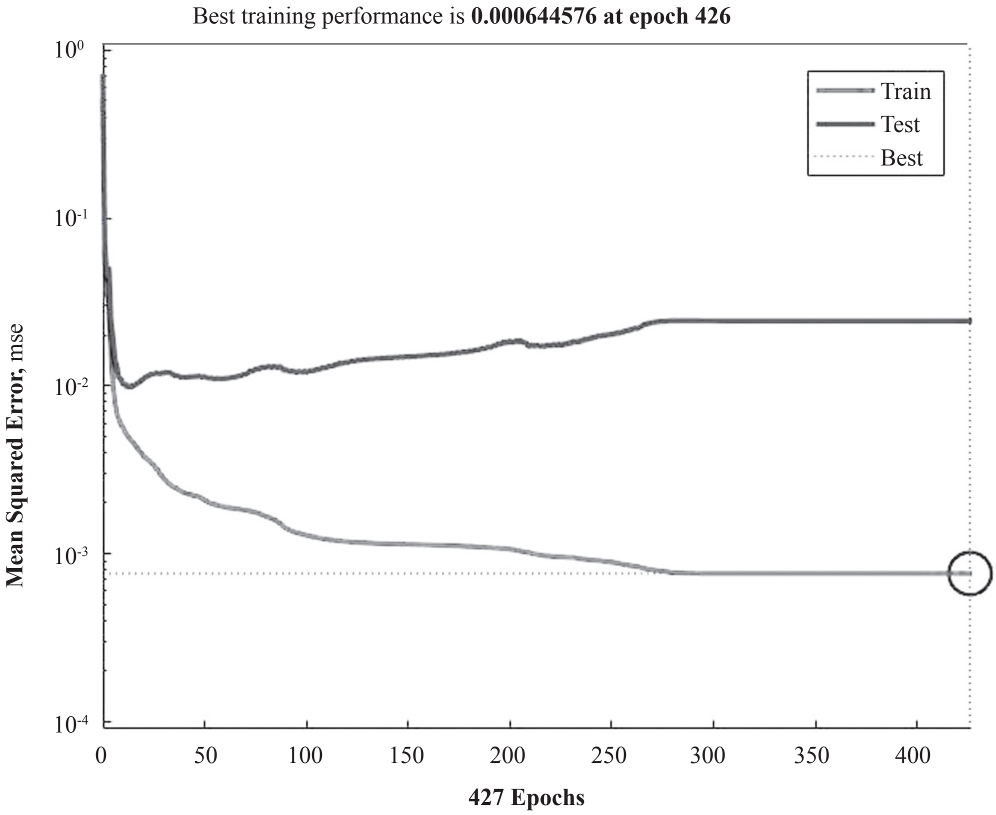

Figure 5 Validation performance
Slika 5. Vrednovanje izvršenja

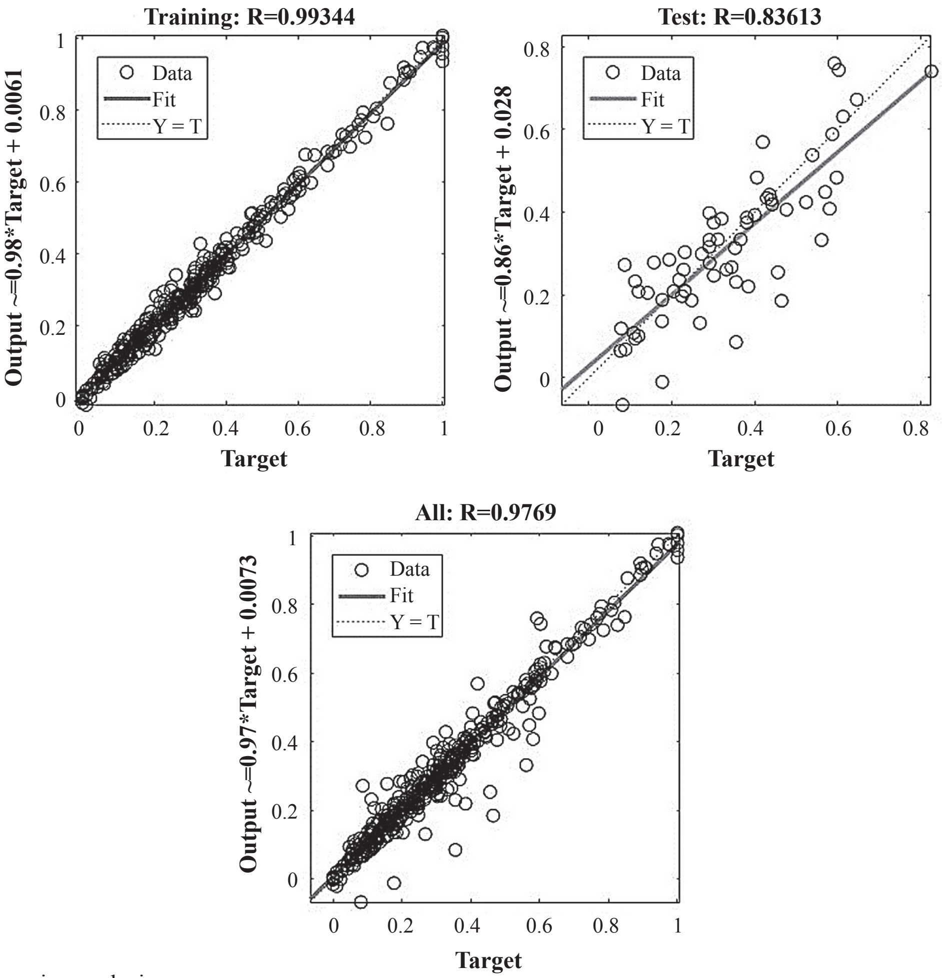

Figure 6 Regression analysis
Slika 6. Regresijska analiza

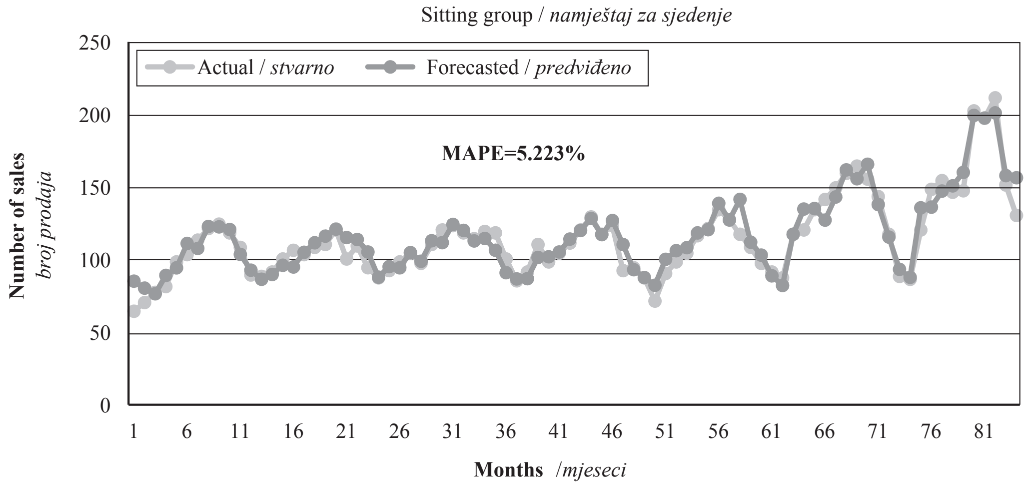

Figure 7 Comparison of actual values and forecasted output values for sitting group product
Slika 7. Usporedba stvarnih i predviđenih vrijednosti prodaje namještaja za sjedenje

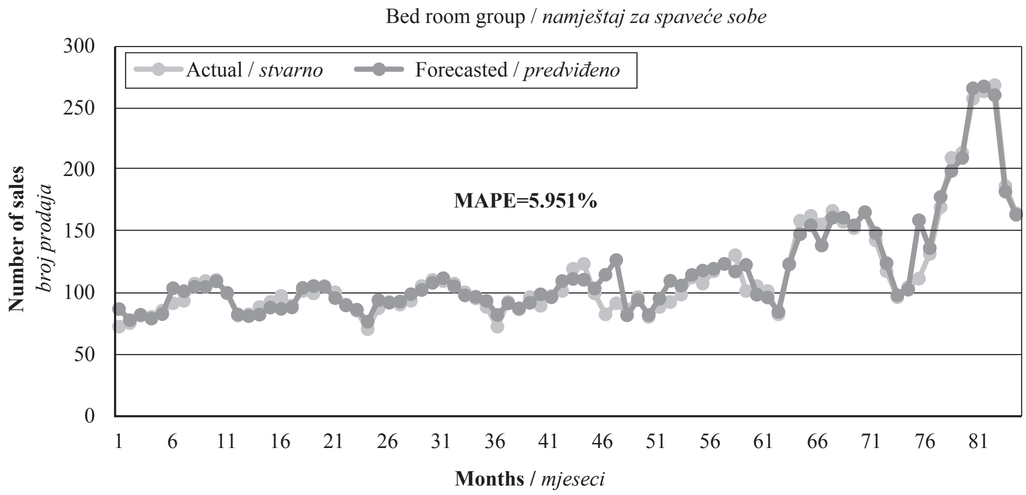

Figure 8 Comparison of actual values and forecasted output values for bedroom product
Slika 8. Usporedba stvarnih i predviđenih vrijednosti prodaje namještaja za spavaće sobe

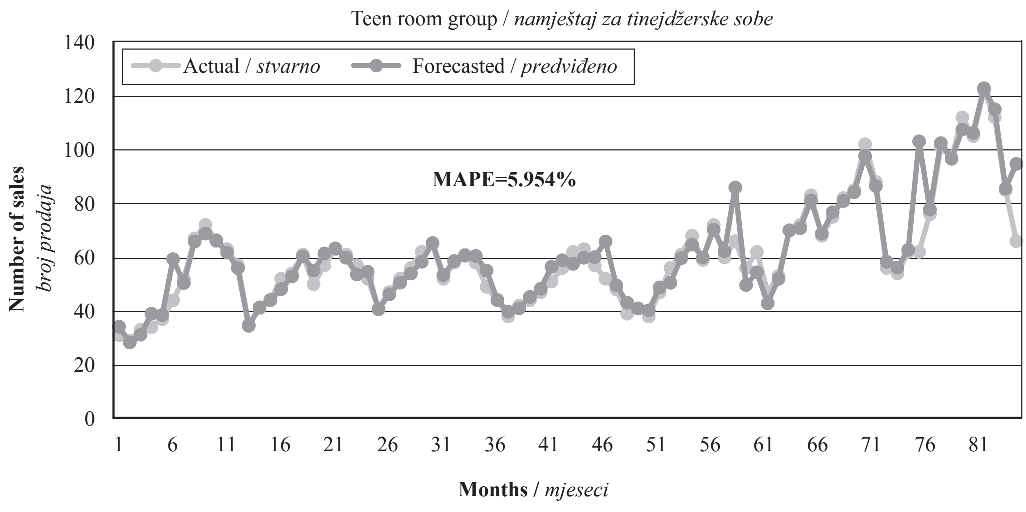

Figure 9 Comparison of actual values and forecasted output values for teen room product
Slika 9. Usporedba stvarnih i predviđenih vrijednosti prodaje namještaja za tinejdžerske sobe

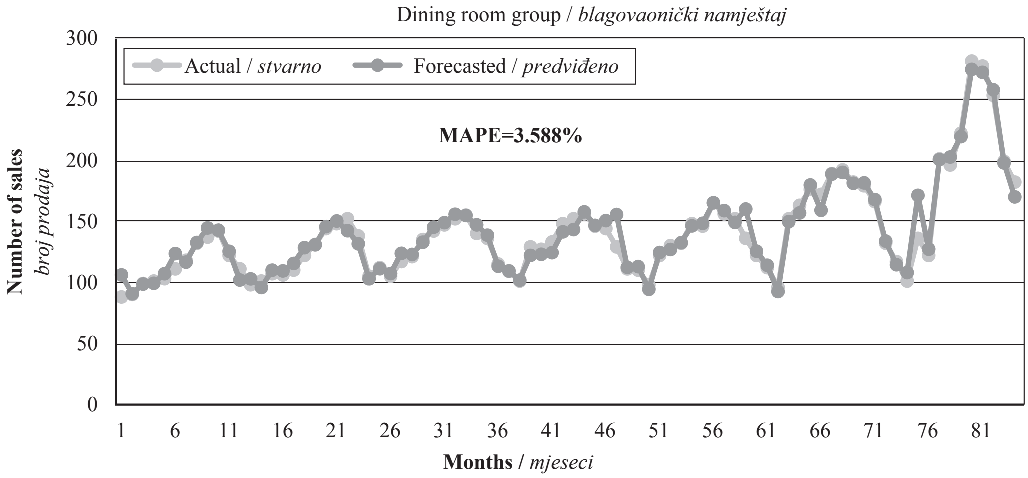

Figure 10 Comparison of actual values and forecasted output values for dining room product
Slika 10. Usporedba stvarnih i predviđenih vrijednosti prodaje blagovaoničkog namještaja

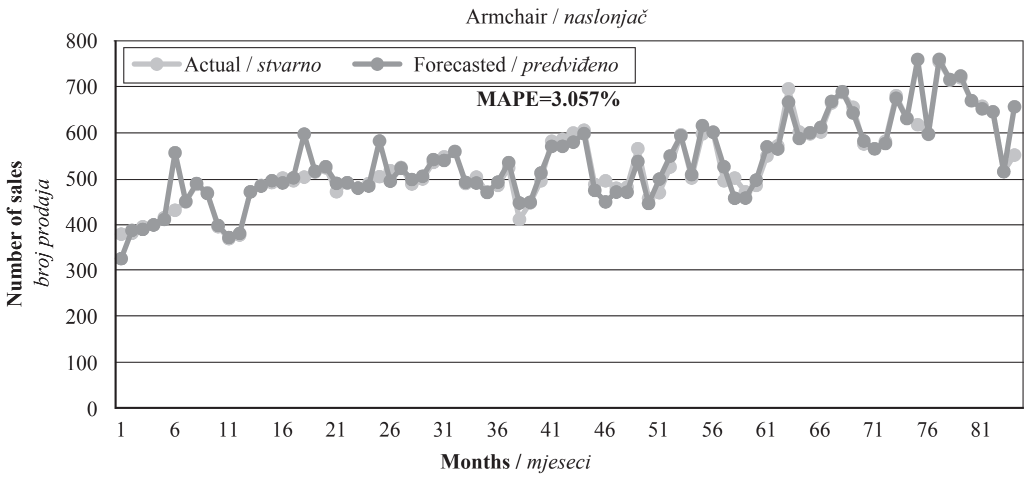

Figure 11 Comparison of actual values and forecasted output values for armchair group
Slika 11. Usporedba stvarnih i predviđenih vrijednosti prodaje naslonjača

5 CONCLUSION
5. ZAKLJUČAK

In this study, a forecasting model was developed based on Bayesian rules training in ANN to solve the problem of sales forecasting. The proposed model is applied to monthly sales of a corporate furniture manufacturing company located in the Black Sea region of Turkey. The results obtained from performance measures proved that ANN model based on Bayesian rules training is an applicable choice for forecasting monthly sales of the observed furniture factory. To the best of our knowledge, this is the first study to consider the problem.

The aim of sales forecasting is to determine the demand level of products in a particular time horizon and it is an important part of production planning. Sales forecasting is the starting point in making aggregate production planning. This part is one of the biggest problems for decision makers. Decision makers should evaluate the costs and benefits of each model before choosing an appropriate forecasting method. The ANN model was chosen because this method is easy to use, incurs low costs and offers effective solutions.

The company is local and it is much more active around the Black Sea region then other parts of Turkey. For that reason, the model can be extended with some other local parameters that influence the demand of the product such as the Black Sea region's population, number of dwellings, number of married couples and other parameters related to the Black Sea region. It should also be noted that no endogenous variables describing the company could be used, because they did not track past data properly.

In the future, the model will be further improved by considering other forecasting tools of autoregressive integrated moving average (ARIMA). From the application point of view, additional factors can be included so as to provide a more precise result, although this was not considered in the case study of the particular furniture manufacturing company.

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Effects of Industrial Heat Treatment on Some Physical and Mechanical Properties of Iroko Wood

Učinci industrijske toplinske obrade iroko drva na neka njegova fizička i mehanička svojstva

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ABSTRACT • *The purpose of this study was to determine the effect of industrial heat-treatment (ThermoWood) effect on some important properties (density, anti-swelling efficiency (ASE), electrical resistance, strength, hardness and color) of Iroko wood (Chlorophora excelsa). Samples were subjected to heat treatment at 190 °C for 120 min during the main heat treatment period (the total time of the process was 60 hours). The results showed that the applied process caused 4.6 % decrease in density. Dimensional stability was considerably improved, with ASE values of 13.2 %. The color became darker after treatment. The process caused a significant (p<0.05) reduction (3.35 to 25 %) of all investigated mechanical properties at a specific moisture level (12 %). However, the mechanical properties of wood are closely related to its moisture content, and heat-treated wood is less hygroscopic than untreated wood. After long-term acclimatization, most heat-treated samples had almost half the equilibrium moisture content of control samples. Although heat treated samples have lower water content and higher electrical resistance at the same soaking time, the obtained data clearly showed that heat treated samples had a slightly lower electrical resistance for the same moisture content compared to control samples.*

Key words: *Industrial heat treatment, Iroko, physical and mechanical properties, ThermoWood.*

SAŽETAK • *Cilj provedenog istraživanja bio je utvrditi utjecaj industrijske toplinske obrade (ThermoWood) na neka važna svojstva iroko drva (Chlorophora excelsa) (gustoću, učinak smanjenja bubrenja – ASE, električnu otpornost, čvrstoću, tvrdoću i boju). Uzorci su bili podvrgnuti toplinskoj obradi pri 190 °C u trajanju 120 minuta tijekom glavnog razdoblja toplinske obrade (ukupno vrijeme procesa bilo je 60 sati). Rezultati su pokazali da primijenjeni proces toplinske obrade uzrokuje smanjenje gustoće od 4,6 %. Dimenzijska stabilnost drva znatno je poboljšana, uz smanjenje bubrenja od 13,2 %. Nakon toplinske obrade drvo je postalo tamno. Toplinska je obrada prouzročila značajno (p <0,05) smanjenje (od 3,35 do 25 %) svih ispitivanih mehaničkih svojstava pri specifičnoj razini sadržaja vode (12 %). Međutim, mehanička svojstva drva usko su povezana sa sadržajem vode u njemu, a toplinski obrađeno drvo manje je higroskopno od neobrađenoga. Nakon dugoročne aklimatizacije većina toplinski obrađenih uzoraka imala je gotovo upola manju vrijednost ravnotežnog sadržaja vode od kontrolnih uzoraka. Premda su toplinski obrađeni uzorci imali niži sadržaj vode i veću električnu otpornost pri jednakom vremenu potapanja, dobiveni su podatci jasno pokazali da toplinski obrađeni uzorci imaju nešto nižu električnu otpornost pri jednakom sadržaju vode nego kontrolni.*

Ključne riječi: *industrijska toplinska obrada, iroko drvo, fizička i mehanička svojstva, ThermoWood*

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1 INTRODUCTION
1. UVOD

Wood has been used for both indoor and outdoor applications from the beginning of human civilization. As a biological material, biodegradability and instability under changing moisture are major disadvantages of the material. Heat treatment is one of wood modification methods applied to improve dimensional stability and durability of the material (Esteves and Pereira, 2009). Since there is no chemical application during the process, heat-treated wood is mostly considered non-biocidal and an eco-friendly method, which is an alternative to classical preservation techniques in some cases (Rapp, 2001; Patzelt *et al*., 2002; Anonymous, 2003; Yildiz *et al*., 2006).

Although thermal wood modification is a long-known technology, it has received increased attention in the last decade particularly in Europe, leading to an intensified industrial production and commercialization (Arnold, 2010). Therefore, lots of researches have been focused on this topic recently. Modification of wood by heat treatment, historical background and methods were very well reviewed by Esteves and Pereira (2009). Depending on the variation of all heat treatment processes, including industrial-scale, semi industrial scale or laboratory experiments, the properties of heat treated wood vary a lot. The extent of change in wood properties mainly depends on the heat treatment method, wood species and its characteristics, initial moisture content of the wood, the surrounding atmosphere, and treatment temperature and the time of duration (Mitchell, 1988; Rapp, 2001; Hill, 2006; Esteves and Pereira, 2009; Dubey, 2010).

Although thermally modified wood tends to be more dimensionally stable than unmodified wood of the same species, mechanical properties generally have a negative effect (Viitaniemi, 1997; Santos, 2000; Militz, 2002; Shi *et al*., 2007; Icel *et al*., 2015; Oliveira Araújo *et al*., 2016) and knowledge on electrical properties of heat treated wood is very limited. There are some recommendations from several authors for determining wood species-specific resistance characteristics in addition to a temperature compensation of the measurements (Du *et al*., 1991; Brischke *et al*., 2008; Meyer *et al*., 2012). Different parameters have an effect on the electrical conductivity/resistivity of wood and need to be considered, such as wood species, grain direction, temperature, amount and type of extractives, and the position and type of electrodes (Davidson, 1958; Brown *et al*., 1963; Kollmann and Cote, 1968; Du, 1991; Brischke *et al*., 2008). Additionally, recent developments in wood modification, the impregnation of wood with preservatives as well as chemical and thermal modification, have the potential to alter electrical properties of wood (Holleboom and Homan, 1998; Smith *et al*., 2007; Meyer *et al*., 2012). Electrical resistivity (ER) is affected primarily by the number or concentration of conducting ions and the mobility of the existing charges, which means the ease with which charges move in an electric field (Hearle, 1953; Brown *et al*., 1963). Thermal modification of wood is known to cause changes of the cell wall nanostructure, coming along with changes of accessibility and transportability of ions and an increase of ions dissociated from acetic and formic acid formed during heat treatment. Different treatment intensity levels may cause different ER characteristics. Thermally treated wood showed significantly lower ER compared to untreated wood, which might be due to acetic and formic acid formed during heat treatment (Tjeerdsma *et al*., 1998; Weiland and Guyonnet, 2003; Wikberg and Maunu, 2004). In contrast, a decrease in density as well as the cleavage of hemicellulose side chains may have the opposite effect on electrical resistivity (Stamm, 1956; Vermaas, 1984; Du, 1991), but these parameters do not superpose the effect of dissociated acids serving as charge carriers in wood (Brischke *et al*., 2014).

ThermoWood (TW), the industrial-scale heat treatment process was developed in the early 90s by the Finnish Research Center (VTT) in Finland and, since then, has been expanding the market. In the process, the wood is heated in low oxygen content (under 3.5 %) with the presence of water steam. Low oxygen contents prevent wood material from burning at high temperatures. Temperatures for the actual heat treatment period range from 150 °C to 240 °C, and the time of duration changes from 0.5 h to 4 h (Viitaniemi, 2000; Homan and Jorissen, 2004; Icel *et al*., 2015).

The purpose of this study was to determine the effect of industrial heat-treatment effect on some important properties (density, anti-swelling efficiency (ASE), electrical resistance, strength and hardness) of Iroko wood (*Chlorophora excelsa*). This wood species was chosen as study material because of its increasing demand and importance in Turkish and European market.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Testing material and specimen preparation
2.1. Ispitni materijal i priprema uzoraka

Iroko (*C. excelsa*) lumber, in the size used by the company for outdoor conditions (38x100x1500 mm), was obtained from an industrial plant. The lumber was stored and pre-dried at a lumber yard. The lumber was cut into two equal pieces (A: Control; B: Heat treatment). The thermal treatment was carried out in the industrial furnace of a forest product company following the industrial process (invented by Pentti Ek,Saila Jamsa, Hannu Viitanen, Pertti Viitaniemi and patented by VTT- EP0695408) with the trade name ThermoWood® (EU trademark number 000922765). The temperature during the heat treatment period was 190 °C and duration time at this temperature was 120 min for this species. The total process time was 60 hours. Test samples were only cut from heartwood parts according to the cutting plan as shown in Figure 1.

2.2 Measurement of physical properties
2.2. Ispitivanje fizičkih svojstava

Treated wood samples were conditioned in a conditioning cabin at temperatures of 20 ±2 °C and rela-

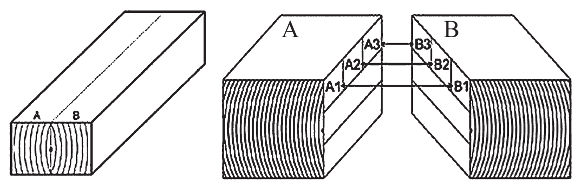

Figure 1 Separation of (A) control and (B) treatment parts of each lumber and a cutting plan sample (Icel *et al.*, 2015)
Slika 1. Razdvajanje kontrolnog dijela (A) i dijela za toplinsku obradu (B) svake piljenice i plan rezanja uzoraka (Icel *et al.,* 2015.)

tive humidity of 65 ±5 % to reach Equilibrium Moisture Content (EMC) in 8 weeks. At the end of the period, the dimensions of wood samples and weights were measured to the nearest 0.01 mm. The density of the samples was measured according to ISO standard (ISO 13061-2, 2014). Since wood density is a highly variable property dependent on the species of and location on the tree, the density was calculated in terms of percentage of decrease to evaluate treatment effects. The percentages of density decrease and mass loss were calculated relative to control samples.

The density data of specimens whose moisture content deviated from 12 percent were corrected (transformed to density of 12 % moisture content) using the following conversion (TS 2472, 1976) Eq. (1):

$$D_{12} = D_r \cdot \left[1 - \frac{(1-K)\,(M-12)}{100}\right] \quad (1)$$

D_{12} – density at 12 % moisture content (g/cm^3) (shown as *p* in the reference standard)
D_r – density of actual moisture content (g/cm^3)
K – coefficient of volumetric shrinkage (for 1 % moisture difference)
M – moisture content of the sample (shown as *W* in the reference standard)

The dimensions in the longitudinal, tangential (width), and radial (thickness) directions were measured to an accuracy of ±0.01 mm. The volumetric swelling coefficients (*S*) were determined using Eq. (2) (Rowell and Young, 1981), given below,

$$S\,(\%) = \frac{V_2 - V_1}{V_1} \cdot 100 \quad (2)$$

Where V_2 is wood volume after wetting with water and V_1 is wood volume of the oven-dried sample before wetting. As the two groups reach *MC* saturation at different immersion time, a fix immersion time was not applied for heat treated and control samples. Samples were immersed in a water bath up to a constant weight at a controlled temperature (20 °C). After removing a sample from the water bath, the surface water was removed by slightly pressing it with a clean filter paper, and the sample was immediately weighed.

A variety of terms can be used to describe the degree of dimensional stability given to wood by treatments. The anti-swelling efficiency (ASE) was determined using Eq. (3) (Rowell and Young, 1981);

$$ASE\,(\%) = \frac{S_2 - S_1}{S_1} \cdot 100 \quad (3)$$

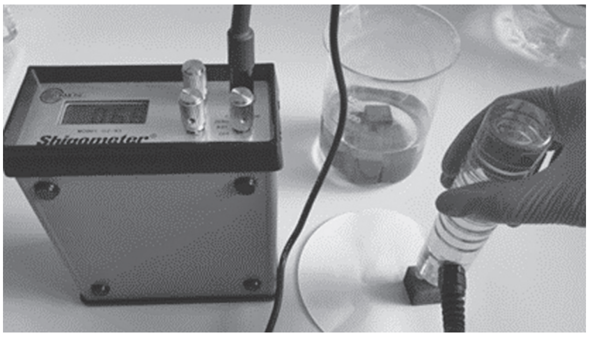

Figure 2 Measurement of electrical resistance
Slika 2. Mjerenje električne otpornosti

Where S_2 is the treated volumetric swelling coefficient and S_1 is the untreated volumetric swelling coefficient.

In this study, the samples of control and heat treated groups were immersed in a water bath at a controlled constant temperature of 20 °C to detect the moisture of samples using immersion cycles of 2, 4, 8, 12, 24, 48, 72, 96,120 and 360 hours.

2.3 Measurement of electrical resistance
2.3. Mjerenje električne otpornosti

Shigometry is a measuring technique based on electrical resistance (ER), commonly used to assess vigor of living trees and estimate degradation of wood decay. The Shigometer is a battery-operated, lightweight field ohmmeter. It generates a pulsed direct electric current and registers the resistance to the current in thousands of ohms (kΩ) as it passes through wood (around and over fiber saturation point) (Shigo and Shigo, 1974; Shortle, 1982). ER decreased with increasing T at constant MC, which has been reported earlier by Lin (1967), James (1968), and Du *et al.* (1991). The electrical resistance was measured with Shigometer in Figure 2 for the same moisture ingredient of control and treatment groups to determine the treatment effect.

2.4 Measurement of mechanical properties and hardness
2.4. Ispitivanje mehaničkih svojstava i mjerenje tvrdoće

Wood is a hygroscopic material and its properties are influenced by moisture content (*MC*). Mechanical properties of wood, which are very important especially for structural applications, are highly influencing properties (Forest Products Laboratory, 1999; Arnold, 2010). All samples were conditioned in an automatically controlled conditioning room at 20 °C (±2 °C) and relative humidity of 65 % (±5 %). Mechanical tests, such as compression strength parallel to grain (*CS//*), modulus of rupture (*MOR*) and modulus of elasticity (*MOE*), were applied according to TS EN 408+A1 in compliance with EN 408 (2010+A1:2012).

After the mechanical tests, the *MC* of each sample was measured according to ISO 13061-1(2014), and the moisture content of specimen whose moisture content deviated from 12 % was determined. To equalize the moisture contents (12 %) of the two groups, the conversion Eq. (4) was used (Icel *et al*., 2015):

(if $M_2 > 12$ %) $\sigma_{12} = \sigma_m$ [1 + α (M_2 – 12)]
(if $M_2 < 12$ %) $\sigma_{12} = \sigma_m$ [1 - α (| M_2 – 12 |)] (4)

Where σ_{12} is the strength at a 12 % moisture content (N/mm^2), σ_m is the strength at a moisture content deviated from 12 % (N/mm^2), α is a constant showing the relationship between strength and moisture content (α = 0.05, 0.04, 0.02, for CS//, MOR, and MOE, respectively), and M_2 is the moisture content determined after tests (%) (Bozkurt and Göker, 1987).

The Brinell hardness was tested according to EN 1534. The diameter of the remaining indentation opened through the sphere was then measured with a microscope (Hill *et al*., 1989; Bektas *et al*., 2001). Since a moisture conversion formula could be used, which was suggested only for Janka hardness in the literature, the moisture content of the two groups (control and heat treatment) was not equalized.

2.5 Color measurement
2.5. Ispitivanje boje

The color was measured on the tangential and radial surface of the wood specimens before and after heat treatment by a Konica Minolta Chroma-Meter CR-400 (Konica Minolta Corp.; Japan) colorimeter according to ISO 7724-2-3 (1984). The sensor head was 6 mm in diameter. Measurements were made using a D65 illuminant and a 10-degree Standard observer. Percentage of reflectance collected at 10-nm intervals over the visible spectrum (from 400 to 700 nm) was converted into the CIELAB color system, where L* describes the lightness and a* and b* describe the chromatic coordinates on the green-red and blue-yellow axes, respectively. From the L*, a*, and b* values, the difference in the lightness (DL*) and chromaticity coordinates (Δa* and Δb*) were calculated using group mean values. The quantities DL*, Δa*, and Δb* are the changes between pre- and post-treatment values. These values were used to calculate total color change (DE*) according to Eq. (5) (ISO 7724/3 1984):

$$\Delta E_{ab}* = [(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2]^{1/2} \quad (5)$$

All statistical calculations were based on a 95 % confidence level. An independent sample t-test was applied to compare control and treatment groups. DTREG (Standard Version 10.6.3, Phillip H. Sherrod, USA) was used for statistical analysis.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The obtained results and descriptive statistics for density and strength properties are shown in Table 1. After acclimatization period under the same conditions, while control samples reached equilibrium between 8.8-15 % moisture content, heat-treated samples reached 4.1-11.5 % MC in our experiments (Table 1 footer). Tankut *et al*. (2014) reported 10-12 % EMC for the control sample and 6-8 % for heat treated samples at 23 °C and 65 % relative humidity conditioning, for the same species and industrial heat treatment process at 180 °C . These results showed that heat treated iroko wood reached 4-5 % lower equilibrium moisture content than untreated ones under the same temperature and relative humidity conditions. Heat treated and control samples showed different sorption behavior and heat treated samples contained lower water content at the same water immersion time as shown in Figure 3. The availability and/or accessibility of the free hydroxyl groups of wood play an important role in water sorption (Boonstra and Tjeerdsma, 2006). The degradation of cellulose causes a reduction in available free polar adsorption sites, including free hydroxyl groups for water (Burmester, 1975; Hillis, 1984; Feist and Sell, 1987; Kartal *et al*., 2007). There was an increase in the relative proportion of the crystalline cellulose, where the hydroxyl groups are not easily accessible to water molecules (Pott, 2004), and the cross-linking of the lignin network (Tjeerdsma *et al*., 1998), which might hinder the accessibility of free hydroxyl groups to water (Pizzi *et al*., 1994). Therefore, the decreased equilibrium moisture content (Table 1), improved dimensional stability (Table 2), and water repellency of heat-treated wood are mainly caused by the decomposition or transformation of hemicellulose at high temperatures (Icel *et al*., 2015). These are the most probable causes of the lower moisture contents of heat-treated samples after acclimatization in our study.

Table 1 Heat treatment effects on density and mechanical properties of iroko wood
Tablica 1. Utjecaj toplinske obrade na gustoću i mehanička svojstva iroko drva

Properties / *Svojstvo*	*N*	**Control** / *Kontrolni uzorak*			**ThermoWood** *Toplinski tretirano drvo*			**% Change** % *promjene*
		Mean	***SE***	***cv***	**Mean**	***SE***	***cv***	
D_0, g/cm^3	40	0.654	0.021	0.003	0.624	0.037	0.005	-4.6
D_{12}, g/cm^3	40	0.693	0.02	0.003	0.685	0.02	0.003	-1.2
MOR (12 % *MC*), N/mm^2	51	99.015	11.705	1.639	74.230	8.553	1.197	-25
MOE (12 % *MC*), N/mm^2	51	7188.890	839.604	117.568	5186.057	572.157	80.118	-27.8
CS// (12 % *MC*), N/mm^2	50	70.757	5.938	0.839	59.613	6.033	0.853	-15.7
**MOR*, N/mm^2	51	104.297 (1)	10.122 (1)	1.417(1)	100.823 (3)	10.826 (3)	1.516(3)	-3.3
**MOE*, N/mm^2	51	7378.289(1)	819.689(1)	114.779(1)	5972.594(3)	635.252(3)	88.953(3)	-19
**CS*//, N/mm^2	50	61.948(2)	4.765(2)	0.673(2)	66.064(4)	5.181(4)	0.732(4)	+6.6

SE – standard error / *standardna pogreška*; *cv* – coefficient of variation / *koeficijent varijacije*, D_0 – oven-dry density / *gustoća standardno suhog drva*, D_{12} – air-dry density / *gustoća drva sušenog na zraku*
(1) 8.8 to 12.9 % *MC*, (2) 12 % to 15 % *MC*, (3) 4.1 to 6.9 % *MC*, (4) 7.8 to 11.5 % *MC*

Table 2 Heat treatment effects on radial, tangential and volumetric swelling and shrinkage
Tablica 2. Utjecaj toplinske obrade na radijalno, tangencijalno i volumno bubrenje i utezanje

Tree *Drvo*		Treat-ment *Obrada*	*N*	**Swelling** / *Bubrenje*				**Shrinkage** / *Utezanje*			
				Mean	***SE***	***cv***	**% Decrease** *Postotak smanjenja, %*	**Mean**	***SE***	***cv***	**% Decrease** *Postotak smanjenja, %*
Iroko	Radial *radijalno*	Control	52	3.041	0.504	0.066	18.3	3.183	0.607	0.084	14.4
		TW	52	2.482	0.405	0.053		2.724	0.283	0.039	
	Tangential *tangencijalno*	Control	52	4.759	0.644	0.084	17.3	4.525	0.737	0.102	13.3
		TW	52	3.935	0.507	0.066		3.923	0.502	0.069	
	Volumetric *volumno*	Control	52	8.220	0.932	0.122	19 (ASE)	7.853	1.241	0.172	13.2
		TW	52	6.658	0.793	0.104		6.815	0.632	0.087	

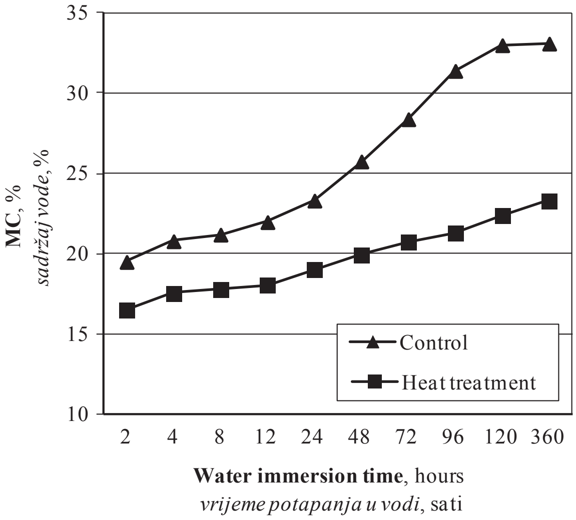

Figure 3 MC of two groups at different water immersion time
Slika 3. Sadržaj vode u uzorcima nakon različitog vremena potapanja u vodi

Compared with the control sample, wood density for the same moisture content (0 %) decreased significantly (p<0.05) with heat treatment. However, decrease in air-dry density (D_{12}) was lower than D_0 (Table 1) and insignificant (p>0.05). Mass loss of heat-treated samples was found to be 3.7 %. These results clearly show that the conversion formula (1) should be reevaluated for more realistic effects of heat treatment on air-dry density. The depolymerization reactions of wood polymers, in particular hemicelluloses, which are less stable under the effects of heat than cellulose and lignin, are the main cause of the decrease in density at high temperatures (Fengel and Wegener, 1989; Hillis, 1984).

The mechanical properties are closely related to the moisture content of wood. Since heat-treated wood is less hygroscopic and the (maximum) amount of bound water is reduced (Boonstra *et al*., 2007), it can be concluded that heat treatment provides a positive contribution to the mechanical strength properties. However, the ThermoWood process caused a significant (p<0.05) reduction (up to 27.8 %) of the investigated mechanical properties (Table 1). There is a general consensus in the literature that high-temperature heat treatments have a negative effect on wood mechanical properties and this can be explained by material losses in cell lumen and hemicellulose degradation caused by high temperature (Rusche, 1973; Esteves *et al*., 2008; Korkut, 2008; Brito *et al*., 2008; Tasdemir and Hiziroğlu, 2014; Icel *et al*., 2015; Tiryaki, 2015; Araújo *et al*., 2016). Tankut *et al*. (2014) reported 23.5 % decrease in MOR and 21.73 % in MOE for heat treated iroko wood, while Yildiz *et al*. (2013) found higher MOE for the same species and similar industrial heat treatment process. The possible explanation for the increase in MOE could lie in the fact that wood is a mixture of polymers of largely amorphous polymeric hemicelluloses, lignin and of partly crystalline microfibrils (Hillis and Rozsa, 1978). It is known that, when heat treatment is carried out above a certain temperature, many amorphous polymeric materials change from their glassy states to rubbery conditions or are prone to large plastic deformation. Individual polymers are exposed to sufficient energy to decrease their attractive forces at the glass-transition or softening temperature, so that they become rubbery or plastic to a greater degree (Yildiz *et al*., 2013).

Although reports on the effects of heat treatment on the anatomical structure of wood are very limited, some anatomical changes in wood structure might also contribute to reductions in mechanical properties. For example, cracks were noticed in treated species (Boonstra *et al*., 2006; Priadi and Hiziroglu, 2013; Tasdemir and Hiziroglu, 2014; Icel *et al*., 2015; Icel and Simsek, 2016). These cracks may contribute to abrupt fractures, which can lead to considerably different failure behavior of heat-treated wood, abrupt fracture at lower forces, as observed in bending tests presented in Figure 4.

The reason for acclimatization at specific conditions (i.e., 20 °C and 65 % relative humidity), before the mechanical test and the use of conversion formulas to equalize sample moistures at a specific level after tests, is to determine the real effects of treatment. Control and treated samples should have the same moisture content. However, changes that occur after heat treatments are irreversible. The current results and literature support the idea that heat treated wood reaches equilibrium at lower *MC* than untreated wood (Dos Santos *et al*., 2014). Moisture content of heat treated samples was found to be lower than that of control samples after 2 years weathering (Tomak *et al*., 2014). After acclimatization under the same conditions, the moisture contents of heat-treated samples were lower than those of untreated ones. The mechanical test results for the actual moisture of heat-treated samples

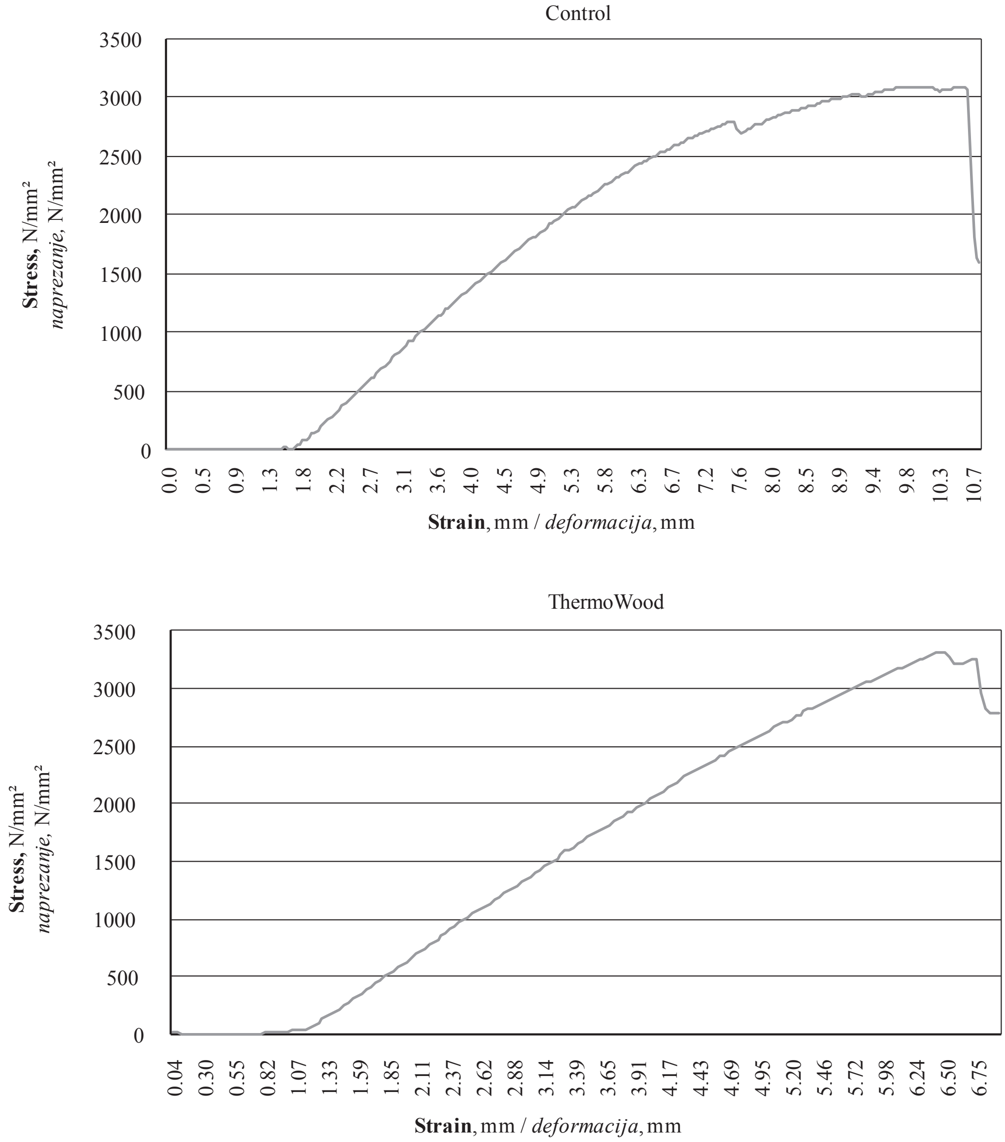

Figure 4 Fracture behavior of heat-treated and control samples in bending
Slika 4. Krivulja loma toplinski obrađenih i kontrolnih uzoraka pri savijanju

showed that the decrease (%) in strength values was lower than in samples with specified moisture (12 %) content, using conversion formulas (Table 1). Therefore, realistic moisture contents should be considered to get a realistic idea about strength properties of heat-treated wood in use (Icel *et al*., 2015). The moisture conversion formulas/coefficients for different strengths should be reevaluated considering *MC* effect on heat treated wood for more realistic results of heat treatment on strength properties.

Dimensional stability is a very important criterion of wooden materials, especially under conditions of high humidity. Therefore, many studies have been conducted on this topic. Reported results of wood stability increases (%) vary from one study to another, depending on differentiations in heat treatment methods, the standards that were followed and wood species. For example, many of previous works were carried out in a laboratory-scale oven in the presence of air, while the ThermoWood heat treatment is carried out in the absence of oxygen. Oxygen acts like a catalyst for changes in wood components during heating, and the presence of air during heat treatment may lead to higher ASE and higher weight loss (Wang, 2014). The general consensus among published works is that heat-treated wood has a dimensional stability advantage compared to its control (Hillis, 1984; Viitaniemi, 1997; Akyildiz and Ates, 2008; Korkut and Guller, 2008; Kaygin *et al*., 2009; Sahin Kol, 2010; Karlsson *et al*., 2011; Aydemir *et al*., 2011; Poncsac *et al*., 2011; Icel *et al*., 2015).

Brinell hardness values for control and heat treated samples are presented in Table 3. The highest decrease occurred in radial section (16.5 %). Additionally, the mean hardness decrease rate between tangential and radial sections for heat treated samples was approximately 4 % higher than that of the control samples. Reported results may change depending on the testing method, heat treatment conditions, anatomical structure of wood species and wood section. Thus, a 50 % hardness reduction was found by Korkut and Guller (2008) for redbud maple samples exposed to 180 °C for 6 h. Different decrease rates were reported for three

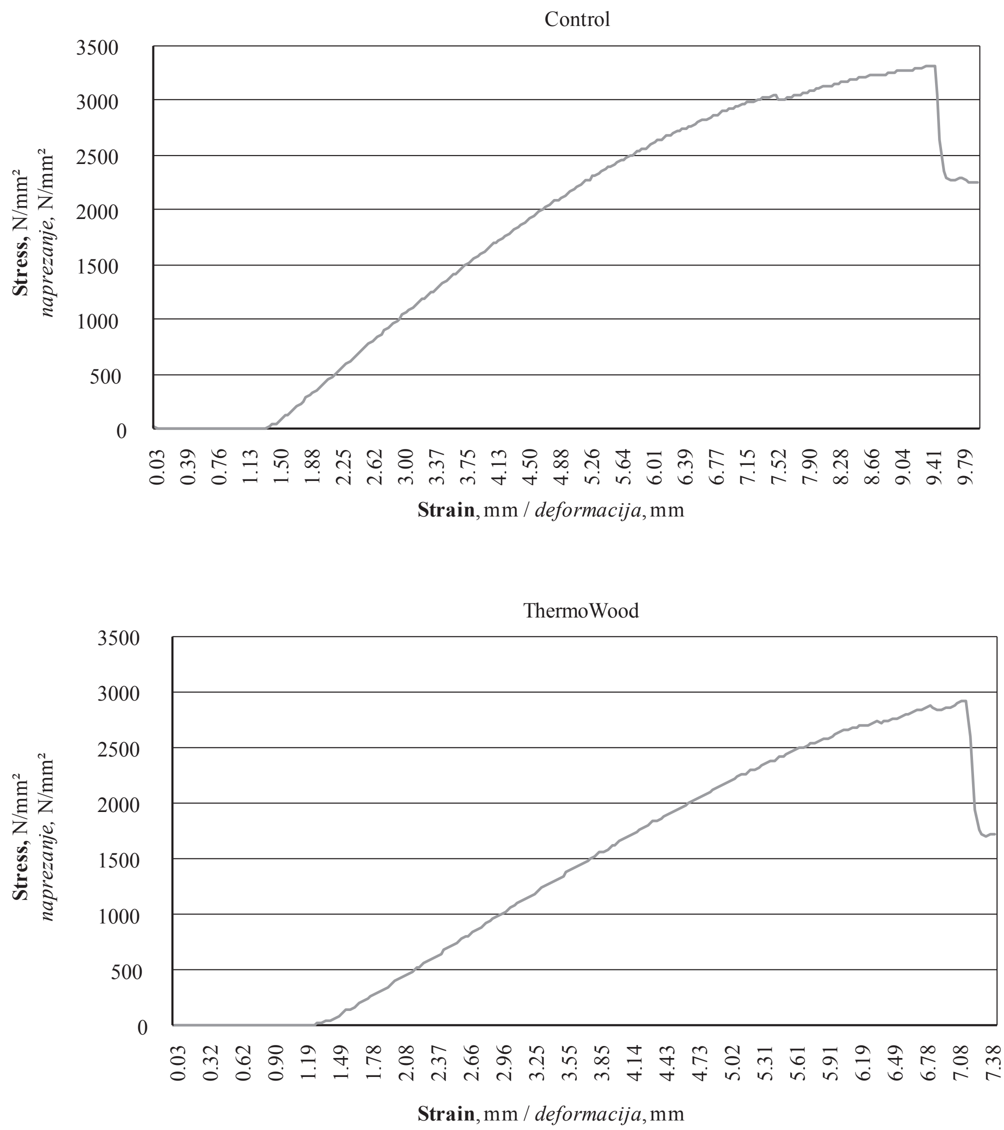

Figure 4 Fracture behavior of heat-treated and control samples in bending
Slika 4. Krivulja loma toplinski obrađenih i kontrolnih uzoraka pri savijanju

species under the same treatment conditions (200 °C for 8 h): for oak samples 42.7 %, for mindi (*Melia azederach*) about 20.0 % and for mahogany (*Swietenia mahagoni*) 17.3 % (Priadi and Hiziroglu, 2013). The possible causes of this reduction can be the result of thermal treatment, degradation of the cell wall components and wood mass loses. Wood becomes more brittle and its strength decreases in relation to the severity of the heat treatment (Santos, 2000; Rapp and Sailer, 2000; Bekhta and Niemz, 2003; Hakkou *et al*., 2005). Although reports on the effects of heat treatment on the anatomical structure of wood are very limited, some anatomical observations of wood structure may also contribute to the reduction in hardness. For example, cracks between cells were noticed on the SEM micrographs of heat-treated samples of both softwood and hardwood species (Boonstra *et al*., 2006; Tasdemir and Hiziroglu, 2014; Icel *et al*., 2015) and these features may cause the reduction in hardness. Wood hardness correlated positively with density and negatively (below FSP) with moisture content (Wiemann and Green, 2007; Kollmann and Cote, 1968). A difference in moisture of 4.64 % (mean) and approximately 5 % in density was observed after acclimatization at the same relative humidity and temperature between the control and heat treated groups. Therefore, hardness values presented in Table 3 were not only affected by heat treatment but also by a combined effect of moisture and density differences caused by heat treatment.

The color values showed clear effects of high temperature on color changes (Table 4). Positive and negative values show a tendency of wood surface to become reddish and greenish for Δa^*, and yellowish and bluish for Δb^*, respectively. Lower L^* value of heat treated samples indicated that color became darker after heat treatment. In this study, L^* and b^* values in color change tests decreased after heat treatment; on the other hand, a^* value generally increased. There was no significant difference (p>0.05) between the color values of radial and tangential sections. Surfaces of iroko wood turned reddish and bluish after heat treatment. Higher darkening (DL^*) and total color

Table 3 Heat treatment effects on hardness
Tablica 3. Utjecaj toplinske obrade na tvrdoću drva

Tree *Drvo*	**Treatment** *Obrada*	**Sections** / *Presjek* **Radial** *Radijalno* N/mm²	**Tangential** *Tangencijalno* N/mm²	**Transverse** *Poprečno* N/mm²	**Moisture %** *Sadržaj vode*
Iroko	Control / *Kontrolni uzorak*	38.64	46.39	79.48	9.95
	TW / *Toplinska obrada*	32.25	40.16	75.60	5.34
Decrease, % / *Smanjenje, %*		16.5	13.4	4.9	

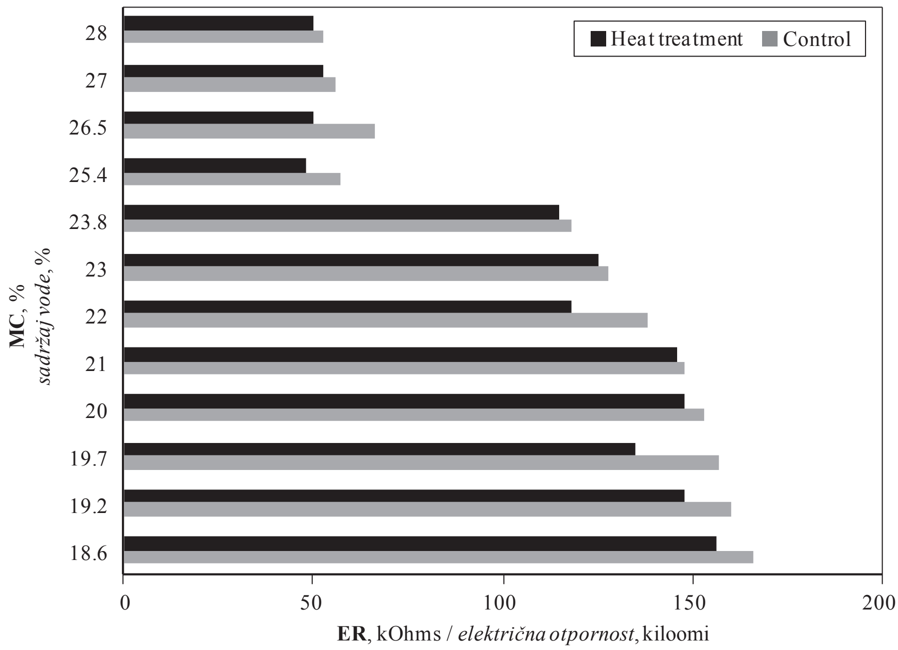

Figure 5 Electrical resistance (*ER*) for control and heat treated samples at the same moisture content (*MC*) (T = 20 °C)
Slika 5. Električna otpornost (*ER*) kontrolnih i toplinski obrađenih uzoraka s jednakim sadržajem vode (*MC*) (T = 20 °C)

change (D*E**) were observed in this study than in a laboratory experiment carried out by Korkut (2012).

Electrical conductivity of wood increases or, in other words, electrical resistivity decreases with the increase of water content at constant temperature (Kollmann and Cote, 1968; Gora and Yanoviak, 2015; Zelinka *et al*., 2016). Higher ER values of heat treated samples for the same immersion time were measured, but it was also determined that MC of two groups was different at the same immersion time (Figure 3). Therefore, *ER* data of the samples with the same *MC* (different immersion time) were compared. Heat treated samples reached 28 % *MC*, which is the maximum for *ER* experiment, after 15-day water soaking, while the control samples reached the same *MC* in 3 days. *ER* data for the same moisture content clearly showed that heat treated samples had lower *ER* compared to untreated wood (Figure 5), which might be due to acetic and formic acid formed during heat treatment (Tjeerdsma *et al*., 1998; Weiland and Guyonnet, 2003; Wikberg and Maunu, 2004) and/or mass loss (Brischke *et al*., 2014). As a result, heat treatment seems to cause a slight reduction in ER under the investigated conditions.

4 CONCLUSION
4. ZAKLJUČAK

1. The ThermoWood process caused a significant (p<0.05) reduction (15.7 % to 27.8 %) of all mechanical properties investigated at a specified moisture level (12 %). The highest decrease in strength

Table 4 Heat treatment effects on color values of ıroko wood on radial and tangential section
Tablica 4. Utjecaj toplinske obrade na parametre boje za iroko drvo na radijalnome i tangencijalnom presjeku

Tree *Drvo*	**Wood section** *Presjek drva*	**Treatment** *Obrada*	***L****	***a****	***b****	**Δ*L****	**Δ*a****	**Δ*b****	**Δ*E****
Iroko	Radial *radijalni*	Control / *kontrolni uzorak*	59.57	10.35	21.82				
		TW / *toplinska obrada*	47.84	14.19	19.13	11.72	-3.83	2.69	12.63
	Tangential *tangencijalni*	Control / *kontrolni uzorak*	57.79	10.57	21.16				
		TW / *toplinska obrada*	45.62	13.14	17.39	12.17	-2.56	3.77	12.99

was observed in the modulus of elasticity. However, the mechanical properties of wood are closely related to moisture content, and heat-treated wood is less hygroscopic than untreated wood. After acclimatization under the same conditions, moisture contents of heat-treated samples were lower than those of untreated ones and the mechanical test results for the real moisture of heat-treated samples showed that the decrease in strength values was lower than in samples with the specified (12 %) moisture content. Exceptionally, compression strength parallel to grain was found higher in heat treated samples at their real moisture content.

2. Heat treatment caused a slight reduction in ER, detectable when the control and heat treated samples had the same moisture content. Mass loss of heat-treated samples was 3.7 %, which may be the possible cause of this small reduction in ER. On the other hand, because of the lower hygroscopicity of heat-treated wood, treated samples attained lower equilibrium than untreated samples under the same relative humidity and temperature. These results showed that the equilibrium moisture content of heat treated iroko wood was 4-5 % lower than that of untreated samples under the same conditions. MC has a higher effect on ER than heat treatment, and under the same humidity conditions, heat treated wood showed lower ER.
3. Different failure behavior (abrupt fracture at lower forces) of heat-treated wood was observed in bending tests.
4. Timber color became uniformly darker after treatment for the clear parts of the lumber. There was no significant (p>0.05) difference between the color values of radial and tangential sections. Iroko wood surfaces turned reddish after heat treatment.
5. The biggest decrease in hardness occurred in radial section (16.5 %). Additionally, the mean decrease in hardness between tangential and radial sections was approximately 4 % higher in heat treated samples than in control samples. Moisture content and density were different for control and heat treated groups. Density decrease and lower equilibrium are the result of heat treatment. Therefore, at least moisture content of the sample should be equalized by changing acclimatization conditions for the two groups to determine the effect of heat treatment. Psychrometric table/chart for heat treated woods requires further research. Additionally, the conversion formula (1) should be reevaluated for more realistic results of the effect of heat treatment on air-dry density.

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Fiber Characteristics of White Poplar (*Populus alba* L.) Juvenile Wood along the Drava River

Svojstva vlakanaca juvenilnog drva bijele topole (*Populus alba* L.) uz rijeku Dravu

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ABSTRACT • *Anatomical properties of white poplar (Populus alba L.) wood have not been sufficiently investigated and quantified, whereas data on fiber characteristics will certainly define its potential as a raw material. Fiber length, double cell wall thickness and fiber lumen diameter of white poplar juvenile wood from two sites along the Drava River in Croatia were measured. Variations in fiber characteristics in radial direction (from pith to bark), within and between white poplar populations from two sites were investigated. Results indicate that fiber Rlength and double cell wall thickness varied significantly from pith to bark, within and between sites. Variation in fiber lumen diameter was non-significant only between sites. The variation in radial pattern was characterized by increase in fiber length with cambial age. Double cell wall thickness and fiber lumen diameter varied in non-consistent radial pattern. In conclusion, variation significance demonstrates nonhomogeneous wood fiber characteristics at both sites.*

Keywords: *Populus alba L., juvenile wood, fiber characteristics, wood anatomical properties variation*

SAŽETAK • *Anatomska svojstva drva bijele topole (Populus alba L.) nedovoljno su istražena i nisu kvantificirana, a podatci o obilježjima drvnih vlakanaca zasigurno će upozoriti na potencijal tog drva kao sirovine. U radu je izmjerena duljina vlakanaca, dvostruka debljina stijenki i promjer lumena vlakanaca juvenilnog drva bijele topole s dva staništa uz rijeku Dravu. Istražene su i varijacije svojstava vlakanaca u smjeru od srčike prema kori, kao i unutar istog staništa odnosno između dvaju promatranih staništa. Rezultati pokazuju značajne varijacije duljine vlakanaca i dvostruke debljine stijenki od srčike prema kori te unutar istog staništa i između dvaju staništa. Varijacije promjera lumena vlakanaca nisu značajne samo među staništima. Radijalne su varijacije određene rastom duljine vlakanaca sa starošću drva. Dvostruka debljina stijenki i promjer lumena vlakanaca mijenjaju se prema promjenjivom modelu između godova. Zaključno, značenje varijacija upućuje na nehomogenost svojstava drvnih vlakanaca na oba staništa.*

Ključne riječi: *Populus alba L., juvenilno drvo, svojstva vlakanaca, varijacije anatomskih svojstava drva*

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1 INTRODUCTION
1. UVOD

Poplar wood is widely used for the manufacture of a large number and variety of products, especially for pulp, paper and other fiber-based products. It is reported that approximately 70 countries worldwide grow poplars, both in mixtures with other natural forest species and in planted forests (Ball *et al.*, 2005). However, the great majority of poplars still grow in natural forests. The value of diverse natural stands of poplars as a basis for tree improvement is well recognized (Ball *et al*., 2005). Acquiring genotypes of forest trees or trying to upgrade the existing properties is one of the main aims of tree improvement (Kajba and Ballian, 2007). It is often carried out in order to increase the productivity of the wood mass. The increase of wood quality is another important goal, which cannot be carried out without an understanding of wood structure.

Cell size and relative cell dimensions have a major influence on the quality of pulp and paper based products, as well as on solid wood products (Clark, 1985). Mechanical properties of wood stiffness and strength are, among others, also related to wood fiber characteristics (Logan, 2006).

As they grow so rapidly, both natural and planted poplar stands can produce large volumes of wood in a short period of time (Dickmann and Kuzovkina, 2014). This suggests that they can be harvested within 10-20 years, having a high portion of juvenile wood. Juvenile wood is characterized by rapid changes in wood structure throughout the zone from the pith outward (Tsoumis, 1991). Maeglin (1987) reported shorter fibers with generally thinner walls at or near the pith. According to Dadswell (1958), fiber length is increased up to two times in the central core of hardwoods.

As one of the most distinctive poplar species, white poplar (*Populus alba* L.) is an indigenous wood species in Europe. In Croatia, white poplar can rarely be found in pure stands covering large areas, but forms mixed stands together with other species, such as white willow and black poplar. However, pure stands of white poplar are found along the Danube, Sava and Drava (Franjić and Škvorc, 2010). For a long period of time, white poplar has not been considered as a commercially important wood species. Due to climate changes and changed ecological conditions, it is becoming more interesting for breeding as a drought tolerant species (Eggens *et al*., 1972; Gilman and Watson, 1994; Isebrands and Richardson, 2014).

Within the *Populus* genus, white poplars have been least investigated. Horvat (1960) investigated some physical and mechanical properties of white poplar wood in Croatia. However, available data on anatomical properties of white poplar wood are limited (FAO 1958). The capacity of white poplar to grow in a wide range of soils and to propagate easily contributes highly to its cultivation. For that reason, the available data on its wood anatomical properties should be completed. Additionally, variability in juvenile wood characteristics significantly affects product quality. Therefore, more emphasis should be put on determining the size of wood variability.

The aim of this study was: (a) to determine fiber characteristics of white poplar juvenile wood from two sites along the Drava River in Croatia; (b) to investigate variations in fiber characteristics in radial direction (from pith to bark), within and between white poplar populations from two sites.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

Five trees of white poplar (*Populus alba* L.) were collected from two sites with continental climate along the Drava River. The first site is located near the city of Osijek, within Osijek Podravina forests. It is characterized by alluvial loamy-sandy soils, where humus is being formed, with mean annual temperature of 11.6 °C and total annual precipitation of 694.4 mm.

The second site is located near the city of Varaždin, within Varaždin Podravina forests. It is characterized by soil on alluvial pebbly-sandy shoals intersected with meanders, with mean annual temperature of 10.8 °C and total annual precipitation of 819.9 mm. Both units are managed by the company Croatian Forests Ltd.

Each test tree was marked on the side facing north because of further investigations on physical and mechanical properties. Relevant parameters on growth locations of all test trees were collected and measured (Table 1).

Disks, approximately 5 cm thick, were cut at breast height (1.3 m) from each tree. Radial segments (north–south orientation) were cut from each disk and annual growth rings were marked along one radius. On both sites, growth rings 2, 4, 6, 8 and 10 from the pith were selected from each tree for further anatomical analysis of wood. A series of radially oriented sample blocks, sized 10 (T) × 10 (R) × 20 (L) mm, was cut from the selected growth rings.

For measuring double cell wall thickness and fiber lumen diameter, transverse sections (30 μm) were cut using Shandon Reichert sliding microtome. Sections were then stained with safranin and astra blue, while excess stain was removed by washing sections successively in 70 % and 96 % ethanol solution. Furthermore, they were mounted on microscope slides with coverslips using euparal. Photographs of samples were then taken at ×160 magnification using stereo microscope, digital camera and Axio Vision program (Carl Zeiss). In each growth ring, five images were taken as random replicates: one from the early wood region, one from late wood region and three from the middle part of the growth ring, according to Peszlen (1994). Fiber lumen diameter was measured by digital photographs, using ImageJ program (ImageJ 2014).

Double cell wall thickness was measured directly on light microscope, using an objective with measurement scale. The magnification ×960 was used. From each growth ring, 30 tangential fiber double cell wall thicknesses were measured (ten in the early wood region, ten in the middle part of each growth ring and ten in the late wood region).

Table 1 Tree characteristics of white poplar (*Populus alba* L.) from two sites along the Drava River
Tablica 1. Karakteristike stabala bijele topole (*Populus alba* L.) s dvaju staništa uz rijeku Dravu

Tree species *Vrsta drva*	**Tree mark** *Oznaka stabla*	**Site** *Stanište*	**Total tree height** *Ukupna visina stabla* m	**Height up to first living branch** *Visina do prve žive grane* m	**Diameter at breast height** *Promjer na prsnoj visini* cm	**Diameter at breast height in first 10 years** *Promjer na prsnoj visini u prvih 10 godina* cm	**Disk thickness** *Debljina koluta* cm
P. alba	6	Osijek	18.1	11	29.5	5.85	5
P. alba	7	Osijek	20	14	35	5.42	5
P. alba	8	Osijek	18.3	11	40.5	6.55	5
P. alba	9	Osijek	18.2	10	33	4.42	5
P. alba	10	Osijek	18.7	14	25.5	3.61	5
P. alba	27	Varaždin	16	7.5	50.5	4.98	5
P. alba	28	Varaždin	14	6	51	7.78	5
P. alba	29	Varaždin	14.3	8	41	3.47	5
P. alba	30	Varaždin	14.1	8.2	44.5	4.77	5
P. alba	31	Varaždin	13	7,3	39.2	2.71	5

For fiber length measurements, wood from each of the previously selected growth rings was separated with a razor blade and placed into an individual test tube. Maceration was performed according to Franklin's method (Franklin, 1945). Macerated material was stained using safranin, then placed on microscope slides and mounted in glycerin gelatin. From each growth ring, 40 unbroken fibers were measured using light microscope, digital camera and DinoCapture 2.0 program (DinoCapture 2.0 2015).

Statistical analysis of results was carried out using Statistica 10. Repeated measures analysis of variance (ANOVA) was used to test significance of differences in radial distribution of selected fiber characteristics, as well as their variations within and between two white poplar populations.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Statistical values of fiber dimensions of white poplar juvenile wood from both sites are given in Table 2.

The mean fiber length of white poplar juvenile wood from Osijek site was 0.87 mm and from Varaždin site 0.84 mm (Table 2). Similar mean values of fiber length were determined by Boessneck, Brossa, Viviani and Demi in white poplar wood from several locations in Europe, and they are all less than 1 mm (in FAO 1958). However, Demi also reported fibers longer than 1 mm. The mean double cell wall thickness of white poplar juvenile wood from Osijek site was 3.72 μm and from Varaždin site 4.16 μm (Table 2). Those mean values are in the range of mean values reported by Demi (between 3.36 μm and 4.95 μm). Data on fiber lumen diameter are not available in previously mentioned studies and thus could not be compared. Measured fiber characteristics could be classified according to the list of microscopic features for hardwood identification, published by IAWA (Wheeler *et al.* 2007). This list is comprised of 163 anatomical features, including fiber length and fiber wall thickness. Fiber length was classified into 3 categories and mean values from both sites fit the first category (fibers ≤ 900 μm). Fiber wall thickness was also defined in 3 ways, by

Table 2 Statistical values of fiber length, double cell wall thickness and fiber lumen diameter of white poplar juvenile wood
Tablica 2. Statističke vrijednosti duljine vlakanaca, dvostruke debljine stijenki i promjera lumena vlakanaca juvenilnog drva bijele topole

Site *Stanište*	**Number of trees** *Broj stabala*	**Value** *Vrijednost*	**Fiber length** *Duljina vlakanaca* mm	**Double cell wall thickness** *Dvostruka debljina stijenki* μm	**Fiber lumen diameter** *Promjer lumena vlakanaca* μm
Osijek	5	*N*	40	30	25*
		MIN	0.45	2.20	7.68
		MEAN	0.87	3.72	13.38
		MAX	1.48	6.60	19.00
		STDEV	0.15	0.17	1.19
Varaždin	5	*N*	40	30	25*
		MIN	0.38	1.10	7.28
		MEAN	0.84	4.16	13.59
		MAX	1.72	6.60	21.51
		STDEV	0.15	0.30	1.45

Key/*Legenda*: *N* – number of specimen / *broj uzoraka*, *MIN* – minimum / *minimum*, *MEAN* – mean value / *aritmetička sredina*, *MAX* – maximum /*maksimum*, *STDEV* – standard deviation / *standardna devijacija.*

* Number of specimen matches number of recorded images for each measured growth ring in five trees (for each of five images, average value of fiber lumen diameter was calculated). / *Broj uzoraka odgovara broju snimljenih fotografija u svakome mjerenom godu svih pet stabala (za svaku od pet fotografija izračunana je prosječna vrijednost promjera lumena vlakanaca).*

Table 3 Results of repeated measures analysis of variance for fiber characteristics of white poplar juvenile wood from two sites and in direction from pith to bark
Tablica 3. Rezultati analize varijance ponovljenih mjerenja svojstava vlakanaca juvenilnog drva bijele topole s dva staništa i u smjeru od srčike prema kori

Source of variation *Izvor varijabilnosti*	**Fiber length** *Duljina vlakanaca* mm		**Double cell wall thickness** *Dvostruka debljina stijenki* μm		**Fiber lumen diameter** *Promjer lumena vlakanaca* μm	
	F	***p***	***F***	***p***	***F***	***p***
Site / *stanište*	10.25	**0.001478**	68.69	**0.000000**	0.302	0.585218
Annual rings / *godovi*	442.02	**0.000000**	11.43	**0.000000**	21.870	**0.000000**
Annual rings*site / *godovi *stanište*	0.90	0.462828	9.29	**0.000000**	2.852	**0.025047**

fiber lumina in relation to double wall thickness. Based on that relation, fibers from both sites are very thin walled (fiber lumina was 3 or more times wider than the double wall thickness).

Significant differences in fiber length and double cell wall thickness were detected between sites (Table 3). Due to soil type and flooding effect on Varaždin site, Osijek site is considered to be more favorable for poplar growth. In this case, the better site accelerated the growth rate and produced trees with longer fibers in the first ten years that were analyzed. This is in agreement with Kennedy and Smith (1959), who found greater fiber length in poplar wood from good sites. According to Peszlen (1994) and Pliura *et al.* (2007), those differences are most likely related to site edaphic and climatic conditions. This may be explained by several factors. The mean length of the fusiform cambial initials increases gradually as the tree matures. Considerable fluctuation in their length may occur at any time as a result of fluctuating environmental conditions that govern seasonal growth (Panshin and de Zeeuw, 1980). However, fast growth of hardwoods does not always result in meaningfully shorter fibers if wood of equal age is compared (Zobel, 1989). The results did not sup-

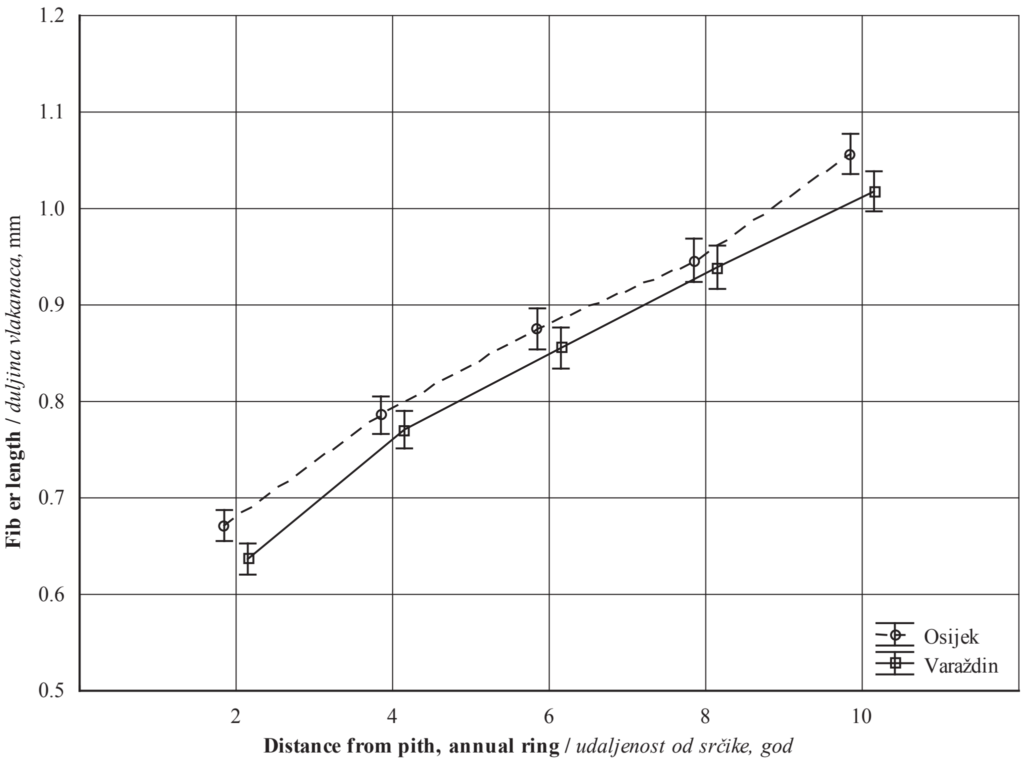

Figure 1 Radial distribution of fiber length of white poplar juvenile wood from two sites
Slika 1. Raspored duljine vlakanaca juvenilnog drva bijele topole s dva staništa u radijalnom smjeru

Table 4 Results of repeated measures analysis of variance for fiber characteristics of white poplar juvenile wood within population from each site
Tablica 4. Rezultati analize varijanci ponovljenih mjerenja svojstava vlakanaca juvenilnog drva bijele topole sa svakog staništa unutar iste populacije

Source of variation / *Izvor varijabilnosti*	**Site** *Stanište*	**Fiber length** *Duljina vlakanaca* mm		**Double cell wall thickness** *Dvostruka debljina stijenki* μm		**Fiber lumen diameter** *Promjer lumena vlakanaca* μm	
		F	***p***	***F***	***p***	***F***	***p***
Trees / *stabla*	Osijek	29.95	**0.000000**	18.86	**0.000000**	5.34	**0.004302**
	Varaždin	19.18	**0.000000**	44.40	**0.000000**	56.99	**0.000000**

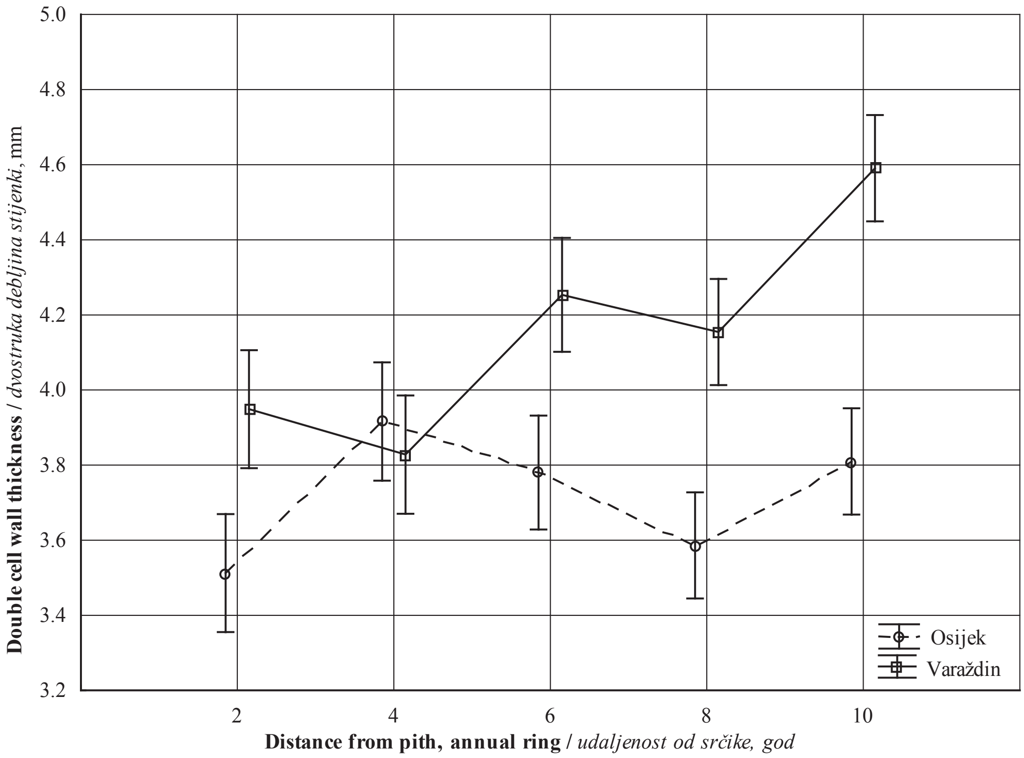

Figure 2 Radial distribution of double cell wall thickness of white poplar juvenile wood from two sites
Slika 2. Raspodjela dvostruke debljine stijenki juvenilnog drva bijele topole s dva staništa u radijalnom smjeru

port earlier findings on poplars and willows (Petrić *et al.*, 1991; Šefc *et al.*, 2009; Zhao *et al.*, 2014). They reported about non-significant difference in selected wood anatomical properties between sites. In this study, difference was non-significant only in fiber lumen diameter (Table 3). According to the results, the change in fiber diameter would be mainly the result of the change in cell wall thickness and not that of fiber lumen diameter.

As expected, fiber length significantly increased linearly from pith to bark in white poplar juvenile wood from both sites (Figure 1 and Table 3). This suggests that cambial age has an important effect on the length of wood fibers. Longer fibers were measured in

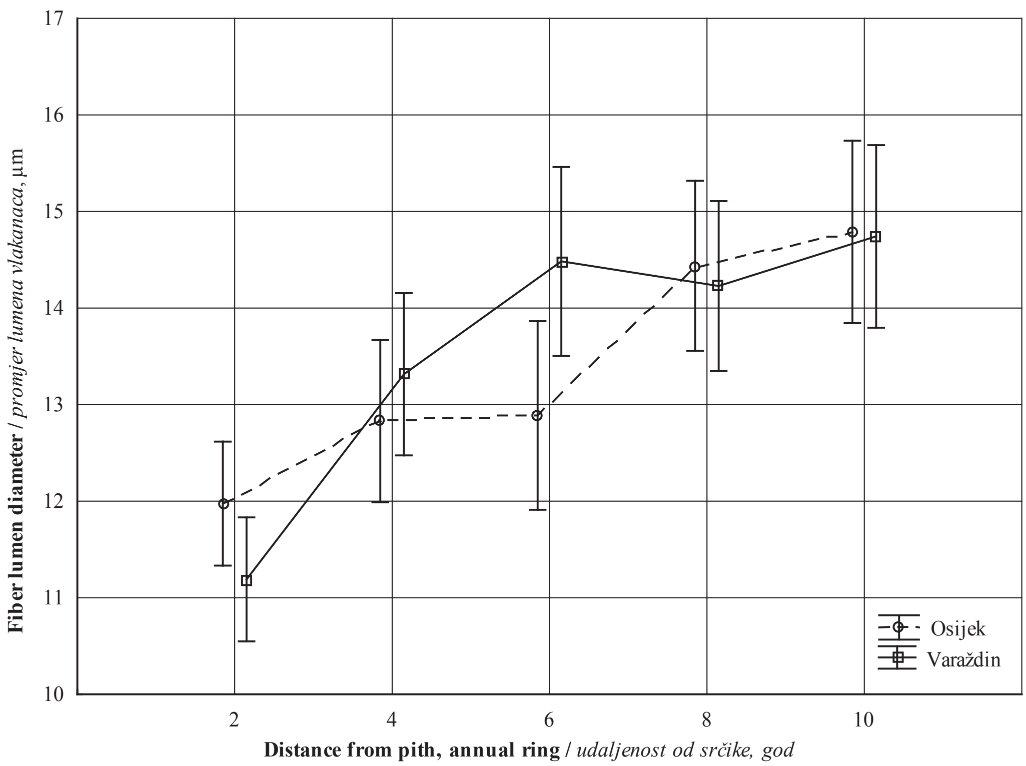

Figure 3 Radial distribution of fiber lumen diameter of white poplar juvenile wood from two sites
Slika 3. Raspodjela promjera lumena vlakanaca juvenilnog drva bijele topole s dva staništa u radijalnom smjeru

all five annual rings from Osijek site (Figure 1). Significant variation in fiber length from pith to bark of poplar wood was reported by many authors over the years (DeBell *et al.*, 1998; Koubaa *et al.*, 1998; Huda *et al.*, 2012). Double cell wall thickness also varied significantly from pith to bark, with more pronounced change between annual rings in white poplar juvenile wood from Varaždin site (Figure 2 and Table 3). Results from Varaždin site are only partially in agreement with Peszlen (1994) and Huda *et al.* (2012). Both reported about continuous increase in cell wall thickness with age. Furthermore, fiber lumen diameter showed similar pattern of radial distribution in white poplar juvenile wood from both sites (Figure 3). However, differences in fiber lumen diameter were most pronounced in growth ring 6 from the pith.

There was highly significant difference in fiber length, double cell wall thickness and fiber lumen diameter among trees within both white poplar populations (Table 4). Significant tree-to-tree variation in fiber length of poplar clones was reported by Klašnja *et al.* (2003), and additionally in fiber lumen diameter and fiber lumen area by Peszlen (1994). This may be explained by response of each tree to differences in its microenvironment, or may be due to large within-tree variation (Zobel and van Buijtenen, 1989; Tsoumis, 1991). Subsequently, variations in a certain site are considered to be higher than between sites. More precisely, variations in wood properties are generally more pronounced within the tree in comparison to variations between trees of one population or between populations (Larson, 1967; Tsoumis, 1991).

4 CONCLUSIONS
4. ZAKLJUČCI

As expected, the measured juvenile wood fiber characteristics were determined to be highly variable. Fiber characteristics of white poplar juvenile wood from two sites differed. Significant site effect was detected for fiber length and double cell wall thickness. Trees within both white poplar populations had highly significant effect on fiber length, double cell wall thickness and fiber lumen diameter.

There was a general trend in radial direction in both white poplar populations, in which fiber length increased from pith to bark. Double cell wall thickness and fiber lumen diameter also varied significantly with age, but no consistent radial pattern was observed.

For the present study, variations in each site (both within and among trees) were generally more significant in comparison to variations between sites.

Forest product manufacture tends for wood uniformity. Due to highly significant variability, nonhomogeneous wood fiber characteristics were determined within both white poplar populations. In conclusion, variation in wood characteristics provides the possibility to select the breeding stock with desirable wood quality.

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Use of 8D Method in Nonconformity Resolution – a Case Study of Production of Spliced Veeners in Slovakia

Primjena metode 8D u rješavanju nesukladnosti – studija slučaja u proizvodnji lijepljenog furnira u Slovačkoj

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ABSTRACT • *A turbulent and competitive environment currently imposes high demands on flexible adaptation to the changing qualitative and quantitative conditions at the European and global stage. One of the criteria used as an expression/declaration of the high level of management of all organisation's activities is to adhere to the principles of total quality management (TQM). In this way, it is possible to achieve high quality outputs. One of the TQM principles is constant improvement. It is one of the main objectives of each organisation. It is focused on constant improvement of the total performance. The aim of this case study is to analyse and improve selected processes in a specific company engaged in production of veneer – IKEA Industry Slovakia, Ltd., enterprise branch - Majcichov, by using combined instruments the way they are used in the quality management system. In this study, 8D method is applied for nonconformity resolution. The applied method showed to be optimal for nonconformity resolution because employees are educated and experienced in this area. However, in future, it will be necessary to adopt further quality instruments for increasing a company's competitiveness.*

Keywords: *improvement instruments, production of spliced veneers, TQM, 8D method*

SAŽETAK • *Današnje turbulentno i konkurentno okruženje postavlja visoke zahtjeve glede fleksibilne prilagodbe poduzeća promjenjivim kvalitativnim i kvantitativnim uvjetima na europskome i svjetskom tržištu. Jedan od kriterija koji se primjenjuju za izražavanje i potvrdu visoke razine upravljanja svim organizacijskim aktivnostima jest primjena načela potpunog upravljanja kvalitetom (TQM). Samo je na taj način moguće postići visokokvalitetne izlazne rezultate poduzeća. Jedno od načela TQM-a jest stalno unapređenje kvalitete proizvodnje. To je ujedno i jedna od glavnih zadaća svakog proizvođača, a temelji se na stalnom unapređenju cjelokupnog rada poduzeća. Cilj ovog istraživanja bio je analizirati i poboljšati određene procese u poduzeću uključenome u proizvodnju furnira – IKEA Industry Slovakia, Ltd., Majcichov, i usredotočiti se na primjenu kombiniranih instrumenata unapređenja na način na koji se oni primjenjuju u modelu potpunog upravljanja kvalitetom. U ovom je radu za rješavanje nesukladnosti primijenjena metoda 8D. Za promatrano poduzeće ta se metoda pokazala optimalnom u*

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rješavanju takvih problema jer su zaposlenici dodatno educirani i imaju iskustva s njezinom primjenom. Međutim, u budućnosti će biti potrebno uključiti i druge instrumente za postizanje kvalitete kako bi se povećala konkurentnost poduzeća.

Ključne riječi: *instrumenti poboljšanja, proizvodnja lijepljenog furnira, TQM, metoda 8D*

1 INTRODUCTION
1. UVOD

IKEA is a well-known company. It has been established in various European countries in the recent period and it is known as a world's producer in furniture industry. IKEA created its branches in more than 12 countries worldwide. One of them is IKEA Industry Branch Majcichov with the seat in the Slovak Republic. The main product specialisation of IKEA Industry Slovakia, Ltd,, Majcichov, is the production of spliced veneers used for producing veneer furniture. The factory in Majcichov was created when it was separated from the original company with the seat in Trnava. In 2014, a branch named IKEA Industry Slovakia, Ltd; Trnava, the branch of the enterprise – Majchichov, was founded, (Holovič, 2016). The main vision of the company is to focus on the production of high quality spliced veneers, and thus help to improve daily life through furniture sold in the trade network of IKEA (Handbook IMS, 2015).

The organisation is managed by the integrated management systems, which is certified under international standards ISO 9001:2008, ISO 14001:2004, ISO 50001:2011 and OHSAS 18001:2007. For its production, the company uses legally logged wood that comes from the areas where civil and traditional rights are not violated. Wood from forests transformed in plantations or for non-forest use and wood from forests planted from genetically modified woody plants are not used for production. No convention of the World Labour Organisation is breached and the Forest Stewardship Council (FSC) is supported, and the suppliers are required to manage forests according to the principles and criteria of FSC.

IKEA Industry has short-term objectives with the implementation period of 1 year and long-term objectives (Handbook IMS, 2015). Ambitions for 2020 are to become a leader in the industry of "green" production of furniture. IKEA Industry wants to deliver large wooden materials and furniture produced with the use of recycled wood or wood coming exclusively from well-managed forests to the IKEA supply chain. The long term objectives for 2020 go from the above considerations to professional experiences of co-operators (IKEA Industry Vision, 2013).

The long term objectives are described below as follows:

(a) *For an objective focus – collaborators, it is possible to achieve objectives:* The top priority is to keep workplace safe and healthy for all people working in the company or visiting its premises. Collaborators are involved in improving the working environment for their own benefit.

(b) *For an objective focus – suppliers, it is possible to achieve objectives:* Our factories are considered "well-developed" and exceeding requirements of IWAY. (IWAY is the IKEA code of conduct, first introduced in 2000. It specifies the requirements placed on suppliers of products and services, and details what they can expect in return from IKEA. IWAY Standard - Minimum Requirements for Environment and Social & Working Conditions when Purchasing Products, Materials and Services). Fair and good conditions, which are always in the best interest of children, workers and environment, are ensured. IKEA customers buy, at low prices, good quality furniture produced according to acceptable working conditions of suppliers, who take care of people and environment, as supported by other relevant documents (Rudy, 2015; Prístavka, 2010).

(c) *For an objective focus – community, it is possible to achieve objectives:* It is focused on adopting measures ensuring that entrepreneurship will comply with the needs of the local community, in compliance with environmental protection regulations as well as other relevant documents (Chovancová, 2014).

(d) *For an objective focus – wood and forestry, it is possible to achieve objectives:* The share of wood coming from FSC certified forests largely prevails and the nutrients are delivered back to wooded land to maintain the forest growth. Measures were developed for preserving biodiversity. The use of our wood and by-products is optimised and used by the IKEA supply chain as much as possible, as supported by other relevant documents (Šebo, 2008; Zákon č. 326/2005; Oznámenie č. 17/2005)

(e) *For an objective focus – chemicals, it is possible to achieve objectives:* Chemical management is implemented and efficient and safe uses of chemicals in our production were elaborated. Pollutants were excluded from the supply chain to ensure the lowest possible impact on the environment, as supported by other relevant documents (Nariadenie č. 416/2011)

(f) *For an objective focus – water, it is possible to achieve objectives:* The local water cycle is supported by re-usage of rainwater at a greater extent than usage of surface and tap water, as supported by other relevant documents (Vyhláška 636/2004).

(g) *For an objective focus – waste. it is possible to achieve objectives:* Using resources effectively and re-using them, recycling waste instead of waste incineration and sending waste at landfills (90 % of material for recycling and zero waste for landfills in 2020), as supported by other relevant documents (Zákon č. 79/2015).

(h) *For an objective focus – energy, it is possible to achieve objectives:* Using renewable energy sourc-

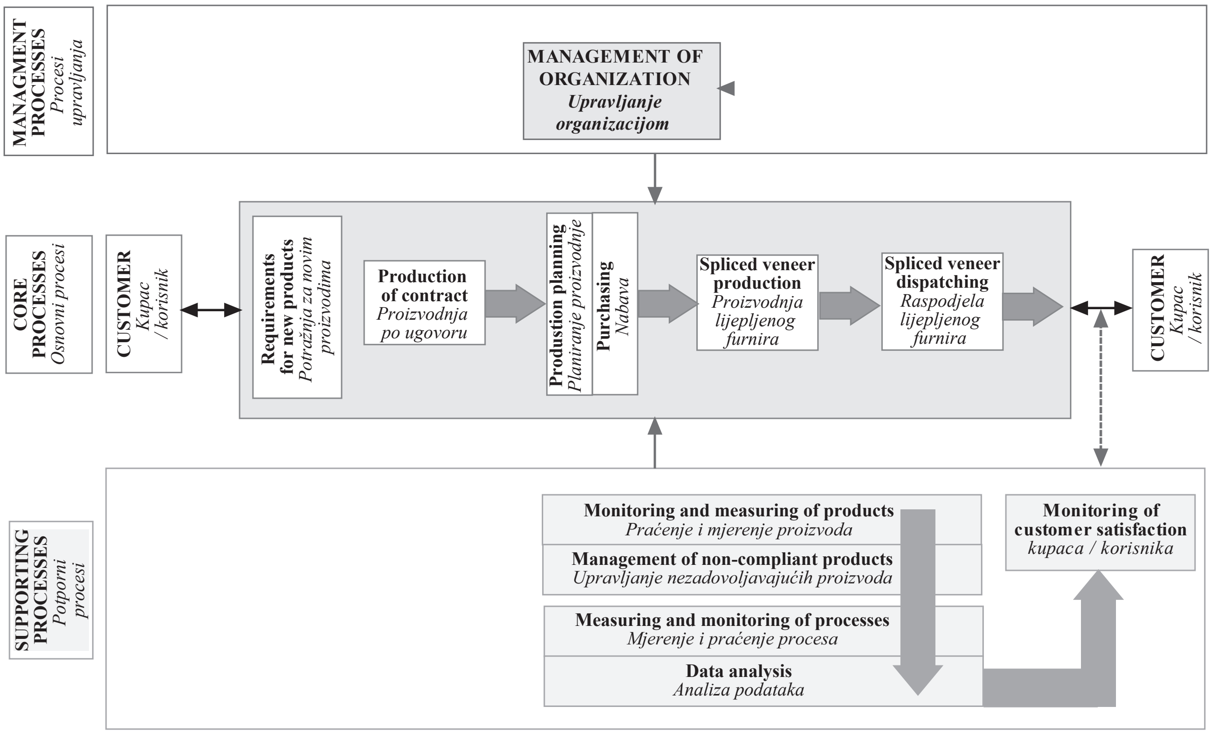


Figure 1 Interaction between managing, core and supporting processes (Source: Handbook IMS, p.63, 2015)
Slika 1. Odnos između upravljanja te osnovnoga i pratećih procesa (izvor: *Handbook IMS*, str. 63, 2015.)

es, according to other relevant documents (Zákon č. 309/2009). Emissions of carbon dioxide (CO_2) to be decreased, according to other relevant documents (Vyhláška č. 271/2011).

(i) *For an objective focus – smart logistics, it is possible to achieve objectives:* The optimal itinerary of suppliers to manufacturing plants. The extent of filling goods in trucks increased thanks to better package solutions and use of bigger facilities, as supported by other relevant documents (Straka, 2013).

(j) *For an objective focus – sustainable development, it is possible to achieve objectives:* The programmes of educational sustainability are available for all collaborators. Collaborators are inspired and they exchange their ideas, knowledge and smart solutions with each other, as supported by other relevant documents (Hurná, 1999).

Short-term objectives related to quality are set at (Handbook IMS, p. 54, 2015): (1) the value of percentage of complaints is max. 0.55 %, and (2) maximum percentage of discarded spliced veneers is 3.14 %.

The processes in the company are divided into core, managing and supporting processes (Handbook IMS, 2015). Fig. 1 shows the interaction between managing, core and supporting processes in the company. Fig. 1 presents purchasing as a core process in spite of the fact that most professional handbooks on company production consider the purchasing as a supporting process. However, there is also a fourth type of business processes: the process of measurement, analysis and improvement, partially presented (green colour) in Fig.1, but authors of this case study did not want to modify the original figure description in Handbook IMS. The authors studied and analysed the actual state and used the actual company's documents in this case study and suggested several corrections in the figures based on the company's documentation.

Manufacturing of products, which belongs to the core processes, consists of sub-processes shown in Fig. 2.

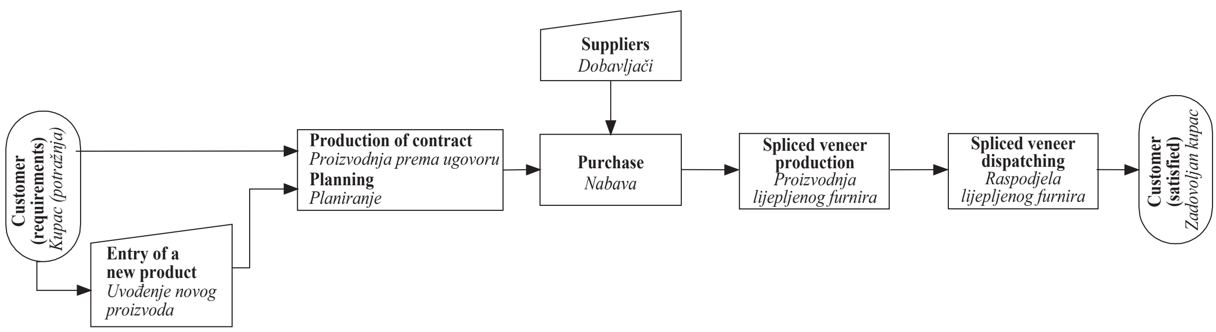


Figure 2 Sequence of processes in manufacturing products (Source: Handbook IMS, p. 65, 2015)
Slika 2. Faze procesa proizvodnje (izvor: *Handbook IMS*, str. 65, 2015.)

2 TECHNOLOGICAL PROCESS OF THE PRODUCTION OF SPLICED VENEERS AND USED METHODOLOGY
2. TEHNOLOŠKI PROCES PROIZVODNJE LIJEPLJENOG FURNIRA I PRIMIJENJENA METODOLOGIJA

The main purpose of the case study, in IKEA Industry, is detailed analysis and development of selected technological processes during spliced veneer production. In this study, 8D method is applied for nonconformity resolution. The applied method showed to be optimal for nonconformity resolution because employees are educated and experienced with the application of Pareto analysis, Ishikawa chart; Poka-Yoke, etc. The main steps of production of spliced veneers (Technological Technique of the Production of Spliced Veneers, p. 85-87, 2012) are divided into two sections.

1. Choice and preparation of material (STN EN 14279+A1)

Environment - there are recommended requirements for the production of spliced veneers: humidity of air: 50±10 % and ambient temperature 25±5°C;

Input material - there are veneers of various woody plants and their thickness: beech h = 0.55 mm, oak, ash h = 0.63 mm, birch h = 0.55 mm with the tolerance ±0.04 mm; veneer humidity 8-12 %; fusion fibre; glue;

Choice of material is carried out in the warehouse of raw veneer;

Preparation of material starts with unpacking a pallet and the preparation of material for the transversal cutting workplace is carried out in the warehouse of input material at a designated place. The generated waste is sorted in accordance with the regulations related to sorting of wastes.

2. Processing of material (STN 22 5205)

Transversal cutting
- According to the type and quantity of defects, veneer is divided into the quality groups Q1, Q2, Q3, in accordance with the specifications in force.
- Cut veneer marked by accompanying cards is placed on pallets. Bundles of veneers that are not suitable and do not meet quality requirements are placed on a special pallet.
- During the shift, the discarded packets of veneers are checked and reassessed.
- At the end of the shift, non-compliant veneers are marked with a veneer separator and information is added in the pallet card. A filled pallet is transported to the place dedicated to complaints.

Longitudinal cutting
- Veneer bundles are arranged in the spliced veneer at the longitudinal cutting workplace.
- The cut bundles are placed on the bases, which results in the look, structure and exact dimension of finished spliced veneer. The spliced veneers are wider than 600 mm, or the compound formats are cut from two halves. The cut spliced veneers are marked with the accompanying cards.
- Veneers that do not meet requirements are put aside on the dedicated place and these discarded veneers are collected by the worker responsible for the transversal cutting during the shift for reprocessing.

Connecting by means of a fusion fibre
- The spliced veneers are connected by means of a fusion fibre into the integrated format at the sewing workplace. A fusion fibre must be fused correctly and must adhere along the whole length of a joint, and veneer sheets must not overlap.
- Veneer sheets are sewed in a way to be spliced and before sewing they must be reversed. Quality is observed visually and when the mechanical or technical defect is detected, the bundle is discarded and substituted by another one.
- A worker has to sew the remaining veneer stripes into a current format of the spliced veneer or he can achieve this format by cutting the spliced veneer by longitudinal scissors. The emphasis is put on the maximum usage of material, i.e. on the minimum accumulation of waste.

Connecting by means of liquid glue
- The correct preparation of the glue is the responsibility of a worker at the gluing workplace.
- The glue must be applied correctly along the whole edge of a bundle and must adhere along the whole length of a joint. If a joint does not have these properties, the worker must check the application of glue or adjust the machine. Quality is observed visually and when the mechanical or technical defect is detected, the bundle is discarded and substituted by another one.

Formatting
- Formatting of the ends of spliced veneers is carried out at the formatting workplace.
- Mechanically damaged spliced veneers are placed on the trolley to be repaired. When technically lower quality is detected, a spliced veneer must be moved to the corresponding category of quality requirements. (In-process and Production Control, 2012)
- Formatted spliced veneers are placed on pallets. Information about pallet quantity, pallet dimensions and direction of spliced veneer fibres are given in a list on an accompanying card. After formatting is finished, all formatted and discarded spliced veneers shall be written off the system.

Exit check and repair of spliced veneers
- Each layer of a spliced veneer is checked before the check and repair step and the correctness of information in the accompanying card specifying quality and dimensions of a spliced veneer is compared.
- Mechanical and technical quality is checked. Checking is carried out in two ways –statistical checking or piece by piece checking.

Packaging
- The packaging workplace prepares pallets for dispatching. Each pallet must be checked before starting packaging and information on an accompanying card needs to be compared.
- Veneers are divided into quality classes and mechanical and technical quality is checked visually. A worker is responsible for correct identification of defects and for the subsequent repair.

- Packed pallets are ready for dispatching. Then, they are written off the system.

Pallets are packed according to instructions for specific buyers and there are 8 different quality specifications in IKEA Industry Branch– Majcichov → 5 for Šoproň (oak, 3D oak, white ash, brown ash, birch) and 3 for Trnava (oak, ash, peeled birch). Quality requirements for spliced veneers were designed in 2013 and are shown in the tables below. Quality signs in individual types of spliced veneers show certain quality requirements of individual types of spliced veneers (STN 49 2301 and STN 49 2316). Description of what is allowed and prohibited in production are shown in Tab. 1, 2 and 3 (Quality requirements for spliced veneers, p. 71÷77, 2013). These tables illustrate the approach to the analysed problems according to the technical standards applicable in the

Table 1 Quality requirements for spliced veneers I
Tablica 1. Zahtijevana kvaliteta lijepljenog furnira I.

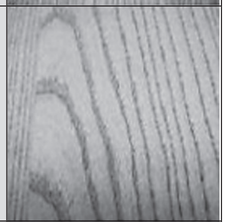
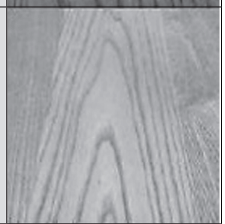
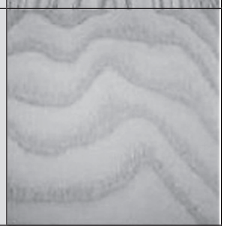
Name *Svojstvo*	**Quality** / *Kvaliteta*					**Picture** *Slika*
	Q3	Q4++	Q4+	Q4	Q5	
Flat fibre (radial) *radijalna tekstura*	✓	✓	✓	✓	✓	
Half grain pattern *polutangentna tekstura*	✓	✓	✓	✓	✓	
Full grain pattern (tangential) *tangentna tekstura*	✓	✓	✓	✓	✓	
Horizontal drawing *horizontalne linije*	×	✓	✓	✓	✓	
Colour *boja*	Spliced veneer can contain min. 35 % and max. 65 % of white ash in total. Distribution of white and brown ash on the surface must be homogenous. *Lijepljeni furnir može sadržavati min. 35 % i maks. 65 % bijelog jasena. Raspodjela bijeloga i smeđeg jasena na površini mora biti podjednaka.*	Distribution of white and brown ash on the surface must be homogenous. *Raspodjela bijeloga i smeđeg jasena na površini mora biti podjednaka.*	Distribution of white and brown ash on the surface must be homogenous. *Raspodjela bijeloga i smeđeg jasena na površini mora biti podjednaka.*	Without limitation *bez ograničenja*	Without limitation *bez ograničenja*	

Table 2 Quality requirements for spliced veneers II
Tablica 2. Zahtijevana kvaliteta lijepljenog furnira II.

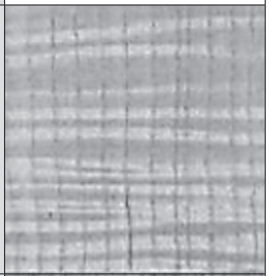
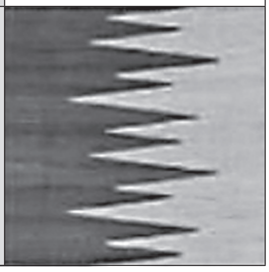
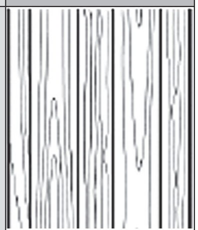
Name *Svojstvo*	**Quality** / *Kvaliteta*					**Picture** *Slika*
	Q3	Q4++	Q4+	Q4	Q5	
Strong swirl grain *jako kovrčava žica drva*	×	✓ max. 1 stripe/ spliced veneer *maks. 1 linija po listu furnira*	✓ max. 1 stripe/ spliced veneer *maks. 1 linija po listu furnira*	✓ max. 1 stripe/ spliced veneer *maks. 1 linija po listu furnira*	✓ max. 2 stripes/ spliced veneer *maks. 2 linije po listu furnira*	
Moderate swirl grain *umjereno kovrčava žica drva*	✓	✓	✓	✓	✓	
Healthy Knots *zdrave kvrge*	✓	✓	✓	✓	✓	
Rigid black knots *oštre crne kvrge*	✓ max. Ø 5mm max.10 pc/m² *maks. 10 kom./m²*	✓ max. Ø 5mm max.15 pc/m² *maks. 15 kom./m²*	✓ max. Ø 5mm max.15 pc/m² *maks. 15 kom./m²*	✓ max. Ø 5mm max.15 pc/m² *maks. 15 kom./m²*	✓ max. Ø 5mm	
Dark stripes, mineral lines *tamne linije, mineralne linije*	✓ max. dimension 3 x 90 mm: max. 20 pc/m² dispersed throughout surface *maks. dimenzija 3 x 90 mm; maks. 20 kom./m² po cijeloj površini*	✓ max. dimension 3 x 90 mm: max. 20 pc/m² dispersed throughout surface *maks. dimenzija 3 x 90 mm; maks. 20 kom./m² po cijeloj površini*	✓ max. dimension 3 x 90 mm: max. 20 pc/m² dispersed throughout surface *maks. dimenzija 3 x 90 mm; maks. 20 kom./m² po cijeloj površini*	✓	✓	
Finger Joint *zupčasti spoj*	×	×	×	×	✓ Type 3	

Table 3 Quality requirements for spliced veneers III
Tablica 3. Zahtijevana kvaliteta lijepljenog furnira III.

Name *Svojstvo*	**Quality** / *Kvaliteta*					**Picture** *Slika*
	Q3	Q4++	Q4+	Q4	Q5	
Stripe Width *širina linija*	40÷220 mm Edge stripes can be narrower *rubne linije mogu biti uže*	40÷300 mm Edge stripes can be narrower *rubne linije mogu biti uže*	40÷300 mm Edge stripes can be narrower *rubne linije mogu biti uže*	40÷300 mm Edge stripes can be narrower *rubne linije mogu biti uže*	40÷300 mm Edge stripes can be narrower *rubne linije mogu biti uže*	
Dimension tolerance *tolerancija dimenzija*	Width / *širina*: -0 mm +1mm per 100 mm of width Length/*dužina*: -0/+5 mm	Width / *širina*: -0 mm +1mm per 100 mm of width Length/*dužina*: -0/+5 mm	Width / *širina*: -0 mm +1mm per 100 mm of width Length/*dužina*: -0/+5 mm	Width / *širina*: -0 mm +1mm per 100 mm of width Length/ *dužina*: -0/+5 mm	Width / *širina*: -0 mm +1mm per 100 mm of width Length/*dužina*: -0/+5 mm	+/-
Connecting method *metoda spajanja*	Glued *lijepljeno*	Glued *lijepljeno*	Glued *lijepljeno*	Glued *lijepljeno*	Glued *lijepljeno*	/
Splicing method (overall look) *metoda lijepljenja (ukupni izgled)*	Balanced random splicing. Spliced veneer cannot be made of the same halves! *Ujednačeno lijepljenje. Lijepljeni furnir ne smije biti izrađen od iste polovice!*	Balanced random splicing. Spliced veneer cannot be made of the same halves! *Ujednačeno lijepljenje. Lijepljeni furnir ne smije biti izrađen od iste polovice.*	Balanced random splicing. *ujednačeno nasumično lijepljenje*	Balanced random splicing. *ujednačeno nasumično lijepljenje*	Balanced random splicing. *ujednačeno nasumično lijepljenje*	

Explanatory notes / *Objašnjenje simbola*					
×	Forbidden *zabranjeno*	✓	Allowed *dopušteno*	✓ xyz	Allowed to a certain extent *dopušteno uz dodatni uvjet*

Note: The basic document of this case study, concerning TQM as well as improvement methods, which are used in production of spliced veneers, is the Handbook IMS, 110 p; 2015 and the book by Hrubec (2009). However, Handbook IMS is continuously modified and improved, so that it would be too much extended to review all the modifications and improvements from the previous handbook issues.

Slovak Republic, which could be similar or different with regard to the foreign technical standards.

3 USE OF INSTRUMENTS FOR IMPROVEMENT – RESOLUTION OF NONCONFORMITIES BY 8D METHOD
3. PRIMJENA INSTRUMENATA POBOLJŠANJA – RJEŠAVANJE NESUKLADNOSTI PREMA METODI 8D

The 8D method is used for a systematic solution of problems in the production process, technical issues, health and safety at work and in the workplace of IKEA Company. The most frequent nonconformities resolved by the 8D method are as follows (Handbook IMS, p. 90, 2015):

- Open ends
- Perpendicularity outside the tolerance
- Formatting
- Blocking of safety sensors
- Rifts.

Description of the 8D method:

D1: Setting up the team - Setting up the team is very important for resolving a defined problem. To solve the problem, the team of 5 members was set up.

D2: Describing the problem – For correct specification and description of the problem, the results of a statistical quality control were considered. The occurrence of various nonconformities in the months of a given financial year FY15 were analysed, and subsequently, showed in a cumulative way in Tab. 4. Tables 6 and 7 were compiled by research cooperation with Mr. Holovič, who summarised data from the real production in the company IKEA, Ltd. Data were supplied by the quality management team.

In order to determine the main group of causes of nonconformity, the instrument of quality, i.e. Pareto

Table 4 Incidence of defects in individual months in the fiscal year 2015 (Holovič, 2016)
Tablica 4. Greške po mjesecima za fiskalnu godinu 2015. (Holovič, 2016.)

Individual months in the fiscal year 2015 *Mjesec u fiskalnoj godini*	**Structural defects pcs** *Stukturne greške* kom.	**Visual defects pcs** *Vizualne greške* kom.	**Stains pcs** *Mrlje* kom.	**Defects in manufacture of veneer pcs** *Greške u proizvodnji furnira* kom.	**Defects in manu-facture of spliced veneer pcs** *Greške u proizvodnji lijepljenog furnira* kom.	**Dimension defects pcs** *Greške u dimenzijama* kom.	**Mechanical damage pcs** *Mehanička oštećenja* kom.
September *rujan*	692	580	277	1,116	3,504	412	99
October *listopad*	116	897	178	1,418	4,291	1,034	184
November *studeni*	334	629	76	1,184	4,899	393	387
December *prosinac*	195	162	92	1,707	3,408	182	155
January *siječanj*	265	422	22	827	4,575	167	247
February *veljača*	48	160	475	581	4,868	23	195
March *ožujak*	0	12	0	13	343	0	8
Total *Ukupno*	1,650	2,862	1120	6,846	25,888	2,211	1,275

analysis, was used. The values of the total incidence of defects were used to elaborate a Pareto analysis. Individual defects were classified in groups from A to G. Each group of defects was assigned the total incidence for the period under investigation. They were arranged in a descending order and their absolute and relative cumulative values were calculated, as shown in Tab. 5.

The assessment of the Pareto chart and the Lorenz curve, in accordance with the 80:20 rule, shows that the main nonconformity group is the defect group E (defects in manufacture of spliced veneer) and D (defects in manufacture of veneer). To solve the above problem, it was necessary to deal with those defects and to decrease their occurrence, and thus decrease the number of nonconformities (Statistical Control of Spliced Veneers, 2015).

The data presented in the table were used to elaborate the Pareto chart and the Lorenz curve, as shown in Fig. 3.

D3: Proposing temporary corrective measures - As far as these problems are concerned, no temporary corrective measures were proposed because the nonconformities were dealt with considering their longer-term occurrence in spliced veneers.

D4: Analysing possible causes and analysing the principal cause - As a matter of priority, the 8D method will be applied to determine the principal cause of nonconformities. The results of the Pareto analysis, therefore, relied on the fact that the main category of defects was established in the manufacture of spliced veneers and veneers. In order to analyse possible causes, more quality instruments have been used. Given the scope of this paper, it is not possible to describe comprehensively all of them.

Two Ishikawa charts were created. The first one demonstrates the causes of the occurrence of defects in the manufacture of spliced veneers and the second one demonstrates the causes of the defects in the manufac-

Table 5 Arrangement according to the number of defects in pcs (Holovič, 2016)
Tablica 5. Kumulativni prikaz grešaka prema pojavnosti (Holovič, 2016.)

Group of defects / *Skupina grešaka*	**Incidence, pcs** *Pojavnost* kom.	**Cumulative number** *Kumulativna vrijednost*	
		Absolute, pcs *Apsolutni broj* kom.	**Relative, %** *Relativni broj, %*
E: Defects in manufacture of spliced veneer / *greške u proizvodnji lijepljenog furnira*	25,888	25,888	61.86
D: Defects in manufacture of veneer / *greške u proizvodnji furnira*	6,846	32,734	78.21
B: Visual defects / *vizualne greške*	2,862	35,596	85.05
F: Dimension defects / *greške u dimenzijama*	2,211	37,807	90.33
A: Structural defects / *strukturne greške*	1,650	39,457	94.28
G: Mechanical damage / *mehanička oštećenja*	1,275	40,732	97.32
C: Stains / *mrlje*	1,120	41,852	100.00

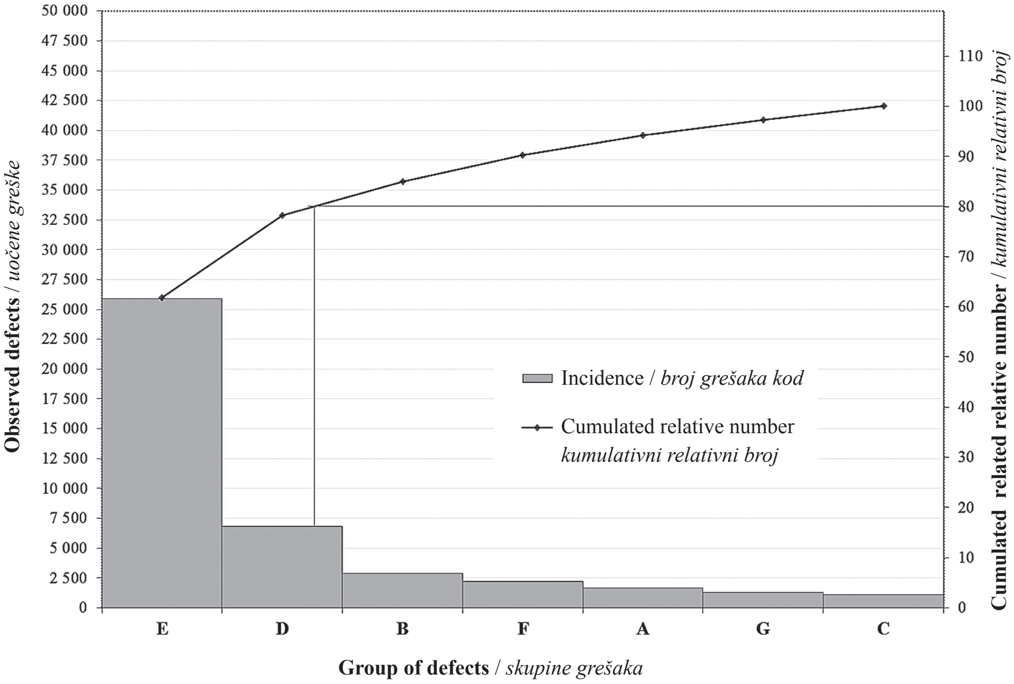


Figure 3 Graphical assessment of incidence of defects in spliced veneers in pcs according to the 80:20 rule (individual groups of defects A, B, …, F are described in detail in Tab.7)
Slika 3. Grafički prikaz broja grešaka na lijepljenom furniru prema pravilu 80 : 20 (pojedine skupine grešaka A, B, … F detaljno su opisane u tab. 7.)

ture of veneers. To assess the Ishikawa chart, the method of scores was used. Afterwards, together with a consultant in the company, the team members assigned the points to the causes, independently of one another. Each member had 3 points (2 points and 1 point), and then assigned the points to different causes. Ishikawa chart of defects in the manufacture is shown in Fig. 4.

Ishikawa chart of defects in the manufacture of veneers is shown in Fig. 5.

This resulted in 5 selected causes, i.e. roughness, folded sheets, rifts, unglued and open ends.

D5: Proposing the permanent corrective solution - In this point, it is necessary to choose and propose corrective measures for improvement. The aim is

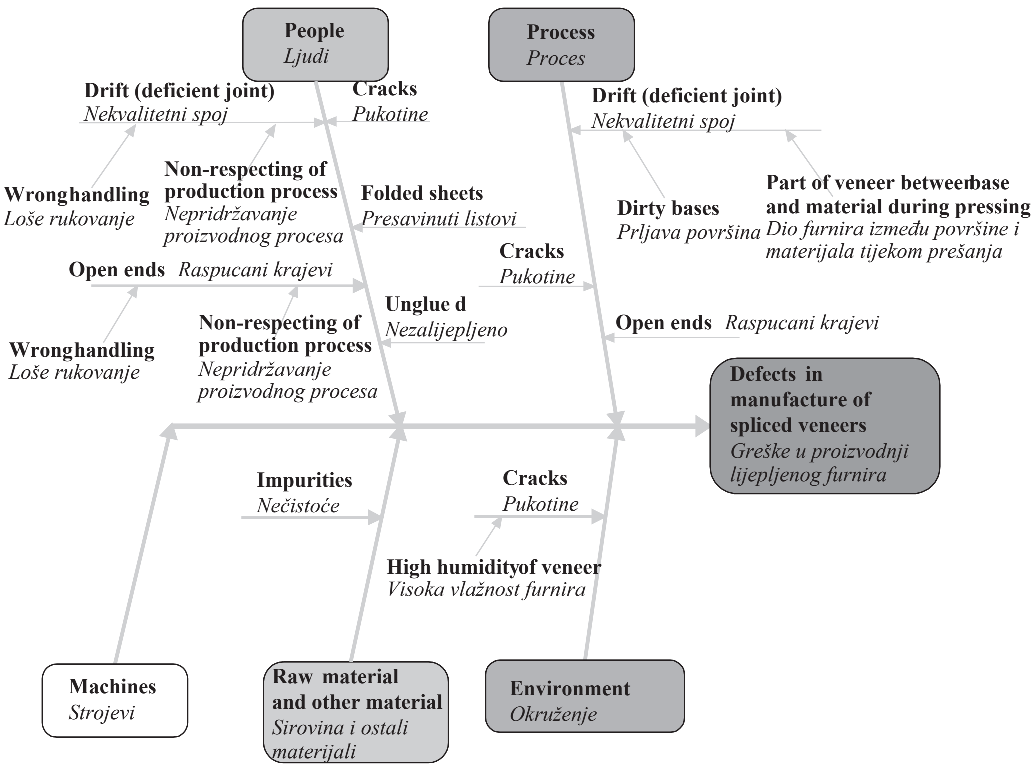


Figure 4 Ishikawa chart of defects in manufacture of spliced veneers
Slika 4. Ishikawa dijagram grešaka u proizvodnji lijepljenog furnira

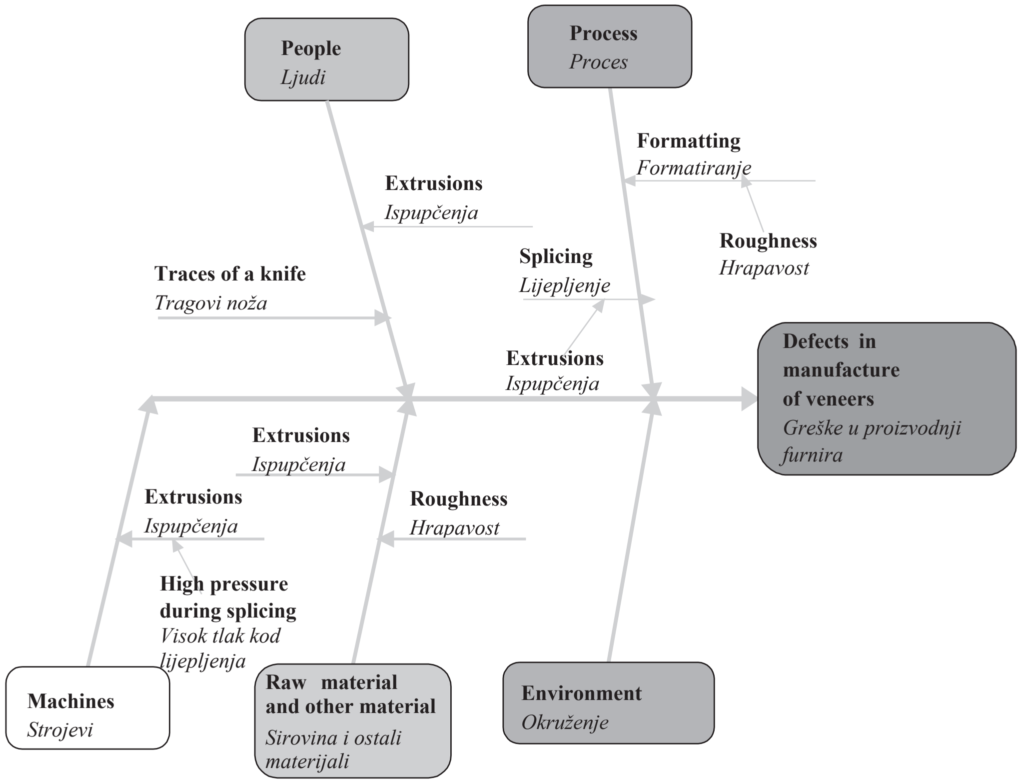


Figure 5 Ishikawa chart of defects in production of veneers
Slika 5. Ishikawa dijagram grešaka u proizvodnji furnira

to eliminate the main causes of a problem on a permanent basis. As mentioned in D4, in the 8D method, the causes of the the nonconformity "open end" are:

A) Formatting machine adjusted incorrectly,
B) Insufficient application of glue and the subsequent ungluing of spliced veneer,
C) Badly sheared package on a two-knife Josting machine.

D6: Implementation and verification of adopted corrective measures - For easier demonstration, a time graphic schedule (i.e. horizontal axis – x) – Gantt chart was developed as presented in Fig. 6. It shows the way of implementation of the proposed measures (i.e. vertical axis – y), which is not binding. It is used to recommend until when the proposed corrective measures should be implemented. A Poka-Yoke is a specific kind of methodology or mechanism applied in lean production processes, which provides support for service staff in order to avoid (yokeru) mistakes (poka), (Fantin, 2014). This method was applied in our study in order to prevent defects in production of spliced veneers. Causes of defects (D5 and D6) in veneer production were neglected in this case study.

D7: Preventive measures - In order to prevent the recurrence of defects, the corrective measures were elaborated in section D5. It is at a company's discretion, whether it will implement the determined proposals or not.

D8: Acknowledgements to the team – This part of the method is important to motivate employees who participate in the overall analyses and solutions.

4 CONCLUSION
4. ZAKLJUČAK

People in IKEA Industry Slovakia, Ltd., enterprise branch – Majcichov, Trnava, the Slovak Republic, focus on nonconformity solutions and thus try to

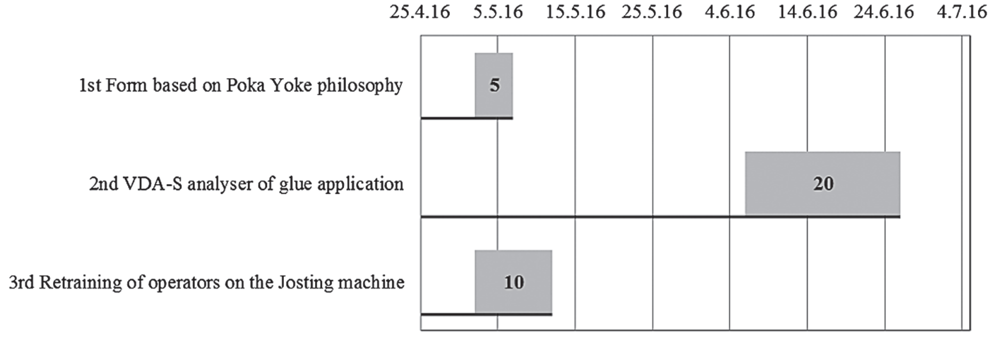


Figure 6 Gantt chart
Slika 6. Ganttov dijagram

satisfy the requirements of their customers and retain stable purchasers. The analysis was needed to reveal the incidence of nonconformities in spliced veneers in the period under investigation from 01/09/2015 to 02/03/2016. In quality management, there are several suitable methods, and we chose the 8D method. Chapter No. 3 describes individual items of the 8D method applied in IKEA Company. Benefits of the 8D method application are significant in the quantitative and qualitative sense and they create the initial base for future progress and improvement in spliced veneer production. The reason for this choice was the fact that the company used this method in the past to solve in-house problems. It is a structured process of problem solving that contributes to the early identification of a problem and to its complete elimination when used correctly.

The main task of the present case study in IKEA Ltd. Trnava, the Slovak Republic, was to make a detailed analysis and improve the future development concerning specific technological processes performed in the spliced veneer production. Emphasis should be put on the application of combined quality tools, which enable to make goal-directed decisions. In this study, 8D method is applied for nonconformity resolution. The method applied proved to be optimal for nonconformity resolution because employees were educated and experienced in the application of Pareto analysis, Ishikawa chart, Poka-Yoke, etc.

It is necessary to implement the One-Month-Team Building Training (scheduled for the third quarter of 2017) in order to obtain supplementary information about the influence of changing working shifts on production quality, as well as about the influence of employment duration on employees' skills.

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Efficient Exploitation of Beech Wood by Production of an Atypical Structural Element - a Hollow Wooden Post

Učinkovito iskorištavanje bukovine proizvodnjom netipičnoga konstrukcijskog elementa – šupljega drvenog stupa

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ABSTRACT • *The aim of the article is to quantify the financial cost of an atypical structural element - a hollow wooden post, and thus determine its market price. This price is subsequently compared to the prices of materials offered by the current market. The calculation of costs is generally defined as balancing costs, profits, and other variables per a labour unit producing the item. A hollow wooden post is a multi-functional construction member. A complex of physical, mechanical, operational and aesthetic properties makes it suitable for use indoors and outdoors, in combination with other materials, as well as for load-bearing and aesthetic purposes. The production of composite materials enhances efficient exploitation of wood raw material. Current advanced technologies not only allow to process less valuable wood assortments, but also wood waste materials from mechanical processing. Thus, the price depends primarily on the input material used, production technology, construction and final design with respect to the purpose of a product. The price of wood raw material is relatively low compared to that of other developed countries. However, the price of engineered wood is high. The price of solid structural timber (KVH) is around € 450.00/m^3. In case of glued wood DUO, TRIO, the market price is € 650.00/m^3. The cost of 1 m^3 of laminated veneer lumber (LVL) of various materials is around € 1,850.00/m^3. Thus, the price of wood materials with higher added value is considerably higher compared to materials from solid wood in the form of timber used for structural members. In case of hollow beech posts, as structural glued materials with added value, the calculated price is € 2,175.00/m^3.*

Keywords: *hollow wooden post, beech wood, construction member, price of the product*

SAŽETAK • *Cilj rada bio je kvantificirati troškove proizvodnje netipičnoga konstrukcijskog elementa – šupljega drvenog stupa, i utvrditi njegovu tržišnu cijenu. Ta je cijena zatim uspoređena s cijenama konstrukcijskih materijala koji se nude na tržištu. Troškovi proizvodnje općenito se definiraju kao troškovi uravnoteženja, dobiti i drugih varijabli izraženi po jedinici rada za proizvodnju određenog proizvoda. Šuplji drveni stup multifunkcionalni je građevni element. Skup fizičkih, mehaničkih, operativnih i estetskih svojstava čine ga pogodnim za uporabu u zatvorenome i vanjskom prostoru, u kombinaciji s drugim materijalima, a služi kao nosivi ili estetski element. Pritom*

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valja napomenuti da današnja proizvodnja kompozitnih materijala povećava učinkovitost iskorištenja drvne sirovine. Naime, napredne tehnologije ne omogućuju samo obradu manje vrijednih drvnih sortimenata nego i drvnih ostataka nastalih pri mehaničkoj obradi drva. Dakle, cijena proizvoda ponajprije ovisi o upotrijebljenome ulaznom materijalu, zatim o tehnologiji proizvodnje, konstrukciji i završnom dizajnu proizvoda s obzirom na njegovu namjenu. Cijena drvne sirovine u Slovačkoj relativno je niska u usporedbi s cijenama sirovine u ostalim razvijenim zemljama, no cijena drvnih građevnih materijala visoka je. Cijena masivnoga konstrukcijskog drva (KVH) iznosi oko 450 eura/m³, a tržišna je cijena lijepljenoga drvnog materijala (DUO, TRIO) 650 eura/m³. Jedan kubni metar lameliranog drva (LVL) od različitog materijala košta oko 1.850 eura. Dakle, cijena drvnog materijala veće dodane vrijednosti znatno je veća u usporedbi s cijenom konstrukcijskog materijala od masivnog drva. Za šuplji bukov stup kao konstrukcijski element izrađen od lijepljenih drvenih elemenata izračunana je cijena koštanja od 2175 eura/m³.

Ključne riječi: *šuplji drveni stup, bukovina, konstrukcijski element, cijena proizvoda*

1 INTRODUCTION
1. UVOD

Nowadays, approximately 500,000 m³ of hardwood logs is processed in Slovakia. The finest wood assortments of exceptional quality are processed on a small scale and wood products with high added value are largely deficient (Zelená správa, 2015). Beech wood, the most prevalent wood species in Slovakia, possesses many physical, mechanical and technological qualities, and it is our most important leafy raw wood material used for industrial processing (Klement and Huráková, 2016). In the past, it was used predominantly as firewood, but also as the main material in the production of charcoal.

More industrial exploitation of beech wood by mechanical means initiated the manufacture of bentwood chairs and furniture, which furthered industrial production of molded plywood (Igaz *et al*., 2016). Gradually, the production of beech timber was launched (Kršťák *et al*., 2014). To date, it has been processed primarily to satisfy the needs of the furniture industry. Beech dimension timber is used to make bent-seating furniture as well as cut furniture, and as construction frames for upholstered furniture. Another significant product is glued wood for various interior elements such as staircases, furniture, flooring and the like. Beech wood is also processed into railway sleepers, whose production took off especially after the World War II. Beech wood is also used for manufacturing of special products such as toys, sports equipment and accessories.

The processing methods are, however, society-driven, and therefore some of the products are on the increase, while others are on the decline. It is essential, though, to investigate new methods of exploitation of the material, especially with respect to efficiency (Kúdela and Čunderlík, 2012; Klement and Huráková, 2015). Recent years have seen rising demand for sawmill products containing false heartwood. The reason was to create unique products, which, however, are not accepted in commercial products (Prekrat *et al.*, 2004). It should be noted that the presence of false heartwood would be tolerated in case of lower quality timber (Popadič *et al*., 2014).

A wooden post is recognised as one of the essential construction components. With regard to an efficient use of raw wood material, a hollow wooden post was designed as an alternative to a solid wooden post. A hollow wooden post has a relatively wide range of applications in wooden constructions (Detvaj *et al*., 2008). From the construction point of view, it is an element, which is made by gluing of twelve pieces of trapezoid-cut staves (Holý and Detvaj, 2011). Such a solution saves 13 – 15 % of material compared to solid wood posts of the same load-bearing capacity. There are various construction designs of a hollow wooden post. The design depends mainly on the currently available technology, purpose and place of its use. Ultimately, the price is a critical factor determining how and for whom to produce. In general terms, the price of goods and services stems from the development of demand and offer of goods and services on the market (Janok and Oláh, 1996).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The experimental measurements were made on beech sawlogs 34 cm in diameter and 300 cm in length, which originate from the forests of the University Forest Enterprise of the Technical University in Zvolen. In order to calculate the production of one hollow wooden post, it was necessary to specify certain parameters such as design, which determines production technology, purpose and the place of its use. The hollow wooden posts were produced in the laboratories of the Technical University in Zvolen.

Beech wood was recommended for the purpose of this experiment, as beech is the most widespread wood species in Slovakia. Beech, however, is also a wood species with a high defect rate. In this case, the occurrence of false heartwood in the logs is not considered a defect because it does not affect the quality and exploitability of the wood for the production of the posts. Thus, such logs can be used as long as they are healthy. What is more, working lower quality raw material can give rise to unique and aesthetically interesting posts. As for their design, trapezoidal cross-section of the staves was chosen. A hollow beech-wood post was assembled from 12 staves glued together. Figure 1 shows the design and cross sectional dimensions. The hollow beech post was 2.6 m in length.

The technological process comprised of the following stages:

- production of special-purpose sharp timber,

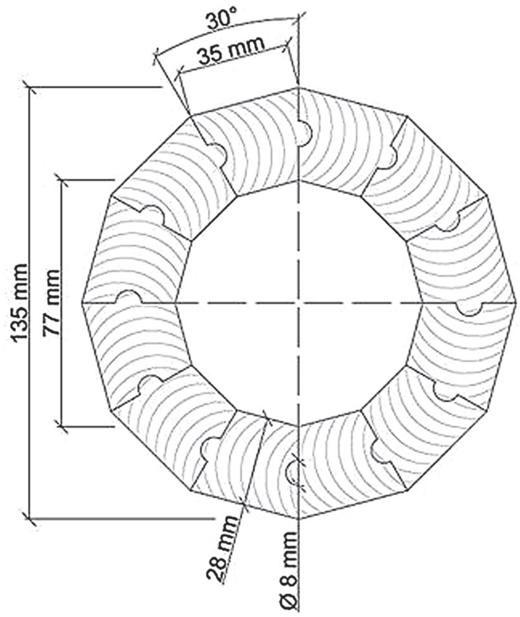

Figure 1 Design and cross sectional dimensions of a beech hollow post
Slika 1. Konstrukcija i dimenzije poprečnog presjeka šupljeg stupa od bukovine

- timber drying to the desired moisture content of 12±2 % for the interior, 20±2 % for the exterior,
- production of dimension timber with required allowance for trim and removal of defects,
- sorting of the dimension timber to sapwood and heartwood,
- cross-cutting to the required length with an allowance for further processing,
- planing and cutting of dimension timber to required thickness,
- CNC machining of dimension timber into a final shape,
- measurement of the dynamic modulus of elasticity (strength class according to STN EN 338),
- gluing and assembly,
- surface treatment.

With regard to their physical, mechanical, utility and aesthetic properties, hollow beech posts can be used in real constructions. It is possible to employ them in interiors as a load-bearing element of staircases, floors, balconies, etc. Considering the properties of the glue used, they can withstand even outdoor conditions. Thus, they are suitable wherever a load-bearing function is needed. If used in the exterior, the application of a special waterproof finish is necessary. Apart from their carrying function, the posts may also play an aesthetical role such as optical division of larger spaces, construction elements of furniture and interiors.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Pricing of the hollow post takes into consideration the production of one batch of posts, so the real costs, and thus also the market price of the product, can be calculated. For this purpose, a number of 40 hollow posts were set, which represent approximately 1 m^3 of raw wood material in the form of dimension timber machined and packed into a compact stack. The moisture content of the dimension timber was 12 ± 2 %.

The volume of one stave V_1 was:

$$V_1 = 0.002002 \text{ m}^3 \tag{1}$$

The volume of one product V_{12} - post (12 staves):

$$V_{12} = 0.024024 \text{ m}^3 \tag{2}$$

The volume of 40 posts V_{480} (480 staves):

$$V_{480} = 0.96096 \text{ m}^3 \tag{3}$$

The volume of unmachined staves V_{US}:

$$V_{US} = 1.82532 \text{ m}^3 \tag{4}$$

The amount of unmachined staves with the allowance for machining was estimated in accordance with STN 49 0231.

The production process of the post staves generated waste in the form of wooden shavings in the following proportion:

$$V_{shavings} = V_{US} - V_{480} = 0.86436 \text{ m}^3, \tag{5}$$

which is 2.27 Scm.

The required amount of unmachined staves was produced from sharp-edged timber of the quality class I, II and III (in accordance with STN 49 1012). Klement and Detvaj (2007) claim that theoretical yield of the staves from these quality classes represent 69.53 %, considering that the class ratio is 1:1:1.

The consumer standard *CS* specifying the amount of special-purpose timber needed for the production of unmachined staves amounts to:

$$CS = \frac{1}{0.6953} = 1.438 \tag{6}$$

For the production of 1.83 m^3 of unworked staves, the following volume of special-purpose sharp-edged timber V_{SST} was used:

$$V_{SST} = V_{US} \cdot CS = 1.83 \cdot 1.438 = 2.63 \text{ m}^3 \tag{7}$$

The production of the staves generated waste in two forms, sawdust and small waste products. Total waste yield comprised 20 % of small waste and 80 % of sawdust (Klement and Detvaj, 2007).

Total waste yield:

$$V_{SST} - V_{US} = 2.63 - 1.83 = 0.8 \text{ m}^3 \tag{8}$$

The amount of waste in the form of sawdust:

$$V_{sawdust} = 0.64 \text{m}^3 = 1.42 \text{ Scm} \tag{9}$$

The amount of waste in the form of waste timber:

$$V_{WT} = 0.16 \text{m}^3 = 0.42 \text{ Scm} \tag{10}$$

It was necessary to calculate the amount of III A class of sawlogs (in accordance with STN 48 0056) required for the production of 2.63 m^3 of sharp-edged timber. Klement and Detvaj (2007) also argued that, by employing a cant sawing method, the average yield of special-purpose timber, in case of a traditional and new method, was 45 %. Apart from the central timber, timber from log sides was also used, and so the total yield reached 58 %.

The consumption standard *CS* specifying the amount of sawlogs for special-purpose timber is as follows:

$$CS = \frac{1}{0.58} = 1.72 \tag{11}$$

The production of 2.63 m^3 of sharp-edged timber required sawlogs *V* amounting to:

$$V = V_{SST} * CS = 2.63 * 1.72 = 4.53\ m^3 \tag{12}$$

17 sawlogs with the desired dimensions have a total volume of 4.54 m^3.

Klement and Detvaj (2007) stated that sawdust yield of 10 % is obtained in the process of timber production, which represents 0.454 m^3 or 1 Scm, while sawmill trimmings yield is 8.5 %, which represents 0.39 m^3 of wood chips or 0.96 Scm.

The calculation of the price depends on the definition of the subject of calculation, the method of assigning the subject of calculation and the structure of costs. This is the framework for determining costs per calculation unit. The classification of costs by means of calculation structuring is based on the calculation formula, whose structure provides a basis for the recommended pricing methodology (Potkány and Merková, 2013).

The structure of the calculation formula includes the following elements:

1. direct material,
2. direct labour costs,
3. other direct costs,

1-3 Direct costs

4. manufacturing overhead,
5. administrative expenses,
6. selling expenses,

1-6 Total performance costs

7. profit.

1-7 Selling price

This cost-oriented pricing method is based on the data of direct and overhead costs. Direct costs are the costs that can be directly determined for a specific product. Overheads cannot be determined directly, and therefore they need to be added to direct costs by means of an appropriate method of calculation (Drábek and Potkány, 2008).

Direct material

Direct material includes production requirements of raw material and basic material, products, intermediate products and services. In this case, beech logs are direct material in the amount of 4.54 m^3 - 17 logs of class III and thickness category III. The unit price stands at € 76.80 / m^3 including VAT, as specified in the price list of the University Forest Enterprise of the Technical University in Zvolen. Thus, direct material totals at € 348.70.

Direct labour costs

Direct labour costs include the labour required for sawing logs, drying timber, production of rough dimension timber, fine dimension stocks, 40 posts and their treatment. The working times of the operators are determined on the basis of the normative consumption in the mechanical processing (determined from the image of the working time, the working performance). Sawing process of 4.54 m^3 of sawlogs requires 2 workers who take 4 hours to perform the work. The price for drying was estimated based on a survey of companies dealing with drying of timber and logs and it amounts to 16.00 €/m^3 of beech timber in the form of 35 mm thick boards. The production of 1.83 m^3 of unmachined dimension timber requires 2 workers who take approximately 2 hours to produce 480 pieces of unmachined staves. As for the production of the fine staves, one person operating a CNC machine was taken into account. The process requires 2 work shifts. The assembly of 40 posts can be performed by 2 workers for 2 work shifts. Finalisation of the hollow beech posts can be carried out by one worker for one work shift. The average hourly wage of the workforce in a sawmill operations in Slovakia is not high and amounts to 6.00 €/hour. + levies. In our case, the total price from the sawing stage to final product hovers at € 551.62.

Other direct costs

Other direct costs include transport costs of direct material to import place. The price for transport of deciduous wood assortments by means of a hydraulic-arm-equipped truck is € 0.22/m^3/km and the price for loading and unloading is € 2.94/m^3 as specified in the price list of the University Forest Enterprise of the Technical University in Zvolen. Furthermore, the costs include other material and tools required, such as glue, brushes, belt clamps to stabilise the posts during the curing of adhesive, and sealing rubber strips to prevent denting and bruising of wood. The production of a batch of 40 posts requires the use of 240 belt clamps, whose price is around € 2.00 a piece. Polyurethane-based adhesive *Xilobond T60* with an open time of 60 minutes is used for gluing. The price of the adhesive is € 12.00/kg. Assuming that the application amount of glue is 140-180 g/m^2, 7 kg of the adhesive must be applied with a brush, which costs 1.90 € per piece. The production of one batch of posts requires the use of 8 brushes. The total of other direct costs is then around € 648.00.

The direct costs, therefore, amount to € 1,590.50.

Manufacturing, administrative overheads and distribution expenses.

Manufacturing overheads include all costs related to the management and operation of the production process and cannot be directly determined per one calculation unit. Administrative expenses represent all primary and secondary costs related to the management and administration of a factory. Distribution expenses are comprised of selling expenses and direct selling expenses. Manufacturing, administrative and distribution overheads represent about 65 % of direct material. Together, these items amount to a total of € 227.00.

Thus, the total production costs are € 1,817.00.

Selling price

The selling price takes into account the profit of 15 %. The profit rate of 15 % was determined from our own costs and is statistically justified for producers of wood-based products. This means that the selling price for 40 hollow beech posts of given structure and dimensions stands at € 2,090.00. It follows that the consumer will pay € 53.00 for one hollow post. Thus, the price of the glued material in the form of hollow beech posts is € 2,175.00/m^3. The price was calculated for the product manufactured under semi-operation conditions in the development workshop.

All prices include VAT.

4 CONCLUSION
4. ZAKLJUČAK

Production of composite materials enhances efficient exploitation of wood raw material. Current advanced technologies not only allow to process less valuable wood assortments, but also wood waste materials from mechanical processing.

Load-bearing members can be produced from various materials. Solid wood is the most typical material because of its relatively low price, simplicity of processing and availability. Given its disadvantages, such as limited carrying capacity, poor fire resistance, low resistance against biological pests, a range of other materials, such as KVH- solid structural timber, glued lamellar wood, glued laminated timber (GLT), laminated veneer lumber (LVL) is used nowadays. The main advantages of these materials are dimensional accuracy of individual components, small shape and volume changes as well as dimensional variability. The advantages of hollow wooden poles are, for example, less weight compared to full wooden poles, material savings, possibility to conceal utilities, possibility of being produced in large lengths and different diameters, and good appearance from an aesthetic point of view. The disadvantage is the cavity of hollow wooden poles, which creates a chimney effect, increasing the risk of fire. Therefore, in order to increase the resistance of wooden hollow poles against fire, the chimney effect should be removed by filling the cavity of the column (e.g. with mineral wool), and treating it with flame retardant.

The price of wood raw material is relatively low compared to that of other developed countries. However, the price of engineered wood is high (Iždinský, 2008). The price of solid structural timber (KVH) is around € 450.00/m^3. In case of glued wood DUO, TRIO, the market price is € 650.00/m^3. The cost of 1 m^3 of laminated veneer lumber (LVL) of various materials is around € 1,850.00/m^3. Thus, the price of wood materials with higher added value is considerably higher compared to materials from solid wood in the form of timber used for structural members. Based on calculations stated above, the calculated price was € 2,175.00/m^3 in case of hollow beech posts as structural glued materials with added value. This higher price is regarded reasonable considering the production technology, efficient use of wood raw material, material savings and various possibilities of use for structural or aesthetic purposes. The cost can be further reduced if the waste products are sold and thus move towards waste-free economy. A lower price can also be achieved by producing a higher number of these hollow beech posts. Employing the abovementioned measures can push the price just under € 2000.00/m^3, which is closer to the glued materials used for building various wooden constructions.

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Italian Standard UNI 9151 – a New Approach to the Design of Industrial Wood Packaging

Talijanska norma UNI 9151 – novi pristup projektiranju industrijske drvene ambalaže

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ABSTRACT • *The Italian wood packaging industry occupies a leading role in Europe and focuses its production on a collection of reference standards that describe the fundamental principles for designing industrial packaging made with lumber, plywood and OSB. The national standard framework, mainly based on UNI 9151 and UNI 10858, has been developed from the need for containers for the shipment of machines and equipment of any size, shape and weight in the global market. The main aim is to ensure maximum protection of goods and safety of operators in charge of the handling and transport of wooden packaging (boxes, crates, etc.). As for structural uses in building, the wood packaging industry adopted the concept of allowable stress design for approximately 50 years. Recently, the introduction of the limit states design according to the Eurocode 5 (EN 1995-1-1) and the availability of CE marked products have offered an opportunity to optimise the design not only of timber structures but also of some critical applications in the field of industrial packaging. In this context, a great effort has recently been dedicated to update the above mentioned national standards in order to implement them with the introduction of CE marked lumber and wood-based panels. The present paper describes the Italian standard framework for the industrial wood packaging and illustrates its evolution and new opportunities.*

Keywords: *allowable stress design, characteristic values, packaging design, state limit design, UNI 9151, UNI 10858.*

SAŽETAK • *Talijanska industrija drvene ambalaže ima vodeću ulogu u Europi i svoju proizvodnju temelji na zbirci referentnih normi kojima se uređuju temeljna načela projektiranja industrijske ambalaže izrađene od drva, furnirskih ploča i OSB-a. Nacionalni normativni okvir, uglavnom utemeljen na UNI 9151 i UNI 10858, razvijen je zbog potrebe za kontejnerima u kojima se strojevi i oprema različite veličine, oblika i težine otpremaju na svjetsko tržište. Glavni je cilj proizvođača ambalaže osigurati maksimalnu zaštitu robe i sigurnost osoba zaduženih za rukovanje drvenom ambalažom (kutijama, sanducima itd.) i za njezin transport. Kao i za konstrukcijsko drvo u graditeljstvu, tako je prije otprilike 50 godina industrija drvene ambalaže prihvatila koncept projektiranja ambalaže utemeljen na dopuštenom naprezanju. U novije se vrijeme uvodi model projektiranja prema graničnim stanjima,*

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sukladno normi Eurocode 5 (EN 1995-1-1), i dostupnost proizvoda s oznakom CE, što je prilika ne samo za optimizaciju projektiranja drvenih konstrukcija već i za neke kritične primjene, posebice u području industrijske ambalaže. U tom kontekstu u proteklom je razdoblju uložen veliki napor da se navedene talijanske norme ažuriraju kako bi se implementirale istodobno s uvođenjem CE oznake za drvnu piljenu građu i ploče na bazi drva. U radu se opisuje talijanski normativni okvir za industrijsku drvenu ambalažu i prezentira njegov razvoj i nove mogućnosti.

Ključne riječi: *projektiranje na temelju dopuštenog naprezanja, karakteristične vrijednosti, dizajn ambalaže, projektiranje prema graničnim stanjima, UNI 9151, UNI 10858*

1 INTRODUCTION
1. UVOD

Industrial wood packaging can be defined as a structural framework of members fastened together to form a rigid enclosure, which protects its content during handling, shipping and storage (Figure 1). This enclosure is usually of rectangular shape and may be sheathed with boards or wood-based panels (plywood or OSB).

In the last decades, the rapid increase in trades generated a high demand for containers for the worldwide shipment of machines and equipment of different size, shape and weight (Moncel and Chanrion, 2004). The wood packaging has always been adjustable to a variety of use conditions, being strong, rigid, light, cheap and quite easy to be realised in several sizes and shapes. Generally this type of packaging is custom-built, with dimensions chosen to match the load and weights of the goods to be packaged.

The Italian national standard framework found its roots in the late 80s (Mainardi, 2009), inspired by the lack of handbooks on wood industrial packaging that, on the contrary, were available in the United States (Anderson and Heebink, 1964). In that period, further needs emerged related to the stability and safety of the wood package aimed at providing adequate protection of its content and meeting specific requirements (phytosanitary treatments, dangerous goods, etc.).

For these reasons, the Italian standard framework was structured in two main standards: UNI 9151 and UNI 10858 (Figure 2).

The first standard prescribes the design requirements of wood packaging without load, shape or dimensional limits, while the second provides a full description of the packing elements specifying load (up to 10,000 kg) and dimensional limits (600 x 250 x 250 cm).

In this term, UNI 10858 does not include superimposition and stacking requirements and refers to UNI 9151 for the design of the packaging base. Other requirements, such as the possibility of walking on the packaging, are optional. The UNI 10858 also takes into account the design and construction of wooden coils or saddles.

The above framework is completed by a series of other standards: UNI 10920, UNI 10986 and EN ISO 780. UNI 10920 and UNI 10986 set the rules in order to develop an audit of the process of design and construction, while EN ISO 780 is the reference for the handling instructions symbols.

More in detail, UNI 10920 specifies how to deal with industrial wood packaging design for an organization that needs to demonstrate its capability to consistently provide packaging that meets the applicable requirements. It also aims to enhance customer satisfaction through the effective application of the system, including processes for the continuous improvement and the assurance of conformity to the requirements set by statutory rules and by costumers.

UNI 10986 represents a guideline for the implementation of a structured management system. Finally, the described framework is completed by EN ISO 780 standard that regards the pictorial marking for the handling of goods.

UNI 9151 was recently implemented in order to optimize the packaging production with the introduction of the limit states design and to improve its integration with ISO 9000 family of standards. Today, this represents the most complete tool available for industrial packaging designers and enables to offer a high safety in the manufacture and handling of wood packaging.

In perspective, the use of design tools described by UNI 9151 will allow to meet the growing needs of the transport sector with more accurate and reliable

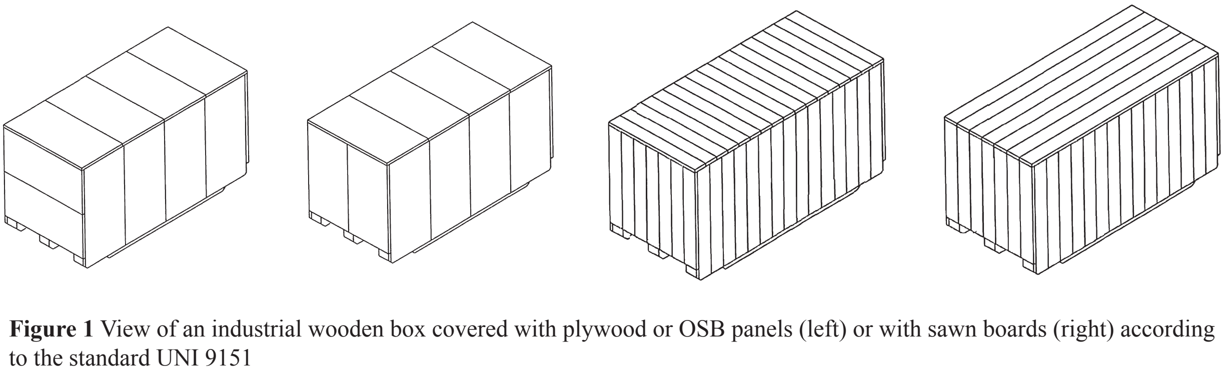

Figure 1 View of an industrial wooden box covered with plywood or OSB panels (left) or with sawn boards (right) according to the standard UNI 9151
Slika 1. Industrijska drvena kutija obložena furnirskim pločama ili OSB pločama (lijevo) odnosno piljenicama (desno) prema standardu UNI 9151

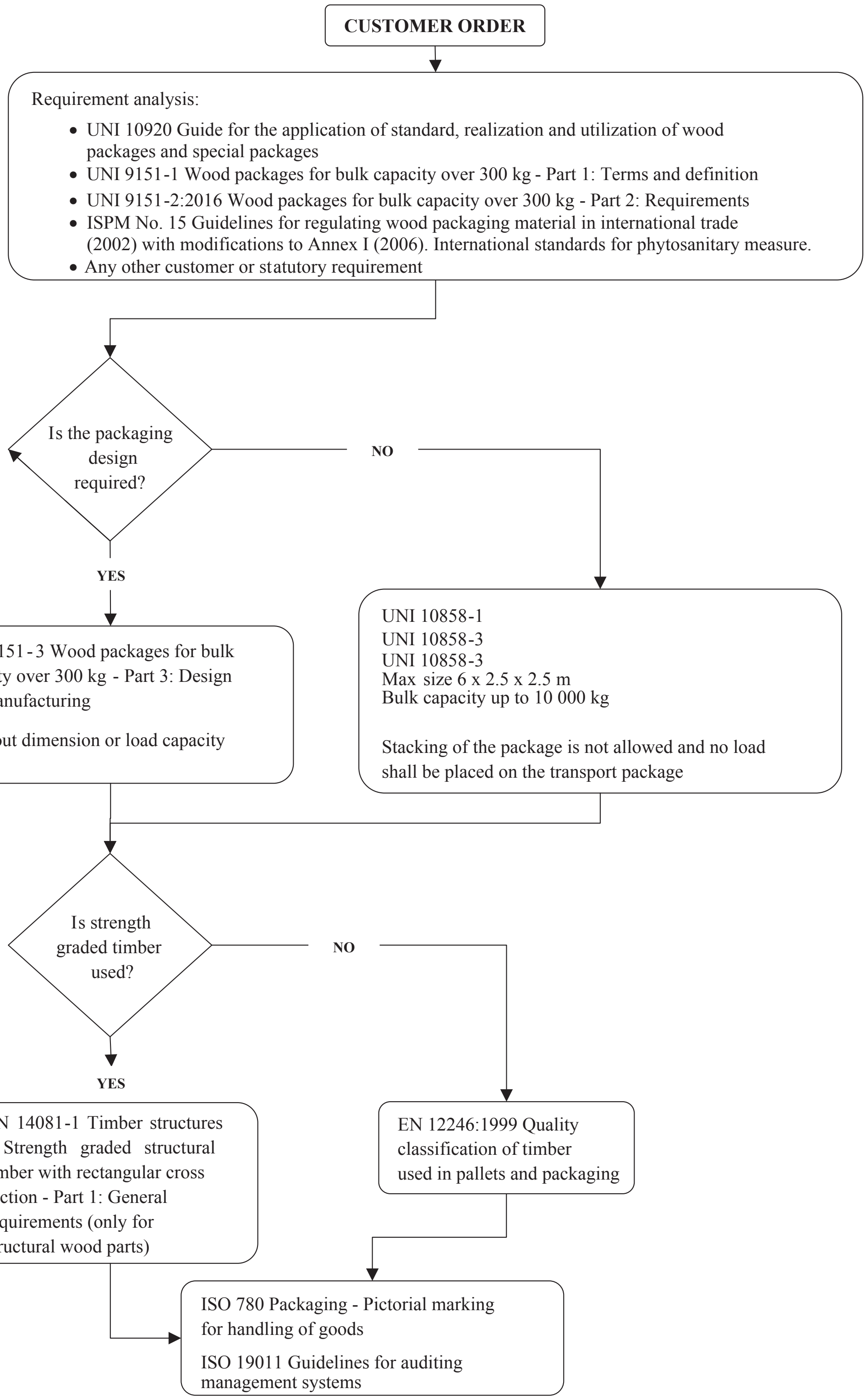

Figure 2 Scheme of Italian standardization framework for industrial wood packaging
Slika 2. Shema talijanskoga normativnog okvira za industrijsku drvenu ambalažu

products through the application of specific guidelines (FEFPEB, 2006; HPE, 2014). These guidelines state that timber (boards, planks, squared battens or joists made from coniferous woods with moisture content below 20 %) shall be graded according to DIN 4074-1, specifying the quality classes to be used (S7 or S10), without providing to the operators any further information on the applicable design methods.

2 UNI 9151 FAMILY OF STANDARDS
2. OBITELJ NORMI UNI 9151

UNI 9151 standard was issued at the end of the 90s in order to design containers for the worldwide shipment of machines and equipment of weight over 300 kg. Its scope was to ensure maximum protection of goods and safety of operators (Trevisani *et al*., 2014). The

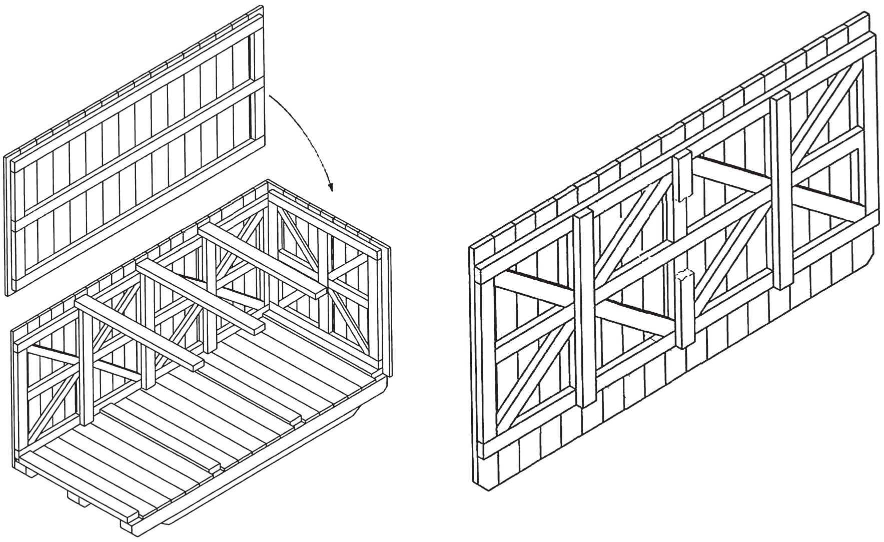

Figure 3 UNI 9151 provides details about manufacturing and assembling of wooden packages (from UNI 9151)
Slika 3. Normom UNI 9151 uređuju se detalji proizvodnje i montaže drvenih paketa (iz UNI 9151)

standard structure is divided into three parts: part 1 reports terms and definitions, part 2 regards the analysis of the requirements, while part 3, as the core section, indicates the design and manufacturing procedures.

As indicated, UNI 9151 has recently been revised not only in order to introduce the use of CE marked wood-based products but also for enhancing its integration with the standards ISO 9001 and ISO 19011. By a specific guideline (UNI 10920) and a standard for the audit process (UNI 10986), it is now possible to implement an efficient management system for wood packaging.

UNI 9151 provides a guarantee of at least 2 years but allows the producer, on the basis of contractual agreements, to cover longer periods. This goal can be obtained with an adequate design that includes a proper shape of wood packaging, an accurate distribution of the load and a correct positioning of the slinging points. In detail this means:

- perfect stability of the load, obtained by the use of necessary clamping;
- taking in due account the stresses related to the environment (handling and logistics, transport, transshipment and storage, maintenance, climatic conditions).

The security and stability of the package shall also be guaranteed in case of shocks, vibrations and roll resulting from handling, loading, unloading, stacking and transport hazards (by road, railway, sea or air).

In fact, as detailed in ISO 9001 (clause 7.3.2), each organization shall ensure that inputs related to product requirements are identified and their records maintained. In this context, UNI 9151 provides an analysis of the main requirements of the wood packaging in order to assist the organization in the design and related processes. Moreover, it establishes the requirements that can be considered essential or optional in function of the type of container.

The second part of UNI 9151 is, therefore, fundamental to identify several design inputs that shall be determined, including:

- functional, performance requirements and costs;
- statutory applicable requirements;
- information derived from previous designs;
- other requirements essential for design and development, such as ISPM No. 15 treatment (Jambreković *et al*. 2010).

Of course, the organization shall not only consider these inputs, but also document the implementation and ensure that they are formulated in a way that can be verified and validated. Inputs shall also be reviewed by the organization before use in order to ensure that they are adequate and that there is sufficient information to carry out the assignment. Considerations shall also be formulated to ensure that inputs are complete, unambiguous and not in conflict.

Finally, the third part of the standard provides the requirements for the design and construction of wooden containers covered with sawn boards or wood-based panels (Figure 3). The requirements are applicable to packaging produced in single units or in small series and provide design guidelines, with particular reference to minimum specific loads (stacking and superimposition) and the related accelerations for land, sea and air transport (Figure 4). In specific cases, the UNI 9151 family of standards can also be used for a weight lower or equal to 300 kg.

This part of the standard was subjected to the most important review and updating and envisaged the introduction of CE marked wood-based materials. Unlike the Italian guidelines and specifications on the industrial packaging (Anonymous, 2006 and 2010), UNI 9151 prescribes rigorous design rules, introducing the limit states approach according to Eurocode 5 (EN 1995-1-1), but also admits the adoption of the "conventional approach" of the allowable stress design method. In this way, the standard encourages the design on limit states principles without penalizing the more traditional and established methods.

The design rules allow the use of different timber and wood-based graded materials for the construction of packages, such as:

- solid sawn timber visually graded according to EN 12246,

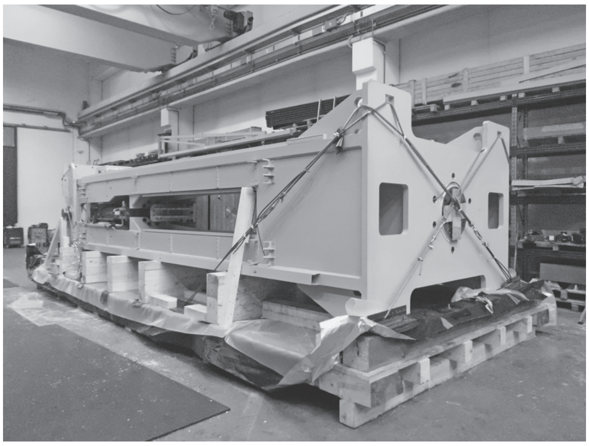

Figure 4 A heavy load industrial wood packaging (about 90 tons of payload) produced according to UNI 9151 before closing of the case (left); industrial wood packaging ready for shipment (right)
Slika 4. Industrijska drvena ambalaža za teške terete (za približno 90 tona tereta) proizvedena prema normi UNI 9151 prije zatvaranja kućišta (lijevo) i industrijska drvena ambalaža spremna za otpremu (desno)

- solid sawn timber CE marked according to EN 14081;
- glulam and glued solid timber (duo/trio) CE-marked according to EN 14080;
- structural finger jointed solid timber (KVH), CE-marked according to EN 15497;
- wood-based products (plywood or OSB/3 or OSB/4, CE-marked according to EN 13986).

As mentioned above, one of the most relevant points of UNI 9151 is its double entry procedure that offers two alternatives for the design of packaging: allowable stress or limit states design, depending on the type of wooden material. When structural wood-based materials are used, in accordance with UNI 9151, the method of calculation is based on partial safety factors for the Limit State Design (LSD). This method requires to verify that, in the main design situations (e.g. transport, handling, etc.), no relevant limit state is exceeded. According to Eurocode 0 (EN 1990), for a specific load case, the design values of the effects of actions (E_d) can be expressed as:

$$E_{\mathrm{d}} = \sum E_{\mathrm{i}} \cdot \gamma_{\mathrm{Sd,i}} \qquad [1.1]$$

Where:
E_i is the characteristic value of the effect of the i-th action;
$\gamma_{Sd,i}$ is a partial coefficient that takes into account uncertainties in modeling the actions and their effects.

According to the Eurocode 5 (EN 1995-1-1), the design values R_d of a strength property shall be calculated as:

$$R_{\mathrm{d}} = R_{\mathrm{k}} \cdot \frac{k_{\mathrm{mod}}}{\gamma_{\mathrm{m}}} \qquad [1.2]$$

Where:
R_k is the characteristic value of a strength property;
γ_m is the partial safety factor for the material;
k_{mod} is the modification factor that takes into account the effect of the duration of load and moisture content.

The recommended partial factors γ_m are, respectively, 1.30 for timber, 1.25 for glued laminated timber, 1.20 for plywood and OSB, and 1.30 for connections.

The modification factor k_{mod} is defined according to EN 1995-1-1, § 3.1.4 for short-term actions and for the service class 2, with reference to a wood moisture content not greater than 20 % and for the service class 3, with reference to a wood moisture content greater than 20 %.

For solid timber and glue laminated timber, the k_{mod} assumes the value of 0.9 for wood packaging exposed to moderate humid condition or 0.7 for that in heavy humid condition (e.g. maritime transports).

In this case, the characteristic value of strength properties derives from the EN 338, that sets the characteristic values of resistance, modulus of elasticity and density for each strength class. The philosophy of the standard is to promote among designers the use of the limit states approach but also to favor the use of local timber visually graded according to the national standard UNI 11035 (Negro *et al*., 2013).

Once the grade is assigned to the element, EN 1912 allows to establish the correspondence between the national grade and the harmonized strength class included in EN 338. In detail, EN 1912 takes into account a combination of three factors (wood species, geographical origin and national grade) to individuate the correspondent strength class of the EN 338. The system of strength classes codified by the EN 338 applies both to softwoods and hardwoods structural timber.

Since the designers of the industrial packaging sector are more familiar with the allowable stresses method, UNI 9151 gives a wide freedom of choice. Using the allowable stresses method, it shall be verified that no stress σ, calculated taking into account the effects of the actions without any safety coefficient, exceeds the allowable values σ_p:

$$\sigma \leq \sigma_{\mathrm{p}} \qquad [1.3]$$

Where:
σ is the design value of properties
σ_p is the allowable stress design.

According to the standard, the values of allowable stresses (σ_p) can be derived, in a simplified way, from the characteristic values f_k using the following equation:

$$\sigma_p = \frac{f_k}{1.70 \cdot \gamma_m} \qquad [1.4]$$

Where:
f_k can be obtained from EN 338 (Table 1)
γ_m is the partial safety factor for the material.

Table 1 Design values from the strength class of structural timber for each different design approach
Tablica 1. Vrijednosti projektiranja za razrede čvrstoće konstrukcijskog drva i različite pristupe projektiranju

Strength class *Razred* čvrstoće **EN 338**	$f_{k, bending}$ **MPa**	σ_p **MPa**
C24	24	10.9
C16	16	7.2

When the wood moisture content is greater than 20 %, the values of the admissible tensions shall be reduced by 30 %. When using non-structural visual graded timber according to EN 12246, the designer must calculate the packaging dimensions only with the allowable stress method (Table 2). It is important to underline that the above standard defines two timber quality classes (P1 and P2) for general uses in reusable pallets and industrial packaging. However, this standard was not specifically developed for wood packaging. In fact, EN 12246 does not admit shakes on square solid timber elements, whereas shakes are inevitably present in dry or semi-dry structural timber (P1) with large cross section used in industrial packaging. It is, therefore, clear that the presence of shrinkage shakes may become a limiting factor in the classification of wood for the industrial packing according to EN 12246. This standard remains valid for the grading of the boards (P2) used in sheeting the sides and lid of the packaging, wooden elements that, in any case, are not taken into consideration in the context of the packing design.

In addition to the design aspects, UNI 9151, through a large number of drawings and exploded views, explains the most significant construction details, including a description of the chemical-physical properties of the protection systems.

In fact, it is well known that many construction details, as well as the design procedures, can affect the wood packaging in terms of quality and reliability.

3 CONCLUSIONS
3. ZAKLJUČAK

The Italian wood packaging industry occupies a leading role in Europe. The national standard framework (UNI 9151 and UNI 10858) was thoroughly updated in order to adapt it to the use of CE marking wood-based materials. This revision, together with the possibility of using CE marked structural timber, represents both a challenge and an opportunity for the wood packaging industry that today, as a result, can better compete with other materials on the international market.

Like other documents and guidelines, UNI 9151 gives the option of using structural graded timber, but still provides rigorous design rules aimed at using more conventional approach of the allowable stress with wood material complying with EN 14081. Actually, the national standard encourages the packaging design

Table 2 Allowable stress design values from UNI 9151-3
Tablica 2. Vrijednosti dopuštenog naprezanja pri projektiranju prema normi UNI 9151-3

Wood species *Vrsta drva*	**Latin name** *Latinski naziv*	**Allowable stress, N/mm²** *Dopušteno naprezanje,* N/mm² // **Compression** *Tlačno, paralelno s vlakancima*	⊥ **Compression** *Tlačno, okomito na vlakanca*	**Bending** *Savijanje*	**Shear** *Smicanje*
Softwood / *Drvo četinjača*					
Norway spruce / *visoka smreka*	*Picea abies* (L.) Karst	8.0	2.0	9.0	0.9
Silver fir / *obična jela*	*Abies alba* Mill.				
Douglas fir / *obična duglazija*	*Pseudotsuga menziesii* (Mirb.) Franco				
European larch / *europski ariš*	*Larix decidua* Mill.	10.0	2.2	11.0	1.0
Scots pine / *obični bor*	*Pinus sylvestris* L.	9.0	2.0	10.0	0.9
Austrian pine / *austrijski bor*	*Pinus nigra* Arnold subsp. *nigra*				
Corsica pine / *korzikanski bor*	*Pinus nigra* Arnold subsp. *laricio* (Poir.) Maire				
Maritime pine / *primorski bor*	*Pinus pinaster* Ait.				
Hardwood / *Drvo listača*					
Sweet chestnut / *pitomi kesten*	*Castanea sativa* Mill.	9.0	2.0	10.0	0.7
European ash / *bijeli jasen*	*Fraxinus excelsior* L.				
Elm / *brijest*	*Ulmus* spp.				
Eucalyptus / *eukaliptus*	*Eucalyptus* spp				
Poplar / *topola*	*Populus* spp.	8.0	1.5	8.5	0.5
Oak / *hrast*	*Quercus* spp.	10.0	2.5	11.0	1.0
Beech / *bukva*	*Fagus sylvatica* L.				
Robinia / *obični bagrem*	*Robinia pseudoacacia* L.	10.0	2.5	11.5	1.0

with graded timber without penalizing the more traditional and consolidated visual grading method described in EN 12246.

In conclusion, the UNI 9151 family of standards is a complete tool for industrial packaging designers and it can offer greater safety for the manufacturing of large packaging. In perspective, the use of this standard will allow the sector to meet the growing needs of the industrial goods logistics with a more accurate and reliable design, implemented by the application of modern practices. Considering that today there is no European standard specifically intended for industrial wood packaging sector, UNI 9151 could represent a solid starting point for developing it.

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Carapa guianensis Aubl.

NAZIVI

Carapa guianensis Aubl. naziv je drva botaničke vrste iz porodice *Meliaceae.* Trgovački su nazivi te vrste andiroba (Njemačka, Brazil); andiroba saruba, camacari, yandiroba (Brazil); cedro macho (Kostarika); bois caille, carapa rouge (Francuska), carapa (Velika Britanija, Venezuela); crabwood (Velika Britanija, Gvajana); empire andiroba (Gvajana); masàbolo (Kolumbija); krappa (Surinam).

NALAZIŠTE

Stabla *Carapa guianensis* Aubl. nalazimo u Srednjoj i Južnoj Americi, i to u Hondurasu, Kostariki, Venezueli, Gvajani, Surinamu i Brazilu. Drveće pretežito raste u tropskim nizinskim trajno zelenim kišnim šumama i u području močvarnih šuma.

STABLO

Stablo naraste 30 – 40 (50) metara visoko, čistog debla dužine 20 (30) metara te prsnog promjera debla do 1,5 metara. Debla su valjkastog oblika. Žica drva je pravilna do blago usukana, a kora mu je pukotinasta i siva.

DRVO

Makroskopska obilježja

Drvo je rastresito porozno. Bjeljika je uska, siva do crvenkastosiva, široka od 3 do 5 centimetara. Srž se bojom neznatno razlikuje od bjeljike, a s vremenom postane crvenkastosmeđa. Granica goda je dobro uočljiva. Pore i drvni traci uočljivi su povećalom. Drvni su traci na tangentnom presjeku visoki do 1 milimetar.

Mikroskopska obilježja

Traheje su pretežito raspoređene pojedinačno, u paru ili u kratkim radijalnim nizovima. Promjer traheja iznosi 80...180...250 mikrometara, a gustoća im je 7...11...16 na 1 mm^2 poprečnog presjeka. Volumni je udio traheja oko 16 %. Traheje su često ispunjene tilama i smeđim sržnim tvarima.

Aksijalni je parenhim paratrahealno oskudan, paratrahealno vazicentričan i apotrahealno marginalan, širok od 1 do 2 stanice. Volumni se udio aksijalnog parenhima kreće od 5 do 10 %. Staničje drvnih trakova je heterogeno. Pojedini su drvni traci visoki 220...500...800 mikrometara, odnosno 6...22...37 stanica, a široki su 40...65...95 mikrometara, odnosno 2...5...6 stanica. Gustoća drvnih trakova je 4...6...8 na 1 mm poprečnog presjeka. Volumni udio drvnih trakova iznosi oko 17 %. U drvnim tracima i aksijalnom parenhimu ima kristala. Drvna su vlakanca libriformska. Dugačka su 800...1500...2000 mikrometara. Debljine staničnih stijenki vlakanaca iznose od 1 do 3 mikrometra, a promjeri lumena vlakanaca 7,0...12,0...18,0 mikrometara. Volumni je udio vlakanaca 57...60...64 %.

Fizička svojstva

Gustoća standardno suhog drva, ρ_o	520...580...680 kg/m^3
Gustoća prosušenog drva, $\rho_{12\text{-}15}$	570...620...700 kg/m^3
Gustoća sirovog drva, ρ_s	oko 800 kg/m^3
Poroznost	oko 61 %
Totalno radijalno utezanje, β_r	3,1...4,9 %
Totalno tangentno utezanje, β_t	7,6...8,0...9,3 %
Totalno volumno utezanje, β_v	9,8...14,3 %

Mehanička svojstva

Čvrstoća na tlak	37...53...64 MPa
Čvrstoća na vlak, paralelno s vlakancima	80...115...155 MPa
Čvrstoća na vlak, okomito na vlakanca	oko 3,9 MPa
Čvrstoća na savijanje	53...100...125 MPa
Tvrdoća prema Brinellu, paralelno s vlakancima	34...39...48 MPa
Tvrdoća prema Brinellu, okomito na vlakanca	16...24...30 MPa
Tvrdoća prema Janki, paralelno s vlakancima	oko 68 MPa
Tvrdoća prema Janki, okomito na vlakanca	oko 51 MPa
Modul elastičnosti	9,5...12,5...17,5 GPa

TEHNOLOŠKA SVOJSTVA

Obradivost

Drvo se dobro ručno i strojno obrađuje. Zbog mogućeg nadizanja odnosno čupanja vlakanaca pri ravnanju i blanjanju za obradu su potrebni oštri alati. Drvo andiroba dobro se lijepi, brusi i politira, no lako puca pri čavlanju. Vijke dobro drži.

Sušenje

Drvo se dobro i polako suši. Za vrijeme sušenja mogu se stvoriti pukotine i drvo se može vitoperiti.

Trajnost i zaštita

Prema normi HRN 350-2, 2005, srž je slabo otporna na gljive uzročnice truleži (razred otpornosti 3 – 4) i slabo otporna na termite (razred otpornosti M). Srž je slabo permeabilna (razred 3). Po trajnosti je u razredu 2 i stoga se to drvo može postavljati u interijeru, a njegova je uporaba u eksterijeru moguća samo ako je prostor natkriven.

Uporaba

Upotrebljava se kao furnirsko drvo, za izradu kvalitetnog namještaja, drvenih obloga unutrašnjih dijelova stuba, podova te za jarbole u brodogradnji. Može se rabiti i za izradu drvenih kutija i sanduka.

Sirovina

Drvo na tržište dolazi u obliku trupaca dužine od 4,0 do 6,0 metara, najčešće srednjeg promjera 50 – 100 centimetara.

Napomena

Carapa guianensis nije na popisu ugroženih vrsta međunarodne organizacije CITES ni na popisu međunarodne organizacije IUCN, premda je na tom popisu srodna endemična vrsta *Carapa megistocarpa*. Andiroba se može upotrebljavati kao zamjena za drvo mahagonija (*Swietenia* spp.). Bruševina drva može prouzročiti iritaciju očiju i kože i izazvati kihanje, a ozbiljnije su reakcije vrlo rijetke. Ulje dobiveno iz sjemenki upotrebljava se u tradicionalnoj medicini i kao repelent za insekte. Drvo sličnih svojstava imaju i ove vrste drveća: *Carapa grandiflora* Sprague, *C. nicaraguensis* C. DC., *C. procera* DC., *C. slaterie* Standl., *C. surinamensis* Miq., *C.* spp., *Entandrophragma angolensse* C. DC., *Swietenia mahagoni* Jacq.

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Upute autorima

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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/node 00.html. First published 1997 (pristupljeno 27. siječnja 2010).

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

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