LES/WOOD

Volume 71 / Number 2
December 2022
ISSN 0024-1067 (printed)
ISSN 2590-9932 (on-line)

University of Ljubljana
Biotechnical Faculty

LES/WOOD

VSEBINA / CONTENTS

Letnik 71, številka 2 / Volume 71, Number 2

Les/Wood

Založila/*Published by*
Založba Univerze v Ljubljani / *University of Ljubljana Press*

Za založbo/*For the Publisher*
Gregor Majdič, rektor Univerze v Ljubljani / *the Rector of the University of Ljubljana*

Izdala/*Issued by*
Univerza v Ljubljani, Biotehniška fakulteta, Oddelek za lesarstvo /
University of Ljubljana, Biotehnical Faculty, Department of Wood Science and Technology

Za izdajatelja/*For the Issuer*
Marina Pintar, dekanja Biotehniške fakultete UL / *the Dean of the Biotehnical Faculty UL*

Naslov uredništva/*Editorial Office Address*
Univerza v Ljubljani, Biotehniška fakulteta, Revija Les/Wood, Jamnikarjeva ulica 101, 1000 Ljubljana, Slovenia

Prelom/*Layout*
Tiskarna Koštomaj, Celje

Tisk/*Print*
Tiskarna Koštomaj, Celje
Natisnjeno v decembru 2022 v 100 izvodih./*Printed in December 2022 in 100 copies.*

ISSN 0024-1067 (tiskana verzija/*printed version*)
ISSN 2590-9932 (spletna verzija/*on-line version*)

https://journals.uni-lj.si/les-wood

Periodičnost/*Frequency*
Dve številki letno/*Two issues per year*

Les/Wood je referiran v mednarodnih bibliografskih zbirkah
Les/Wood is indexed in the international bibliographic databases
AGRIS, CAB Abstracts, Directory of Open Access Journals

Izdajanje revije sofinancira Javna agencija za raziskovalno dejavnost Republike Slovenije (ARRS)
The journal is co-financed by Slovenian Research Agency (ARRS)

LES/WOOD

UVODNIK / EDITORIAL

Katarina Čufar, Jože Kropivšek
Urednika / Editors

Revija Les/Wood med tradicijo in novimi izzivi

V letu 2022 je delo pri reviji Les/Wood zaznamovalo delovanje v okviru Založbe Univerze v Ljubljani, o čemer smo že poročali. Tako je revija dostopna na novi spletni strani, https://journals.uni-lj.si/les-wood. Novost za avtorice in avtorje ter vse, ki soustvarjajo revijo, je prenovljeni portal za oddajo, recenzijo in spremljanje prispevkov do končne objave. Na isti strani so dostopne tudi vse številke od leta 2017, v pripravi pa je tudi arhiv starejših letnikov revije.

Uredniškemu odboru se je kot tehnična urednica pridružila Teja Bizjak Govedič, ki je že v tej številki revije uredila večino prispevkov. Tako se je znatno skrajšal čas od sprejetja do objave prispevkov. Nove tehnične urednice smo zelo veseli in ji želimo uspešno delo v naši uredniški ekipi.

Revija ostaja zvesta dolgoletni tradiciji, a se na drugi strani hitro odziva na nove smernice znanstvene periodike. Tu bi vas radi opozorili na nekaj prednosti revije, najprej odprti dostop, ki postaja vse bolj pomembna zahteva financerjev raziskovalne dejavnosti. Odprti dostop revije odgovarja na priporočilo (oz. določilo, ki na primer velja za projekte Obzorje Evropa) za takojšnjo odprto dostopnost recenziranih člankov in daljših besedil z licencami Creative Commons (CC BY ali CC0). Priporoča se, da morajo biti dostopni tudi preko repozitorijev. Zato so članki, objavljeni v Les/Wood, dostopni tudi preko repozitorija Univerze v Ljubljani RUL. Revija že dlje časa ob objavi člankov omogoča tudi objavo raziskovalnih podatkov, večinoma v repozitoriju RUL, kar je tudi v skladu s priporočilom odprte znanosti.

V povezavi z zahtevami odprtega dostopa smo začeli članke sistematično opremljati tudi z odprtim identifikatorjem za raziskovalce in sodelavce ORCID (Open Researcher and Contributor ID), ki ga pripenjamo imenom avtoric in avtorjev. ORCID je enolični in trajni identifikator, s katerim upravlja nepridobitna organizacija ORCID Inc., prek njega pa je mogoče spremljati objave posameznih avtorjev. ORCID je trenutno med najbolj razširjenimi tovrstnimi identifikatorji v globalni akademski skupnosti. Vse to pomaga, da objave v reviji Les/Wood samodejno prepoznajo tudi baze kot so Google učenjak in Research Gate, ki dodatno omogočajo razširjanje, promocijo in posredno večjo citiranost člankov.

Revija ostaja pomembna za učenje strokovnega izrazoslovja. Les/Wood je skupaj z drugimi revijami, ki objavljajo slovenska in angleška besedila, pomemben vir za razvoj in izpopolnjevanje orodij za strojno prevajanje iz slovenščine v angleščino in obratno ob podpori umetne inteligence.

Revija še naprej ostaja prepoznavna tudi za objavo del mladih avtoric in avtorjev na začetku kariere, ki so skupaj z mentorji napisali kar štiri od petih člankov te številke.

Zahvaljujemo se vsem, ki soustvarjate revijo, še posebej recenzentom in recenzentkam, katerih anonimno delo je neprecenljivo za njeno delovanje. Glede na izzive med tradicijo in novostmi bo glavna skrb revije Les/Wood tudi v prihodnosti usmerjena v pridobivanje kritičnega števila kakovostnih prispevkov ter skrb za razširjanje objavljenega znanja, ki se izraža v prosti dostopnosti, branosti, citiranosti ter napredku znanosti in stroke.

Les/Wood between tradition and future challenges

In 2022, *Les/Wood*'s work has evolved with the help of the University of Ljubljana Press. The journal is now available on a new website, https://journals.uni-lj.si/les-wood. It has a new portal for submission, review, and follow-up of submissions to final publication. All issues from 2017 are also available on the same site, and an archive of older issues of the journal is in the works.

Teja Bizjak Govedič, who has edited most of the articles in this journal, has joined the Editorial Board as the new Technical Editor. This has significantly shortened the time from acceptance to publication. We are very pleased to welcome the new technical editor and wish her successful co-operation with our editorial team.

The journal remains faithful to its long-standing tradition, but on the other hand responds quickly to new trends in scientific journals. At this point, we would like to mention some of the journal's strengths. The first is open access, which is becoming an increasingly important requirement of research funders. The open access nature of *Les/Wood* is in line with the recommendation that peer-reviewed articles and longer texts be made immediately freely available with Creative Commons licences (CC BY or CC0) and accessible through repositories. For this reason, articles published in *Les/Wood* are also accessible through the University of Ljubljana's RUL repository. In addition to publishing articles, the journal has also made research data available, mostly in the RUL repository, which is also in line with the open science recommendation.

Furthermore, we have started to systematically assign an Open Researcher and Contributor ID (ORCID) to the names of authors of articles. ORCID is a unique and persistent identifier managed by the non-profit organisation ORCID Inc. through which individual authors' publications can be tracked.

All of this helps ensure that publications in *Les/Wood* are automatically recognised by databases such as Google Scholar and Research Gate, further facilitating dissemination and promotion and indirectly increasing the citation of articles.

The journal remains important for learning technical terminology. Together with other journals that publish both Slovenian and English texts, *Les/Wood* is an important resource for the development and refinement of AI-assisted machine translation tools from Slovenian into English and vice versa.

The journal continues to be recognised for publishing the work of young authors at the beginning of their careers, who co-authored four of the five articles in this issue.

Finally, we would like to thank all those who help shape the journal, especially the reviewers, whose anonymous work is invaluable to the journal. Given the challenges between tradition and novelty, *Les/Wood*'s primary concern will continue to be attracting a critical mass of high-quality manuscripts and disseminating published knowledge that leads to open access, readership, citations, and advances in science and the profession.

LES/WOOD Vol. 71, No. 2, 25-30
DOI: https://doi.org/10.26614/les-wood.2022.v71n02a01

AIR PERMEABILITY OF THERMALLY MODIFIED HEMLOCK WOOD

PLINSKA PERMEABILNOST TERMIČNO MODIFICIRANEGA LESA ZAHODNE ČUGE

Yaohui Liu[1*], Stavros Avramidis[1]

UDK 630*812.23
Original scientific article / Izvirni znanstveni članek

Received / Prispelo: 29.7.2022
Accepted / Sprejeto: 11.8.2022

Abstract / Izvleček

Abstract: Western hemlock (*Tsuga heterophylla*) is a prevalent coastal species in British Columbia (BC). Its wood has a high potential for thermal modification, a process that can affect numerous physical properties, including air permeability. The current study investigates the longitudinal air permeability of hemlock wood modified at three temperature levels, 170 °C, 212 °C, and 230 °C, and a two-hour treatment length. Permeability values obtained using Darcy's law and the water-falling volume displacement method were positively correlated with treatment temperature up to 212 °C, after which the permeability decreased slightly. ANOVA followed by the Duncan test revealed that thermal treatment at 212 °C and 230 °C significantly increased air permeability, whereas it was insignificant at 170 °C.

Keywords: wood, thermal modification, western hemlock, longitudinal air permeability, specific permeability, temperature effect

Izvleček: Zahodna čuga (*Tsuga heterophylla*) je prevladujoča obalna vrsta v Britanski Kolumbiji (BC) z velikim potencialom za termično modifikacijo lesa, ki lahko vpliva na številne fizikalne lastnosti, vključno s plinsko permeabilnostjo. Ta študija preučuje vzdolžno plinsko permeabilnost lesa čuge, termično modificiranega pri treh temperaturah, 170 °C, 212 °C in 230 °C, ter 2-urni obdelavi. Vrednosti plinske permeabilnosti, določene iz Darcyjevega zakona z metodo izpodrivanja prostornine vode, so bile pozitivno povezane s temperaturo obdelave do 212 °C, nato pa se je permeabilnost nekoliko zmanjšala. Analiza variance (ANOVA) skupaj z Duncanovim testom mnogoterih primerjav sta pokazala, da je termična obdelava pri 212 °C in 230 °C znatno povečala plinsko permeabilnost, medtem ko so bile spremembe pri 170 °C neznačilne.

Ključne besede: termična modifikacija, zahodna čuga = *Tsuga heterophylla*, vzdolžna plinska permeabilnost, specifična permeabilnost, vpliv temperature

1 INTRODUCTION
1 UVOD

The increasing demand for sustainable construction materials calls for improved wood performance, including UV-stability, fire resistance, and anti-fungal properties, because future bio-economies rely on renewable biomaterials to design and manufacture new products. Wood as a raw material has a wide variety of applications, such as furniture, construction, many objects, and toolmaking. However, wood has several shortcomings that restrict its application. For example, it can easily absorb water (moisture), resulting in dimensional instability, checking, and biodegradation by wood-destroying organisms such as fungi and insects (Bahmani et al., 2016; Bahmani & Schmidt, 2018). Researchers have developed different chemical methods such as acetylation (Hill et al., 1999) and salinization (Donath et al., 2006) to reduce wood's hydrophobicity and hygroscopicity, and thus improve dimensional stability. Thermal modification is a non-chemical method of decreasing hygroscopicity with an increasing market acceptance that improves specific properties and results in a material that does not pose an environmental hazard compared to chemically treated wood. Thermally modified wood

[1] Department of Wood Science, Faculty of Forestry, University of British Columbia, Vancouver, BC, Canada
* e-mail: lyaohui@student.ubc.ca

has various applications in furniture construction, flooring, sauna/bathroom furnishings, doors, and cladding (Hill, 2006).

Permeability is a critical wood property because it directly affects drying (Perre, 2007; Rahimi et al., 2019; Rahimi et al., 2022) and impregnation with fluids (Mansouryar et al., 2010; Chu et al., 2019a; Chu et al., 2019b; Dong et al., 2020). It is worth evaluating the permeability of thermally modified wood because different levels of permeability are desired based on the application of the modified wood. For example, cladding requires low permeability, whereas post-treatment with fluid fire retardants requires high permeability.

Yuan (1994) reported increased air permeability in eucalyptus that was heat-treated at 140 °C for 5 hours. A study by Kang et al. (2018) revealed that air permeability increased after the heat treatment of malas (*Homalium foetidum*) at 190 °C for 3 hours. Taghiyari and Malek (2014) reported that heat treatment affected air permeability. At temperatures below 60 °C, permeability increased due to bound water reduction and shrinkage. Hermawan et al. (2020) investigated the effects of drying temperatures on preservative retention and penetration of some Malaysian fast-growing species timbers. The results demonstrated that high-temperature drying has a positive impact on preservative penetration. However, other studies revealed no effect of temperature on permeability. Rhatigan et al. (2003) reported no differences in air permeability between lumber dried at conventional and high temperatures. Other studies revealed that heat treatment did not change the permeability of *Populus robusta* (Rousset et al., 2004) or subalpine fir (*Abies lasiocarpa*) (Poonia et al., 2015).

Although thermal modification is a well-developed industrial process in Europe, it is still in its infancy in Canada. Therefore, establishing that such a method adds value to local wood species may lead to the development of new products and markets. Western hemlock (*Tsuga heterophylla*) forms extensive forests along the coastal mountains of the North American Pacific Northwest, and its wood is light in colour and typically resin-free, but the heartwood routinely contains wet pockets and extractives (Ward & Pong, 1980). Its attributes, such as high-quality machinability, smooth sanding, easy gluing, and high nail and screw holding, make it suitable for plywood, roof decking, and general construction (Alden, 1995).

This work hypothesizes that thermal treatment significantly increases permeability in western hemlock, and the treatment temperatures are positively correlated with permeability (Nourian & Avramidis, 2021). As such, the objective here is to evaluate the effects of thermal modification under three temperatures on hemlock air permeability.

2 MATERIALS AND METHODS
2 MATERIALI IN METODE

Two hundred permeability samples of 70 mm × 13 mm × 13 mm in the longitudinal, radial, and tangential directions were cut from second-growth western hemlock lumber that was commercially thermally modified in a past study (Nourian & Avramidis, 2021). Thermal modification was carried out at 170 °C, 212 °C, and 230 °C, with a holding time of 2 hours in a Jartek industrial heat treatment chamber at Scottywood Corporation in Squamish, BC, Canada.

The superficial air permeability (*kg,* m^3 (gas)/m Pa s) of the specimens was measured by the falling-water volume displacement method using an apparatus similar to that described by Siau (1995). The specific permeability (*K*, m^3/m) was thereafter calculated by multiplying *kg* by the air viscosity of $1.81 \cdot 10^{-5}$ Pa s.

Analysis of variance (ANOVA) followed by the Duncan test to determine the significance of the differences between the air permeability of samples in four different groups was performed with the *K* dataset.

3 RESULTS AND DISCUSSION
3 REZULTATI IN DISKUSIJA

Table 1 lists the *K*-values for the four sample groups. The average ± standard deviation in the controls was $0.72 \times 10^{-11} \pm 0.59 \times 10^{-11}$ and $1.00 \times 10^{-11} \pm 1.01 \times 10^{-11}$ for 170 °C. The average specific permeability values for the samples treated at 212 °C to 230 °C were $1.26 \times 10^{-11} \pm 1.01 \times 10^{-11}$ and $1.21 \times 10^{-11} \pm 0.78 \times 10^{-11}$, respectively. After heat treatment at 212 °C, the permeability was 1.75 times greater than the controls. This finding accords with Lin and Kozlik (1971) and Rhatigan et al. (2003) for

Table 1. Central tendency and dispersion for the specific permeability.
Preglednica 1. Osrednja tendenca in razpršenost za specifično permeabilnost.

Statistical parameter	Specific permeability at different thermal treatment levels			
	Control	170 °C	212 °C	230 °C
Measures of central tendency				
Mean ($m^3 \cdot m^{-1} \cdot$)	0.72×10^{-11}	1.00×10^{-11}	1.26×10^{-11}	1.21×10^{-11}
Median ($m^3 \cdot m^{-1} \cdot$)	0.58×10^{-11}	0.70×10^{-11}	0.93×10^{-11}	1.13×10^{-11}
Measures of dispersion				
Standard deviation ($m^3 \cdot m^{-1}$)	0.59×10^{-11}	1.01×10^{-11}	1.01×10^{-11}	0.78×10^{-11}
Coefficient of variation (%)	81.85	101.31	80.09	64.62
Range ($m^3 \cdot m^{-1}$)	2.86×10^{-11}	5.21×10^{-11}	4.80×10^{-11}	3.82×10^{-11}

eastern hemlock, where permeability increased with increasing temperature.

Measures of dispersion (standard deviation, coefficient of variation, and range) indicated a high variation of air permeability within each treatment group. The high variation in the permeability in each group is possibly related to anatomical differences, namely differences in the sapwood and heartwood content in specimens. Table 2 summarizes the ANOVA results of the different temperatures on the permeability of hemlock wood. The effect of different temperatures on the permeability of the samples was statistically significant ($P \leq 0.05$). According to Duncan's test, thermal treatment at 170 °C increased air permeability insignificantly compared to the controls, while thermal treatment at 212 °C and 230 °C significantly increased air permeability. In addition, the air permeability in modified wood showed insignificant changes among the three thermally treated groups.

Figure 1 shows a direct relation between permeability and treatment levels until 212 °C. According to several studies, treatment temperature and air permeability are positively correlated (Hermawan et al., 2020; Kang et al., 2018; Yuan, 1994). The one-way ANOVA tests revealed an insignificant difference in permeability values between samples treated at 212 °C to 230 °C, although specific permeability for T–212 °C was slightly higher.

Table 2. Analysis of variance results for the specific permeability.
Preglednica 2. Rezultati analize variance za specifično permeabilnost.

	Sum of Squares	df	Mean Square	F	Sig.
Between groups	0.000	3	0.000	3.985	0.009*
Within groups	0.000	196	0.000		
Total	0.000	199			

*Significant at 95%

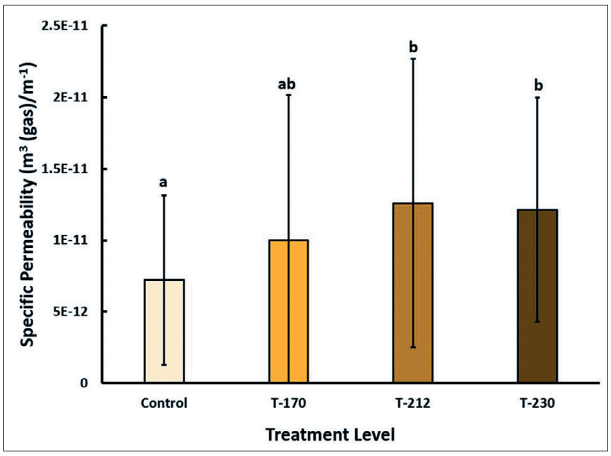


Figure 1. Mean and standard deviation for specific permeability in untreated and thermally treated western hemlock. The histograms show the mean, and the whiskers represent the standard deviation. Different letters above the whiskers (a or b or ab) indicate statistically significant differences between groups in the Duncan test.
Slika 1. Povprečje in standardni odklon specifične permeabilnosti za neobdelan in termično obdelan les zahodne čuge. Histogrami prikazujejo povprečje, ročaji pa standardni odklon. Različne črke (a, b ali ab) označujejo statistično značilne razlike med skupinami po Duncanovem testu.

Bordered pits affect wood permeability considerably, and thermal treatment can change or restructure these. In addition, extractives may obstruct the pit membranes, which hinders fluid flow through the wood elements (components). The process of thermal modification also alters the extractives and redistributes them such that they may be deposited on the cell walls and pits (Esteves & Pereira, 2009). Overall, the findings of this study indicate that permeability reaches its maximum at 212 °C. Further research is required to reveal the possible effects of temperature on wood permeability above 230 °C.

4 CONCLUSION
4 ZAKLJUČKI

This project investigated the influence of three different temperatures, namely 170 °C, 212 °C, and 230 °C, on the specific permeability of western hemlock wood. The findings revealed that by increasing the temperature the permeability of the hemlock wood samples increased, where there was a significant difference between the samples heated above 170 °C and the control ones. Moreover, the permeability of the samples heat-treated at 212 °C was 1.75 times greater than that of the control samples. Overall, the findings of this study suggest that thermal modification is potentially an effective method for increasing the permeability of hemlock wood. It is worth mentioning that permeability is strongly affected by anatomical properties, and thus future research should focus on the effects of thermal treatment on different regions of hemlock wood, such as juvenile wood vs. mature wood and sapwood vs. heartwood.

5 SUMMARY
5 POVZETEK

Les je znan kot vsestranska surovina, ki se lahko uporablja na različne načine. Vendar pa je uporaba lesa v nekaterih primerih lahko omejena zaradi njegovih specifičnih lastnosti, vključno s higroskopnostjo in dovzetnostjo za razkroj (Bahmani et al., 2016; Bahmani & Schmidt, 2018). Natančneje, obstajajo nekateri primeri uporabe lesa, pri katerih ima permeabilnost, ki se nanaša na enostavnost prehajanja tekočine skozi porozne materiale pod gradientom tlaka, ključno vlogo (Rahimi et al., 2011). Zato je pomembno oceniti permeabilnost, saj lahko to pomaga pri izdelavi boljših izdelkov za določene uporabe. V tej študiji je bila ocenjena plinska permeabilnost lesa zahodne čuge (*Tsuga heterophylla*, angleško hemlock) pri treh različnih temperaturah termične modifikacije.

Za to študijo je bilo zbranih 200 vzorcev lesa zahodne čuge, ki so bili razrezani na določene dimenzije. Vzorci so bili termično modificirani z industrijsko pripravo za termično modifikacijo Jartek. Glede na temperaturo, pri kateri so bili vzorci termično modificirani, so bile oblikovane štiri skupine: 170 °C, 212 °C, 230 °C in kontrolna skupina. Za določitev plinske permeabilnosti na podlagi poroznosti mikrostrukture lesa je bila uporabljena naprava na osnovi metode izpodrivanja prostornine vode, kot jo je opisal Siau (1995). Plinska permeabilnost vzorcev v štirih različnih skupinah je bila analizirana z ANOVA, ki ji je sledil Duncanov test za določitev značilnosti razlik.

Rezultati te študije so pokazali, da je plinska permeabilnost pozitivno povezana s temperaturo, saj se je permeabilnost vzorcev lesa zahodne čuge, segretih nad 170 °C, bistveno razlikovala od kontrolne. Na podlagi podrobnejšega opazovanja so vzorci, termično modificirani pri 212 °C, pokazali 1,75-kratno povečanje prepustnosti v primerjavi z nemodificiranimi.

REFERENCES
VIRI

Alden, H. (1995). Softwoods of North America, FPL-GTR-102. Madison, WI. U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory, 151pp.

Bahmani, M., & Schmidt, O. (2018). Plant essential oils for environment-friendly protection of wood objects against fungi. Maderas. Ciencia y tecnología, 20(3), 325-332.

Bahmani, M., Schmidt, O., Fathi, L., & Frühwald, A. (2016). Environment-friendly short-term protection of palm wood against mould and rot fungi. Wood Material Science & Engineering, 11(4), 239-247.

Chu, D., Mu, J., Avramidis, S., Rahimi, S., Liu, S., & Lai, Z. (2019a). Functionalized surface layer on poplar wood fabricated by fire retardant and thermal densification. Part 1: compression recovery and flammability. Forests, 10(11), 955.

Chu, D., Mu, J., Avramidis, S., Rahimi, S., Liu, S., & Lai, Z. (2019b). Functionalized surface layer on poplar wood fabricated by fire retardant and thermal densification. Part 2: dynamic wettability and bonding strength. Forests, 10(11), 982.

Donath, S., Militz, H., & Mai, C. (2006). Creating water-repellent effects on wood by modification with silanes. Holzforschung, 60(1), 40-46.

Dong, H., Bahmani, M., Rahimi, S., & Humar, M. (2020). Influence of copper and biopolymer/Saqez resin on the properties of poplar wood. Forests, 11(6), 667.

Esteves, B., & Pereira, H. (2009). Wood modification by heat treatment: A review. BioResources, 4(1), 370-404.

Hermawan, A., Sakagami, H., Sobri, S. A., Amini, M. H. M., Ramle, S. F. M., & Rasid, S. (2020). The effects of drying temperatures on preservative retention and penetration of some Malaysian fast-growing species timbers. Drying Technology, 39(4), 566-75.

Hill, C. A. (2006). Wood modification: chemical, thermal, and other processes (Vol. 5). Chichester, John Wiley & Sons, 237 pp.

Hill, C. A. S., Jones, D., Strickland, G., & Cetin, N. S. (1999). Kinetic and mechanistic aspects of the acetylation of wood with acetic anhydride. Holzforschung, 52(6), 623-629.

Kang, C. W., Li, C., Jang, E. S., Jang, S. S., & Kang, H. Y. (2018). Changes in sound absorption capability and air permeability of Malas (*Homalium foetidum*) specimens after high temperature heat treatment. Journal of the Korean Wood Science and Technology, 46(2), 149-54.

Lin, R. T., Kozlik, C. J. (1971). Permeability and drying behavior of western hemlock. Proc. 22 nd Annual Meeting Western Dry Kiln Club, pp. 44-50. Oregon State Univer., Corvallis, OR.

Mansouryar, E., Karimi, A., Ebrahimi, G., Mirshokraei, A., & Rahimi, S. (2010). Water repelling Populus Alba by emulsion of paraffin, Quaternary ammonium and hydrated starch. IJWP, 25, 211–222. (In Farsi)

Nourian, S., & Avramidis, S. (2021). Exploratory thermal modification of western hemlock. Wood Material Science & Engineering, 16(4), 221-228.

Perre, P. (2007). Fundamental Wood Drying. *European COST*. Nancy, France, 366pp.

Poonia, P. K., Tripathi, S., Sihag, K., & Kumar, S. (2015). Effect of microwave treatment on air permeability and preservative impregnation of Eucalyptus tereticornis wood. Journal of the Indian Academy of Wood Science, 12(2), 89-93.

Rahimi, S., Singh, K., DeVallance, D., Chu, D., & Bahmani, M. (2022). Drying behavior of hardwood components (sapwood, heartwood, and bark) of red oak and yellow-poplar. Forests, 13(5), 722.

Rahimi, S., Singh, K, & DeVallance, D. (2019). Effect of different hydrothermal treatments (steam and hot compressed water) on physical properties and drying behavior of yellow poplar (*Liriodendron tulipifera*). Forest Products Journal, 69, 42-52.

Rahimi, S., Faezipour, M., & Tarmian, A. (2011). Drying of internal-check prone poplar lumber using three different conventional kiln drying schedules. Journal of the Indian Academy of Wood Science, 8(1), 6-10.

Rhatigan, R. G., Milota, M. R., Morrell, J. J., & Lavery, M. R. (2003). Effect of high temperature drying on permeability and treatment of western hemlock lumber. Forest products journal, 53.

Rousset, P., Perré, P., & Girard, P. (2004). Modification of mass transfer properties in poplar wood (*P. robusta*) by a thermal treatment at high temperature. Holz als Roh-und Werkstoff, 62(2), 113-9.

Siau, J. F. (1995). Wood-Influence of moisture on wood properties. Blacksburg, Va.: Dept. of Wood Science and Forest Products, Virginia Polytechnic Institute and State University.

Taghiyari, H. R., & Malek, B. M. (2014). Effect of heat treatment on longitudinal air and liquid permeability of circular and square-shaped native hardwood specimens. Heat and Mass Transfer, 50(8), 1125-36.

Ward, J. C., & Pong, W. Y. (1980). Wetwood in trees: a lumber resource problem. USDA Forest Service General Technical Report PNW 112, Pacific North West Forest Range Station, Portland, Oregon, 56pp.

Yuan, L. (1994). Heat treatment of Eucalyptus wood and its permeability improvement. China Wood Industry, 1994; 8(3), 30-3. (In Chinese).

LES/WOOD Vol. 71, No. 2, 31-44
DOI: https://doi.org/10.26614/les-wood.2022.v71n02a02

CORRELATION BETWEEN DRY DENSITY AND SHRINKAGE IN EIGHT TROPICAL HARDWOOD SPECIES

ZVEZA MED GOSTOTO IN KRČENJEM LESA OSMIH TROPSKIH VRST

Adedeji Robert Ojo[1*], Samson Oluwaseun Ogutuga[1], Lawrence Olanipekun Aguda[1]

UDK 630*812:176.1
Original scientific article / Izvirni znanstveni članek

Received / Prispelo: 16.7.2022
Accepted / Sprejeto: 29.9.2022

Abstract / Izvleček

Abstract: Eight tropical hardwood species were assessed for their density and radial, tangential and volumetric shrinkage, after which the relation between the density and different shrinkages was checked through correlation and regression. The results showed that the highest mean density was observed in *Milicia excelsa* with 900.63±50.13 kg/m³, followed by *Afzelia africana*, *Nesogordonia kabingaensis* and *Nauclea diderichii* with 831.25±41.67 kg/m³, 808.75±20.88 kg/m³ and 801.88±46.40 kg/m³, respectively. The mean density for *Cassia simea* was 781.88±27.71 kg/m³, *Mansonia altissima* 593.13±65.98 kg/m³, and *Sterculia tragacantha* 481.25±111.73 kg/m³, while the least density was observed in *Treculia africana* with 463.75±67.88 kg/m³. The highest volumetric shrinkage was observed in *Nesogordonia kabingaensis* with 14.71±2.28%, and the least in *Cassia simea* with 5.11±2.65%. It is concluded that there exists positive but weak correlation between density and the shrinkages in the eight tropical hardwood species.

Keywords: wood, topical hardwoods, density, shrinkage

Izvleček: V raziskavi ocenjujemo zvezo med gostoto in krčenjem za osem tropskih lesnih vrst. Raziskali smo gostoto ter radialno, tangencialno in prostorninsko krčenje osmih tropskih lesnih vrst. Rezultati so pokazali, da je imela največjo povprečno gostoto vrsta *Milicia excelsa* z 900,63±50,13 kg/m³, sledijo *Afzelia africana*, *Nesogordonia kabingaensis* in *Nauclea diderichii* z 831,25±41,67 kg/m³, 808,75±20,88 kg/m³ in 801,88±46,40 kg /m³. Povprečna gostota za vrste *Cassia simea* je bila 781,88±27,71 kg/m³, *Mansonia altissima* 593,13±65,98 kg/m³, *Sterculia tragacantha* 481,25±111,73 kg/m³, medtem ko je bila najmanjša gostota opažena pri vrsti *Treculia africana* s 463,75±67,88 kg/m³. Največje prostorninsko krčenje je bilo zaznano pri vrsti *Nesogordonia kabingaensis* (14,71 ± 2,28 %), najmanjše pa pri vrsti *Cassia simea* (5,11 ± 2,65 %). Ugotavljamo, da obstaja šibka pozitivna korelacija med gostoto in krčenjem pri osmih tropskih vrstah listavcev.

Ključne besede: les, tropski listavci, gostota, krčenje

1 INTRODUCTION
1 UVOD

Water is a natural constituent of a living tree, and it commonly makes up over half the total weight; that is, the weight of water in green wood is commonly equal to or greater than the weight of the dry wood substance (Haygreen & Bower, 1996).

It is well known that wood is an anisotropic material which presents differential dimensional changes in the different structural directions. The magnitude of shrinkage and swelling is affected by the amount of moisture gained or lost by wood when the moisture content fluctuates between zero and the fibre saturation point (Usta & Guray, 2000).

Shrinking and swelling occur as the wood changes moisture content in response to daily as well as seasonal changes in the relative humidity of the atmosphere. That is, when the air is humid wood adsorbs moisture and swells, while when the

[1] Department of Forest Products Development and Utilization. Forestry Research Institute of Nigeria. P.M.B 5054, Jericho, Ibadan, Nigeria
* e-mail: ojo.ar@frin.gov.ng

air is dry, wood loses moisture and shrinks. Various finishes and treatments may be used to slow this process, but, in general, they do not stop it (Eckelman, 2012). Likewise, air and kiln drying do not prevent the wood from subsequently gaining or losing moisture. Thus, wood that is kiln dried to 6% moisture content and stored in a dry shed outdoors in a temperate climate, such as that found in Indiana, USA, will regain moisture until it eventually reaches about 12% moisture content. Under the same conditions in a tropical climate, the wood will come to a moisture content of about 16%. The resulting dimensional changes in the wood are a major source of defects in furniture and other wood structures (Ojo et al., 2016).

The changes in wood dimensions as a result of its shrinkage as it dries and swelling during moisture absorption are of great importance to anyone who uses wood, because wood readily takes on or gives off moisture, even from the atmosphere. When wood loses moisture below fibre saturation point (FSP), it shrinks and swells when water is absorbed. The percentage change in wood dimensions as a result of moisture loss is termed shrinkage (Dinwoodie, 1989). The observed changes in wood dimensions as a result of shrinkage are unequal along the three structural directions. This behaviour of wood has been documented widely by various authors (Panshin & de Zeeuw, 1980; Lausberg et al., 1995; Ogunsanwo, 2000; Ojo et al., 2016).

However, Panshin and de Zeeuw (1980), noted that the geometric disposition of cells along the principal directions is mainly responsible for this observation.

The moisture content is the water contained in wood and it is a natural constituent of all parts of a living tree and makes up about half of the total weight (Hossain et al., 1991). Desch and Dinwoodie (1983), reported that timber of living trees and freshly felled logs contains a large amount of water which has a profound influence on the properties of wood, such as weight and strength. Wood is also liable to attack by some insects and fungi when the moisture content is high.

Density is the amount of wood substance per unit volume. Panshin and de Zeeuw (1980), Dinwoodie (1981), and Desch (1988), explained that the density of wood is a function of the cell wall thickness and also depends on the level of cell wall development.

In research activities, densities are frequently reported on an oven-dry weight and volume basis. At any other condition the moisture content has a marked effect on density (Kellog, 1981). As the moisture content increases from the oven-dry condition up to fibre saturation point, the weight increases and as a result of swelling so does the volume (Kellog, 1981). Meanwhile, high density is associated with thick fibre walls and a higher proportion of fibres. These are the qualities which contribute to water absorption and resultant dimensional changes (Shrivastava, 1997). It is therefore necessary to ascertain that in the absence of any other data about the dimensional stability of a particular species, wood density is used as a guide to its utilization by establishing the relationship between the density and dimensional stability of some tropical hard wood species so as to serve as guide for their general technical application.

The eight tropical timbers assessed in this study are as follows: *Nauclea diderrichii* (African peach; opepe) is an evergreen tree that reaches a height of about 30-40 m and a diameter of 0.9-1.5 m; bole cylindrical, slender, straight and branchless, rising to 20-30 m and a broad spherical crown with thick foliage (Orwa, 2009).

It is a commercial timber of West Africa. The wood is yellow and darkens slightly when exposed to light. It is semi-heavy and of medium hardness. Because of its good mechanical properties and natural durability, which can be enhanced by preservative treatment, it is sought after as a timber for outdoor uses (harbour works, railway sleepers), buildings (carpentry, floors, facings, indoor and outdoor woodwork) and for cabinet making. The wood is also suitable for fence posts and bridges as it is moderately termite-resistant and resistant to fungi and marine borers (Orwa, 2009).

The wood is strong and moderately hard to hard. At 12% moisture content the modulus of rupture is 85–166 N/mm², modulus of elasticity 10,490–14,660 N/mm², compression parallel to grain 52–78 N/mm², shear 8.5–17 N/mm², cleavage (7–)12–24 N/mm, Janka side hardness 5790–7260 N, Janka end hardness 7140–9160 N and Chalais-Meudon side hardness 3.0–8.6. (Protabase, 2010).

Milicia excelsa (African teak; iroko) is large deciduous tree, growing up to 50 m high and 350 cm in trunk diameter. The trunk is often buttressed and can be branchless for up to 20 m (Barwick, 2004). The heartwood is pale yellow to yellow, darkening on exposure to yellowish or greenish brown or sometimes to chocolate brown. The wood is somewhat greasy and is odourless (Protabase, 2022).

The wood is of medium weight, moderately hard, of good durability, being resistant to fungi, dry wood borers and termites. The wood is a highly valued commercial timber in Africa, for which demand is also high. It is used for construction work, shipbuilding and marine carpentry, sleepers, sluice gates, framework, trucks, draining boards, outdoor and indoor joinery, stairs, doors, frames, garden furniture, cabinet work, panelling, flooring and profile boards for decorative and structural uses. It is also used for carving, domestic utensils, musical instruments and toys. As it is resistant to acids and bases, it is used for tanks and barrels for food and chemical products and for laboratory benches. It is used as sliced veneer but only rarely as rotary veneer. The wood is also used as firewood and for making charcoal (Protabase, 2022). At 12% moisture content, the modulus of rupture is 75–156 N/mm², modulus of elasticity 8300–13,300 N/mm², compression parallel to grain 42–65 N/mm², shear 5.4–14.1 N/mm², cleavage 10.3–20.9 N/mm, Janka side hardness 4400–5610 N, and Janka end hardness 5360–6640 N (Protabase, 2010).

Afzelia africana (afzelia) is an evergreen, small to fairly large tree up to 40 m tall; bole branchless for up to 20 m, usually straight and cylindrical, up to 150(–200) cm in diameter. Like other *Afzelia* spp., the wood of *Afzelia africana* is characterized by excellent stability with little susceptibility to variations in humidity and a good natural durability. The wood is durable and treatment with preservatives is unnecessary, even for usage in permanently humid conditions or in localities where wood-attacking insects are abundant. This makes it an excellent wood for use in pleasure-crafts, especially for keels, stems and panels, for bridges, as well as interior fittings. The wood is also valued for joinery and panelling, both interior and exterior, parquet floors, doors, frames, stairs, furniture and sporting goods. The wood is also used as firewood and for charcoal production (Gerard & Louppe, 2011).

The heartwood is orange-brown to golden brown, becoming red-brown upon prolonged exposure, sometimes with darker streaks. It is distinctly demarcated from the whitish to pale yellow, up to 8 cm wide sapwood. At 12% moisture content, the modulus of rupture is 105–145(–200) N/mm², modulus of elasticity (9100–)14,000–17,000 N/mm², compression parallel to grain 57–85 N/mm² (Gerard & Louppe, 2011).

Cassia siamea (*Senna siamea*; yellow casia; kassod tree) is large-sized tree species, with a height up to 20-25 m, diameter 50-60 cm. Its stem is cylindrical, twisted. The bark is grey, with regular small and narrow cracks, sometimes segments are formed due to the stem twisting at some points. (SSR-VINA, 2022). Sapwood and heartwood have different colours; sapwood is pale yellow, heartwood got yellowish-brown to blackish brown. *Senna siamea* wood can be used for structures requiring high durability in construction, and transport (SSR-VINA, 2022).

The pressure strength along the grain is 615kg/cm², the static bending strength is 1520kg/cm², splitting strength is 20kg/cm, collision bending is 0.64, Janka hardness 1,490 lbf (6,640 N), modulus of rupture 12,440 lbf/in2 (85.8 MPa), elastic modulus 1,581,000 lbf/in2 (10.90 GPa), crushing strength 10,150 lbf/in2 (70.0 MPa) (Wood database, 2018).

Mansonia altissima (African black walnut; African walnut) is an evergreen medium-sized to fairly large tree up to 45 m tall; bole branchless for up to 30 m, up to 100(–150) cm in diameter, generally straight, cylindrical. The wood is used for general and high-quality joinery, cabinet work, furniture, turnery, decorative veneer and handicrafts. It is also used in construction for doors and windows, in railway coaches and shop fittings, and for boxes and crates (Ohene-Coffie, 2008).

The heartwood is yellowish brown to dark grey-brown or even dark brown, often with purple, reddish or greyish green streaks, often in alternating light and dark bands. It fades on exposure to a somewhat dull brown. It is distinctly demarcated from the 2–4(–6) cm wide, white to pinkish sapwood. The grain is usually straight and the texture fine. The wood is moderately lustrous (Ohene-Coffie, 2008). At 12% moisture content the modulus of rupture is (61–)114–177(–183) N/mm², modulus of elasticity 9320–12,800 N/mm², compression parallel to grain 43–68(–96) N/mm², shear 6–15 N/mm², cleavage 9–23 N/mm, Janka side hardness 5690–7470 N and Janka end hardness 5740–7470 N (Protabase, 2010).

Treculia africana (African breadfruit) is a large, slow-growing, evergreen tree with a dense, spreading crown; usually growing 15–30 m tall but with some specimens up to 50 m. The bole is fluted. It is a very valuable food crop in Africa, providing a nutritious protein and oil rich food. It is thus often grown in and around African villages where it is commonly harvested for its edible seeds, which are sold in local markets. Trees are often protected when land is cleared for agriculture (Ken Fern, 2022).

The heartwood is yellow with very narrow pale sapwood that is very dense, fairly elastic and flexible, rather heavy, with a fine, even structure. It is suitable for furniture, carving, turnery and inlay wood, as well as for pulp and papermaking. The wood is used for fuel and making charcoal (Ken Fern, 2022). The wood density of the species is 674 kg/m³ (Keay, 1989). The wood is fairly elastic and flexible (Torelli & Čufar, 1995) and has an even structured fine grain, and saws and planes very easily.

Sterculia tragacantha (African tragacanth) is a tree to about 28 m high, the bole sometimes with buttresses, girth up to 1.5 m by 10–15 m long, bearing a crown of pseudo-whorled branches. It used for building materials (made from the bark), fibre (wood), pulp and paper (wood), carpentry and related applications (gum, wood), farming, forestry, hunting and fishing equipment (gum) (Burkill, 1985).

Nesogordonia kabingaensis (danta) is a medium-sized to large tree up to 45(–50) m tall, mostly evergreen but sometimes briefly deciduous. The bole is usually straight and cylindrical, branchless for up to 25 m and 80(–120) cm in diameter, with narrow buttresses up to 3 m high (Oyen, 2005).

The heartwood is pale brown to purplish brown with a tendency to become lighter on exposure to light, distinctly demarcated from the pale brown to pink sapwood, which is 2–5(–10) cm thick. The grain is straight or interlocked, the texture fine. At 12% moisture content the modulus of rupture is 108–183(–231) N/mm², modulus of elasticity (7800–)10,900–16,200 N/mm², compression parallel to grain 45–75 N/mm², shear 8–16 N/mm², and cleavage 13–31 N/mm (Oyen, 2005).

The species *Nauclea diderrichii*, *Mansonia altissima*, *Nesogordonia kabingaensis*, *Cassia simea*, *Afzelia africana* and *Milicia excelsa* are all well known, while *Treculia africana* and *Sterculia tragantha* are less familiar. They grow in the natural forests in Nigeria, and due to the afforestation and reforestation efforts of the government and private individuals a number of plantations of the species are being established. The trees are very important in Nigeria and elsewhere because the woods are hardwood and naturally durable, and thus suitable for various construction purposes.

The general objective of this study is to establish the relationship between the density and shrinkage/swelling of the wood of the selected species, and thus its specific objectives are as follows: determination of density, evaluation of the radial, tangential and volumetric shrinkage of the wood and their correlations with the density.

2 MATERIALS AND METHODS
2 MATERIALI IN METODE

2.1 DETERMINATION OF WOOD DENSITY
2.1 DOLOČANJE GOSTOTE LESA

Two discs, 20 cm long were cut from each of the species at the base and top. Selection of representative samples for test was carried out from the central planks obtained from each of the discs to give 16 planks from where test samples for all the experiments were obtained. Ten samples were collected for each of the species from the bark to the pith resulting in eighty (80) test samples. For the determination of density, test samples of dimensions 20 x 20 x 60 mm were produced from the central planks. The test samples were oven-dried to a constant weight, and the density was thus determined as given below in accordance with the American Standard for Testing Materials (ASTM D) 2395 (1983):

$$D = \frac{M}{V}\left(\frac{kg}{m^3}\right) \tag{1}$$

Where:
D = density
M = weight of the wood
V = volume of wood

2.2 DETERMINATION OF PERCENTAGE SHRINKAGE
2.2 DOLOČANJE KRČENJA

Test specimens of 20 x 20 x 60 mm were produced, which were then properly aligned and denoted 'T' and 'R' for tangential and radial planes, respectively. They were soaked in water for 48 hrs in order to get them conditioned to moisture above the fibre saturation point (FSP). Specimens were removed one after the other, and their dimensions in wet condition were taken to the nearest millimetre with the aid of a vernier calliper. The percentage shrinkages along the two planes were measured after specimens had been oven-dried as

$$S = \frac{D_S - D_O}{D_S} x100 \tag{2}$$

Where:
S = shrinkage %
D_S = dimensions at saturated condition
D_O = dimensions at oven dry condition

Volumetric shrinkage is approximately equal to the sum of radial and tangential shrinkage, as given below:

$$S_v = S_R + S_T \tag{3}$$

Where:
S_V = volumetric shrinkage
S_R = radial shrinkage
S_T = tangential shrinkage

This is in accordance with the approximations done by Dinwoodie (1989).

$$Anisotropy = \frac{S_T}{S_R} \tag{4}$$

2.3 EXPERIMENTAL DESIGN AND DATA ANALYSIS
2.3 EKSPERIMENTALNA ZASNOVA IN ANALIZA PODATKOV

The design adopted for the experiment was a completely randomized design with ten replications each and the data obtained were subjected to analysis of variance (ANOVA), correlation, linear and non-linear regression.

3 RESULTS AND DISCUSSION
3 REZULTATI IN RAZPRAVA

3.1 DENSITY
3.1 GOSTOTA

The highest mean density was observed in *Milicia excelsa* with 900.63±50.13 kg/m³, followed by *Afzelia africana*, *Nesogordonia kabingaensis* and *Nauclea diderichii* with 831.25±41.67 kg/m³, 808.75±20.88 kg/m³ and 801.88±46.40 kg/m³, respectively. The mean density for *Cassia simea* was 781.88±27.71 kg/m³, *Mansonia altissima* 593.13±65.98 kg/m³, and *Sterculia tragacantha* 481.25±111.73 kg/m³, while the least density was observed in *Treculia africana* with 463.75±67.88 kg/m³.

According to Brandon (2005), who classified wood species based on their density (the density of seasoned timber is usually measured for classification purposes at 12% air-dry MC) as follows: exceptionally light – under 300 kg/m³, light – 300 to 450 kg/m³, medium – 450 to 650 kg/m³, heavy – 650 to 800 kg/m³, and very heavy – 800 to 1000+ kg/m³. Based on this classification, *Milicia excelsa*, *Afzelia africana*, *Nesogordonia kabingaensis* and *Nauclea diderichii* are termed very heavy density wood while *Cassia simea* to be heavy and *Mansonia altissima*, *Sterculia tragacantha* and *Treculia africana* have medium density wood (Table 1).

According to Jane (1970), wood from different parts of a tree is noted to show differences in density, and according to Panshin and de Zeeuw (1980) this variation exists horizontally from the pith to the periphery, and vertically from the base to the crown of the tree. According to the United nations Food and Agriculture Organization (1985), timber should be graded hard, intermediate or soft, corresponding to high, medium and low densities. The technical limits between the grades are: high density above 500 kg/m³, medium density between 500

Table 1. Mean values of the parameters from the eight hardwood species; density = oven dry density, ST, SR, SV – tangential, radial and volumetric shrinkage.
Preglednica 1. Povprečne vrednosti parametrov lastnosti lesa za osem tropskih listavcev; density – gostota lesa v absolutno suhem stanju, ST, SR, SV – tangencialni, radialni in prostorninski skrček, anisotropy – anizotropija krčenja.

Species	Density (kg/m³)	S_T (%)	S_R (%)	S_V (%)	Anisotropy
Nauclea diderrichii	801.88^{a}±46.40	4.44^{a}±1.42	4.36^{a}±1.64	8.79^{a}±1.67	1.32^{a}±1.00
Mansonia altissima	593.13^{c}±65.98	3.96^{a}±1.34	5.20^{ab}±1.74	9.16^{a}±1.55	0.88^{a}±0.49
Treculia africana	463.75^{b}±67.88	3.30^{a}±1.23	3.91^{a}±1.49	7.21^{ab}±1.42	1.08^{a}±0.76
Sterculia tragacantha	481.25^{b}±111.73	3.92^{a}±1.59	3.71^{a}±1.06	7.64^{ab}±0.96	1.24^{a}±0.71
Nesogordonia kabingaensis	808.75^{a}±20.88	7.74^{b}±1.40	6.98^{b}±1.63	14.71^{c}±2.28	1.15^{a}±0.20
Cassia siamea	781.88^{a}±27.71	3.77^{a}±3.21	3.65^{a}±1.56	5.11^{b}±2.65	2.09^{a}±0.10
Afzelia africana	831.25^{a}±41.67	4.30^{a}±2.01	3.12^{a}±2.24	7.42^{ab}±3.02	2.01^{a}±1.57
Milicia excelsa	900.63^{d}±50.13	4.34^{a}±0.90	3.98^{a}±1.02	8.32^{a}±1.34	1.17^{a}±0.45

Values with the same letters are not significantly different from one another.
Vrednosti z isto črko niso značilno različne.

and 350 kg/m³, low density less than 350 kg/m³, and only high density timber is acceptable for structural purposes.

Chaffe (1991) reported that high cellulose content in wood is a good indication of high density and low lignin content. Density varies greatly depending on the anatomical structure of the wood.

However, the results of ANOVA show that there is a significant difference among the wood species (Table 2) regarding density. The results of correlation analysis indicated that there was a positive correlation between density and tangential shrinkage (0.236) at a 0.01 level of probability, and a positive but not significant correlation among density, radial shrinkage and volumetric shrinkage (Table 3).

Table 2. Analysis of variance of all parameters.
Preglednica 2. Analiza variance vseh parametrov.

		F-values				
SV	df	density	SR	ST	SV	Anisotropy
Species	7	79.07*	5.8112*	5.9619*	19.756*	0.76ns
Error	72					
Total	79					

* = significant at 0.05 level of probability
ns = not significant at 0.05 level of probability
* = značilno pri stopnji verjetnosti 0,05
ns = ni značilno pri stopnji verjetnosti 0,05

3.2 RADIAL SHRINKAGE
3.2 RADIALNO KRČENJE

The highest mean radial shrinkage was observed in *Nesogordonia kabingaensis* with 6.98±1.63%, followed by *Nauclea diderichii*, *Milicia excelsa* and *Mansonia altissima* with 4.36±1.64%, 3.98±1.02% and 3.96±1.34%, respectively. The mean RS for *Cassia simea* was 3.65±1.56%, *Afzelia africana* 3.12±2.24%, *Sterculia tragacantha* 3.71±1.06% and for *Treculia africana* 3.30±1.23% (Table 1).

Ogunsanwo (2000), in his work on *Triplochiton scleroxylon*, and Choong et al. (1989) as well as Poku et al. (2001), all reported significant differ-

Table 3. Pearson correlation matrix for the tested parameters.
Preglednica 3. Matrika s Pearsonovimi korelacijskimi koeficienti za testirane parametre.

	D	S_R	S_T	S_V
D	1.00			
S_R	0.107	1.00		
S_T	0.236*	0.232*	1.00	
S_V	0.191	0.671**	0.644**	1.00

** Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level
** Korelacija je značilna na ravni 0,01
* Korelacija je značilna na ravni 0,05

Table 4. Linear and non-linear models of the relationship between oven dry density and shrinkage (S_T, S_R, S_V – tangential, radial and volumetric shrinkage) for each of the species.
Preglednica 4. Linearni in nelinearni modeli za proučevanje zveze med gostoto lesa in krčenjem (S_T, S_R, S_V – tangencialni, radialni in prostorninski skrček) vsako vrsto.

Species	Models	ST	SR	SV
Nauclea diderrichii	Simple Linear	y = -7.967x + 837.2 R^2 = 0.059	y = 17.77x + 724.4 R^2 = 0.396	y = 11.42x + 701.3 R^2 = 0.169
	Exponential	y = 837.9e-0.01x R^2 = 0.063	y =726.9e0.022x R^2 = 0.397	y =707.6e0.014x R^2 = 0.164
	Logarithmic	y = -11.4ln(x) + 817.6 R^2 = 0.025	y = 58.76ln(x) + 720.1 R^2 = 0.341	y = 88.21ln(x) + 611.5 R^2 = 0.142
	Polynomial	y = -10.58x2 + 55.96x + 781.2 R^2 = 0.234	y = -0.392x2 + 21.43x + 716.9 R^2 = 0.397	y = 3.413x2–48.16x + 952.8 R^2 = 0.232
	Power	y = 817.3x-0.01 R^2 = 0.028	y = 722.9x0.073 R^2 = 0.343	y = 634.1x0.108 R^2 = 0.137
Mansonia altissima	Simple Linear	y = 11.73x + 546.6 (R^2 = 0.056)	y = 12.85x + 530.1 R^2 = 0.053	y = 22.32x + 388.6 R^2 = 0.275
	Exponential	y = 537.4e0.023x R^2 = 0.057	y = 520.8e0.025x R^2 = 0.053	y = 398.2e0.042x R^2 = 0.265
	Logarithmic	y = 47.69ln(x) + 529.6 R^2 = 0.052	y = 12.85x + 530.1 R^2 = 0.053	y = 226.1ln(x) + 95.09 R^2 = 0.318
	Polynomial	y = -1.357x2 + 24.15x + 520.9 R^2 = 0.057	y = 19.12x2–176.5x + 974.9 R^2 = 0.165	y = -16.05x2 + 330.1x–1049. R^2 = 0.534
	Power	y = 519.3x0.094 R^2 = 0.054	y = 505.8x0.097 R^2 = 0.035	y = 226.3x0.434 R^2 = 0.309
Treculia africana	Simple Linear	y = 32.89x + 355.1 R^2 = 0.377	y = -7.649x + 493.6 R^2 = 0.028	y = 17.56x + 337.1 R^2 = 0.136
	Exponential	y = 364.4e0.07x R^2 = 0.366	y = 494.0e-0.01x R^2 = 0.036	y = 357.4e0.034x R^2 = 0.114
	Logarithmic	y = 55.04ln(x) + 403.3 R^2 = 0.178	y = -6.03ln(x) + 471.4 R^2 = 0.001	y = 113.5ln(x) + 241.6 R^2 = 0.128
	Polynomial	y = 33.18x2–161.3x + 586.5 R^2 = 0.882	y = -9.652x2 + 69.81x + 357.6 R^2 = 0.219	y = 3.794x2–34.50x + 508.3 R^2 = 0.144
	Power	y = 404.4x0.115 R^2 = 0.168	y = 471.4x-0.02 R^2 = 0.004	y = 295.9x0.224 R^2 = 0.107
Sterculia tragacantha	Simple Linear	y = -22.10x + 568.1 R^2 = 0.099	y = 60.91x + 255.1 R^2 = 0.332	y = -2.491x + 534.2 R^2 = 0.013
	Exponential	y = 595.0e-0.06x R^2 = 0.084	y = 232.0e0.185x R^2 = 0.303	y = 534.4e-0.00x R^2 = 0.013
	Logarithmic	y = -34.2ln(x) + 522.4 R^2 = 0.054	y = 244.2ln(x) + 170.3 R^2 = 0.420	y = -18.9ln(x) + 553.5 R^2 = 0.015
	Polynomial	y = -9.615x2 + 37.15x + 505.6 R^2 = 0.138	y = -74.71x2 + 621.7x–721.9 R^2 = 0.672	y = 2.589x2–40.01x + 667.6 R^2 = 0.032
	Power	y = 521.5x-0.10 R^2 = 0.047	y = 178.4x0.745 R^2 = 0.387	y = 555.3x-0.03 R^2 = 0.015

Species	Models	ST	SR	SV
Nesogordonia kabingaensis	Simple Linear	y = -7.817x + 869.2 R^2 = 0.273	y = -5.706x + 848.5 R^2 = 0.200	y = -5.892x + 895.4 R^2 = 0.413
	Exponential	y = 871.2e-0.01x R^2 = 0.273	y = 848.7e-0.00x R^2 = 0.196	y = 899.3e-0.00x R^2 = 0.408
	Logarithmic	y = -57.0ln(x) + 924.6 R^2 = 0.276	y = -41.9ln(x) + 889.2 R^2 = 0.206	y = -83.0ln(x) + 1031. R^2 = 0.431
	Polynomial	y = 0.335x2–12.78x + 886.9 R^2 = 0.273	y = 0.259x2–9.625x + 862.6 R^2 = 0.202	y = 0.580x2–22.30x + 1008. R^2 = 0.440
	Power	y = 932.8x-0.07 R^2 = 0.276	y = 891.8x-0.05 R^2 = 0.201	y = 1062.x-0.10 R^2 = 0.426
Cassia siamea	Simple Linear	y = -3.671x + 795.7 R^2 = 0.181	y = -6.415x + 807.8 R^2 = 0.063	y = -5.760x + 815.4 R^2 = 0.064
	Exponential	y = 795.1e-0.00x R^2 = 0.180	y = 807.4e-0.00x R^2 = 0.063	y = 814.5e-0.00x R^2 = 0.062
	Logarithmic	y = -18.0ln(x) + 800.0 R^2 = 0.329	y = -22.6ln(x) + 812.9 R^2 = 0.041	y = -43.0ln(x) + 856.9 R^2 = 0.099
	Polynomial	y = 0.745x2–12.59x + 811.8 R^2 = 0.280	y = -6.455x2 + 52.86x + 680.5 R^2 = 0.148	y = 10.06x2–131.3x + 1192. R^2 = 0.379
	Power	y = 799.4x-0.02 R^2 = 0.324	y = 812.4x-0.02 R^2 = 0.041	y = 857.6x-0.05 R^2 = 0.095
Afzelia africana	Simple Linear	y = 1.969x + 822.7 R^2 = 0.009	y = 4.403x + 817.5 R^2 = 0.056	y = 3.310x + 806.6 R^2 = 0.057
	Exponential	y = 821.4e0.002x R^2 = 0.010	y = 4.403x + 817.5 R^2 = 0.056	y = 805.3e0.004x R^2 = 0.064
	Logarithmic	y = 18.81ln(x) + 805.6 R^2 = 0.047	y = 24.28ln(x) + 808.6 R^2 = 0.176	y = 31.82ln(x) + 770 R^2 = 0.111
	Polynomial	y = -4.708x2 + 49.52x + 722.5 R^2 = 0.222	y = -3.664x2 + 41.90x + 752.7 R^2 = 0.331	y = -1.561x2 + 28.64x + 717.5 R^2 = 0.209
	Power	y = 804.7x0.023 R^2 = 0.050	y = 807.8x0.029 R^2 = 0.187	y = 770.2x0.039 R^2 = 0.120
Milicia excelsa	Simple Linear	y = 21.91x + 805.4 R^2 = 0.157	y = 8.825x + 865.4 R^2 = 0.032	y = 15.17x + 774.3 R^2 = 0.165
	Exponential	y = 809.2e0.024x R^2 = 0.163	y = 865.7e0.009x R^2 = 0.032	y = 782.6e0.016x R^2 = 0.169
	Logarithmic	y = 93.44ln(x) + 765.4 R^2 = 0.166	y = 40.23ln(x) + 846.3 R^2 = 0.047	y = 115.7ln(x) + 657.0 R^2 = 0.169
	Polynomial	y = -9.791x2 + 105.7x + 633.4 R^2 = 0.177	y = -19.18x2 + 160.7x + 582.8 R^2 = 0.165	y = -2.082x2 + 47.29x + 654.6 R^2 = 0.170
	Power	y = 774.2x0.103 R^2 = 0.172	y = 848.0x0.043 R^2 = 0.047	y = 687.5x0.127 R^2 = 0.173

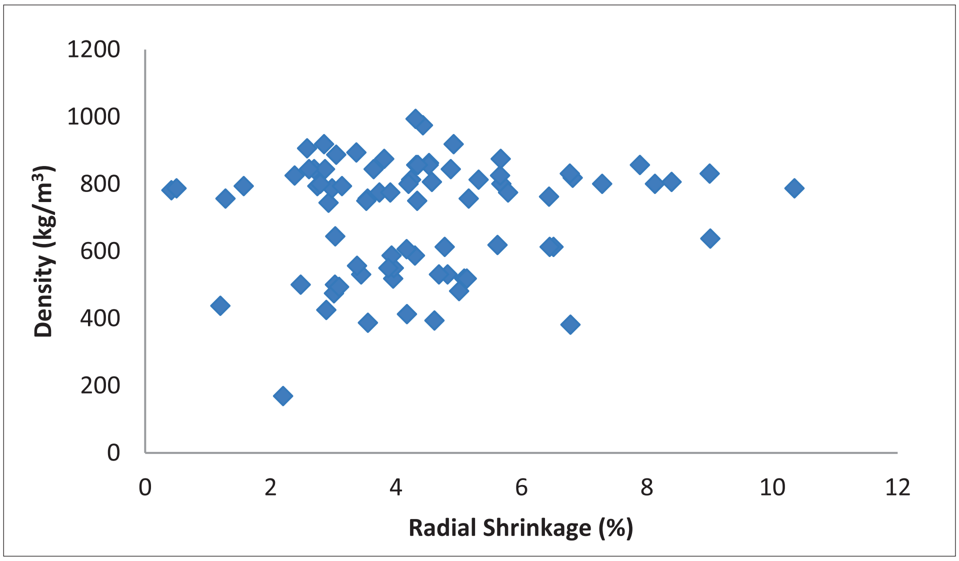


Figure 1. Wood density and radial shrinkage of the eight tropical wood species.
Slika 1. Gostota lesa in radialno krčenje osmih tropskih lesnih vrst.

ences between radial and tangential shrinkage on lesser-used hardwood species from Ghana. Lausberget et al. (1985), reported that this could have been caused by the presence of ray cells on the radial plane, with their horizontally aligned cells producing a restraining effect on radial shrinkage. However, Panshin and de Zeeuw (1980) noted that it is related to the rapid reduction of the microfibril angle in the cell wall.

The results of the analysis of variance of radial shrinkage show that there were significant differences among the wood species at a 0.05 level of probability (Table 2). However, the results of correlation analysis indicate that there was strong and positive significant correlation between radial and tangential shrinkage (0.644**) at a 0.05 level of probability (Table 3), but of all the models developed none of them has a good fit because of the low R^2 for all the species (Fig. 1 and Table 4)

The observed changes in wood dimensions as a result of shrinkage are unequal along the three structural directions. This behaviour of wood has been documented widely by various authors (Panshin and de Zeeuw 1980; Dinwoodie, 1981; Lausberg et al., 1995; Ogunsanwo, 2000). However, Panshin and de Zeeuw (1980) noted that the geometric disposition of cells along the principal directions is mainly responsible for this observation.

Osadare (2001) observed that the noticeable variations in wood properties are influenced principally by (i) the changes in activities of cambium as it grows older, (ii) genetic constitutions which govern the form and growth of the tree, and (iii) environmental influences. However, the interaction of these factors made it difficult to attribute the observed variations in wood properties to only a single factor. The variability of wood characteristics within individual trees is basically related to changes resulting from ageing of the cambium and modifications imposed on the cambial activity by the environmental conditions, genetic and silvicultural effects, as noted by Evans (1991).

3.3 TANGENTIAL SHRINKAGE
3.3 TANGENCIALNO KRČENJE

The highest tangential shrinkage was observed in *Nesogordonia kabingaensis* with 7.74±1.40%, followed by *Mansonia altissima* (5.20±1.74%), *Nauclea diderichii* (4.44±1.42%) and *Milicia excelsa* (4.34±0.90%). The mean tangential shrinkages for *Sterculia tragacantha*, *Afzelia africana*, *Treculiaafricana* were 3.92±1.59%, 4.30±2.01% and 3.91±1.49%, respectively, while the least tangential shrinkage was observed in *Cassia simea* with 3.77±3.21% (Table 1). According to the classification of Bolza and Keating (1972), TEDB (1994) and Upton and Attah (2003), the tangential shrinkage values are classified as small (3.5-5.0%), medium (5.1-6.0%), large (6.1-8.0%) and very large (above 8.0%)

The results of the analysis of variance of tangential shrinkage show that there were significant differences among the wood species at a 0.05 level of probability (Table 2), while the follow-up analy-

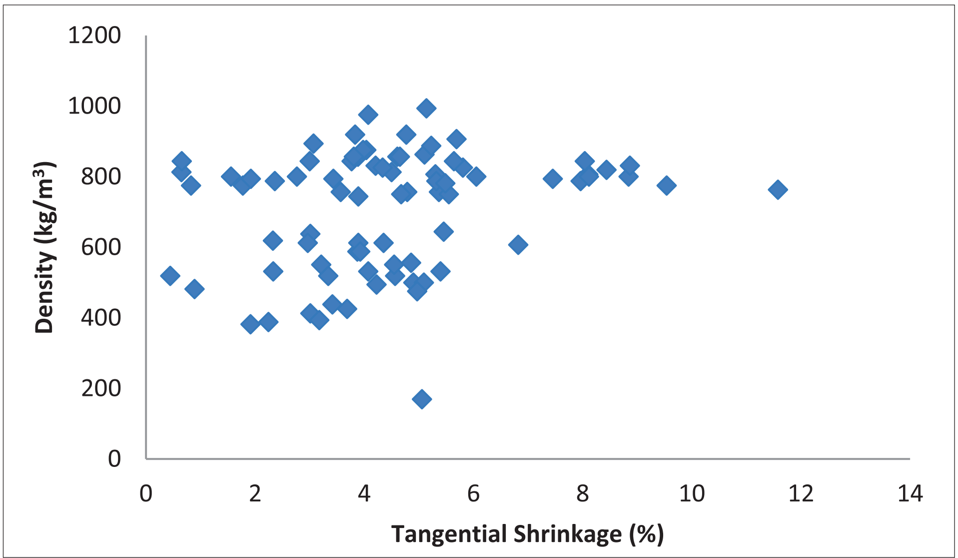


Figure 2. Wood density and tangential shrinkage of the eight tropical wood species.
Slika 2. Gostota lesa in tangencialno krčenje osmih tropskih lesnih vrst.

sis shows that there was no significant difference among the species except for *Nesogordonia kabingaensis* (Table 1). However, the results of the correlation analysis indicated that there was a strong and positive significant correlation between tangential shrinkage and radial shrinkage (0.232*) at the 0.01 level of probability, and a positive but not significant correlation between tangential and volumetric shrinkage (Table 3). Likewise, of all the models developed none of them had a good fit with the data because of the low R^2 for all the species (Fig. 2 and Table 4).

The greatest dimensional shrinkage occurs along the tangential plane, followed by shrinkage along the radial plane while longitudinal shrinkage has been widely reported to be the smallest, ranging from 0.1 to 0.3% (Desch, 1988; Dinwoodie, 1989). The suitability of wood for various end uses has been linked with the tangential/radial shrinkage ratio (ST/SR), also known as anisotropy. Panshin and de Zeeuw (1980) noted that a low value of T/R is synonymous with high suitability of wood for end uses. In this study, it is observed that the anisotropy found for the eight species is low, as can be seen in Table 1.

3.4 VOLUMETRIC SHRINKAGE
3.4 PROSTORNINSKO KRČENJE

The highest volumetric shrinkage was observed in *Nesogordonia kabingaensis*, at 14.71±2.28%, followed by *Mansonia altissima* (9.16±1.55%) *Nauclea diderichii* (8.79±1.67%) and *Milicia excelsa* (8.32±1.34%). The mean volumetric shrinkages for *Sterculia tragacantha*, *Afzelia africana*, and *Treculia Africana* were 7.64±0.96%, 7.42±3.02% and 7.21±1.42%, respectively. The least volumetric shrinkage was observed in Cassiasimea, at 5.11±2.65% (Table 1). Poku et al. (2001), recorded volumetric shrinkages of 7.51%, 11.51% and 6.21% for *Alstonia boonei. Pterocarpus macrocarpus* and *Ricinodendron hendelotti*, respectively, while Kiaei and Samariha (2011) obtained 12.39% for *Ulmus glabra* grown in Iran.

The wide disparity among the eight species could be attributed to their densities and probably the presence of more biomass in latewood cells, as noted by Chudnoff (1976). However, many other factors, such as spiral grain and latewood proportion, also affect the variation in the shrinkage of wood (Pilura et al, 2005; Walker, 2006)

The results of the analysis of variance of tangential shrinkage show that there were significant differences among the wood species at a 0.05 level of probability (Table 2). Moreover, none of the models developed in this work had a good fit because of the low R^2 for all the species (Fig. 3 and Table 4).

4 CONCLUSIONS
4 SKLEPI

The use of the eight tropical hardwood species for this study has provided useful information

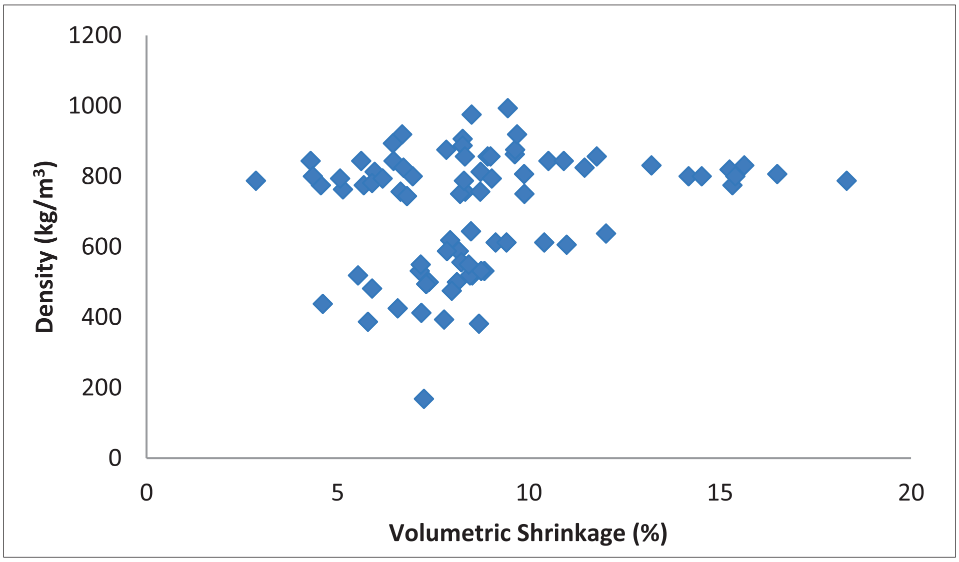


Figure 3. Wood density and volumetric shrinkage of the eight tropical wood species.

Slika 3. Gostota lesa in prostorninsko krčenje osmih tropskih lesnih vrst.

regarding the density, shrinkage and anisotropy of the wood and the relationships among them.

Based on the findings of this study, the following conclusions were made. *Nesogordonia kabingaensis* shrinks more than the other species studied. Along the radial and tangential plane, there was a positive correlation between wood density, radial, tangential, and volumetric shrinkage but a weak coefficient of fitness R^2 for the linear and non-linear models for all the species. Statistically significant differences among the eight species could not be established for all the studied parameters.

5 SUMMARY

5 POVZETEK

Izbrali smo les osmih tropskih vrst: *Nauclea diderichii*, *Mansonia altissima*, *Treculia africana*, *Sterculia tragacantha*, *Nesogordonia kabingaensis*, *Cassia simea*, *Afzelia africana*, *Milicia excelsa* in raziskali gostoto, radialno, tangencialno in volumsko krčenje ter anizotropijo krčenja ter povezave med njimi. Večina vrst je uveljavljenih, samo *Treculia africana* in *Sterculia tragantha* sta z vidika lastnosti lesa manj znani.

Za določanje gostote lesa v absolutno suhem stanju so bili izdelani testni vzorci dimenzij 20 x 20 x 60 mm iz centralnih desk spodnjega dela debel. Testni vzorci so bili posušeni v laboratorijskem sušilniku do konstantne mase, gostota lesa pa je bila tako določena v skladu z ameriškim standardom za testiranje materialov (ASTM D) 2395 (1983). Izdelani so bili orientirani vzorci velikosti 20 x 20 x 60 mm; za merjenje tangencialnih in radialnih skrčkov. Les so namočili v vodo za 48 ur, da je dosegel vlažnost nad točko nasičenja celičnih sten (FSP). Dimenzije v mokrem stanju so bile natančno določene s pomočjo Venierovega merilnika. Odstotek krčenja vzdolž obeh ravnin je bil izmerjen po tem, ko so vzorci v sušilniku dosegli ravnovesno, absolutno suho stanje.

Največjo povprečno gostoto je imel les vrste *Milicia excelsa* z 900,63±50,13 kg/m³, sledijo *Afzelia africana*, *Nesogordonia kabingaensis* in *Nauclea diderichii* z 831,25±41,67 kg/m³, 808,75±20,88 kg/m³ oziroma 801,88±46,40 kg/m³. Povprečna gostota za les vrst *Cassia simea* je bila 781,88±27,71 kg/m³, *Mansonia altissima* 593,13±65,98 kg/m³, *Sterculia tragacantha* 481,25±111,73 kg/m³, medtem ko je imela najmanjšo gostoto vrsta *Treculia africana* s 463,75±67,88 kg/m³ (preglednica1).

Največje povprečno radialno krčenje je bilo pri lesu vrste *Nesogordonia kabingaensis* s 6,98 ± 1,63 %, sledijo *Nauclea diderichii*, *Milicia excelsa* in *Mansonia altissima* s 4,36 ± 1,64 %, 3,98 ± 1,02 % in 3,96 ± 1,34 %. Povprečen radialni skrček pri vrsti *Cassia simea* je bil 3,65 ± 1,56 %, pri vrsti *Afzelia africana* 3,12 ± 2,24 %, pri *Sterculia tragacantha* 3,71 ± 1,06 % in pri *Treculia africana* 3,30 ± 1,23 % (preglednica 1).

Največje tangencialno krčenje je bilo zabeleženo pri vrsti *Nesogordonia kabingaensis* s 7,74 ± 1,40 %, sledijo *Mansonia altissima* (5,20 ± 1,74 %), *Nauclea diderichii* (4,44 ± 1,42 %) in *Milicia excelsa*

(4,34 ± 0,90 %), srednje tangencialno krčenje je imel les vrst *Sterculia tragacantha*, *Afzelia africana* in *Treculia africana* (3,92±1,59 %, 4,30±2,01 % in 3,91±1,49 %), medtem ko je bilo najmanjše tangencialno krčenje opaženo pri vrsti *Cassia simea* s 3,77 ± 3,21 % (preglednica1).

Največje prostorninsko krčenje so opazili pri vrsti *Nesogordonia kabingaensis* s 14,71 ± 2,28 %, sledijo *Mansonia altissima* (9,16 ± 1,55 %), *Nauclea diderichii* (8,79 ± 1,67 %) in *Milicia excelsa* (8,32 ± 1,34 %), povprečno prostorninsko krčenje za vrste *Sterculia tragacantha*, *Afzelia africana*, *Treculia africana* je bilo 7,64±0,96 %, 7,42±3,02 % oziroma 7,21±1,42 %. (preglednica 1).

Za les osmih raziskanih tropskih listavcev smo ovrednotili tudi povezave med gostoto absolutno suhega lesa in krčenjem lesa, vendar nismo mogli potrditi statistično značilne povezave.

Na podlagi raziskav ugotavljamo, da se les vrste *Nesogordonia kabingaensis* krči bolj kot les drugih vrst. Determinacijski koeficient R^2 je bil v vseh primerih prenizek, da bi lahko potrdili zvezo med gostoto lesa ter radialnim, tangencialnim in prostorninskim krčenjem.

REFERENCES
VIRI

American Society for Testing and Materials D 2395-83 (ASTM) (1983). Standard test methods for specific gravity of wood and wood-base materials. West Conshohocken, Pennsylvania. Reapproved in 2007, 9.

Barwick, M. (2004). Tropical and subtropical trees–A worldwide encyclopaedic guide. London: Thames & Hudson.

Bolza, E., & Keating, W. G. (1972). African timbers – the properties, uses and characteristics of 700 species. Melbourne: CSIRO, Division of Building Research, 1-9.

Brandon, J. (2005). Properties of wood. Builders guide to aircraft materials – Wood, plywood and adhesives modules. AUF Australia, 9.

Burkill, H.M. 1985. The useful plants of west tropical Africa, Vol 5. Sterculia tragacantha Lindl. [family STERCULIACEAE]. Herbarium: Royal Botanic Gardens, Kew (K). URL: https://plants.jstor.org/stable/10.5555/al.ap.upwta.5_294 (30.7.2022)

Chaffe, S. C. (1991). A relationship between equilibrium moisture content and specific gravity in wood. Journal of institute of wood science, 12(3), 119-122.

Choong, E. T., Fogg, P. J., & Shoulders, E. (1989). Effect of cultural treatments and wood types on some physical properties of long leaf and slash pine wood. Wood and fibre science, 21(2), 193-206.

Chudnoff, M. (1976). Density of tropical timbers as influence by climatic life zones. Commonwealth Forestry Review, 55(3), 203-217.

Desch, H. E. (1988). Timber: Its structure, properties and utilization. 6th Edition. London: Macmillian Education, 410.

Desch, H. E., & Dinwoodie, J. M. (1983). Timber: Its structure, properties and utilization. 6th Edition. London: Macmilliam Education, 410.

Dinwoodie, J. M. (1981). Timber: Its nature and behaviour. New York: Van Nostrand Reinhold, 190.

Dinwoodie, J. M. (1989). Wood: Nature's cellular, polymeric fibre composite. London: The Institute of Metal, 138.

Eckelman, C. A. (2012). The shrinking and swelling of wood and its effect on furniture. Forestry and natural resources. FRN 163. Purdue university cooperative Extension Service. Department of Forestry &Natural Resources 1159 Forestry Bldg. West Lafayette, IN 479071.

Evans, P. D. (1991). The strength properties of clear wood materials forum 15, 231 – 244.

Food and Agriculture Organization of the United Nations (FAO), (1985). Coconut wood processing and use. FAO paper 57, Rome, 64.

Gerard, J., & Louppe, D. (2011). *Afzelia africana* Sm. ex Pers. In: Lemmens, R. H. M. J., Louppe, D. & Oteng-Amoako, A.A. (Editors). PROTA (Plant Resources of Tropical Africa/Ressources-végétales de l'Afriquetropicale), Wageningen. URL: https://www.feedipedia.org/sites/default/files/public/gerard_2011.pdf (29.7.2022)

Haygreen, J. G., & Bowyer, J. L. (1996). Forest product and wood science. An introduction. Third Edition. IOWA State University Press/ AMES 232.

Hossain, S. N., Khan, M. A., & Hossain, M. (1991). Moisture auditor water absorption characteristic of *Leucea naleucocephala* of different ages and some physical parameters of the woods. Leuceana Research Report. A publication of the Nitrogen Fixation Association. Wiaimanalo, USA, 12, 19.

Jane, F. W. (1970). The Structure of wood. 2nd Edition, London: Adam and Charless Black Limited, 487.

Keay, R. W. J. (1989). Trees of Nigeria. A revised version of "Nigerian trees" (Keay et al., 1964). Oxford: Clarendon Press.

Kellog, R. M. (1981). Physical properties in wood. In: Wangaard, FF (1981). Wood, its Structure and Properties. Pub. University USA, 195 – 223.

Ken Fern (2022). Tropical Plants Database, tropical.theferns.info. 2022-07-29. URL: <tropical.theferns.info/viewtropical.php?id=Treculia+africana> (29.7.2022)

Kiaei, M., & Samariha, A. (2011). Wood density and shrinkage of *Ulmus glabra* in northwestern of Iran. American-Eurasian J. Agric. & Environ. Sci., 11(2), 257-260.

Lausberg, M. J. F., Cown, D. J., MacConchie, J., & Skipmith, H. (1995). Variation in some wood properties of *Pseudotsugamenziensii.* Provenances grown in New Zealand. New Zealand Journal of Forestry Science, 25(2), 133- 146.

Ogunsanwo, O. Y. (2000). Characterization of wood properties of plantation grown obeche (*Triplochiton sceleroxylon* K. Schum) in Omo Forest Reserve. Ogun State, Nigeria, Ph.D Thesis in the department of Forest Resources Management. Ibadan: University of Ibadan, 253.

Ohene-Coffie, F. (2008). *Mansonia altissima* (A.Chev.) A. Chev. In: Louppe, D., Oteng-Amoako, A., A., & Brink, M. (Editors). PROTA (Plant Resources of Tropical Africa / Ressourcesvégétales de l'Afriquetropicale), Wageningen, Netherlands. URL: https://brill.com/view/journals/afoc/22/2/article-p105_16.xml (29.7.2022)

Ojo, A. R., Adejoba, O. R., Adesope, A. S., & Ogutuga, S. O. (2016). Evaluation of dimensional stability of *Bambusa vulgaris* Schrad Ex J. C. Wendl. Culm along the three orthotropic axes growing in Nigeria. Journal for Worldwide Holistic Sustainable Development. JWHSD, 2(2), 24-30.

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., & Anthony, S. (2009). Agroforestree Database: A tree reference and selection guide version 4.0 URL: https://www.scirp.org/(S(czeh2tfqyw2orz553k1w0r45))/reference/referencespapers.aspx?referenceid=1957749 (29.7. 2022)

Osadare, A. O. (2001). Basic wood and pulp properties of Nigeria grown Caribbean pine (*Pinus caribea* Movelet) and their relationships with tree growth indices. Ph. D Thesis. Ibadan: University of Ibadan, 384.

Oyen, L. P. A. (2005). *Nesogordonia kabingaensis* (K. Schum.) *Capuron* ex R.Germ. In: Louppe, D., Oteng-Amoako, A. A., & Brink, M. (Editors). PROTA (Plant Resources of Tropical Africa / Ressourcesvégétales de l'Afriquetropicale), Wageningen, Netherlands. URL: https://tropical.theferns.info/viewtropical.php?id=Nesogordonia+kabingaensis (30.7.2022)

Panshin, A. J., & de Zeeuw, C. (1980).Textbook of wood technology. 4th Ed. New York: MacGraw-Hill Book Company, 722.

Pilura, A., Yu, Q., & Zhang, S. Y. (2005). Variation in wood density and shrinkage and their relationship to growth of selected young poplar hybrid crosses. Forest Science, 51(5), 472-482.

Poku, K., Wu, Q., & Viosky, R. (2001). Wood properties and their variations with the tree stem of lesser-used species of tropical hardwood from Ghana. Wood and Fibre Science*,* 33(22), 284-291.

Protabase (2010). Plant Resources of Tropical Africa – Your guide to the use of African plants. URL: https://www.prota4u.org/database/protav8.asp?g=psk&p=Nauclea%20diderrichii (30.7.2022)

Protabase, Plant Resources of Tropical Africa (2022). URL: http://www.prota.org (30.7.2022)

Shrivastava, M. B. (1997). Wood technology. New Delhi: Vikas Publishing House, 181.

SSR VINA CO., LTD (2022) URL: https://ssr.vn/wenge-wood-senna-siamea-wood-things-to-know/ (30.7.2022)

TEDB (1994). The Tropical Timbers of Ghana. Timber Export Development Board, Takoradi. A report: 1-87.

Torelli, N., & Čufar, K. (1995). Mexican tropical hardwoods. Comparative study of ash and silica content. Holz als Roh und Werkstoff, 53(1), 61-62.

Upton, D. A. J., & Attah, A. (2003). Commercial timbers of Ghana – The potential for lesser used species. Accra: Forestry Commission of Ghana, 56.

Usta, I., & Guray, A. (2000). Comparison of the shrinkage and swelling and shrinkage characteristics of Corcisonpine (*Pinus nigra* var. *mantima*). Turk. Agric. For. J., 24, 461-464.

Walker, J. C. F. (2006). Primary wood processing: Principles and practices*.* 2nded., Dordrecht: Springer, 596.

Wood database (2018). The Wood Dictionary. A new old book. URL: https://www.wood-database.com/the-wood-dictionary/ (30.7.2022)

LES/WOOD Vol. 71, No. 2, 57-66
DOI: https://doi.org/10.26614/les-wood.2022.v71n02a03

ANALIZA ŽIVLJENJSKEGA CIKLA IN PRILOŽNOSTI ZA ZMANJŠANJE VPLIVOV LESNE INDUSTRIJE NA OKOLJE

LIFE CYCLE ASSESSMENT AND OPPORTUNITIES TO IMPROVE ENVIRONMENTAL IMPACTS IN THE WOOD SECTOR

Katarina Remic[1*], Matej Jošt[1]

UDK 674*620.97
Pregledni znanstveni članek/Review scientific article

Prispelo / Received: 14.11.2022
Sprejeto / Accepted: 29.11.2022

Izvleček / Abstract

Izvleček: Analiza življenjskega cikla (LCA) je metoda ocene vplivov na okolje, ki jih ima nek izdelek ali storitev v času celotnega cikla – od pridobivanja surovin do odlaganja na deponijo. LCA sestavljajo štiri faze, ki se med seboj prepletajo in so standardizirane s standardoma ISO 14040:2006 in ISO 14044:2006. Zaradi vsestranske uporabnosti in celostnosti pri sprejemanju strateških odločitev uporaba LCA hitro narašča. Porast uporabe se opaža tudi v lesnopredelovalnem sektorju.

Ključne besede: LCA, trajnost, življenjski cikel, okoljski vplivi, krožno gospodarstvo, lesnopredelovalni sektor

Abstract: Life cycle assessment (LCA) is a method that analyses the environmental impact of products or services throughout their life cycle – from the acquisition of raw materials to the end-of-life scenario in landfill. LCA consists of four phases that interact with each other and is standardized with ISO 14040:2006 and ISO 14044:2006. Due to its versatility and comprehensive nature with regard to strategic decision making, the use of LCA is growing rapidly, including in the wood sector.

Keywords: LCA, sustainability, life cycle, environmental impacts, circular economy, wood sector

1 UVOD
1 INTRODUCTION

Analiza življenjskega cikla (Life Cycle Assessment – LCA) je metodološki proces, ki se postopoma razvija že od leta 1960, prvi ISO standard na to temo pa je bil objavljen 1970. LCA obravnava in ocenjuje potencialne regijske in globalne vplive na okolje in na zdravje ljudi med celotno življenjsko dobo nekega izdelka (ali specifične funkcije izdelka) s pomočjo vhodnih in izhodnih parametrov. Zajema vse faze življenjske dobe, od pridobivanja surovin, pridobivanja energetskih virov, proizvodnje in distribucije potrebne energije, proizvodnje polizdelkov, sestavnih delov in dodatkov, proizvodnje končnih izdelkov in soproduktov, transporta med posameznimi proizvodnimi sistemi, transporta in distribucije končnih izdelkov, pakiranja, uporabe, vzdrževanja, morebitnega recikliranja ter končnega odlaganja na deponijo. Glavna funkcija analize življenjskega cikla je omogočanje informiranega odločanja npr. v namene strateških odločitev, načrtovanja, postavitve prioritet, dizajna ter redizajna izdelkov in procesov. Uporablja se tako v industriji kot tudi v vladnih in nevladnih organizacijah in postaja ena izmed najbolj popularnih strategij za kontroliranje količin odpadkov (Ellingsen & Vildåsen, 2022; Pirc Barčić et al., 2022; Quintana-Gallardo et al., 2021; Saadatian et al., 2022; Vilén et al., 2022).

Obravnavanje življenjskega cikla je ključno za podporo trajnostnega razvoja pri postopku sprejemanja zakonov, oblikovanju krožnega gospodarstva, pri standardizaciji, določanju označb, izdaji znanstvenih napotkov, pri odgovornosti korporacij in doseganju političnih ciljev. LCA omogoča identifikacijo priložnosti za izboljšanje trajnostnega vidika posameznih izdelkov ali storitev v različnih obdob-

[1] Univerza v Ljubljani, Biotehniška fakulteta, Oddelek za lesarstvo, Jamnikarjeva 101, 1000 Ljubljana, SLO
* e-mail: katarina.remic@bf.uni-lj.si

jih njihove življenjske dobe. Hkrati je sledenje in kontroliranje izdelkov (storitev), njihovega življenjskega cikla in različnih vidikov trajnostnega razvoja glavno izhodišče za boljše razumevanje treh glavnih stebrov trajnosti (3P) v celotni verigi ponudbe-povpraševanja. Ti stebri so prebivalstvo, planet in profit oziroma uspeh. Ker analiza življenjskega cikla nudi vpogled v celotni cikel izdelka, se z njo izognemo problematiki, kjer zavestno zmanjšamo vplive na okolje v eni fazi življenjskega cikla, pri tem pa (nezavedno) povečamo negativne vplive na okolje v neki drugi fazi cikla. Posledično lahko takšna analiza poveča učinkovitost upravljanja s surovinami in energetskimi viri. Kljub čedalje bolj razširjeni uporabi in konstantni optimizaciji programske opreme, ki se uporablja za izvedbo LCA, nekatere slabosti te metode še vedno ostajajo. Glavna pomanjkljivost je ogromna količina podatkov, ki jih moramo pridobiti iz baz. Podatki pa so običajno tudi nepopolni ali pa celo neobstoječi za specifično področje in jih moramo kombinirati s podatki iz drugih področij. Za izvedbo analize življenjskega cikla potrebujemo veliko časa, poglobljeno znanje o izdelku in proizvodnih tehnikah ter poglobljeno znanje in izkušnje o vrednotenju raziskave. Kljub temu, da se LCA celostno ukvarja z okoljsko problematiko, pa ne preučuje tehničnih sposobnosti sistema, ekonomskih posledic ter socialnih in političnih vidikov sprememb v preučevanih sistemih (de Carvalho Araújo et al., 2022; Füchsl et al., 2022; Rey-Álvarez et al., 2022; Vance et al., 2022).

2 METODOLOGIJA LCA
2 LCA METHODOLOGY

LCA je strukturirana, obširna in mednarodno standardizirana metoda, ki zajema štiri faze: fazo definiranja ciljev in obsega raziskave, fazo analize inventarja, fazo analize vplivov na okolje in fazo interpretacije rezultatov. SAIC (Scientific Applications International Corporation (SAIC), 2006) in (ILCD European Commission. Joint Research Centre. Institute for Environment and Sustainability., 2010) vsako fazo tudi razdelita in definirata kot sosledje korakov, ki jih mora raziskovalec sprejeti med obravnavanjem posamezne faze.

Faza definiranja ciljev in obsega raziskave opredeljuje podatke, ki narekujejo celotno raziskavo. Postavljeni cilji definirajo razloge za izvedbo raziskave, določijo, kako detajlno bo raziskava izvedena in ali bo pokrivala široko področje ali bo zelo specifično usmerjena. Obseg raziskave pa poleg količine detajlov, ki bodo upoštevani, opredeljuje tudi omejitve sistema določene raziskave. V kateri fazi sistema se bo raziskava začela in v kateri končala, je zelo različno in pogojeno s subjektivno percepcijo raziskovalca, kaj v danem primeru predstavlja “cradle” in kaj “grave”. Glede na določen začetek in konec cikla mora biti predmet raziskave jasno zastavljen (izdelki oziroma storitve, trženjski segmenti, alternative). Jasno morajo biti opredeljene funkcije sistema (primarne in sekundarne), razdelitve obremenitev in referenčni diagram, LCIA metodologija, vrste vplivov, geografske, časovne in tehnološke omejitve, interpretacija, ki bo uporabljena, vrsta kritičnega vrednotenja, opredeljeno mora biti, kateri podatki so potrebni in kakšna mora biti njihova kvaliteta, lahko pa sta definirana tudi vrsta in format poročila raziskave. Jasno morajo biti opredeljene tudi vse funkcionalne enote, ki predstavljajo referenčne enote, na katere so preračunani in normirani vsi vhodni in izhodni podatki ter njihovi vplivi na okolje. Poenotenje funkcionalnih enot je pomembno predvsem pri primerjavi različnih izdelkov. Pomembno je, da so cilji in omejitve zasnovani v skladu z nameravano uporabnostjo raziskave in da je vseskozi znano ali bodo rezultati namenjeni primerjavi javnega značaja ali bodo morda zaupne narave (Hassan et al., 2022; Pirc Barčić et al., 2022; Vance et al., 2022; Vilén et al., 2022). Pri izvajanju prve faze LCA procesa mora raziskovalec sprejeti in definirati šest odločitev:

- definiranje cilja projekta;
- opredelitev, katera vrsta informacij je potrebna za pomoč pri sprejemanju odločitev;
- opredelitev potrebne specifičnosti;
- opredelitev, kako naj bodo podatki in rezultati predstavljeni;
- definiranje obsega, omejitve raziskave;
- opredelitev osnovnih pravil in pogojev dela (beleženje predvidevanj in predpostavk, postopki za kontrolo kakovosti, zahteve poročila).

Fazo analize inventarja (LCI faza) predstavlja proces kvantifikacije potrebne energije, potrebnih surovin ter nastalih emisij in odpadkov in zajema popis vseh zbranih podatkov, ki so potrebni za doseganje definiranih ciljev raziskave (Hassan et al., 2022; Pirc Barčić et al., 2022; Vance et al., 2022;

Vilén et al., 2022). Glavni koraki za izvedbo LCI faze so:

- razvoj diagrama procesa (“flow diagram”);
- razvoj načrta zbiranja podatkov;
- proces zbiranja podatkov;
- evalvacija in poročanje rezultatov.

Diagram procesa (življenjskega cikla izbranega izdelka) grafično prikazuje vse primarne in sekundarne procese v obravnavanem sistemu, pridobljeni podatki pa vključujejo kvalitativne in kvantitativne podatke za vsako fazo procesa znotraj omejitev. Pomembno je, da je vsaka faza procesa natančno opisana, da ne prihaja do napak oziroma napačnega razumevanja. Pri postavljanju diagrama procesa je najpomembnejša ohranitev sistemske enakosti, ki predstavlja ohranitev mase in energije znotraj oblikovanega diagrama. Osnovni problem analize življenjskega cikla je določevanje mej med aktivnostmi, ki sodijo v preučevani sistem, in aktivnostmi, ki spadajo v življenjski cikel predelanih ali že recikliranih izdelkov. V primeru odprte zanke recikliranja, ko se reciklirani materiali porabijo za drug izdelek, se delež materiala “odcepi” od glavnega sistema, posledično mora ocenjevalec presoditi, kateri način razmejitve obremenitev na okolje bo uporabil. Prvemu (glavnemu) izdelku pripadajo obremenitve pridobivanja surovin, procesa proizvodnje, uporabe in odstranjevanja nerecikliranih materialov, drugemu (odcepljenemu) pa obremenitve pridobivanja manjkajočih primarnih materialov, obremenitve proizvodnje, uporabe in odstranjevanja tega izdelka. Obremenitve na okolje, ki nastajajo v procesu reciklaže, lahko v celoti pripišemo ali prvemu ali drugemu izdelku. Obremenitve lahko tudi razdelimo in vsakemu pripišemo polovico. Lahko pa upoštevamo skupne obremenitve prvega in drugega izdelka v fazah pridobivanja primarnih materialov, recikliranja in odstranjevanja ter jih delimo na pol. Pri zaprti zanki recikliranja do tega problema ne prihaja. Poleg razmejitve sistema z deljenjem obremenitev, čemur standard ni naklonjen, obstaja tudi razširitev sistema. Pri tem soprodukte, ki nastajajo, obravnavamo kot samostojne proizvode, ki služijo kot (okoljsko boljša) alternativa drugim izdelkom na trgu/v industriji in pri izračunu zmanjšujejo vplive celotnega cikla na okolje. Podatke za izvedbo LCA delimo na glavne informacije, ki se nanašajo direktno na obravnavani sistem, npr. emisije pri lakiranju stola, in na informacije “iz ozadja”, ki jih prav tako pridobimo iz baz podatkov, vendar se ne nanašajo direktno na obravnavani sistem, npr. predhodna analiza življenjskega cikla sadike drevesa (Ellingsen & Vildåsen, 2022; Pirc Barčić et al., 2022; Vilén et al., 2022).

Namen faze analize vplivov na okolje je pridobivanje dodatnih informacij, ki so v pomoč pri razumevanju in vrednotenju rezultatov iz LCI faze. Tretjo fazo imenujemo tudi LCIA faza. Zajema razumevanje in ocenjevanje razsežnosti in pomembnosti nekega potencialnega vpliva na okolje in zdravje ljudi. Kljub temu da lahko na podlagi podatkov inventarja preučujemo mnogo različnih področij in tez, je faza analize vplivov namenjena predvsem pridobivanju ključnih osnov za izvedbo primerjav (med različnimi scenariji in posledično različnimi vrstami emisij) (Hassan et al., 2022; Pirc Barčić et al., 2022; Vance et al., 2022; Vilén et al., 2022). Glavni koraki izvedbe LCIA faze so:

- izbor in definiranje vplivnih kategorij;
- klasifikacija (razporeditev rezultatov iz LCI faze v izbrane kategorije vpliva, npr. vpliv CO_2 razporedimo v kategorijo segrevanje ozračja);
- karakterizacija (pretvorba vplivov iz LCI faze v kategorije vpliva s pomočjo skupnih faktorjev karakterizacije (npr. vpliv CO_2 preračunamo kot potencialni vpliv na segrevanje ozračja);
- normalizacija (potencialne vplive izrazimo tako, da jih lahko med samo primerjamo);
- združevanje (razvrščanje npr. po razsežnosti merila);
- razvrščanje po pomembnosti, dodelitev uteži;
- evalvacija in priprava poročila LCIA rezultatov.

Faza interpretacije rezultatov združuje rezultate LCI in LCIA faz (fazi sta lahko obravnavani združeno ali pa vsaka posebej), ki so obravnavani in oblikovani v povzetek. Ta služi kot razprava rezultatov za izdelavo napotkov pri odločanju in kot usmeritev za sprejemanje odločitev v skladu s postavljenimi cilji. Vsebovati mora identifikacijo ključnih problemov glede na rezultate LCI in LCIA faz, celostno vrednotenje, kontrolo občutljivosti in doslednosti, zaključke, omejitve in priporočila (Ellingsen & Vildåsen, 2022; Hassan et al., 2022; Pirc Barčić et al., 2022; Vance et al., 2022; Vilén et al., 2022). Interpretacija rezultatov zajema:

- identifikacijo ključnih problematik na osnovi LCI in LCIA faz;

Preglednica 1. Kategorije vplivov za analizo življenjskega cikla izdelkov in storitev (de Carvalho Araújo et al., 2022; Klein et al., 2015; Scientific Applications International Corporation (SAIC), 2006; Vance et al., 2022).
Table 1. Impact categories for life cycle assessment of products and services (de Carvalho Araújo et al., 2022; Klein et al., 2015; Scientific Applications International Corporation (SAIC), 2006; Vance et al., 2022).

Kategorija vpliva		Razsežnost merila	Klasifikacija podatkov analize inventarja	Skupen faktor karakterizacije	Enota
Segrevanje ozračja	Skupno	Globalno	CO_2 (ogljikov dioksid), NO_2 (dušikov dioksid), CH_4 (metan), CFC (klorofluoro-ogljikovodiki), HCFC (hidroklorofluoro-ogljikovodiki), CH_3Br (metil bromid)	Potencialno segrevanje ozračja	kg CO_2 ali ekvivalent
	Fosilna goriva				
	Biogeni vplivi				
Tanjšanje stratosferske ozonske plasti		Globalno	CFC, HCFC, CH_3Br, haloni	Potencialno tanjšanje ozonske plasti	kg CFC-11 ali ekvivalent
Zakisovanje		Regijsko in lokalno	SOx (žveplovi oksidi), NOx (dušikovi oksidi), HCl (klorovodikova kislina), HF (fluorovodikova kislina), NH_4 (amonijak)	Potencialno zakisovanje	kg mol H+
Evtrofikacija	Evtrofikacija sladkih voda	Lokalno	PO_4 (fosfati), NO (dušikov oksid), NO_2, nitrati, NH_4	Potencialna evtrofikacija	kg PO_4 ali ekvivalent
	Evtrofikacija morskih voda				kg N ali ekvivalent
	Evtrofikacija zemlje				mol N
Fotogemičen smog		Lokalno	NMHC (ne-metanski ogljikovodiki)	Potencial pojava fotokemičnega smoga	kg NMVOC ali ekvivalent
Izraba surovin	Izraba abiotskih surovin – mineralov in kovin	Globalna, regijska in lokalna	Količina porabljenih mineralov in kovin	Potencial izrabe surovin	kg Sb ali ekvivalent
	Izraba abiotskih surovin – fosilna goriva		Količina porabljenih fosilnih goriv		MJ (neto)
Toksični vplivi na človekovo zdravje	Karcinogeni	Globalno, regijsko in lokalno	Skupni izpusti kemikalij v zrak, vodo in zemljo	LC_{50}	CTU (št. bolezni na kg kemikalije)
	Nekarcinogeni				
Ekotoksičnost	Sladkih voda	Lokalno	Toksične kemikalije, za katere je bila ugotovljena smrtna koncentracija za določeno vrsto organizmov	LC_{50} (za sladkovodne organizme)	CTU (št. Referenčnih toksičnih vplivov na kg kemikalije)
	Morske vode			LC_{50} (za morske organizme)	
	Zemlje			LC_{50} (za glodalce)	
Raba vode		Regijsko in lokalno	Porabljena voda	Potencialno pomanjkanje vode	Pomanjkanje povprečne količine porabljene vode na svetovnem nivoju v m^3

Kategorija vpliva	Razsežnost merila	Klasifikacija podatkov analize inventarja	Skupen faktor karakterizacije	Enota
Raba tal	Globalno, regijsko in lokalno	Količina odloženih odpadkov na organizirana in neorganizirana odlagališča ter ostali posegi v prostor/tla	Razpoložljivost tal	Ni merljivo v konstantnih enotah, spremembe v kvaliteti zemlje
Radioaktivnost	Lokalno, regijsko	Pojavljanje negativnih stranskih učinkov na ljudeh in ekosistemih zaradi sevanja	Potencialni vpliv na človeško zdravje	KBq U-235
Emisije drobnih delcev	Lokalno, regijsko	Indikator pogostosti obolenj zaradi emisij drobnih delcev	Potencialna pogostost obolenj	Pogostost obolenj

- evalvacijo, ki zajema preverjanje celostnosti, občutljivost in doslednosti;
- pripravo zaključkov, priporočil in poročila.

3 KATEGORIJE IN PARAMETRI
3 CATEGORIES AND PARAMETERS

V preglednici 1 so prikazane kategorije vplivov na okolje, ki jih lahko obravnavamo v okviru LCA raziskave. Kategorije lahko na okolje in človeka vplivajo na različnih nivojih razsežnosti (lokalnem, regijskem ali globalnem nivoju), oziroma se vplivi kažejo na večrazsežnostnih nivojih. Preglednici je dodana klasifikacija podatkov, ki nastane v fazi analize inventarja in predstavlja najpogostejše podatkovne parametre, ki vplivajo na določeno kategorijo. Vse te podatke se pri izračunih združuje na skupni faktor karakterizacije s funkcionalno enoto, ki je glavna referenčna vrednost za primerjavo (Quintana-Gallardo et al., 2021).

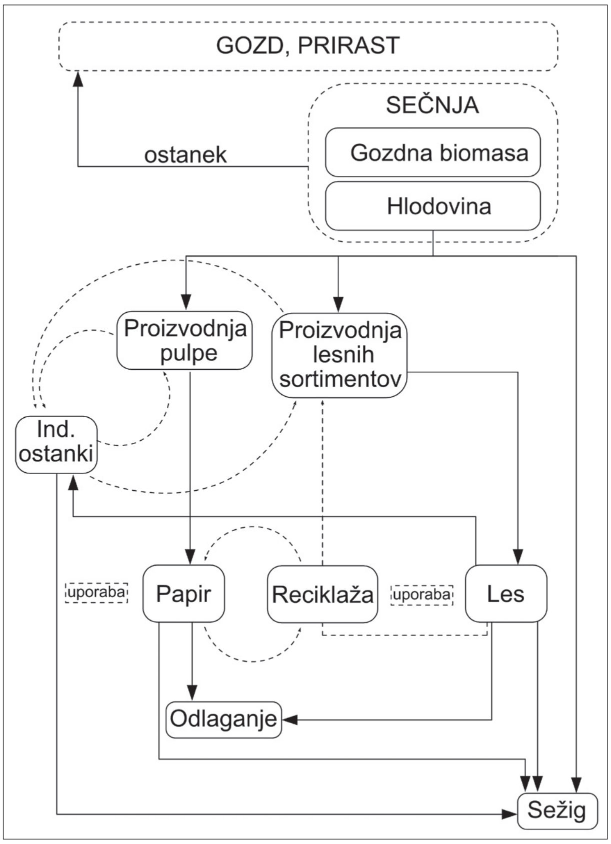
4 KROŽENJE OGLJIKA IN IMPLEMENTACIJA LCA V LESNOPREDELOVALNO INDUSTRIJO
4 CARBON CYCLE AND IMPLEMENTATION OF LCA IN WOOD SECTOR

Ogljik je četrti najbolj razširjen element v vesolju in glavni vir življenja na Zemlji. Največji delež ogljika na Zemlji je vezan v kamenje in skalovje, preostali del pa je v oceanu, atmosferi, rastlinah, zemlji in fosilnih gorivih. S kopičenjem ogljika v skalovju se regulira količina ogljika v atmosferi, posledično pa tudi temperatura na Zemlji. Količina vodne pare v ozračju sorazmerno narašča in pada s povečanjem oziroma zmanjšanjem koncentracij CO_2 v atmosferi, zemlja pa se segreje pri povečanih količinah vodne pare v ozračju in obratno. Ogljikov dioksid, ki je vezan v rastlino (ali fitoplankton), se sprosti nazaj v atmosfero šele, ko pride do fotosintezi obratne kemijske reakcije. Ta nastopi v štirih različnih scenarijih. V želji po pridobivanju energije lahko rastline same porabijo sladkor, ko potrebujejo energijo za rast ali pa živali in ljudje pojedo rastline. Do sproščanja CO_2 prihaja tudi, ko rastline odmrejo in se razkrajajo ali pa če zgorijo. Lesni izdelki vsebujejo ogljik, ki so ga absorbirali v fazi rasti drevesa v procesu fotosinteze. Znano je, da drevo za vsak kubik svoje rasti absorbira 1 tono CO_2 iz atmosfere in proizvede 0,7 tone kisika. Večinski del (0,9 tone) CO_2 drevo obdrži absorbiranega po procesu rasti in se v lesu ohranja ne glede na to, kako ga predelujemo (v kakšne izdelke). Izloči se šele, ko nastopi eden izmed štirih scenarijev. Lesna biomasa je pogosto opisana kot obnovljiv, trajnostni vir surovine in energije. Čeprav se les smatra kot zelo dobra alternativa marsikateremu drugemu materialu z večjim ogljičnim odtisom, pa je nivo dejanske obnovljivosti in trajnosti odvisen od količine neobnovljivih virov, ki smo jih vnesli v sistem predelave. Ogljično nevtralnost zmanjšujejo gojeni sistemi dreves in netrajnostno upravljanje z gozdnimi sistemi. V splošnem življenjski cikel lesnih izdelkov zajema fazo pridobivanja surovin (aktivnosti gojenja gozdov, sečnja in spravilo lesa iz gozda), fazo proizvodnje materialov (predelava hlodovine v žagane elemente, ploščne kompozite, itd.), fazo uporabe in vzdrževanja ter fazo uničenja in odstranjevanja na deponijo. Med vsemi fazami se pojavljata distribucija in transport. V fazo proizvodnje so zajete tudi vse aktivnosti sekundarne predelave, kjer so posamezni materiali uporabljeni in vgrajeni v izdelek. Nadaljnja uporaba se lahko pojavlja v različnih oblikah. Kot ponovna uporaba, kjer izdelek uporabimo za isti namen, kot predelava, kjer izdelek uporabimo za drug namen ali pa kot recikliranje, kjer izdelek predelamo v surovino za nadaljnjo rabo (Aryapratama & Pauliuk, 2022; Cordier et al., 2022; Duan et al., 2022; Fimbres Weihs et al., 2022; Klein et al., 2015; Pirc Barčić et al., 2022).

Na sliki 1 je prikazano kroženje lesa v Evropi, ki si prizadeva za čimbolj celovito rabo lesa in lesnih ostankov.

Prvotne LCA raziskave za lesnopredelovalno verigo so se osredotočale na manjše segmente (produkte) lesne industrije, danes pa se analiza življenjskega cikla večinoma uporablja za celostno vrednotenje lesnih alternativ v gradbeništvu. Gradnja bivalnih in javnih objektov je v zadnjih letih močno narasla, hkrati pa je gradbeni sektor postal ciljni sektor za zmanjševanje vplivov na okolje, saj vsako leto proizvede kar 39 % vseh svetovnih emisij (Andersen et al., 2022). Podatki kažejo, da bi z uvedbo 17 % lesa kot alternativnega materiala, emisije v gradbeništvu zmanjšali za 20 %. Pri LCA, kjer je bila lesena gradnja celostno obravnavana (Duan et al., 2022), pa je bilo ugotovljeno, da bi emisije lahko zmanjšali za kar 22-50 %. Najnovejše direktive Evropske unije izpostavljajo nujo po zmanjšanju emisij stavb do leta 2050, kar podpira tudi iniciativa novi evropski Bauhaus, ki temelji na okolju prijazni gradnji in zajema estetska, trajnostna in inkluzivna načela.

Izvedene so bile analize občutljivosti (Duan et al., 2022) za izolacije, osnovne materiale, uporabo fenol-formaldehidne smole, razdaljo transporta, vrsto uporabljene energije, energijsko učinkovitost, prehajanje zraka, uporabo recikliranih materialov, upravljanje z ostanki biomase, življenjsko dobo, učinkovitost toplotne črpalke in še posebej za delež ponovno uporabljenega lesa. Kot najbolj vplivni in ključni za nadaljnjo raziskovanje njihovih alternativnih možnosti so se izkazali: izolacija (Bucklin et al., 2022; Duan et al., 2022; Füchsl et al., 2022; Galimshina et al., 2022), vrsta uporabljenih lesnih kompozitov (Andersen et al., 2022; Bucklin et al., 2022; Cascione et al., 2022; Duan et al., 2022; Kromoser et al., 2022), transport materiala za gradnjo (Duan et al., 2022), vrsta uporabljene energije (Duan et al., 2022; Saadatian et al., 2022; Tushar et al., 2022)



Slika 1. Kroženje lesa v Evropi (prirejeno po Mantau, 2012).

Figure 1. Wood flow in Europe (adapted from Mantau, 2012).

in vrsta oken (Duan et al., 2022; Saadatian et al., 2022; Tushar et al., 2022), kjer so še posebej opazne prednosti uporabe lesenih oken v primerjavi s PVC, aluminijastimi oziroma kompozitnimi (les-aluminij) sistemi oken. Pomembno vplivajo tudi ostali dejavniki, kot sta razmerje velikosti oken glede na steno in orientacija oken v objektu. Analiza vplivov na okolje (Quintana-Gallardo et al., 2021) pri bivanju v primerljivih stanovanjskih objektih na različnih lokacijah po Evropi kaže, da je prav lokacija najbolj vplivala na okoljsko obremenjujoče razlike pri emisijah, še posebej na porabo elektrike in vrsto vira energije. Zaradi potrebe po ponovni uporabi odsluženega lesa (Szichta et al., 2022) se uveljavljajo tudi LCA raziskave, ki se osredotočajo na rušenje objektov z (deloma) lesenimi konstrukcijami in upravljanje z njimi po končani življenjski dobi, še posebej pa pretvarjanje odsluženega lesa v izdelke, surovino ali snovi z višjo dodano cenovno in funkcionalno vrednostjo (Ivanica et al., 2022; Khodaei et al., 2022). Hkrati se razvijajo inovativni kompoziti, ki vključujejo les. Pri razvoju lesno-betonskega kompozita za talne obloge (Tighnavard Balasbaneh et al., 2022) so se prednosti pokazale ne samo pri zmanjšani rabi betona in zmanjšanju negativnih vplivov na okolje, ampak tudi pri mehanskih lastnostih tega kompozita. Duan in sodelavci (2022) poudarjajo, da lesena gradnja ni vedno upravičena, oziroma ne pomeni avtomatskega zmanjšanja emisij na okolje, še posebej v državah in pokrajinah, ki niso bogato poraščene z gozdom. Quintana-Gallardo in sodelavci (2021) izpostavljajo še pretirano poenostavljanje okoljske učinkovitosti lesene gradnje in dodatno pojasnjujejo, da je za dejansko zmanjšanje vplivov na okolje potrebna implementacija različnih biomasnih materialov tudi v druge elemente celotne stavbe – ne samo uporaba lesa za konstrukcijo objekta.

Velik delež negativnih vplivov na okolje predstavljajo nelesni materiali v lesnih sistemih npr. smole in površinski premazi. S pomočjo LCA raziskovalci poskušajo opredeliti možnosti na zmanjšanje vplivov že med proizvodnjo smol in veziv (Vujanović et al., 2022) oziroma razviti alternativne »zelene smole« na osnovi taninov (Hu et al., 2023) sojinih proteinov (Liu et al., 2022), agro-industrijskih ostankov lignina (de Carvalho Araújo et al., 2022). S tem bi se izognili (tolikšni) uporabi fenol-formaldehida. De Carvalho Araújo in sodelavci (2022) poudarjajo tudi pomembnost biomimikrije in nanodelcev pri razvoju novih sistemov in rešitev. Razširjena pa postaja tudi proizvodnja in uporaba lesno-plastičnih kompozitov, tudi na osnovi odsluženega lesa (de Carvalho Araújo et al., 2022; Friedrich, 2022; Huang et al., 2022).

Potreba po produktih iz biomasnih ostankov z višjo dodano vrednostjo se v veliki meri obravnava v okviru biorafinerij in manjših predelovalnih obratov. Ti na podlagi LCA ter stroškovnih analiz opredelijo smiselnost pridobivanja, ekstrakcije, produkcije, zbiranja odpadkov in njihove pretvorbe (Zhang et al., 2023). V praksi se iz lignocelulozne biomase že pridobiva vodik (Buffi et al., 2022; Wu et al., 2023), nanoceluloza (Shahzad et al., 2023), mlečne kisline, ksilitol, etanol, metan, različne lipide, betakaroten (Zhang et al., 2023), itd. To so običajno zgolj ciljni produkti, tehnološke izboljšave pa bi omogočile še dodatne stranske produkte, ki so bili do sedaj namenjeni le sežigu – pridobivanju energije. V to skupino velikokrat odpade lignin, ki je kljub njegovi uporabnosti stroškovno ugodnejši za pridobivanje energije kot za nadaljnjo predelavo v vanilin, polihidroksialkanoate in aldehide. Raziskave zato ocenjujejo možnosti uporabe lignina kot celote za različne namene npr. kot del asfaltnega sistema (Moretti, 2023). Ugotovljeno je bilo, da znotraj lesnopredelovalne biorafinerije lignifikacija predstavlja 80 % vseh vplivov ekotoksičnosti sladkih voda in zemlje, saharifikacija pa predstavlja nezanemarljivo generacijo drobnih delcev, evtrofikacijo sladkih voda, segrevanje ozračja, toksičnost za ljudi in ekotoksičnost zemlje (Zhang et al., 2023).

5 ZAKLJUČKI
5 CONCLUSIONS

Analiza življenjskega cikla je standardizirana metoda ocene vplivov nekega izdelka ali storitve na okolje v času celotnega življenjskega cikla. Zajema pridobivanje surovin, pridobivanje potrebnih energetskih virov, proizvodnjo in distribucijo potrebne energije, proizvodnjo polizdelkov, potrebnih sestavnih delov in dodatkov, proizvodnjo končnih izdelkov in soproduktov, transport med posameznimi proizvodnimi sistemi, transport in distribucijo končnih izdelkov, pakiranje, uporabo, vzdrževanje, morebitno recikliranje ter končno odlaganje na deponijo.

LCA zajema štiri faze, ki se med seboj interaktivno prepletajo in dopolnjujejo. Prva faza je faza definiranja ciljev in obsega raziskave. V samem začetku mora raziskovalec jasno definirati razloge za raziskavo in posledično postaviti cilje raziskave. Ključna je ustrezna izbira omejitev LCA, ki zajema obseg, specifičnost, količino podatkov, začetno in končno fazo obravnavanega sistema in vse vmesne faze sistema ter način raziskave in njeno kontrolo doslednosti. Sledi faza analize inventarja, ki zajema popis vseh potrebnih podatkov za izvedbo raziskave in njihovo vrednotenje. Faza zajema tudi razvoj diagrama procesa, ki grafično prikazuje vse faze znotraj življenjskega cikla izdelka. Tretja faza je faza analize vplivov na okolje, kjer raziskovalec podatke iz druge faze smiselno pripiše kategorijam, ki predstavljajo različne vplive na okolje in jih normalizira tako, da so vrednosti primerljive med sabo. V zadnji fazi, fazi interpretacije, so obravnavani rezultati druge in tretje faze. Oblikuje se povzetek raziskave, ki mora vsebovati identifikacijo ključnih problemov glede na rezultate LCI in LCIA faz, celostno vrednotenje, kontrolo občutljivosti in doslednosti, zaključke, omejitve in priporočila.

Les je pogosto opisan kot obnovljiv in trajnostni vir surovine, energije in kot okoljsko zelo dobra alternativa marsikateremu drugemu materialu. Če drevesa rastejo v gozdnih sistemih, ki so upravljani po trajnostnih načelih, lahko les predstavlja ogljično nevtralno surovino. Kljub temu pa lahko lesen izdelek v svojem življenjskem ciklu ustvari nezanemarljivo količino negativnih vplivov na okolje, zato je izvedba LCA smiselna za ohranitev okoljske nevtralnosti v čim večji meri. Dosedanje raziskave so opredelile izzive lesne industrije s problematičnimi vplivi na okolje, ki se nanašajo predvsem na pomožne materiale in transport, in izpostavile učinkovitejše možnosti upravljanja z lesno biomaso za pridobivanje trajnostnih produktov z višjo dodano vrednostjo. To podpira tudi iniciativa novi evropski Bauhaus, ki predlaga LCA metodologijo kot možnost za vodilo oblikovanja stavb, saj bi celostno obravnavanje pripomoglo k praksam, ki stremijo k dolgi življenjski dobi, uporabljajo obnovljive vire, ponovno uporabljajo odslužen material in zmanjšujejo vplive na okolje, ki nastajajo zaradi transporta. Hkrati takšne prakse vseeno ohranjajo raznoliko kulturo in ne omejujejo kreativnega razvoja.

6 POVZETEK
6 SUMMARY

Life cycle assessment (LCA) is a methodological process that has been developing since 1960. It discusses and evaluates products and services throughout their life cycle. It covers the acquisition of raw materials and energy, production and distribution of energy, production of intermediate products, main products and by-products, production of final products and co-products, transport between production systems, transport and distribution of final products, packaging process, use, maintenance, possible recycling and final landfill scenario. LCA is mainly a tool for strategic decision making, but it can also be used to identify opportunities for improvement throughout the product production process. The main disadvantage of LCA is the huge amount of data needed coupled with the lack of accurate data that is available.

LCA consists of four phases. The first phase is the definition of the aim and scope, in which the researcher defines the main purpose of the LCA and, accordingly, the goals of the research. It is also very important to define the scope properly – where is the beginning of the analysed system, where is the end and which production phases are included in the system. This is followed by the inventory analysis (LCI phase), where a flow chart is created, a plan for data collection is designed and all the necessary data is collected and analysed. The third phase is the impact assessment phase. In this phase of the research process, all data from the previous phase are classified into impact categories and further normalized so that all data have the same functional unit. The following impact categories are considered in LCA: climate change (which is described as the potential for global warming and can be divided into general climate change, climate change from fossil fuels and climate change from biogenic emissions), ozone depletion (which is caused in particular by the presence of CFCs, HCFCs, CH_3Br and halogens in the atmosphere), acidification (especially of soil), eutrophication (which is subdivided into eutrophication of freshwater, marine eutrophication or terrestrial eutrophication), photochemical ozone formation (which occurs due to NMHCs in the atmosphere), resource depletion (resources are subdivided into minerals and metals and fossil fuels), human toxicity (subdivided into carcinogenic and non-carcinogenic due to the presence of certain chemicals in the atmosphere), ecotoxicity (of freshwater, marine and terrestrial ecotoxicity), water use, land use, ionizing radiation and particulate matter emissions (indicating how frequently various diseases occur due to the presence of such emissions). Finally, the interpretation phase takes place, in which all data sorted by category are evaluated, the most important hotspots (phases in the system with the most problematic environmental impacts) are identified and conclusions and recommendations are formulated.

Wood products contain carbon that was absorbed by the trees during their growth phase through photosynthesis. As long as the wood does not rot or burn, CO_2 remains in the wood. And even then, only the amount of CO_2 that was absorbed during growth is released. The goal is, however, is to delay incineration by reusing it as much as possi-

ble. Although wood is often seen as a more environmentally friendly solution than many other materials, it is important to understand that its processing can have a significant impact on the environment. In order to maximize the use of wood, and in particular reclaimed wood before incineration, many sectors are developing new technologies and products with the support of LCA. The most important sector is construction, where the goal of sustainable buildings can be achieved with timber structures. In addition to timber construction, LCA also supports innovation research in wood-based materials, energy, chemistry, pharmaceuticals and other sectors.

ZAHVALA
ACKNOWLEDGEMENT

Raziskavo je finančno podprla Javna agencija za raziskovalno dejavnost Republike Slovenije (ARRS), v okviru programa Les in lignocelulozni kompoziti (P4-0015).

VIRI
REFERENCES

Andersen, J. H., Rasmussen, N. L., & Ryberg, M. W. (2022). Comparative life cycle assessment of cross laminated timber building and concrete building with special focus on biogenic carbon. Energy and Buildings, 254, 111604. DOI: https://doi.org/10.1016/J.ENBUILD.2021.111604

Aryapratama, R., & Pauliuk, S. (2022). Life cycle carbon emissions of different land conversion and woody biomass utilization scenarios in Indonesia. Science of The Total Environment, 805, 150226. DOI: https://doi.org/10.1016/J.SCITOTENV.2021.150226

Bucklin, O., Menges, A., Amtsberg, F., Drexler, H., Rohr, A., & Krieg, O. D. (2022). Mono-material wood wall: Novel building envelope using subtractive manufacturing of timber profiles to improve thermal performance and airtightness of solid wood construction. Energy and Buildings, 254, 111597. DOI: https://doi.org/10.1016/J.ENBUILD.2021.111597

Buffi, M., Prussi, M., & Scarlat, N. (2022). Energy and environmental assessment of hydrogen from biomass sources: Challenges and perspectives. Biomass and Bioenergy, 165, 106556. DOI: https://doi.org/10.1016/J.BIOMBIOE.2022.106556

Cascione, V., Roberts, M., Allen, S., Dams, B., Maskell, D., Shea, A., Walker, P., & Emmitt, S. (2022). Integration of life cycle assessments (LCA) in circular bio-based wall panel design. Journal of Cleaner Production, 344, 130938. DOI: https://doi.org/10.1016/J.JCLEPRO.2022.130938

Cordier, S., Blanchet, P., Robichaud, F., & Amor, B. (2022). Dynamic LCA of the increased use of wood in buildings and its consequences: Integration of CO_2 sequestration and material substitutions. Building and Environment, 226, 109695. DOI: https://doi.org/10.1016/J.BUILDENV.2022.109695

de Carvalho Araújo, C. K., Bigarelli Ferreira, M., Salvador, R., de Carvalho Araújo, C. K. C., Camargo, B. S., de Carvalho Araújo Camargo, S. K., de Campos, C. I., & Piekarski, C. M. (2022). Life cycle assessment as a guide for designing circular business models in the wood panel industry: A critical review. Journal of Cleaner Production, 355, 131729. DOI: https://doi.org/10.1016/J.JCLEPRO.2022.131729

Duan, Z., Huang, Q., & Zhang, Q. (2022). Life cycle assessment of mass timber construction: A review. Building and Environment, 221, 109320. DOI: https://doi.org/10.1016/J.BUILDENV.2022.109320

Ellingsen, O., & Vildåsen, S. S. (2022). Developing circular business models: LCA and strategic choice. Procedia CIRP, 109, 437–442. DOI: https://doi.org/10.1016/J.PROCIR.2022.05.275

European Commission. Joint Research Centre. Institute for Environment and Sustainability. (2010). International Reference Life Cycle Data System (ILCD) Handbook general guide for life cycle assessment: detailed guidance. Publications Office.

Fimbres Weihs, G. A., Jones, J. S., Ho, M., Malik, R. H., Abbas, A., Meka, W., Fennell, P., & Wiley, D. E. (2022). Life cycle assessment of co-firing coal and wood waste for bio-energy with carbon capture and storage – New South Wales study. Energy Conversion and Management, 273, 116406. DOI: https://doi.org/10.1016/J.ENCONMAN.2022.116406

Friedrich, D. (2022). Success factors of Wood-Plastic Composites (WPC) as sustainable packaging material: A cross-sector expert study. Sustainable Production and Consumption, 30, 506–517. DOI: https://doi.org/10.1016/J.SPC.2021.12.030

Füchsl, S., Rheude, F., & Röder, H. (2022). Life cycle assessment (LCA) of thermal insulation materials: A critical review. Cleaner Materials, 5, 100119. DOI: https://doi.org/10.1016/J.CLEMA.2022.100119

Galimshina, A., Moustapha, M., Hollberg, A., Padey, P., Lasvaux, S., Sudret, B., & Habert, G. (2022). Bio-based materials as a robust solution for building renovation: A case study. Applied Energy, 316, 119102. DOI: https://doi.org/10.1016/J.APENERGY.2022.119102

Hassan, S. R., Megahed, N. A., Abo Eleinen, O. M., & Hassan, A. M. (2022). Toward a national life cycle assessment tool: Generative design for early decision support. Energy and Buildings, 267, 112144. DOI: https://doi.org/10.1016/J.ENBUILD.2022.112144

Huang, Y., Lu, L., Ding, C., & Pan, M. (2022). Eco-friendly wood-plastic composites from laminate sanding dust and waste poly(propylene) food pails. Waste Management, 149, 96–104. DOI: https://doi.org/10.1016/J.WASMAN.2022.06.012

Hu, J., Skinner, C., Ormondroyd, G., & Thevenon, M. F. (2023). Life cycle assessment of a novel tannin-boron association for wood protection. Science of The Total Environment, 858, 159739. DOI: https://doi.org/10.1016/J.SCITOTENV.2022.159739

ISO (2006). Environmental management — Life cycle assessment — Principles and framework (ISO 14040:2006).

ISO (2006). Environmental management — Life cycle assessment — Requirements and guidelines (ISO 14044:2006).

Ivanica, R., Risse, M., Weber-Blaschke, G., & Richter, K. (2022). Development of a life cycle inventory database and life cycle impact assessment of the building demolition stage: A case study in Germany. Journal of Cleaner Production, 338, 130631. DOI: https://doi.org/10.1016/J.JCLEPRO.2022.130631

Khodaei, H., Olson, C., Patino, D., Rico, J., Jin, Q., & Boateng, A. (2022). Multi-objective utilization of wood waste recycled from construction and demolition (C&D): Products and characterization. Waste Management, 149, 228–238. DOI: https://doi.org/10.1016/J.WASMAN.2022.06.021

Klein, D., Wolf, C., Schulz, C., & Weber-Blaschke, G. (2015). 20 years of life cycle assessment (LCA) in the forestry sector: state of the art and a methodical proposal for the LCA of forest production. The International Journal of Life Cycle Assessment, 20(4), 556–575. DOI: https://doi.org/10.1007/s11367-015-0847-1

Kromoser, B., Reichenbach, S., Hellmayr, R., Myna, R., & Wimmer, R. (2022). Circular economy in wood construction – Additive manufacturing of fully recyclable walls made from renewables: Proof of concept and preliminary data. Construction and Building Materials, 344, 128219. DOI: https://doi.org/10.1016/J.CONBUILDMAT.2022.128219

Liu, Z., Liu, T., Jiang, H., Zhang, X., Li, J., Shi, S. Q., & Gao, Q. (2022). Biomimetic lignin-protein adhesive with dynamic covalent/hydrogen hybrid networks enables high bonding performance and wood-based panel recycling. International Journal of Biological Macromolecules, 214, 230–240. DOI: https://doi.org/10.1016/J.IJBIOMAC.2022.06.042

Mantau, U. (2012). Wood flows in Europe. CEPI, CEI-Bois.

Moretti, C. (2023). Reflecting on the environmental impact of the captured carbon feedstock. Science of The Total Environment, 854, 158694. DOI: https://doi.org/10.1016/J.SCITOTENV.2022.158694

Pirc Barčić, Klarić, K., & Kruhak, T. (2022). The role of life cycle assessment in business and production processes in wood industry: a literature review. In Jelačić. Denis (Ed.), Controlling of business and production processes in forest based industry (1st ed., Vol. 1, pp. 47–64). WoodEMA, i.a.

Quintana-Gallardo, A., Schau, E. M., Niemelä, E. P., & Burnard, M. D. (2021). Comparing the environmental impacts of wooden buildings in Spain, Slovenia, and Germany. Journal of Cleaner Production, 329, 129587. DOI: https://doi.org/10.1016/J.JCLEPRO.2021.129587

Rey-Álvarez, B., Sánchez-Montañés, B., & García-Martínez, A. (2022). Building material toxicity and life cycle assessment: A systematic critical review. Journal of Cleaner Production, 341, 130838. DOI: https://doi.org/10.1016/J.JCLEPRO.2022.130838

Saadatian, S., Rodrigues, C., Freire, F., & Simões, N. (2022). Environmental and cost life-cycle approach to support selection of windows in early stages of building design. Journal of Cleaner Production, 363, 132624. DOI: https://doi.org/10.1016/J.JCLEPRO.2022.132624

Scientific Applications International Corporation (SAIC). (2006). Life cycle assessment: principles and practice. Cincinatti: National risk management research laboratory.

Shahzad, A., Ullah, M. W., Ali, J., Aziz, K., Javed, M. A., Shi, Z., Manan, S., Ul-Islam, M., Nazar, M., & Yang, G. (2023). The versatility of nanocellulose, modification strategies, and its current progress in wastewater treatment and environmental remediation. Science of The Total Environment, 858, 159937. DOI: https://doi.org/10.1016/J.SCITOTENV.2022.159937

Szichta, P., Risse, M., Weber-Blaschke, G., & Richter, K. (2022). Potentials for wood cascading: A model for the prediction of the recovery of timber in Germany. Resources, Conservation and Recycling, 178, 106101. DOI: https://doi.org/10.1016/J.RESCONREC.2021.106101

Tighnavard Balasbaneh, A., Sher, W., Yeoh, D., & Koushfar, K. (2022). LCA & LCC analysis of hybrid glued laminated Timber–Concrete composite floor slab system. Journal of Building Engineering, 49, 104005. DOI: https://doi.org/10.1016/J.JOBE.2022.104005

Tushar, Q., Bhuiyan, M. A., & Zhang, G. (2022). Energy simulation and modeling for window system: A comparative study of life cycle assessment and life cycle costing. Journal of Cleaner Production, 330, 129936. DOI: https://doi.org/10.1016/J.JCLEPRO.2021.129936

Vance, C., Sweeney, J., & Murphy, F. (2022). Space, time, and sustainability: The status and future of life cycle assessment frameworks for novel biorefinery systems. Renewable and Sustainable Energy Reviews, 159, 112259. DOI: https://doi.org/10.1016/J.RSER.2022.112259

Vilén, A., Laurell, P., & Vahala, R. (2022). Comparative life cycle assessment of activated carbon production from various raw materials. Journal of Environmental Management, 324, 116356. DOI: https://doi.org/10.1016/J.JENVMAN.2022.116356

Vujanović, A., Puhar, J., Krajnc, D., Awad, P., & Čuček, L. (2022). Reducing the environmental impacts of the production of melamine etherified resin fibre. Sustainable Production and Consumption, 29, 479–494. DOI: https://doi.org/10.1016/J.SPC.2021.10.014

Wu, N., Lan, K., & Yao, Y. (2023). An integrated techno-economic and environmental assessment for carbon capture in hydrogen production by biomass gasification. Resources, Conservation and Recycling, 188, 106693. DOI: https://doi.org/10.1016/J.RESCONREC.2022.106693

Zhang, Y., Ding, Z., Shahadat Hossain, M., Maurya, R., Yang, Y., Singh, V., Kumar, D., Salama, E. S., Sun, X., Sindhu, R., Binod, P., Zhang, Z., & Kumar Awasthi, M. (2023). Recent advances in lignocellulosic and algal biomass pretreatment and its biorefinery approaches for biochemicals and bioenergy conversion. Bioresource Technology, 367, 128281. DOI: https://doi.org/10.1016/J.BIORTECH.2022.128281

LES/WOOD Vol. 71, No. 2, 5-24
DOI: https://doi.org/10.26614/les-wood.2022.v71n02a04

WOOD IDENTIFICATION IN OBJECTS OF THE BAMBUTI PEOPLE FROM THE CONGO IN THE COLLECTION OF THE SLOVENE ETHNOGRAPHIC MUSEUM

IDENTIFIKACIJA LESA PREDMETOV LJUDSTVA BAMBUTI IZ KONGA V ZBIRKI SLOVENSKEGA ETNOGRAFSKEGA MUZEJA

Katarina Čufar[1], Hans Beeckman[2], Marko Frelih[3], Luka Krže[1], Wannes Hubau[2,4], Maks Merela[1*]

UDK članka: UDK 630*811:630*176.1
Original scientific article / Izvirni znanstveni članek

Received / Prispelo: 15.11.2022
Accepted / Sprejeto: 1.12.2022

Abstract / Izvleček

Abstract: The African collection of the Slovene Ethnographic Museum (SEM) in Ljubljana, Slovenia, holds objects of everyday life from the Bambuti people from the Ituri forest, in the northeastern part of the Democratic Republic of the Congo. The items were collected by the anthropologist Paul Joachim Schebesta, possibly during his expeditions around 1930. The objects containing wood were selected for wood identification by using microscopic wood identification, with the help of the InsideWood database and reference samples from the xylarium of the Royal Museum for Central Africa in Tervuren, Belgium. The investigated musical instrument, a wooden zither, was made of wood of *Musanga cecropioides*, the handle of the shield of *Alstonia* sp., the dagger and sheath of *Autranella congolensis* or another high density species of Sapotaceae, and the crossbow of *Nauclea diderichii* (bow) and *Xylopia* sp. (stock). Wood identification helped us to gain additional information on the origin, knowledge of wood, and time of the collection of objects in the Congo.

Keywords: museum objects, wood identification, *Musanga cecropioides*, *Alstonia*, *Autranella congolensis*, *Nauclea diderichii*, *Xylopia*, Africa

Izvleček: Afriška zbirka Slovenskega etnografskega muzeja (SEM) v Ljubljani hrani predmete iz vsakdanjega življenja ljudstva Bambuti iz gozda Ituri, na severovzhodu Demokratične republike Kongo. Predmete je zbral antropolog Paul Joachim Schebesta med svojimi odpravami verjetno okoli leta 1930. Predmeti, ki so vsebovali adultni les, so bili izbrani za raziskavo in mikroskopsko identifikacijo lesa s podporo platforme InsideWood ter referenčne zbirke lesa Kraljevega muzeja za Srednjo Afriko v Tervurnu v Belgiji. Raziskano glasbilo (lesene citre) je bilo izdelano iz lesa vrste *Musanga cecropioides*, ročaj ščita iz vrste *Alstonia* sp., nožnica in bodalo iz *Autranella congolensis* ali sorodne vrste z visoko gostoto iz družine Sapotaceae, samostrel pa iz *Nauclea diderichii* (lok) in *Xylopia* sp. (ročaj). Identifikacija lesa je ponudila dodatne informacije o izvoru, poznavanju lesa in času zbiranja predmetov v Kongu.

Ključne besede: muzejski predmeti, identifikacija lesa, *Musanga cecropioides, Alstonia*, *Autranella congolensis, Nauclea diderichii, Xylopia,* Afrika

1 INTRODUCTION

1 UVOD

The Slovene Ethnographic Museum (SEM) in Ljubljana holds an African collection with objects collected by the anthropologist Paul Joachim Schebesta. They were possibly collected during his expeditions in 1929 and 1930 when he visited the Ituri rainforest on the Congo River and lived among the central African Pygmy people and explored their culture (Frelih et al., 2017).

[1] University of Ljubljana, Biotechnical Faculty, Department of Wood Science and Technology, Jamnikarjeva 101, 1000 Ljubljana, Slovenia
[2] Royal Museum for Central Africa, Laboratory for Wood Biology, Leuvensesteenweg 13, B-3080 Tervuren, Belgium
[3] Slovene Ethnographic Museum, Metelkova ulica 2, 1000 Ljubljana, Slovenia
[4] Ghent University, Faculty of Bioscience Engineering, Coupure Links 653, B-9000 Gent, Belgium
* e-mail: maks.merela@bf.uni-lj.si

Paul Joachim Schebesta (Šebesta) was born in 1887 in Groß Peterwitz, Upper Silesia, at that time in the Austro-Hungarian Empire. During his studies in Mödling, near Vienna, he was dedicated to philosophy, theology, linguistics and ethnography. Under the influence of his professor, Wilhelm Schmidt, he developed a passion for studying the origin of religions which was later the main reason for his expeditions and extensive field research in Africa and Asia (Gütl, 2010). For this purpose, he searched for peoples who lived in remote, hard to reach areas and who were not yet affected by external influences from other cultures.

Schebesta undertook several research expeditions in the Congo (Figure 1). He was most attracted by the Bambuti (Mbuti) people in the rainforest on the Ituri catchment. In his first two expeditions in 1929 and 1930, he visited the Ituri rainforest, where the Pygmies had moved under pressure from other tribes (Schebesta, 1932). He was considered to be the first European who managed to live among the shy rainforest people for a significant period of time, and learned about their way of living, customs and traditions, which in some ways would be considered prehistoric in Europe (Frelih et al., 2017). The culture, which in the first half of 20th century was already in danger of becoming extinct, was important for exploration of the cultural history of mankind due to its ancientness.

The Pygmies from the Ituri rainforest in the Congo Basin seemed to have had a simple material culture, but they had impressive knowledge of flora, fauna and survival in the rainforest habitat. During his expeditions, Schebesta systematically documented and published what he observed (e.g., Schebesta, 1957). He also collected photographs, many of which are publicly available at the Bildarchiv Austria (2022) (Figure 1). He also systematically collected a selection of objects related to life of the investigated cultures, and presented his research through numerous lectures to the scientific community, students, and general public all over Europe (Frelih et al., 2017).

Schebesta's private collection, acquired during his fieldwork in the Congo, contained several thousands of objects, which he brought home to Mödling near Vienna. He later gradually gave or sold objects to museums in Brussels, Prague, and Vienna. However, it is less well known that a part of Schebesta's African collection is also kept in the Slovene Ethnographic Museum. Most likely it arrived there in October 1933, when Schebesta held a number of lectures in Ljubljana and other locations in Slovenia. He most likely donated the collection to

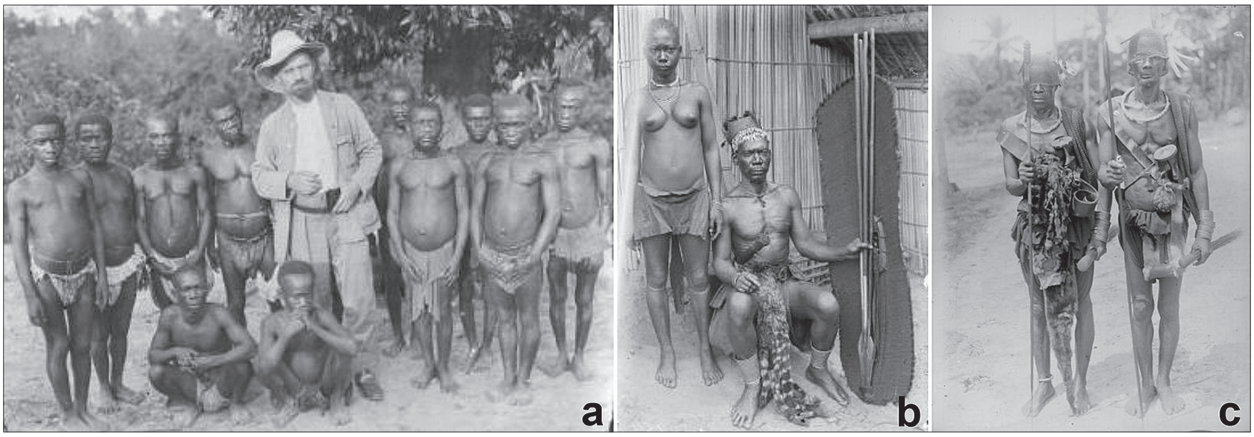


Figure 1. Photos from the archive of Paul Joachim Schebesta in the Bildarchiv Austria (2022): (a) Bambuti Pygmies in the village of Kero, with Schebesta surrounded by men (#10818394); (b) Bandaka Pygmies, specifically the headmen with his daughter, with the shield resembling the one investigated in this study (#12348274); (c) Nkundo Pygmies, with two men and weapons, including daggers like the ones in this study (#12452720)

Slika 1. Fotografije iz arhiva Paula Joachima Schebeste, ki ji hrani Bildarchiv Austria (2022): (a) Bambutiji v vasi Kero–Schebesta obkrožen z moškimi (#10818394), (b) ljudstvo Bandaka–poglavar s hčerjo–ščit je podoben tistemu, ki je bil raziskan v tej študiji (#12348274), (c) ljudstvo Nkundo–dva moška z orožjem, vključno z bodalom, podobnim bodalu v tej študiji (#12452720).

Figure 2. Some of the objects from the collection of Pavel Schebesta in the Slovene Ethnographic Museum (SEM) in Ljubljana (from Frelih et al., 2017).
Slika 2. Nekaj predmetov iz zbirke Pavla Schebeste, Slovenskega etnografskega muzeja (SEM) v Ljubljani (iz Frelih et al., 2017).

Professor Lambert Ehrlich, who lived and worked in Ljubljana. The existing sources also do not reveal when Ehrlich transferred the collection to the Slovene Ethnographic Museum, since two dates are mentioned – 1940 and 1941 – and whether he sold or donated the collection (Frelih et al., 2017). Due to these facts, it is extremely likely that the collection originates from the two expeditions Schebesta made to the Congo in 1929 and 1930.

Schebesta's collection at the Slovene Ethnographic Museum consists of 96 objects. Although it is not large, it contains a diversity of systematically collected objects, providing a basic presentation of the principal activities in the everyday life and material culture of different Bambuti groups native to the Ituri rainforest, Congo. The collection was not extensively researched or published until 2017, i.e. 130 years after Schebesta's birth and 50 years after his death, when the Slovene Ethnographic Museum and the Slovene Museum of Christianity prepared an exhibition and publication entitled *Baba wa Bambuti*, the name Schebesta was given by the natives on the Ituri River (Frelih et al., 2017). In addition to objects from Schebesta's collection, an example of a wooden crossbow from the second half of the 19^{th} century is also included in this research. The crossbow is from the Congo, and nothing is known about the collector.

The objects examined in this collection are mainly made of plant and animal material, and only few seem to be made of wood, which has not been investigated so far. In this study we thus focused on a few selected objects to perform wood research and identification. Our aim was to find out if such research can help answer various questions related to origin and history of the objects, and to explore how such information can help the museum curators.

2 MATERIALS AND METHODS
2 MATERIAL IN METODE

2.1 SELECTION OF MUSEUM OBJECTS
2.1 IZBOR MUZEJSKIH OBJEKTOV

In the depository of the Slovene Ethnographic Museum (SEM) in Ljubljana we inspected a list of objects from Schebesta's collection and selected ones that were presumably made of adult wood. The selected objects were a musical instrument (wooden zither), a shield, a dagger with sheath, and a crossbow consisting of bow and stock (Figure 2, Table 1). Each of the objects was carefully inspected by the museum curator, conserver-restorer and wood specialist in order to define the optimal location for sampling for wood identification.

For sampling we developed a minimally destructive method which allowed us to take small samples of wood to prepare thin microscopic slides (Koren, 2017). The wood samples were taken under the supervision of a museum curator and conserver on the least exposed and if possible hidden parts of the objects. For this purpose we used a special small drilling tool, an oscillating saw, and a surgical knife (Figure 3). The locations for wood sampling were carefully selected for each of the items, depending on its form and size. The samples contained enough wood tissue to produce cross-, radial- and tangential sections for microscopic wood identification.

2.2 SAMPLE PREPARATION
2.2 PRIPRAVA VZORCEV

After sampling, the wood was softened in a mixture of distilled water, glycerol and ethanol (in a ratio of 1:1:1) for about one week. Afterwards, the samples were observed under a magnifying glass and oriented to define the anatomical planes for cutting cross-, radial- and tangential sections with the help of a Leica SM2000R sliding microtome equipped with steel knives. The thickness of the sections was 10-20 µm. In one case the sample was taken with a surgical knife (Figure 3) and was embedded in paraffin; in this case 9 µm thick sections were cut with a Leica RM 2245 rotary microtome. Finally, the sections were stained with a water mixture of safranin and astra blue (i.e., 40 mg safranin and 150 mg astra blue in 100 ml demineralized water and 2 ml acetic acid) for at least 20 min, then washed, gradually dehydrated in ethanol (50, 70 and 100%) and finally mounted in Euparal according to the standard procedure (e.g., Prislan et al., 2022).

In this way, we produced one permanent slide for each of the objects or their parts, if they were made of more than one wood species.

Table 1. The investigated objects and their description from the catalogue (Frelih et al., 2017).
Preglednica 1. Preučevani objekti in njihov opis iz kataloga (Frelih et al., 2017).

Museum code Muzejska koda	Name Ime	Description Opis
EM 2953	Wooden zither	Musical instrument – a wooden zither with twelve plant-fibre strings (originally 15 strings).
	Lesene citre	Glasbeni instrument – lesene citre z 12 strunami iz rastlinskih vlaken (prvotno 15 strun).
EM 2866	Shield	Shield made of interwoven thin sticks and plant fibres with a carved handle plate, made of a single piece of wood and fixed to two vertical parallel sticks.
	Ščit	Ščit iz prepletenih tankih palic in rastlinskih vlaken z izrezljanim ročajem, izdelanim iz enega kosa lesa in pritrjenim na dve navpični vzporedni palici.
EM 2864	Dagger and sheath (scabbard)	Dagger with wooden hilt and iron blade, in a wooden sheath with an attached leather belt.
	Bodalo in nožnica	Bodalo z lesenim ročajem in železnim rezilom v leseni nožnici s pritrjenim usnjenim pasom.
EM 2675	Crossbow	Not in the catalogue/unknown collector from 19th century.
	Samostrel	Ni v katalogu/ neznan zbiralec iz 19. stoletja.

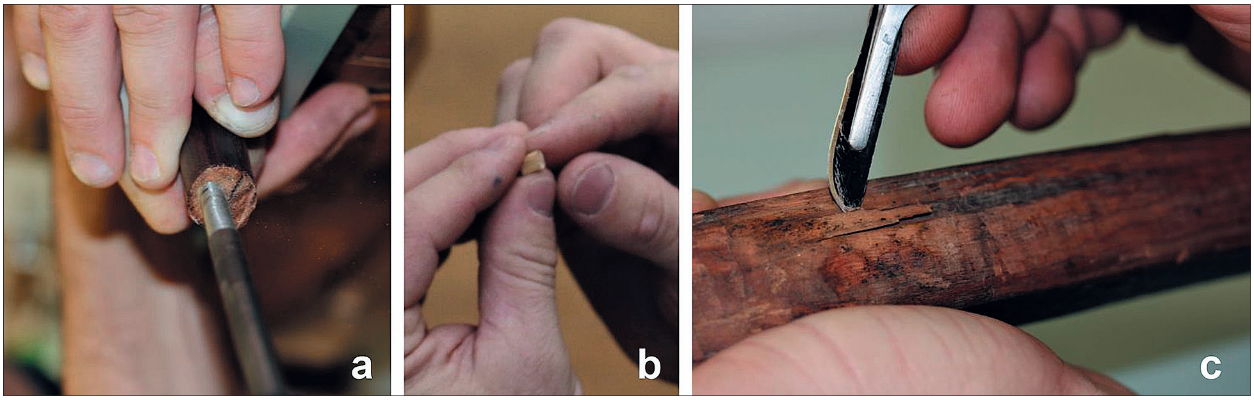


Figure 3. Collection of small samples for microscopic slides: (a) small drilling tool, (b) dimensions of wood sample, (c) collection of wooden splinter with a surgical knife.
Slika 3. Odvzem majhnih vzorcev za mikroskopske preparate: (a) majhno vrtalno orodje, (b) dimenzija lesenega vzorca, (c) odvzem lesene trske s kirurškim skalpelom.

2.3 WOOD IDENTIFICATION
2.3 IDENTIFIKACIJA LESA

Microscopic wood identification was performed by observing the sections under a Nikon Eclipse E800 light microscope equipped with a Nikon DS-Fil digital camera and using the NIS Elements BR 3.0 image analysis computer program to capture the images. We examined the sections and recorded the observed features using the IAWA list of microscopic features for hardwood identification (IAWA committee, 1989) and InsideWood database (Wheeler, 2011; InsideWood, 2022). Afterwards the combinations of features were compared with reference data from the InsideWood database and xylarium of the Royal Museum of Central Africa, Tervuren, Belgium.

3 RESULTS AND DISCUSSION
3 REZULTATI IN RAZPRAVA

3.1 WOODEN ZITHER
3.1 LESENE CITRE

The musical instrument, a wooden zither (EM2953), was made of wood of low density. The body was about 70 cm long, 20 cm wide, and 2 cm thick, and the wood working was rough. The instrument contained twelve plant-fibre strings whereas the body had 15 incisions at each end, where the strings were attached (Figure 4). Two wooden sticks, about 2 cm thick, positioned between the strings and the body, were used for tensioning the strings. They were not fixed, so their position could be changed to achieve the desired tone.

Based on its wood structure (Figure 5) the wood of the body was identified as *Musanga cecropioides* R. Br., Urticaceae, with the most frequently used common names being African corkwood or parasolier (InsideWood, 2022).

The wood is diffuse porous with indistinct or absent growth ring boundaries and large vessels (tang. diameter ≥ 200 µm), thin walled fibres, paratracheal axial parenchyma (scanty, vasicentric), heterogeneous rays (body ray cells procumbent with 1-4 rows of upright and / or square marginal cells), 1-3 cells wide with sheath cells and prismatic crystals.

The species *Musanga cecropioides* grows in tropical Africa (PlantUse *Musanga*, 2022). Its wood is of low commercial importance and is not available on international markets. It has low density wood, with an air dry density of 190–370 kg/m^3. The colour of the wood is basically white, sometimes with a pinkish tinge when freshly cut, turning to pale yellow or pale brown upon exposure. Heartwood cannot be distinctly demarcated from the sapwood. The wood is nondurable, class 5 (CEN, 2016), as reported by Wagenführ and Wagenführ (2022).

The wood belongs to one of the lightest ones in the central African forests. It is easy to cut and work. It is occasionally locally used for light interior constructions, partitions, doors, fences, roof rafters, stools, beds, musical instruments, toys,

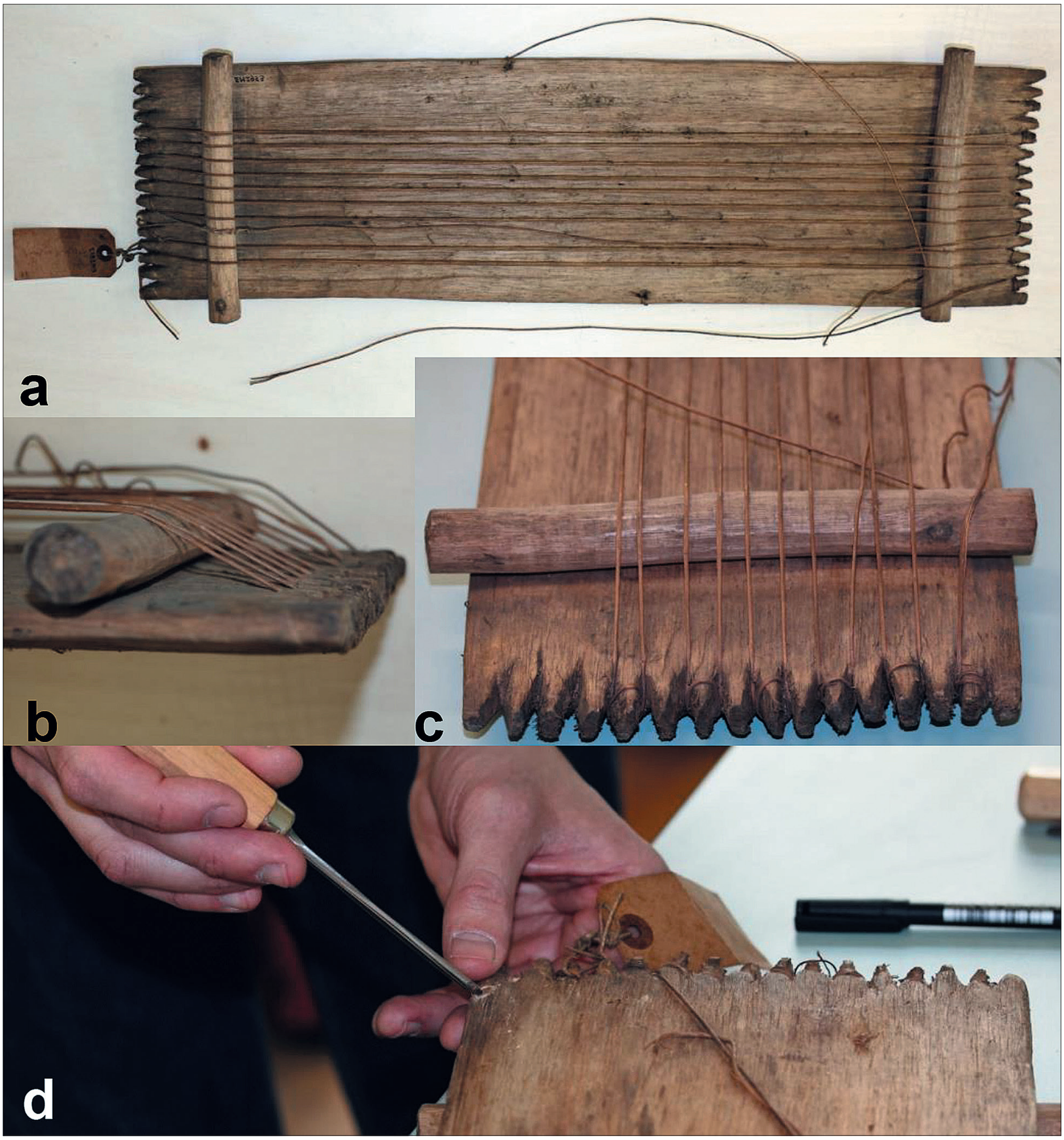


Figure 4. Wooden zither (length about 70 cm): (a) entire instrument, (b, c) details, and (d) location of wood sampling.
Slika 4. Lesene citre (dolžine približno 70 cm): (a) celoten instrument, (b, c) podrobnosti ter (d) mesto odvzema vzorca lesa.

walking sticks, paddles, trays, baskets, and as a cork substitute to make floats for fishing nets and small canoes. It is suitable for sporting goods, boxes, crates, carvings, veneer, plywood, hardboard, particle board and wood-wool. The wood is traditionally used to produce thin split boards. It can potentially be used as industrial insulation. The boles were traditionally hollowed out to make containers for liquids and small canoes, and to produce carved objects.

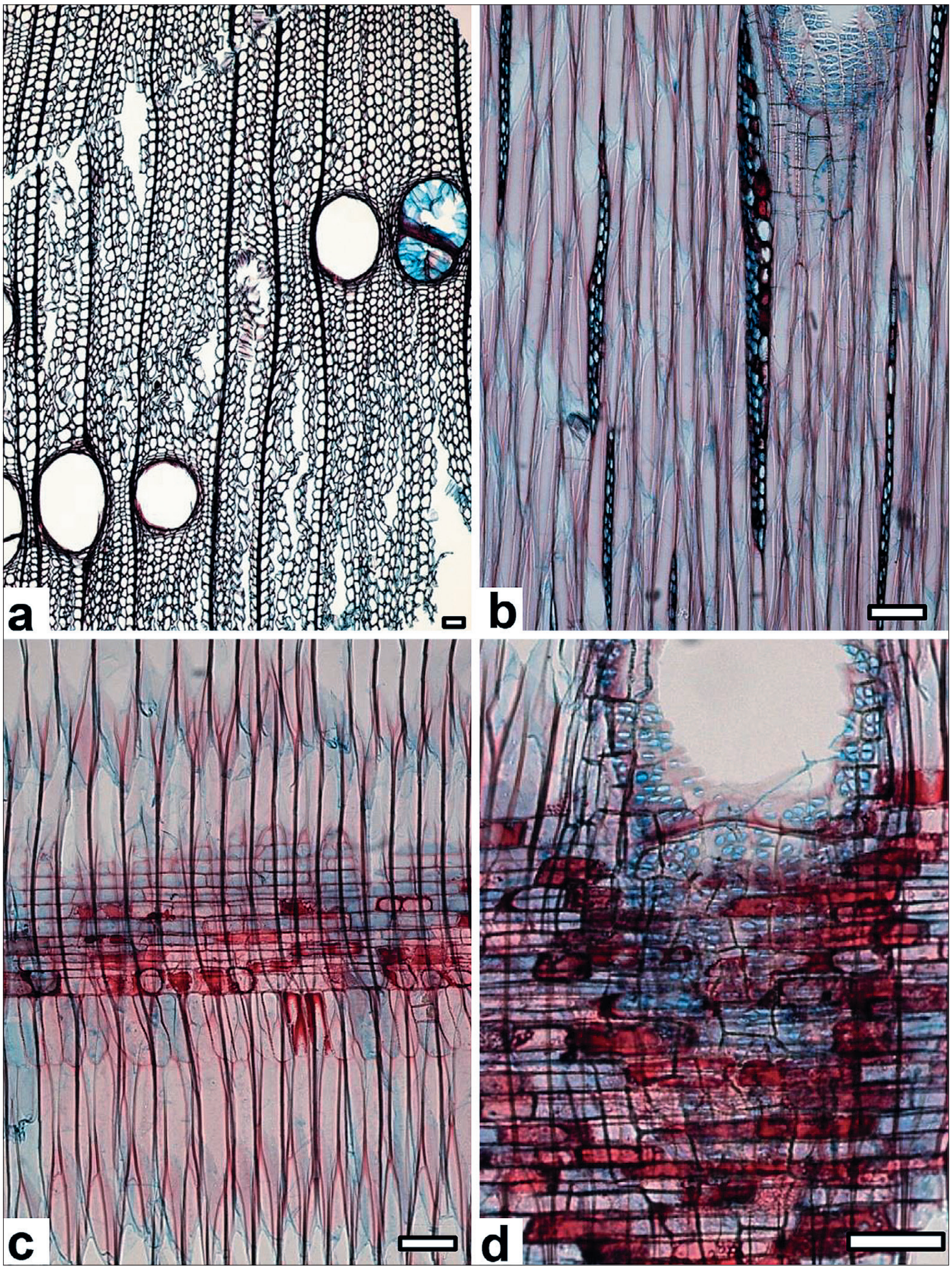


Figure 5. Wood from the body of the wooden zither *Musanga cecropioides* with: (a) cross-, (b) tangential-, and (c, d) radial sections. Scale bars–100 µm.
Slika 5. Les glavnega dela citer vrste *Musanga cecropioides*: (a) prečni, (b) tangencialni in (c, d) radialni prerez. Merilne daljice -100 µm.

Musanga cecropioides is an outspoken pioneer species, often growing on clear cuts or in disturbed areas in wetter forests and on small scale canopy-gaps, in regions with a mean annual temperature of 25–30°C and annual rainfall of 1300–2500 mm or more. The trees are generally characterized by quick growth, and are often found around villages and along roads. The species usually occurs below 800 m altitude, and in the Democratic Republic of Congo occasionally up to 1200 m (PlantUse *Musanga*, 2022).

3.2 THE SHIELD
3.2 ŠČIT

The shield is labelled EM2866 and is made of different types of plant material. The base of the shield is formed by two sticks, which support the handle and the front part (mask) of the shield, which is artificially made of intertwined plant material. The central sticks are positioned along the shield, which is about 140 cm long (Figure 6), and provide a quality construction solution to improve the strength of the shield. The central sticks are

Figure 6. The shield (length 140 cm): (a) front and (b, c) back view with the wooden handle.
Slika 6. Ščit (dolžine 140 cm): (a) sprednji in (b, c) zadnji del z lesenim ročajem.

connected by the handle and a skilfully made piece of interlaced plant material, which also serves for decoration. The handle is made of one piece of wood and is attached to the shield with a rope. The object is very light, and therefore was possibly used as a ceremonial shield.

The wood of the shield handle was identified as *Alstonia boonei* De Wild. or *A. congensis* Engl., Apocynaceae with the vernacular names cheesewood, ekouk or emien. The two species cannot not be distinguished based on wood structure (InsideWood, 2022; PlantUse *Alstonia..., 2022*).

The wood is diffuse porous (Figure 7). Intervessel pits are vestured and vessel-ray pits similar to intervessel pits in size and shape appear throughout the ray cell, the fibres are very thin-walled, axial parenchyma is reticulate, aligned in narrow bands or lines up to three cells wide. Rays are one to three cells wide and heterogeneous, with procumbent body cells and one to four rows of upright and / or square marginal cells. Laticifers are present but they are very small (with a similar size to the ray cells) and difficult to distinguish in the ray on tangential section (Figure 7b) (InsideWood, 2022).

The heartwood is creamy white and indistinctly demarcated from the up to 20 cm wide sapwood. The wood darkens upon exposure to light. The grain is straight, occasionally wavy, and the texture moderately coarse. Growth rings are indistinct or absent. The wood has a disagreeable smell when green. It is lightweight, and the mean air-dry density is 360 kg/m^3. The wood is not durable and belongs to durability class 5 (CEN, 2016). The wood is easy to saw, although the presence of latex may cause clogging of sawblades (CIRAD *Alstonia*, 2022; PlantUse *Alstonia boonei,* 2022; PlantUse *Alstonia congensis,* 2022).

The wood of *Alstonia boonei*, called alstonia in international trade, is used for light constructions, light carpentry, open boats, moulding, furniture, interior joinery, implements, boxes, crates, matches, pencils, sculptures, and for veneer and plywood. It is locally popular for the production of household implements because of its good working properties and stability. It is easy to carve therefore it is also used for masks, sculptures and so on.

The genus *Alstonia* comprises about 40 species with a pantropical distribution. Only two, *Alstonia congensis* and *Alstonia boonei*, are indigenous in

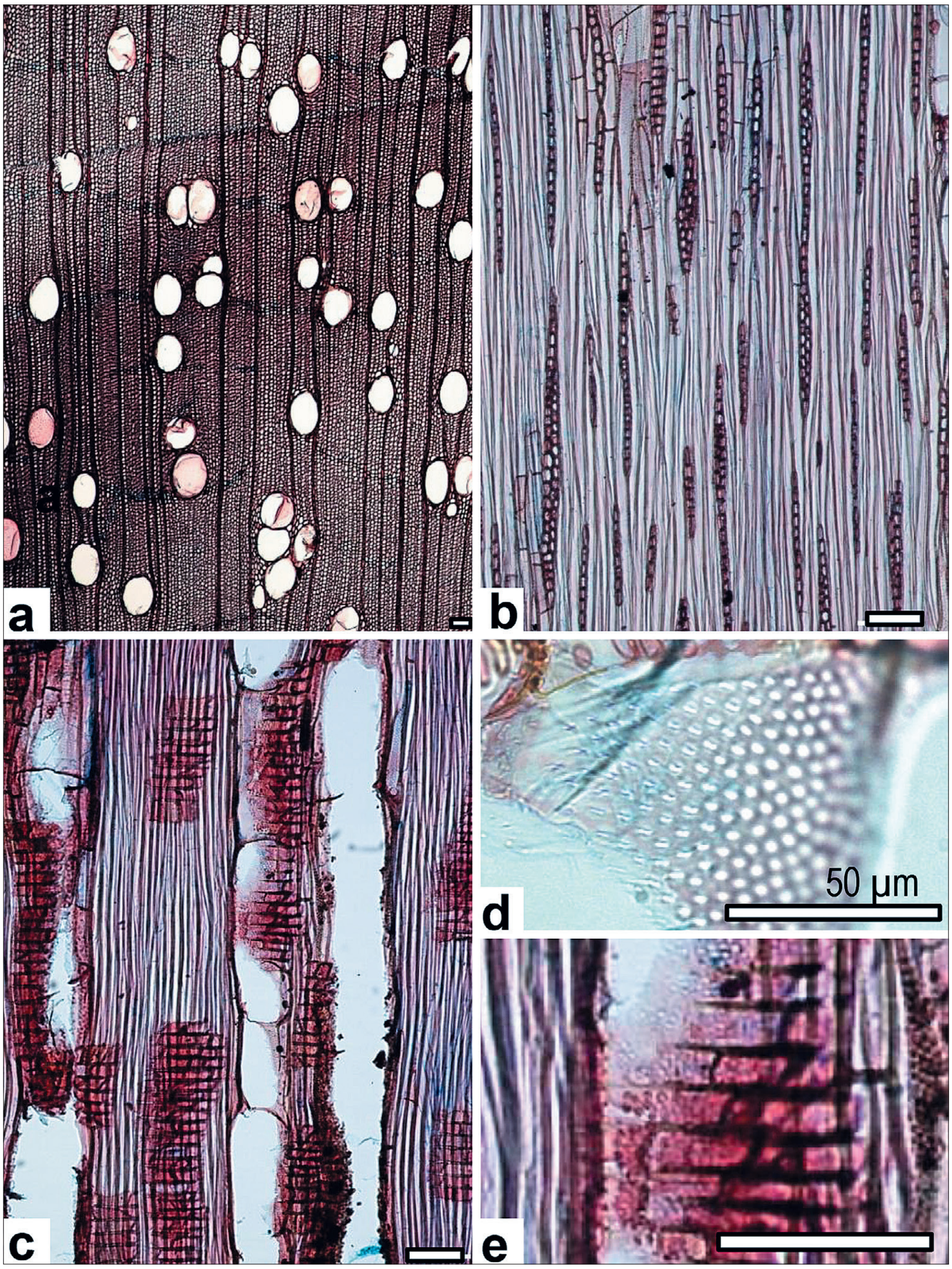


Figure 7. Wood of *Alstonia* sp. from the shield handle: (a) cross-, (b) tangential-, and (c) radial sections, (d) vestured intervessel pits, (e) detail showing vessel ray pits. Scale bars–a, b, c, e–100 µm, d–50 µm.

Slika 7. Les ročaja ščita vrste *Alstonia* sp.: (a) prečni, (b) tangencialni in (c) radialni prerez, (d) okrašene intervaskularne piknje, (e) pogled, kjer so vidne piknje med trakom in trahejo. Merilne daljice: a, b, c, e–100 µm, d–50 µm.

Africa. The wood of the two species is closely related, and the two species are not discriminated in use.

3.3 DAGGER AND SHEATH
3.3 BODALO IN NOŽNICA

The dagger with a wooden hilt, iron blade and a wooden sheath (EM2864) is a decorated object which could be produced and used for ritual purposes (Figure 8). Macroscopic inspection of the wood revealed that the hilt and sheath were made of the same wood species. The sheath is approximately 35 cm long and is made of one piece of wood. It contains a precisely made opening which fits the blade of the dagger. A leather belt is attached through a hole and enables fitting the objects around the waist. The sheath is made with exceptional precision, which is evident from the wood processing, decoration and precise dimensions. The dagger with an about 30 cm long blade and over 10 cm long wooden hilt is also precisely made. The blade is decorated with cuts. The pom-

Figure 8. Dagger with a wooden hilt and iron blade, and a wooden sheath with leather belt.
Slika 8. Bodalo z lesenim ročajem in železnim rezilom ter leseno nožnico z usnjenim pasom.

mel of the hilt is decorated with bronze rivets. One of the photos taken by Paul Joachim Schebesta shows two warriors of the Nkundu people in full gear, including a dagger, similar to the one investigated in this study (Figure 1c).

The wood of the dagger hilt and sheath was identified as similar to *Autranella congolensis* A. Chev., Sapotaceae, with the most common vernacular names being elang and mukulungu (InsideWood, 2022).

This diffuse-porous wood species with small vessels (Figure 9) has the following features: intervessel pits alternate, vessel-ray pits with much reduced borders to apparently simple pits rounded or angular, non-septate fibres present, fibres very thick-walled, axial parenchyma diffuse and diffuse in aggregates, axial parenchyma in narrow bands or lines up to three cells wide (mainly one cell wide), eight (five to eight) cells per parenchyma strand, ray width one to three cells, body ray cells procumbent with mostly two to four rows of upright and / or square marginal cells, body ray cells procumbent with over four rows of upright and / or square marginal cells (InsideWood, 2022).

The wood has a high air-dry density (940 kg/m^3). The heartwood is red brown and can be clearly distinguished from sapwood. The wood is very durable, class 5 (CEN, 2016). The wood is used for hydraulic works, sleepers, heavy constructions, poles, heavy carpentry, flooring, stairs, sliced veneer, exterior panelling, and cooperage (CIRAD, *Autranella congolensis*, 2022).

Autranella congolensis occurs in primary evergreen rainforest, and is usually scattered, rarely abundant. Natural regeneration is currently poor. The growth of trees is slow and very long cutting cycles are probably required for sustainable harvesting. This makes *Autranella congolensis* a tree with few prospects for timber production, and attention should concentrate on its protection.

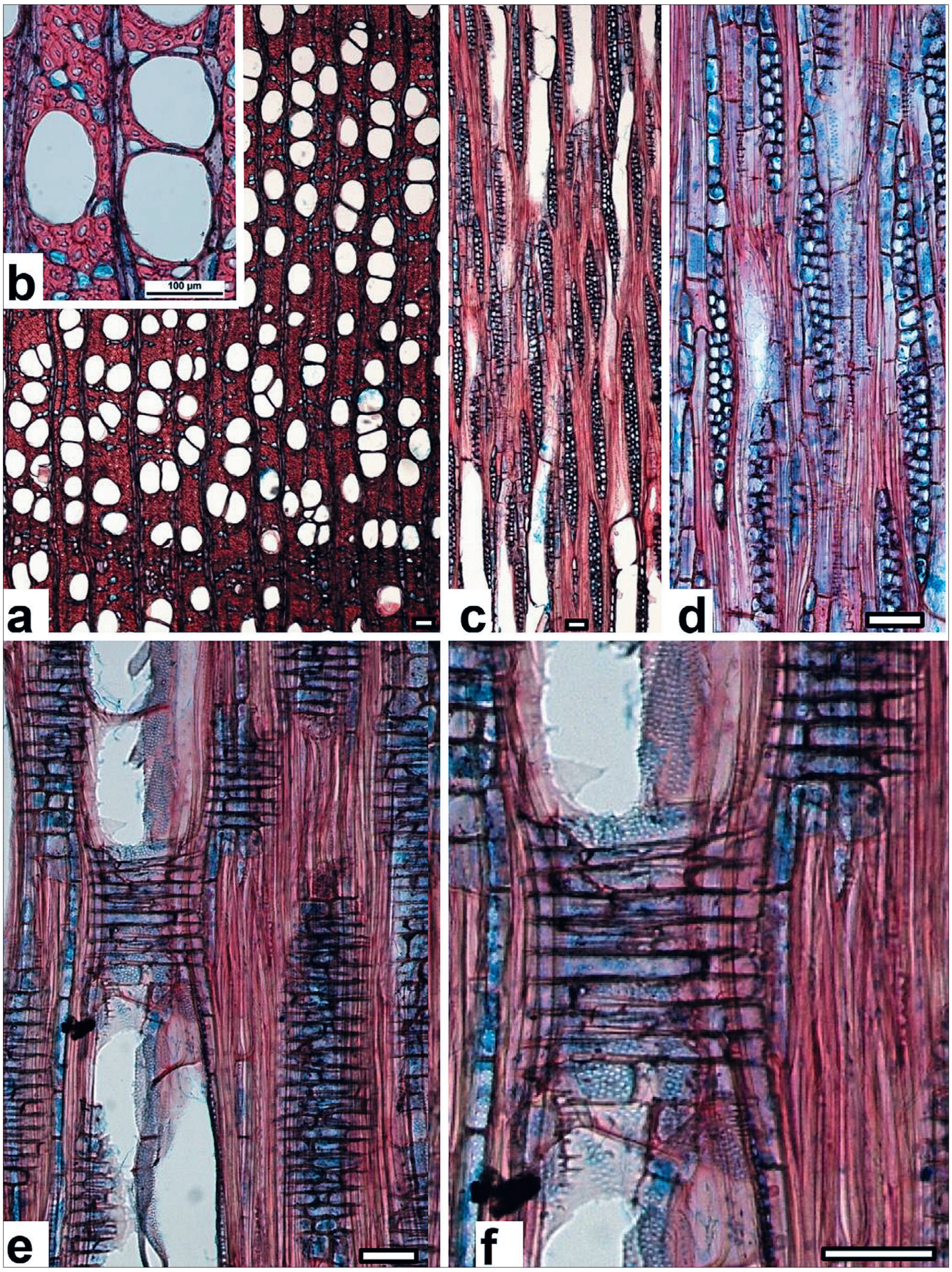


Figure 9. Wood from the dagger hilt and sheath, *Autranella congolensis*, Sapotaceae with (a, b) cross-, (c, d) tangential-, and (e, f) radial sections. Scale bars–100 µm.

Slika 9. Les ročaja in nožnice bodala iz lesa vrste *Autranella congolensis*, Sapotaceae: (a, b) prečni, (c, d) tangencialni in (e, f) radialni prerez. Merilne daljice–100 µm.

3.4 CROSS-BOW
3.4 SAMOSTREL

The cross-bow (label EM 2675) is entirely made of wood and consists of two parts, a bow and handle (stock) (Figure 10). Based on the macroscopic examination, we supposed that the two parts must be made of two different wood species. The handle is about 120 cm long. Approximately two-thirds of its length is the trigger mechanism. From the structural point of view, the trigger mechanism is remarkably well made (Frelih et al., 2017). The handle is evenly split into two parts, all the way to the chisel for the bow string. The bow is about 80 cm long. It is made of one piece of bent wood. As the distance between both ends of the bow and the incisions for the string are short, it is necessary to use a wood of exceptional toughness to produce an effective weapon.

The wood of the bow is identified as *Nauclea diderrichii* Merr., Rubiaceae, with the most common vernacular names being bilinga and opepe.

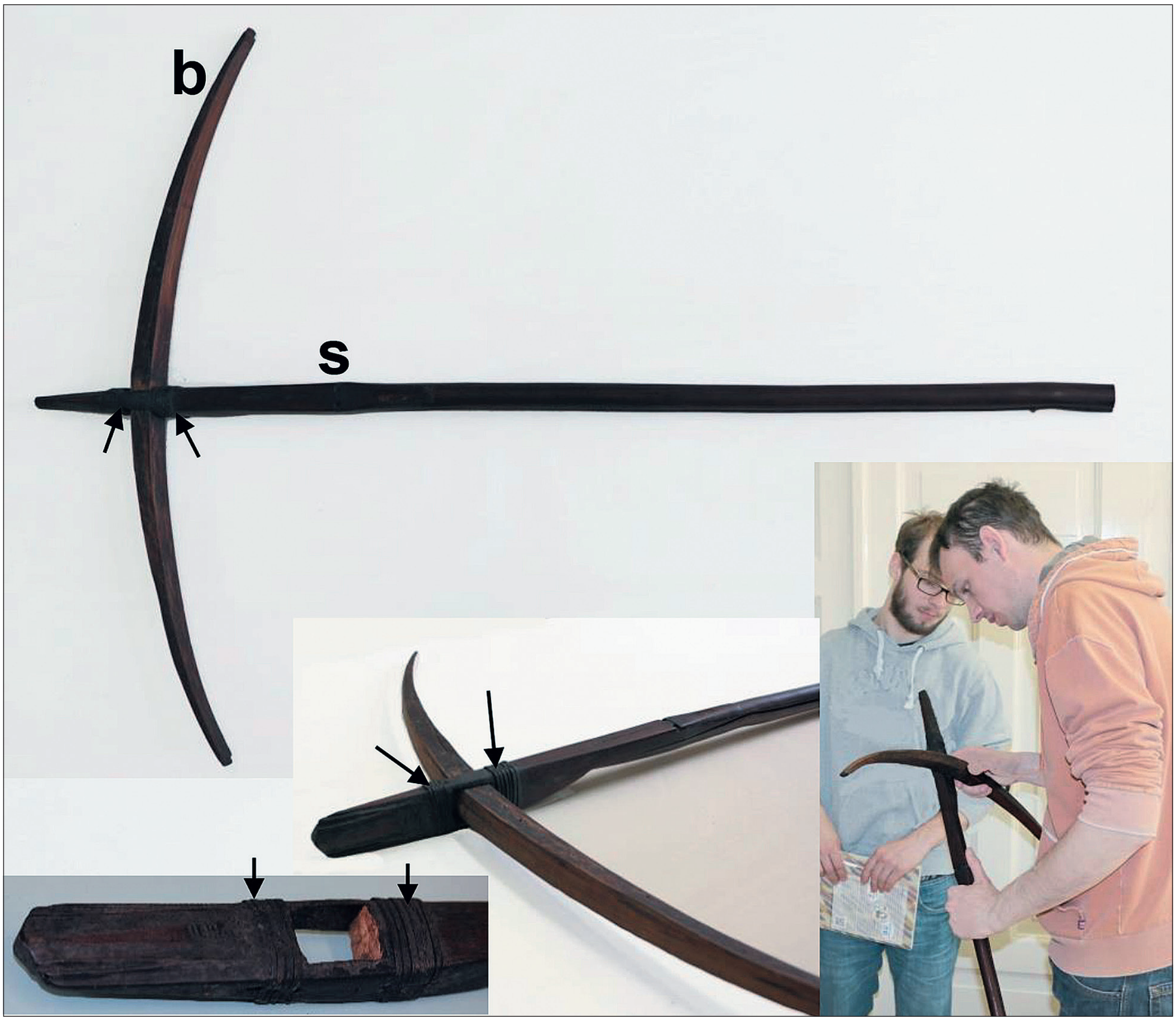


Figure 10. Crossbow – different views showing: (b) the bow made of *Nauclea diderichii* and (s) the stock made of *Xylopia* sp.; arrows show iron belts for reinforcement.
Slika 10. Samostrel, različni pogledi: (b) lok iz lesa *Naeuclea diderichii* in (s) ročaj iz lesa vrste *Xylopia* sp.; puščice kažejo železne trakove za ojačitev.

This wood species is diffuse porous and has very small, isolated vessels (Figure 11). Other IAWA features of the species are: vessel-ray pits with distinct borders that are similar to intervessel pits in size and shape throughout the ray cell, bordered pits in fibres can be seen in radial and also in tangential fibre walls, axial parenchyma is diffuse, diffuse-in-aggregates or scanty paratracheal, ray width one to three cells. Rays have multiseriate portion(s) as wide as uniseriate ones, body ray cells are procumbent with mostly two to four or over four rows of upright and / or square marginal cells orperforated ray cells, and the ray-body cells are procumbent.

Nauclea diderichii is on the list of commercial hardwoods (Richter and Dallwitz, 2002; CIRAD, *Nauclea diderrichii*, 2022). Its heartwood is golden yellow or orange yellow, clearly demarcated from the sapwood. Its wood is hard, dense (average air-dry density 760 kg/m^3) and very durable, in durability class 1 (CEN, 2016), and it is resistant to fungi and insects (CIRAD, *Nauclea diderrichii*, 2022). It is used in joinery, flooring and marine constructions.

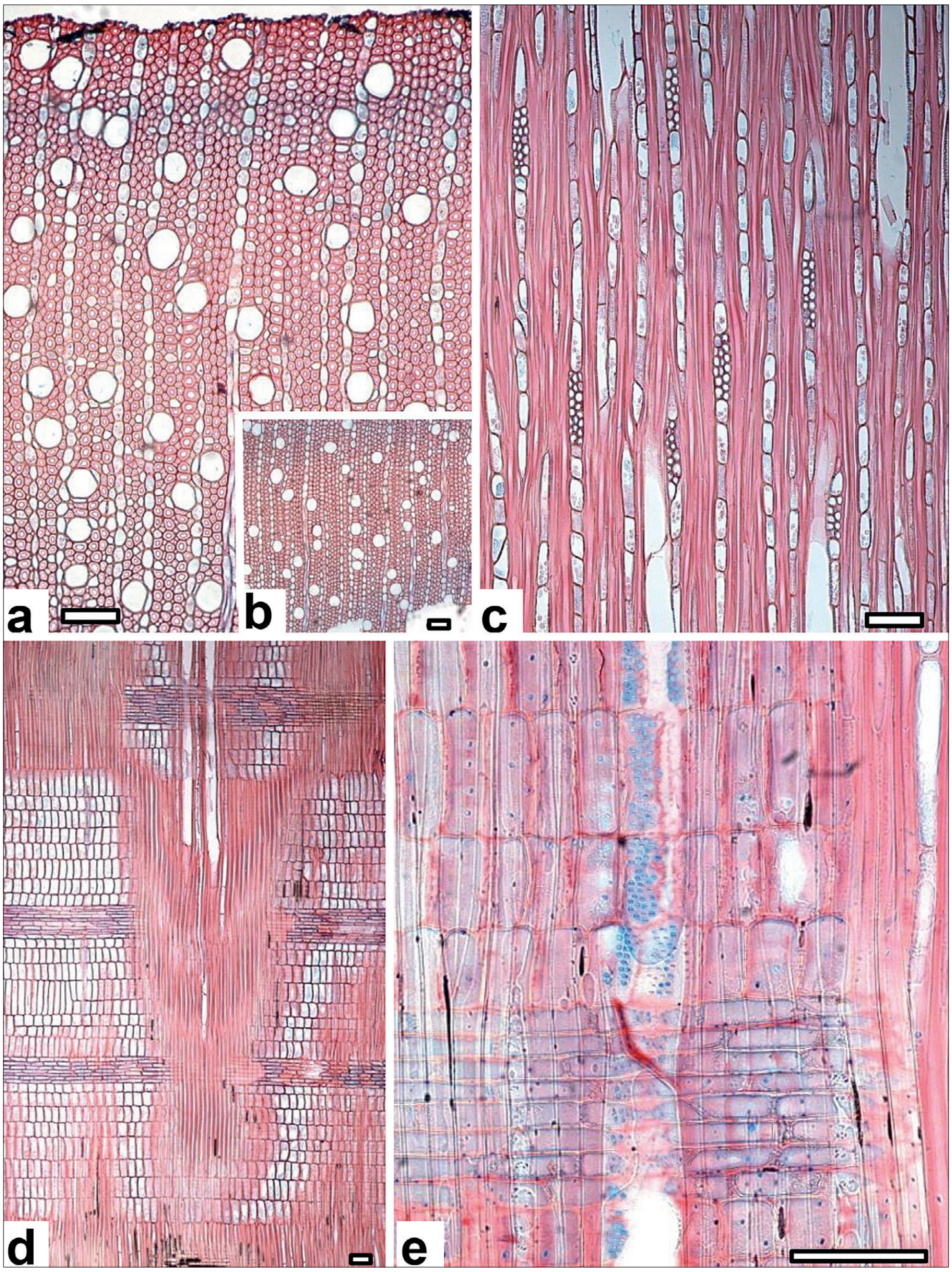


Figure 11. Wood from the bow of the cross-bow (*Nauclea diderichii*): (a, b) cross-, (c) tangential- and (d, e) radial sections; (d) detail showing vessel ray pits and pits in fibres. Scale bars–100 µm.

Slika 11. Les iz loka samostrela (*Nauclea diderichii*): (a, b) prečni, (c) tangencialni in (d, e) radialni prerez; (d) detajl s piknjami med trakom in trahejo in piknjami vlaken. Merilne daljice–100 µm.

It is used for railway sleepers, heavy carpentry, poles, heavy constructions, hydraulic works, flooring, cabinetwork, sliced veneer, ship building, planking and panelling (CIRAD, *Nauclea diderrichii*, 2022). It was as a rule also used for numerous ethnographic objects.

Nauclea diderichii is a tree species natural in subtropical or tropical moist lowland forests. It is threatened by habitat loss (IUCN, 2022).

The wood of the stock belongs to the genus *Xylopia*, Annonaceae and we could not identify it to a species level. The wood is diffuse-porous with radial diameters of vessels of ca. 200 µm. Vessel-ray pits have distinct borders and are similar to intervessel pits in size and shape throughout the ray cell. Fibres have simple to minutely bordered pits. Fibres are thick-walled. Axial parenchyma is in narrow bands or lines up to three cells wide, reticulate. Ray width is one to three, all ray cells are procumbent. Density is medium, 400-750 kg/m^3 (InsideWood, 2022).

Wood structure with a great proportion of thick-walled fibres and a homogenous struc-

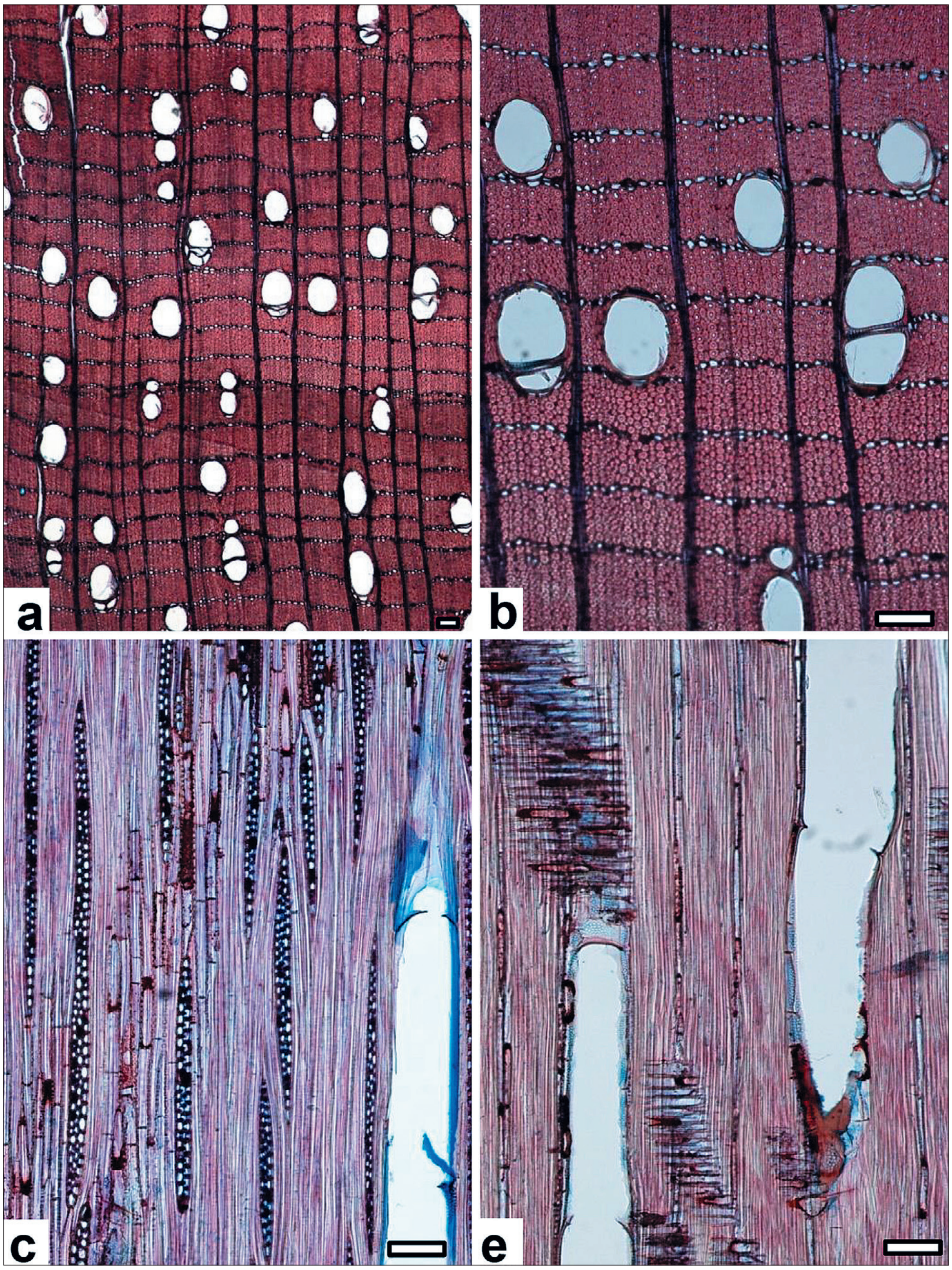


Figure 12. Wood from the stock of the crossbow (*Xylopia* sp.): (a, b) cross-, (c) tangential-, and (d) radial sections. Scale bars–100 µm.
Slika 12. Les ročaja samostrela (*Xylopia* sp.): (a, b) prečni, (c) tangencialni in (d) radialni prerez. Merilne daljice–100 µm.

ture with uniformly distributed axial parenchyma strands indicate that the wood may have a high density and favourable mechanical properties.

Up to twenty different species of *Xylopia* grow in the Congo. Although the trees can be large enough to be used as timber, the wood is relatively unknown in international markets, but has some commercial potential if available in significant stocks. The wood is moderately hard and heavy, moderately durable to durable, of durability class 2-3 (CEN, 2016), and has good machining characteristics, as shown for *Xylopia hypolampsa* from the forests of the Central African Republic (Možina & Torelli, 1977; Torelli, 1983; Čufar, 1984). Wood of *Xylopia* sp. has some decorative value for applications such as parquet flooring and furniture (Dahms, 1999). One species growing in the Ituri forest that is a candidate for the botanical identity of the crossbow is *Xylopia chrysophyllum*.

3.5 POTENTIAL OF WOOD RESEARCH IN MUSEUM OBJECTS

3.5 POTENCIAL RAZISKAV LESA MUZEJSKIH OBJEKTOV

The collection of 96 objects from the SEM contained only few objects which were made of wood of larger trees. Nearly all of these objects have inventory labels (Figure 2), featuring their names and how the natives possibly used them. Interestingly, the labels show two, three, or even four different inventory numbers, written with different pens. Schebesta probably inventoried and numbered the objects in the field, but they were later renumbered in Mödling, and perhaps finally once more in Ljubljana (Frelih et al., 2017). The pictures from Schebesta's archive stored in the picture archive Bildarchiv Austria (2022) additionally help us to understand the use of the objects (Figure 1).

The wood of the objects has never been studied, so its potential to shed light on the wood species used by the Bambuti and to provide additional information on the origin and history of the objects could not be exploited.

In four studied objects, we identified five different species (Table 2) from different families, all of which grow in the tropical rainforest of Ituri in the Congo. The species are mostly unknown in international markets. They have different densities and other characteristics, and have been effectively used to make various objects, confirming that their characteristics are well known to the local people, the Bambuti.

The choice of species confirms the origin of the wood from the Congo, more precisely from the dense tropical rainforest of Ituri. Since the species are not known internationally and have never been used in Slovenia, their identification could only be done by making high quality microscopic sections for observation under a microscope. This required destructive sampling, which in our case was less invasive because the process was optimized and very small wood particles were taken. Despite high quality microscopic sections, identification could not be done without the InsideWood collection and collaboration with the Royal Museum of Central Africa and its xylarium, with collections of wood samples and microscopic slides.

The objects in the Ljubljana collection resemble numerous objects in the Weltmuseum Wien in Vienna. Archival sources indicate that the objects in Vienna originate from the Congo region and come from Schebesta's expeditions in 1929-1930 and 1934-35 (Frelih et al., 2017).

Our enquiries in Austria and Belgium have shown that systematic identification of the wood of ethnographic objects from the Schebesta collection has mostly not been carried out, as also observed for other African collections (e.g., Bontadi & Bern-

Table 2. Wood taxa in the wooden objects from the museum collection and main information; *density of air-dry wood from the literature.

Preglednica 2. Vrste lesa v lesenih predmetih iz muzejske zbirke in glavni podatki; *gostota zračno suhega lesa iz literature.

Name and museum code Ime in muzejska koda	Wood species Vrsta lesa	Family Družina	Density* Gostota*
			kg/m³
Wooden zither EM 2953 Lesene citre	*Musanga cecropioides*	Urticaceae	190–370
Shield (handle) EM 2866 Ščit (ročaj)	*Alstonia boonei* *Alstonia congensis*	Apocynaceae	360
Dagger and sheath EM2864 Bodalo in nožnica	*Autranella congolensis*	Sapotaceae	940
Crossbow EM 2675 Samostrel			
-bow / lok	*Neuclea diderichii*	Rubiaceae	760
-stock / ročaj	*Xylopia* sp.	Annonaceae	possibly >750

abei, 2016; Petrovčič, 2016). However, at least the botanical identity of a few objects from the material culture of the Bambuti is known, thanks to the research of Tanno (1981), who analysed their plant use with particular reference to their material culture and the use of wild vegetables as food.

Since the Bambuti had to move their camps regularly, their baggage was rather light. The men carried only the hunting equipment and axes, while the women carried the household items in baskets. Other items were shared with other families and used by the group as a whole, or made locally when needed (Tanno, 1981). The number of items in the material culture of the Bambuti is rather limited compared to that seen with sedentary cultures, but they testify to a close connection with nature and natural resources, and to an exceptional knowledge of forest products, including the wood characteristics of various trees, which were used for a wide range of applications.

4 CONCLUSIONS
4 SKLEPI

Although the Congolese indigenous objects collected by anthropologist Paul Joachim Schebesta are stored in several museums throughout Europe, and his missions to the Congo are well documented, the identification of wood in the objects has generally not been undertaken.

This study shows that five different wood species – namely *Musanga cecropioides*, *Alstonia boonei* or *Alstonia congensis*, *Autranella congolensis*, *Neuclea diderichii*, and *Xylopia* sp. – were identified in four studied objects. They all grow in the tropical rainforest of Ituri, Congo, and are largely unknown in international markets. Their identification could therefore only be achieved by making high quality microscopic sections and carrying out microscopic wood identification with the help of the InsideWood database and the wood collection of the Royal Museum of Central Africa. Wood research has thus helped us to obtain additional information on the origin and history of objects representative of the material culture of the Bambuti. The selection of wood species confirms their excellent knowledge of the wood properties of species growing in the Ituri rainforest habitat.

5 SUMMARY
5 POVZETEK

Slovenski etnografski muzej (SEM) v Ljubljani hrani zbirko predmetov, ki jih je zbral antropolog Paul Joachim Schebesta na svojih odpravah v Kongu, verjetno v letih 1929 in 1930, ko je obiskal deževni gozd Ituri ob reki Kongo in živel med srednjeafriškimi Pigmejci ter raziskoval njihovo kulturo (Frelih et al., 2017). Sistematično zbrani predmeti so povezani z življenjem raziskovanih kultur, ki jih je predstavil v številnih publikacijah in predavanjih po Evropi (Frelih et al., 2017). Veliko zbranih predmetov je postopoma podaril ali prodal muzejem v Bruslju, Pragi in na Dunaju, del Schebestove afriške zbirke pa hrani tudi SEM v Ljubljani. Najverjetneje je tja prišla oktobra 1933, ko je imel Schebesta predavanja v Ljubljani in drugih krajih v Sloveniji. V raziskavo smo vključili tudi leseni samostrel iz Konga, ki ga je muzej pridobil v drugi polovici 19. stoletja. Kdo je muzeju izročil samostrel, ni znano.

Schebestova zbirka v SEM obsega 96 predmetov, ki omogočajo osnovno predstavitev glavnih dejavnosti v življenju in materialni kulturi različnih skupin ljudstva Bambut, ki živijo v deževnem gozdu Ituri. Predmeti so večinoma izdelani iz rastlinskega in živalskega materiala. Le nekaj predmetov je izdelanih iz lesa večjih dreves. Les doslej še ni bil raziskan. V tej študiji smo se osredotočili na izbor in raziskavo lesenih predmetov, kjer smo opravili identifikacijo lesa. Zanimalo nas je tudi, ali lahko raziskave lesa prispevajo k razjasnitvi vprašanj, povezanih z izvorom in zgodovino predmetov, ter kako lahko pomagajo muzejskim kustosom.

V depoju SEM smo pregledali nabor predmetov in izbrali tiste, ki so domnevno izdelani iz adultnega lesa dreves. Izbrali smo štiri predmete: leseno glasbilo–citre, ščit z lesenim ročajem, bodalo z nožnico in samostrel, sestavljen iz loka in ročaja (preglednica 1, slike 2, 4, 6, 8, 10). Vsak predmet so skrbno pregledali muzejski kustos, konservator–restavrator in strokovnjaki za les, da bi določili optimalno mesto za odvzem vzorcev za identifikacijo lesa.

Za odvzem lesa smo razvili metodo, ki je omogočila odvzem majhnih vzorcev, mikroizvrtkov ali trsk, za pripravo tankih mikroskopskih preparatov. Vzorce lesa smo pod nadzorom muzejskega kustosa in konservatorja odvzeli na čim bolj skritih delih predmetov. V ta namen smo uporabili posebno

majhno orodje za vrtanje, vrtalnik in nihajno žago ter kirurški nož (slika 3).

Pripravljeni so bili trajni mikroskopski preparati treh anatomskih ravnin, mikroskopska identifikacija lesa pa je bila opravljena s pomočjo platforme Inside Wood ter referenčnih vzorcev lesa in preparatov iz zbirke Kraljevega muzeja za Srednjo Afriko v Tervurnu v Belgiji.

Po odvzemu vzorcev smo les nekaj dni mehčali v mešanici destilirane vode, glicerina in etanola. Nato smo vzorce opazovali pod povečevalnim steklom in jih orientirali ter določili smer rezanja za pridobitev prečnih, radialnih in tangencialnih rezin. Rezine debeline 10–20 μm smo odrezali s pomočjo drsnega mikrotoma Leica SM2000R. V enem primeru je bil vzorec odvzet s kirurškim nožem (slika 3) in vklopljen v parafin (Prislan et al., 2022). V tem primeru so bili z rotacijskim mikrotomom Leica RM 2245 narezani 9 μm debeli preparati, ki smo jih obarvali z vodno raztopino barvil safranin in astra modro, izprali, dehidrirali in nazadnje vklopili v Euparal po standardnem postopku. Na ta način smo izdelali po en trajni preparat (prečni, radialni in tangencialni prerez) za vsak predmet ali njegov del, če je bil narejen iz več kot ene vrste lesa.

Za mikroskopsko identifikacijo lesa smo uporabili svetlobni mikroskop Nikon Eclipse E800, opremljen z digitalnim fotoaparatom Nikon DS-Fil in računalniškim programom za analizo slik NIS Elements BR 3.0. Preparate smo pregledali in poiskali znake za mikroskopsko identifikacijo lesa (IAWA Committee, 1989) ter opravili identifikacijo s pomočjo računalniškega ključa podatkovne zbirke Inside Wood (Wheeler, 2011; Inside Wood, 2022). Identifikacijo lesa smo opravili na osnovi kombinacije anatomskih znakov. Po oceni rodu ali lesne vrste smo opravili natančne primerjave z referenčnimi podatki in slikami iz zbirke Inside Wood in z referenčnim materialom iz ksilarija Kraljevega muzeja Srednje Afrike v Tervurnu. Tako smo potrdili ali izboljšali predhodno identifikacijo, opravljeno v okviru diplomske naloge (Koren, 2017).

Raziskali smo les štirih predmetov. To so glasbilo–lesene citre, ščit z lesenim ročajem, bodalo in nožnica ter samostrel, izdelan iz dveh sestavljivih delov, loka in ročaja. Predmeti so prikazani na slikah 1, 2, 4, 6, 8 in 10.

Raziskano glasbilo–lesene citre–je bilo izdelano iz lesa vrste *Musanga cecropioides*, ki ima gostoto zračno suhega lesa 190–370 kg/m^3, uspeva v tropski Afriki in ni trgovsko pomemben.

Lažji ščit, narejen iz rastlinskih materialov, ki je imel verjetno obredni pomen, je imel ročaj iz lesa iz rodu *Alstonia* (*Alstonia boonei* ali *Alstonia congensis*). Rod *Alstonia* vsebuje okoli 40 vrst, od tega samo omenjeni vrsti uspevata v Afriki. Vrsti *Alstonia boonei* in *Alstonia congensis* sta zelo sorodni, njunega lesa pa ni mogoče zanesljivo razlikovati. Les gostote okoli 360 kg/m^3 je biološko neodporen in je priljubljen za lažje konstrukcije.

Bodalo z lesenim ročajem in leseno nožnico je iz lesa vrste *Autranella congolensis* ali sorodne vrste z visoko gostoto iz družine Sapotaceae. Gostota zračno suhega lesa je okoli 940 kg/m^3. Les ima obarvano jedrovino in je odporen proti biološkim škodljivcem.

Samostrel ima lok, narejen iz vrste *Nauclea diderichii*, ki je na seznamu komercialnih lesnih vrst. Les ima visoko gostoto 760 kg/m^3 in zlato do oranžno rumeno jedrovino. Je trd in trden ter odporen proti biološkim škodljivcem. Ročaj samostrela je narejen iz lesa ene od vrst iz rodu *Xylopia*. V Demokratični republiki Kongo uspeva okoli 20 vrst iz rodu *Xylopia*. Ena od vrst, ki uspeva v gozdu Ituri, je *Xylopia chrysophyllum*. Les vrst *Xylopia* je v splošnem srednje gostote 400–750 kg/m^3 in je malo znan na mednarodnih trgih. Raziskovalci z Oddelka za lesarstvo so podrobneje raziskali les vrste *Xylopia hypolampsa* iz Centralnoafriške republike (CAR) (Možina & Torelli; Torelli, 1983; Čufar, 1984), ki so poleg anatomije ter fizikalno mehanskih lastnosti raziskali tudi njegovo obdelavnost. Centralnoafriški Pigmejci so les vrste *Xylopia hypolampsa* zaradi izjemne žilavosti uporabljali za izdelavo strelskih lokov in samostrelov (Torelli, osebna komunikacija).

Za vsako od ugotovljenih lesnih vrst so prikazane slike treh anatomskih prerezov s tipičnimi mikroskopskimi znaki, ključnimi za identifikacijo lesa (slike 5, 7, 9, 11, 12). Vsaka od vrst je tudi opisana z vidika lastnosti in rabe lesa (preglednica 2).

Ugotovljene vrste lesa večinoma niso predmet mednarodne trgovine in niso široko znane. Njihova identifikacija ne bi bila mogoča brez baze podatkov za identifikacijo lesa listavcev Inside Wood in primerjav z lesom in preparati iz zbirke Kraljevega muzeja za Srednjo Afriko v Tervurnu.

Čeprav so predmeti, ki jih je zbral antropolog Paul Joachim Schebesta, shranjeni v več muzejih po Evropi in so njegove misije v Kongu dobro dokumentirane, identifikacija lesa predmetov doslej v glavnem še nikjer ni bila opravljena.

Ta študija kaže, da je bilo v štirih preučevanih predmetih mogoče identificiranih pet različnih vrst lesa, ki vse rastejo v tropskem deževnem gozdu Ituri v Kongu in so na mednarodnih trgih precej neznane. Raziskave lesa so tako pomagale potrditi izvor lesa in nudijo dodatne podatke o domnevni zgodovini predmetov, ki predstavljajo materialno kulturo ljudstva Bambuti. Izbor lesnih vrst potrjuje, da so domačini odlično poznali drevesne vrste in lastnosti lesa vrst, ki uspevajo v deževnem gozdu Ituri.

ACKNOWLEDGEMENTS
ZAHVALE

This study was supported by the Slovenian Research Agency ARRS, program P4-0015. International collaboration was supported by COST Actions FP1106, STReESS, and FP 1302 Wood Musick. We thank Gregor Kos for great support during wood sampling, as well as students Luka Koren and Domen Petrovčič for their help in the initial stages of the work. We thank the InsideWood platform with Elisabeth Wheeler and her numerous co-workers and contributors for maintaining the database, which is indispensable for work with the wood anatomy of rare wood species from all over the world, including Africa.

REFERENCES
VIRI

Bildarchiv Austria. URL: www.bildarchivaustria.at (2.11.2022)

Bontadi, J., & Bernabei, M. (2016). Inside the Dogon Masks: The Selection of Woods for Ritual Objects. IAWA Journal, 37, 84–97, DOI: 10.1163/22941932-20160122.

CIRAD, *Alstonia*. URL: https://tropix.cirad.fr/FichiersComplementaires/EN/Africa/EMIEN.pdf (25.11.2022)

CIRAD, *Autranella congolensis*. URL: https://tropix.cirad.fr/FichiersComplementaires/EN/Africa/MUKULUNGU.pdf (25.11.2022)

CIRAD*, Nauclea diderrichii*. URL: https://tropix.cirad.fr/FichiersComplementaires/EN/Africa/BILINGA.pdf (25.11.2022)

Čufar, K. (1984). Ocena obdelavnosti s primerjavo relevantnih lastnosti neznane in znanih lesnih vrst na primeru devetih centralnoafriških lesov. (Magistrsko delo). Ljubljana: Biotehniška fakulteta, Oddelek za lesarstvo.

Dahms, K. G. (1999). Afrikanische Exporthölzer. 3. Auflage. DRW Verlag Leinfelder-Echterdingen.

CEN (2016). European Standard EN 350 – Durability of Wood and Wood- Based Products. Testing and classification of the durability to biological agents of wood and wood-based materials. Brussels, Belgium: European Committee for Standardisation, 67.

Frelih M., Rovšnik R., & Koren A. (2017). Baba wa Bambuti. Obisk misijonarja in antropologa Paula Schebeste na Slovenskem leta 1933 in njegova afriška zbirka v Slovenskem etnografskem muzeju = Baba wa Bambuti. The visit of the missionary and anthropologist Paul Schebesta to Slovenia in 1933 and his African collection at the Slovene Ethnographic Museum: Muzej krščanstva na Slovenskem, Slovene Museum of Christianity, December 2017–April 2018.

Gütl, C. (2010). Paul Joachim Schebesta URL: http://www.afrikanistik.at/pdf/personen/schebesta_paul.pdf (31.7.2018)

IAWA Committee (1989). IAWA List of microscopic features for hardwood identification. Wheeler E. A., Baas P., Gasson, P. E. Eds. IAWA Bulletin n.s., 10 (3), 226–332.

InsideWood. 2004-onwards. Published on the Internet. URL: http://insidewood.lib.ncsu.edu/search (30.10.2022)

IUCN red list of threatened species. URL: https://www.iucnredlist.org/ (30.10.2022)

Koren, L. (2017). Raziskave lesenih predmetov iz muzejske zbirke pigmejske kulture = Investigations of wooden objects from the museum collection of Pygmy culture. (Diplomsko delo). Ljubljana: Biotehniška fakulteta, Oddelek za lesarstvo.

Možina I., Torelli N. (1977). Research on physical and mechanical properties of tropical wood species. Ljubljana: University of Ljubljana, Biotechnical Faculty, Department of Wood Science and Technology.

Petrovčič, D. (2016). Raziskave kultnih lesenih mask bambara iz Malija = Research of the Malian bambara culture cult wooden masks. (Diplomsko delo). Ljubljana: Biotehniška fakulteta, Oddelek za gozdarstvo in obnovljive gozdne vire.

PlantUse, *Alstonia boonei*. URL: https://uses.plantnet-project.org/en/Alstonia_boonei (2.11.2022)

PlantUse, *Alstonia congensis.* URL: *https://uses.plantnet-project.org/en/Alstonia_congensis* (2.11.2022)

PlantUse, *Autranella congolensis* (PROTA). URL: https://uses.plantnet-project.org/en/Autranella_congolensis_(PROTA) (2.11.2022)

PlantUse, *Musanga cecropioides* (PROTA), *Musanga*. URL: https://uses.plantnet-project.org/en/Musanga_cecropioides_(PROTA) (2.11.2022)

Prislan, P., Martinez del Castillo, E., Skoberne, G., Špenko, N., & Gričar, J. (2022). Sample preparation protocol for wood and phloem formation analyses. Dendrochronologia, 73. 125959. DOI: 10.1016/j.dendro.2022.125959.

Richter, H. G., & Dallwitz, M. J. (2002) onwards. Commercial timbers: descriptions, illustrations, identification, and information retrieval: Computer program.

Schebesta, P. (1932). Bambuti, die Zwerge vom Kongo. Leipzig.

Schebesta, P. (1957). Baba wa Bambuti: Vier Fahrten zu den Ituri-Pygmäen. Mödling 1957.

Tanno, T. (1981). Plant utilization of the Mbuti Pygmies: with special reference to their material culture and use of wild vegetable foods. African Study Monographs 1, 1–53. DOI: https://doi.org/10.14989/67981

Torelli, N. (1983). Machining and related characteristics of five wood species from Bayanga Region (Central African Republic). Ljubljana: Edvard Kardelj University, Biotechnical Faculty, Department of Wood Science and Technology.

Wheeler, E. A. (2011). InsideWood–a web resource for hardwood anatomy. IAWA Journal, 32 (2), 199–211.

Wagenführ, R., & Wagenführ, A. (2022). Holzatlas. 7. überarbeitete und ergänzte Auflage, Carl Hanser Verlag München.

LES/WOOD Vol. 71, No. 2, 45-56
DOI: https://doi.org/10.26614/les-wood.2022.v71n02a05

VPLIV NARAVNEGA STARANJA NA IZBRANE FIZIKALNE IN MEHANSKE LASTNOSTI KONSTRUKCIJSKEGA LESA

EFFECTS OF NATURAL AGEING ON SELECTED PHYSICAL AND MECHANICAL PROPERTIES OF STRUCTURAL TIMBER

Matjaž Dremelj[1*], Aleš Straže[1]

UDK 630*814.1:812
Pregledni znanstveni članek / Review scientific article
Prispelo / Received: 4.11.2022
Sprejeto / Accepted: 30.11.2022

Izvleček / Abstract

Izvleček: Les je po poseku in uporabi za konstrukcije izpostavljen staranju, ki je med drugim odvisno od pogojev izpostavitve. V času življenjske dobe oz. uporabe je les izpostavljen fotodegradaciji, biodegradaciji, površinskim in notranjim strukturnim spremembam in staranju, ki se kaže v spremembi barve, kemijske sestave, higroskopnosti, dimenzijske stabilnosti ter nekaterih mehanskih lastnosti. Podajamo pregled literature, s posebnim poudarkom vpliva pogojev izpostavitve na spremembe lastnosti lesa ter pregled kemijskih in mikrostrukturnih sprememb ter sprememb barve, sorpcijskih in mehanskih lastnosti. V splošnem so spremembe zaradi staranja lahko zelo počasne in jih je težko ovrednotiti tudi zaradi velike naravne variabilnosti lesnih lastnosti. Poznavanje sprememb v naravno staranem lesu je ključno pri ohranjanju kulturne dediščine. Pri načrtovanju vzdrževanja, konzerviranja ter pri obnovi kulturne dediščine, z upoštevanjem staranja konstrukcijskega lesa bolje razumemo strukturne spremembe, vlažnostna in napetostno-deformacijska stanja lesenih konstrukcij ter interakcije z drugimi gradbenimi materiali.

Ključne besede: les, staranje, barva, higroskopnost, dimenzijska stabilnost, sorpcija, mehanske lastnosti

Abstract: After harvesting, wood in constructions undergoes an ageing process that depends, among other things, on exposure conditions. During its lifetime wood is subject to photodegradation, biodegradation, surface and internal structural changes, and ageing, which is reflected in changes in colour, chemical composition, hygroscopicity, dimensional stability, and mechanical properties. We present a literature review, with particular emphasis on the influence of exposure conditions on changes in wood properties, chemical and microstructural changes, and changes in colour, sorption, and mechanical properties. In general, ageing-related changes can be very slow and difficult to detect, in part because of the wide natural variability in wood properties. Knowledge of the changes in naturally aged wood is critical for preserving cultural heritage, evaluating the safety of wood structures, and planning their conservation. When planning maintenance, conservation, and restoration of cultural heritage, we can better understand the structural changes, moisture and stress deformation states of wood structures, and interactions with other building materials if we consider the ageing of structural wood.

Keywords: wood, ageing, colour, hygroscopicity, dimensional stability, sorption, mechanical properties

1 UVOD

1 INTRODUCTION

Les je kot naraven polimerni kompozit med življenjsko dobo oz. uporabo izpostavljen fotodegradaciji, biodegradaciji, površinskim in notranjim strukturnim spremembam in tudi staranju (Kránitz et al., 2016; Turkulin & Živković, 2018). Naravno staranje lesa se večinoma razlaga kot počasen proces blage termične oksidacije, t.j. v območju naravnega temperaturnega nihanja, kjer je kisik prisoten v zraku ali raztopljen v vodi, in hidrolize zaradi vsebnosti kislin ter vezane vode v lesu (Stamm, 1956; Matsuo et al., 2011). V vlažnih razmerah se lahko s staranjem v lesu v zelo nizkih koncentracijah tvorijo nekatere organske kisline, kot sta 4-metilglukuronska in galaktoronska kislina, a le velika količina

[1] Univerza v Ljubljani, Biotehniška fakulteta, Oddelek za lesarstvo, Jamnikarjeva 101, 1000 Ljubljana, Slovenija
* e-pošta: matjaz.dremel@gmail.com

kislin v dovolj dolgem obdobju lahko povzroči tudi razgradnjo celuloze in izgubo mase ter trdnostnih lastnosti (Sundqvist, 2006; Kránitz et al., 2016). Kot posledice staranja lesa so pogosto vidne majhne spremembe v barvi, blage kemijske spremembe, zlasti nižanje deleža hemiceluloz, spremenjena higroskopnost in dimenzijska stabilnost ter tudi nekatere mehanske lastnosti (Straže et al., 2018). Zaradi higroskopne narave lesa prihaja v njem do napetosti zaradi nihanja vlažnosti, kljub temu, da je les viskoelastični material (Matsuo et al., 2011; Kránitz, 2014). Poznavanje lastnosti naravno staranega lesa je ključno pri ohranjanju kulturne dediščine, saj les poleg kamna in opeke predstavlja pomemben del konstrukcij v zgodovinskih objektih. Lastnosti staranega lesa so ključne pri razumevanju obnašanja in ocenjevanju varnosti konstrukcij kot tudi pri načrtovanju sanacij starih stavb, poškodovanih zaradi naravnih ujm, kot je na primer bil potres v Zagrebu marca 2020 (Turkulin, osebna komunikacija).

2 SPREMEMBE LASTNOSTI LESA MED NARAVNIM STARANJEM
2 CHANGES IN WOOD PROPERTIES DURING NATURAL AGEING

2.1 POGOJI IZPOSTAVITVE IN POSLEDICE
2.1 EXPOSURE CONDITIONS AND CONSEQUENCES

Čeprav ima les v drevesu različno kambijevo starost, odvisno od tega, v katerem letu je nastala posamezna branika, velja, da se staranje lesa začne s posekom drevesa. Spremembe v lesu potekajo zelo počasi in so odvisne od okoljskih mikroklimatskih razmer. V vročem, suhem puščavskem podne-

Slika 1. Del stare strešne konstrukcije cerkve sv. Barbare v vasi Ravnik pri Hotedršici.
Figure 1. Part of the old wooden roof structure of the St. Barbara church located in the village of Ravnik near Hotedrščica.

bju se leseni predmeti in tekstil na osnovi rastlinskih vlaken lahko ohranijo celo več tisočletij, medtem ko njihovo razgradnjo pospešujejo razmere, v katerih uspevajo mikroorganizmi. Razlikujemo dva tipa razmer, v katerih potekajo procesi staranja: anaerobne in aerobne.

Les se lahko zelo dolgo ohrani v anaerobnih razmerah (brez prisotnosti zraka), ki veljajo za lesene predmete, potopljene v vodo ali zakopane v zemljo brez prisotnosti kisika. V takih razmerah se lahko nahajajo temelji stavb, stebri, ladje ipd. Razmere, v katerih je les, ki je potopljen v vodi ali zakopan v zemlji, sprožijo zelo počasen proces fosilizacije, pri katerem se kemijske sestavine celične stene v več tisoč letih pretvorijo v visoko kondenzirane spojine (koalifikacija) ali se nadomestijo z minerali (silicifikacija). V to kategorijo spada subfosilni les debel močvirskih hrastov, ki se v mokrem okolju lahko ohranijo več tisoč let (Pearson et al., 2014; Rede et al., 2022) in les različnih predmetov z Ljubljanskega barja, kot je les s koliščarskih naselbin, najstarejše leseno kolo na svetu ter različni deblaki (Čufar & Velušček, 2012).

Različne komponente lesa so izpostavljene različnim vrstam razgradnje in pretvorbe (Fengel, 1991). Praviloma spremembe najprej doživijo hemiceluloze in celuloza, zato v lesu narašča delež lignina (npr. Čufar et al., 2008). Ker je v omenjenih razmerah kisik redko popolnoma odsoten, je les pogosto podvržen počasnemu razkroju bakterij (Kim & Singh, 2000; Singh et al., 2019; Balzano et al., 2022).

V tem pregledu nas zanima predvsem les konstrukcij stavb, ki se stara v aerobnih razmerah (Slika 1). Kadar so razmere ugodne (ugodna temperatura, odsotnost UV sevanja ter vode oz. zamakanja), se zdi, da je učinek staranja na strukturo lesa minimalen, tudi pri arheološkem lesu iz piramid, starem do 4400 let (Van Zyl et al., 1973). V nadaljevanju podajamo pregled sprememb lesa, vgrajenega v stavbah.

2.2 KEMIJSKE SPREMEMBE

2.2 CHEMICAL CHANGES

Pri naravnem staranju lesa se najpogosteje z vidika osnovnih lesnih komponent omenjajo spremembe na hemicelulozah, najmanj stabilni komponenti, ki ima zaradi svoje manj urejene strukture večjo topnost in se lažje hidrolizira (Hedges, 1989; Fengel, 1991). V večini dosedanjih raziskav so zaznali zmanjšanje deleža hemiceluloz zaradi hidrolize (Chowdhury et al., 1967; Pishik et al., 1971; Erhardt et al., 1996; Yonenobu & Tsuchikawa, 2003; Tsuchikawa et al., 2005; Popescu et al., 2007; Ganne-Chédeville et al., 2012; Kránitz, 2014; Kačík et al., 2014; Hudson-McAulay, 2016; Belec, 2017). Holz (1981) pa pri vzorcih manjše starosti, 60-180 let, ni zaznal značilnih razlik v primerjavi z recentnim lesom. Hudson-McAulay (2016) v svoji raziskavi navaja, da se z zmanjšanjem deleža acetilnih skupin v polimerih hemiceluloz zaradi te kemijske reakcije sprošča ocetna kislina.

Celuloza je bolj odporna na staranje kot hemiceluloze, saj ima višjo stopnjo kristaliničnosti in visoko stopnjo medmolekularne povezanosti znotraj fibril, kaže nizko topnost v večini topil in razmeroma močno odpornost na hidrolizo (Hedges, 1989; Fengel, 1991). V nekaterih raziskavah so zaznali zmanjšanje deleža celuloze (Chowdhury et al., 1967; Pishik et al., 1971; Tomassetti et al., 1990; Campanella et al., 1991; Belec, 2017), v drugih pa niso zaznali bistvenih sprememb v količini celuloze (Holz, 1981; Erhardt et al., 1996; Kránitz, 2014). Yonenobu in Tsuchikawa (2003) sta zaznala degradacijo v amorfnih regijah celuloze.

Nekatere raziskave podajajo spremembe za holocelulozo, ki vključuje celulozo in hemiceluloze. Tako Kohara in Okamoto (1955) in drugi viri poročajo o zmanjšanem deležu holoceluloze, Van Zyl in sodelavci (1973) poročajo o povečanem deležu holoceluloze, Kačík in sodelavci (2014) pa o rahlem zmanjšanju.

Lignin se zdi med glavnimi gradniki celične stene najbolj odporen na staranje. Etrske vezi in vezi med ogljikovimi atomi naredijo lignin odporen proti hidrolizi, vendar pa je dovzeten za oksidacijske procese (Kránitz, 2014). Oksidacija lignina skupaj z drugimi reakcijami lahko privede do degradacije makromolekul lignina na manjše enote (Borgin et al., 1975a). Od gradnikov celične stene spada lignin med najbolj občutljive na ultravijolično svetlobo (UV). Nekatere raziskave ugotavljajo, da pride s staranjem do povečanja deleža lignina (Narayanamurti et al., 1961; Tomassetti et al., 1990; Campanella et al., 1991), druge pa poročajo o zmanjšanju (Pishik et al., 1971; Van Zyl et al., 1973; Borgin, et al. 1975a; Ganne-Chédeville et al., 2012; Kačík et al., 2014). Več avtorjev (Kránitz, 2014; Hudson-McAulay, 2016; Belec, 2017) ni zaznalo bistvenih sprememb, je pa bila zaznana oksidacija lignina. Za procentualno povečanje deleža lignina v elementarni sestavi je verjetno odgovorna razgradnja hemiceluloz in zmanjšanje njihovega deleža (Dremelj, 2018).

Glede kristaliničnosti celuloze si raziskave niso tako enotne. Nekatere poročajo o povečanju stopnje kristaliničnosti (Popescu et al., 2007; Saito et al., 2008; Gawron et al., 2012), druge o zmanjšanju (Borgin et al., 1975a; Erhardt et al., 1996; García Esteban et al., 2006; Kránitz, 2014), nekatere pa govorijo, da sprememb niso opazili (Yonenobu & Tsuchikawa, 2003; Inagaki et al., 2008).

Kohara in Okamoto (1955) sta pri lesu japonske paciprese *(Chamaecyparis obtusa,* jap. hinoki) zaznala povečanje kristaliničnosti do starosti 100 let, nato pa pri starejših vzorcih zmanjšanje, medtem ko je bilo pri lesu listavca zelkova (*Zelkova serrata*, jap. keyaki) opaženo stalno zmanjševanje stopnje kristaliničnosti. Kohara in Okamoto (1955), razlagata povečanje deleža kristaliničnosti z ustvarjanjem novih intermolekulskih vezi v amorfnih delih celuloznih mikrofibril. Fukada (1965) je proučeval les Japonske ciprese (*Cryptomeria japonica,* jap. sugi), indeks kristaliničnosti celuloze je bil največji pri lesu starosti 350 let, nato pa je indeks padal do starosti lesa 1400 let. Navaja, da so dobre akustične lastnosti povezane s samo kristaliničnostjo, in so najboljše pri največji kristaliničnosti celuloze.

Kačík in sodelavci (2014), Kohara in Okamoto (1955), Pishik in sodelavci (1971) poročajo o povečanju deleža ekstraktivov, Ganne-Chédeville in sodelavci (2012) pa o njihovi degradaciji.

Več virov (Pishik et al., 1971; Van Zyl et al., 1973; Borgin et al., 1975a; Tomassetti et al., 1990) poroča o povečanem deležu pepela pri staranem lesu, pri raziskavah, ki sta jih opravila Holz (1981) in Kránitz (2014), pa se delež pepela ni bistveno spremenil. Kránitz (2014) navaja zmanjšanje količine ekstraktivov pri lesu, starem 150 let ali manj, kot posledico izhlapevanja hlapnih komponent. Pri starejšem lesu ista avtorica ponovno povečanje deleža ekstraktivov pojasnjuje kot posledico povečanja deleža oksidacijskih produktov lignina in hemiceluloz.

2.3 MIKROSTRUKTURNE SPREMEMBE
2.3 MICROSTRUCTURAL CHANGES

Več virov navaja spremembe v mikrostrukturi naravno staranega lesa. Na makroskopskem nivoju samih sprememb pogosto ni možno opaziti, šele z mikroskopskimi metodami, kot je mikroskopija v svetlem polju, elektronska mikroskopija z uporabo vrstičnega (SEM) in transmisijskega elektronskega mikroskopa (TEM) daje vpogled v samo mikrostrukturo in spremembe v njej, ki so posledica staranja lesa.

Več raziskav poroča o delaminaciji S3 sloja celične stene (Narayanamurti et al., 1958; Froidevaux et al., 2012; Kránitz, 2014), prav tako tudi o delaminaciji srednje lamele (Kollmann & Schmidt, 1962; Borgin et al., 1975b; Froidevaux et al., 2012; Kránitz, 2014) ter pojavu radialnih razpok v sekundarni steni (Kollmann & Schmidt, 1962; Froidevaux et al., 2012; Kránitz, 2014). Chowdhury in sodelavci (1967) pa poročajo tudi o helikalnih razpokah v celičnih stenah vlaken.

Brez poznavanja natančne zgodovine lesa ni mogoče zagotoviti, da so napake posledica samo staranja. Priprava vzorca, zunanje ali notranje napetosti lahko prav tako vplivajo na mikrostrukturo, vendar se napake večinoma pojavljajo na območjih, kjer je več hemiceluloz, pektinskih materialov in lignina (Borgin et al., 1975b).

Kojiro in sodelavci (2008) so raziskovali poroznost lesa in poroznost celične stene. Število por v celični steni, manjših od 0,6 nm, se je zmanjšalo s starostjo lesa. S starostjo lesa je prišlo tudi do prostorninskega zmanjšanja por na maso lesa.

2.4 BARVA LESA
2.4 WOOD COLOUR

V procesu staranja lesa je najbolj opazna sprememba barve površine. Najbolj pride do izraza pri lesu, ki je izpostavljen direktnim sončnim žarkom. Izpostavljenost lesa sončnim žarkom v kombinaciji z vodo pripelje do barvnih sprememb na površini lesa, kjer voda lahko tudi spere produkte fotodegradacije lignina, ki nastanejo zaradi UV sevanja in les posivi. Prav tako pa lahko nastanejo razpoke na površini in med samimi celicami in znotraj celične stene. Fotodegradacija pojasnjuje spremembo barve na površini lesa, medtem ko sprememba barve lesa v notranjosti lesnih elementov ni natančno pojasnjena. Obstaja le malo dosedanjih študij barvnih sprememb znotraj lesenih elementov. Matsuo in sodelavci (2011) v svoji raziskavi pojasnjujejo, da je sprememba barve med naravnim staranjem predvsem posledica počasnega in blagega procesa ter-

Slika 2. Videz tipičnih hrastovih preizkušancev od najmlajše do najstarejše starostne skupine (100–600 let) (po Straže et al., 2018).
Figure 2. Appearance of typical oak specimens sorted from the youngest to the oldest (age groups 100 – 600 years) (after Straže et al., 2018).

mične oksidacije lesa. Do spremembe barve lesa pa lahko pride tudi zaradi spreminjanja deleža ekstraktivov in njihove kemijske strukture. Delež ekstraktivov se pri starem lesu povečuje kot posledica razpada strukturnih elementov lesa, oksidacije lignina in hemiceluloz (Kačík et al., 2014; Kránitz, 2014).

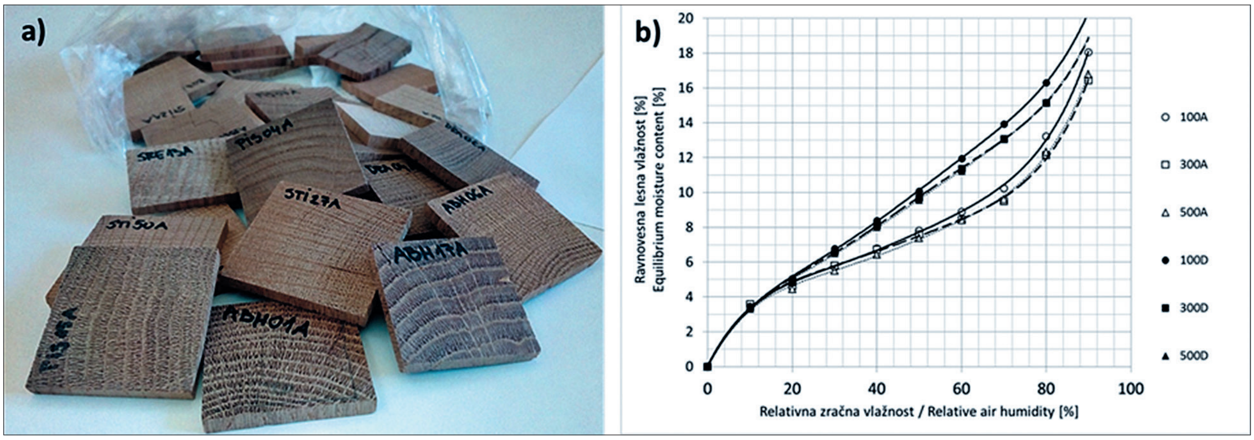
Avtorji (Kohara, 1955; Matsuo et al., 2011; Kránitz, 2014; Dremelj, 2018) enotno opažajo temnenje barve in povečanje kromatičnosti barvnega odtenka na zeleno-rdeči (+a) in rumeno-modri (+b) osi s starostjo lesa (Slika 2). Kránitz (2014) večje razlike v barvi opaža pri iglavcih, manjše pa pri hrastovini. Sprememba barve lesa ni odvisna samo od okoljskih razmer, temveč tudi od vrste lesa in razlik v kemični sestavi med lesnimi vrstami (slika 2). Matsuo in sodelavci (2011) navajajo, da so barvne spremembe zaradi naravnega staranja in toplotne obdelave podobne.

2.5 HIGROSKOPSKE LASTNOSTI
2.5 HYGROSCOPIC PROPERTIES

V različnih klimatskih razmerah les, ki je higroskopen material, vzpostavlja ravnovesno vlažnost in s tem tudi svoje stabilne dimenzije. Dimenzijsko stabilnost določajo sorpcijske lastnosti materialov (Noack et al., 1973; Gorišek, 2009). Osnovni gradniki celične stene izkazujejo različne higroskopske lastnosti. Hemiceluloze so najbolj higroskopne, sledi celuloza, najmanj higroskopen pa je lignin. V zgodovinskih stavbah so pohištvo, leseni izdelki in konstrukcije izpostavljeni različnim nihajočim relativnim zračnim vlažnostim (Gereke et al., 2011), to lahko povzroči velika dimenzijska nihanja lesa, kar pa lahko privede zaradi razlik v krčenju in/ali nabrekanju lesa tudi do ireverzibilnih strukturnih poškodb lesa (Hudson-McAulay, 2016).

Kohara in Okamoto, (1955) sta poročala o zmanjšanju koeficienta nabrekanja, prav tako Dremelj (2018) poroča tudi o zmanjšanju diferencialnega nabreka. Schulz in sodelavci (1984) pa pri smrekovini starosti 300 let ugotavljajo nasprotno, da se koeficient nabrekanja (h) povečuje. Holz (1981) ni odkril bistvenih razlik v nabrekanju vzorcev smreke, stare 60–180 let, prav tako pri boru (Erhardt et al., 1996) niso mogli dokazati nobenih sprememb. Kránitz (2014), ki je proučevala les smreke, jelke in hrasta, ni zaznala bistvenih razlik pri sorpciji in ravnovesni vlažnosti v primerjavi z recentnim lesom.

Opravljenih je bilo več študij sorpcijskih izoterm in ravnovesne vlažnosti starega lesa. Buck (1952) navaja, da čeprav so sorpcijske izoterme pokazale rahlo zmanjšanje ravnovesne vlažnosti pri starih vzorcih, razlik ni bilo mogoče jasno ugotoviti zaradi majhnega števila vzorcev in možnih napak med meritvami. Več avtorjev je zaznalo nižje sorpcijske izoterme za staran les in s tem nižje ravnovesne vlažnosti (Kohara & Okamoto, 1955; Burmester, 1967; Lang, 2004; Inagaki et al., 2008; Kawai et al., 2008; Kurtoglu, 1983; Dremelj, 2018). Dremelj (2018) na stari hrastovini pri preverjanju velikosti histerezne zanke in adsorpcijsko-desorpcijskega razmerja ni potrdil bistvenih razlik (Slika 3). Esteban in sodelavci (2006) ugotavljajo na vzorcu juvenilnega lesa rdečega bora večjo histerezno zanko in višjo ravnovesno vlažnost na vsakem posamičnem intervalu dinamičnega sorpcijskega testiranja. Razlika je lahko posledica nižje stopnje kristaliničnosti celuloze, opažene pri staranih vzorcih. Nekatere raziskave pa omenjajo tudi ožanje sorpcijske histerezne zanke starega in recentnega lesa, če se les za več tednov izpostavi vlažnejši klimi. To povezujejo s sproščanjem napetosti v materialu, oz. celičnem matriksu. Staranje lesa s tem podobno kot toplotno obdelavo lesa razlagajo kot delno reverzibilen proces (Obataya, 2017). Na testih absorpcije oz. navzemanja tekoče vode, ki jih je izvedel Narayanamurti s sodelav-



Slika 3. Vzorci hrasta, odvzeti iz starih konstrukcijskih elementov lesenih zgradb (a) in primer sorpcijske histereze adsorpcijsko-desorpcijskega eksperimenta za starostne skupine lesa 100, 300 in 500 let po poseku (b) (Straže et al., 2018).

Figure 3. Oak wood samples from old structural elements of wooden buildings (a) and the sorption hysteresis for the adsorption-desorption test for the age groups 100, 300 and 500 years after tree felling (b) (Straže et al., 2018).

ci (1958) na 1500 let starih vzorcih tikovine, so prav tako pokazali zmanjšanje higroskopnosti, pri čemer je skupna količina adsorbirane vode znatno nižja pri starih vzorcih.

Če povzamemo predhodne ugotovitve, lahko domnevamo, da se ravnovesna vlažnost s staranjem lesa zmanjšuje, vendar vzrok sprememb v večini primerov ostaja neznan. V procesu staranja lesa pride do razgradnje higroskopnih hemiceluloz, prav tako se spremeni stopnja kristaliničnosti celuloze, ki se s staranjem lesa povečuje (Kohara & Okamoto, 1955; Gawron et al., 2012), vendar si pretekle raziskave niso enotne. To je pojasnjeno z ustvarjanjem novih intermolekularnih vezi med celuloznimi verigami, ki nastajajo v amorfnih področjih (Kohara et al., 1955). Povečanje stopnje kristaliničnosti celuloze povzroči manjše nabrekanje lesa, manjšo higroskopnost, višjo gostoto, višjo trdoto in trdnost (Gawron et al., 2012)

2.6 MEHANSKE LASTNOSTI
2.6 MECHANICAL PROPERTIES

Večina študij mehanskega obnašanja naravno staranega lesa obravnava le nekaj izbranih lastnosti. Tlačna trdnost je bila razmeroma pogosto raziskana predvsem za oceno stanja staranih lesenih konstrukcij. Meritve na konstrukcijah iz lesa iglavcev kot so smreka, jelka in rdeči bor, v večini raziskav ne kažejo sprememb v tlačni trdnosti vsaj do starosti 400 let (Ehlbeck & Görlacher, 1988, 1993; Deppe & Rühl, 1993; Nier, 1994; Weimar, 2000; Lang, 2004; Lissner & Rüg, 2004; Kránitz, 2014). Narayanamurti in sodelavci (1961) na listavcih paduk (*Pterocarpus soyauxii*) in tik (*Tectona grandis*), starosti 500 let, prav tako niso zaznali sprememb v tlačni trdnosti. Medtem ko so (Schulz et al., 1984) na 300 let stari smrekovini, (Attar-Hassan, 1976) na 140 let stari borovini, (Kohara, 1955) na japonski pacipresi (hinoki) do starosti 100 let in Narayanamurti in sodelavci (1958) na 1500 let stari tikovini zaznali povečano tlačno trdnost v primerjavi z recentnim lesom. Hudson-McAulay (2016) pa je zaznala na stari borovini veliko zmanjšanje tlačne trdnosti, podobno sta jo zaznala Kohara in Okamoto (1955) na lesu zelkove. Trdota staranega lesa kaže podobne težnje kot tlačna trdnost (Kohara & Okamoto, 1955; Attar-Hassan, 1976; Kavčič, 2019).

Določanje upogibne trdnosti in modula elastičnosti v vzdolžni smeri se pogosto ugotavlja tudi pri preiskavah staranega lesa. Več študij na lesu iglavcev in listavcev ni pokazalo razlik med upogibno trdnostjo recentnega in staranega lesa, starega do 400 let (Ehlbeck & Görlacher, 1988, 1993; Rug & Seemann, 1989; Nier, 1994; Horie, 2002; Baron, 2009; Hudson-McAulay, 2016; Zupanc et al., 2021), oz. kažejo, da se trdnost staranega lesa lahko celo poveča (Schulz et al., 1984), pri lesu zelkove do starosti 650 let, japonske paciprese nad starostjo 100 let in zelenega bora starosti do 140 let zmanjša (Kohara & Okamoto, 1955; Attar-Hassan, 1976).

Zmanjšanje upogibnega statičnega modula elastičnosti so opazili pri starani smrekovini ter lesu zelenega bora, zelkove, paduka in kino (Kohara & Okamoto, 1955; Narayanamurti et al., 1961; Attar-Hassan, 1976; Lang, 2004), vendar so z ultrazvočnimi testi izmerili povečanje dinamičnega modula elastičnosti (Attar-Hassan, 1976; Kránitz, 2014).

Pri starem rdečem boru niso bile ugotovljene nobene značilne spremembe modula elastičnosti (Erhardt et al., 1996). Pri smreki vrste jezoensis (*Picea jezoensis*), jelki vrste sachalinensis (*Abies sachalinensis)* in japonski pacipresi niso opazili poslabšanja modula elastičnosti (Horie, 2002; Yokoyama et al., 2009). Poleg tega nekateri članki poročajo o povečanju elastičnega modula, kot npr. Kawai in sodelavci (2008) na vzorcih japonske paciprese, starih 500–1600 let, ter Noguchi s sodelavci (2011), ki obravnava 300 let star japonski rdeči bor (*Pinus densiflora*). Poskusi na slednjem so razkrili tudi večjo hitrost zvoka, manjše dušenje (nižji kot izgub) in večje razmerje med elastičnim in strižnim modulom. Saito in sodelavci (2008) na vzorcih japonskega rdečega bora poročajo o zmanjšanju modula elastičnosti, Kohara in Okamoto (1955) pa govorita o povečanju modula elastičnosti v prvih 100 letih, nato pa sledi zmanjšanje.

Froidevaux in sodelavci (2012) so opravili mikro natezne teste v radialni smeri na 200–500 let starih primerkih smreke. Opazili so približno 25-odstotno zmanjšanje trdnosti, vendar niso ugotovili razlik v modulu elastičnosti. Yokoyama in sodelavci (2009) so določili upogibno trdnost v radialni smeri za stare vzorce japonske paciprese, stare do 1580 let. Vrednosti za star les so bile bistveno nižje kot pri recentnih vzorcih.

Raziskave natezne trdnosti so protislovne. Medtem ko poročajo o povečanju trdnosti 300 let starega smrekovega lesa (Schulz et al., 1984), se ta pri 140 let starem lesu zelenega bora v primerjavi z recentnim lesom zmanjša (Attar-Hassan, 1976).

Zdi se, da se večina trdnostnih lastnosti lesa s staranjem spreminja precej počasi, da sprememb ni mogoče zaznati ali pa sploh ne nastanejo. Vendar je bilo ugotovljeno, da je obnašanje staranega lesa pri zlomu pogosto drugačno od obnašanja recentnega lesa. Les lahko s staranjem postane bolj krhek, kot so omenili Attar-Hassan (1976) in Kawai in sodelavci (2008). Številni avtorji poročajo o zmanjšanju absorbirane energije ob preskusu udarne žilavosti pri staranem lesu (Kohara & Okamoto, 1955; Schulz et al., 1984; Weimar, 2000; Lang, 2004; Baron, 2009; Yokoyama et al., 2009).

Vzorci, raziskani v teh študijah, predstavljajo predvsem les iglavcev, edina izjema je študija, ki sta jo opravila Kohara in Okamoto (1955), kjer obravnavata tudi les zelkove, ki je listavec. Vsi preiskani vzorci lesa so služili v konstrukcijah 300–1600 let. Pregledi lomnih površin so razkrili večji delež krhkih lomov pri starem kot pri recentnem lesu (Weimar, 2000; Lang, 2004) ter več neravnih in kompleksnih lomnih površin na mikroskopski ravni (Ando et al., 2006). Pri smreki jezoensis (*Picea jezoensis*), jelki (*Abies sachalinensis)* z dobo uporabe 30–80 let niso opazili nobene razlike v udarni žilavosti (Horie, 2002). Erhardt in sodelavci (1996) ne poročajo o nobenih spremembah v porušitveni deformaciji in meji elastičnosti v več ponovitvah statičnega nateznega obremenjevanja 300–400 let starih vzorcev rdečega bora.

Kar zadeva strižno trdnost so se vrednosti staranega zelenega bora s starostjo povečale, vrednosti lesa japonske paciprese in zelkove pa zmanjšale (Kohara & Okamoto, 1955; Attar-Hassan, 1976), na drugi strani pa ni bilo mogoče zaznati razlik med strižno trdnostjo 270 let starega japonskega rdečega bora in recentnega lesa. Vendar je analiza akustične emisije med strižnimi testi pokazala večjo krhkost staranega lesa. Ugotovljeno je bilo razmeroma dolgo in stabilno napredovanje mikrorazpok pred končnim zlomom v primerjavi z recentnim lesom, kjer mikrorazpok ni bilo, pri čemer so bile lomne površine videti bolj neravne in kompleksne na mikroskopski ravni. Prav tako se v primeru staranega lesa poleg loma znotraj celične stene pojavljajo tudi številni lomi med celicami, ki so nastali predvsem na obrobju pikenj (Ando et al., 2006). Avtor meni, da so mikrorazpoke že obstajale na robu pikenj pred samim lomljenjem.

Froidevaux in sodelavci (2012) so raziskovali lezenje in mehano-sorptivne deformacije smrekovega lesa, starega 200–500 let v radialni smeri. Glede viskoelastičnosti se zdi, da je recentni les nekoliko bolj viskozen kot staran les. Vendar pa so bili lomni parametri v plastičnem območju mehanskih obremenitev pri staranem lesu močno poslabšani. Z vidika mehano-sorpcijskega obnašanja je ireverzibilna deformacija bistveno večja pri recentnih vzorcih, kar kaže na določeno degradacijo lesa, ki se pojavi z naravnim staranjem.

3 ZAKLJUČKI
3 CONCLUSIONS

V preteklih študijah je bil uporabljen velik nabor različnih metod za prepoznavanje sprememb, ki nastanejo v lesu pri naravnem staranju. Iz preteklih študij lahko sklepamo, da razgradnja zaradi staranja lesa najbolj prizadene hemiceluloze. Celuloza je nekoliko bolj odporna in je degradirana predvsem v amorfnem delu. Glede kristaliničnosti celuloze si raziskave niso tako enotne, nekatere poročajo o povečanju kristaliničnosti, druge o zmanjšanju. Vsebnost pepela praviloma narašča z naraščanjem starosti lesa. Pri deležu lignina niso zaznali bistvenih sprememb v odvisnosti od starosti, vendar pa so v več raziskavah našli produkte oksidacije lignina. Dosedanje raziskave poročajo o mikrostrukturnih spremembah, kjer so najpogosteje opažene poškodbe kot je delaminacija srednje lamele in S3 sloja ter radialne razpoke v sekundarnem sloju celičnih sten lesnih vlaken. Pri barvnih spremembah s staranjem avtorji enotno opažajo temnenje barve in povečanje kromatičnosti barvnega odtenka na zeleno-rdeči (+a) in rumeno-modri (+b) osi. Ravnovesna vlažnost se s starostjo lesa praviloma zmanjšuje. Glede na rezultate mehanskih testov je mogoče ugotoviti v splošnem bolj krhko obnašanje staranega lesa z zmanjšano udarno žilavostjo (Kranitz et al., 2016). Zmanjša se lahko tudi trdnost v prečni ravnini, v vzdolžni smeri pa ni mogoče opaziti jasnega trenda glede trdnosti in togosti. Različne ugotovitve številnih študij so verjetno deloma posledica v splošnem velike variabilnosti lesnih lastnosti, različnih mikroklimatskih pogojev izpostavitve, ki jim je les izpostavljen med dolgotrajno uporabo, in razliki v metodologiji raziskav. Zelo verjetno je, da se zaradi inherentnih strukturnih in kemijskih lastnosti lesne vrste tudi različno obnašajo v procesu staranja.

4 POVZETEK
4 SUMMARY

Wood is a natural polymer composite, and over its lifetime its structures are subjected to photodegradation, biodegradation, structural changes of the surface and interior, and ageing (Straže et al., 2018). Natural ageing of wood is usually interpreted as a slow process of mild thermal oxidation in the range of natural temperature fluctuations, where oxygen is dissolved in air or water, and hydrolysis occurs due to the presence of acids and bound water in wood (Stamm, 1956; Matsuo et al., 2011). The consequences of ageing of wood can be seen in its properties, such as changes in colour and chemistry, altered hygroscopicity and dimensional stability, and changes in some mechanical properties (Straže et al., 2018). The hygroscopic nature and variations of moisture content in the material, as well as the viscoelasticity of wood, cause internal stresses (Matsuo et al., 2011; Kránitz, 2014). Knowledge of the properties of naturally aged wood is critical for its conservation, as wood forms an important part of the structures in cultural heritage buildings. The properties of aged wood are also critical for evaluating the safety of structures.

In this review article, we provide an overview of the literature, focusing on the influence of exposure conditions on changes in wood properties, and provide an overview of chemical and microstructural changes, as well as changes in colour, hygroscopic, and mechanical properties.

A wide range of methods have been used in previous studies to determine the changes that occur during the natural ageing of wood. From previous studies, it can be concluded that the age-related degradation of wood mainly affects the hemicelluloses. Cellulose seems to be more resistant, and is more likely changed in its amorphous form. As for the crystallinity of cellulose, the reports in previous studies vary, with some reporting an increase in the degree of crystallinity and others a decrease. In general, the amount of extractives increases with the age of the wood. No significant age-related changes were found in lignin content, but lignin oxidation products were found in wood in several studies. Microstructural changes have been noted in earlier research, with the most commonly observed damage being delamination of the middle lamella and S3 layer and radial cracks in the secondary wall. In terms of colour changes with ageing, various authors uniformly observe a decrease in colour lightness and an increase in chromaticity in the green-red (+a) and yellow-blue (+b) axes.

Equilibrium moisture content generally decreases with age. According to the results of the mechanical tests, the aged wood is generally more brittle with a consistently lower impact bending strength (Kranitz et al., 2016). Strength perpendicular to the grain may also decrease. However, no clear trend can be seen with respect to strength and stiffness in the longitudinal direction.

Knowledge of the changes in naturally aged wood is essential for preserving cultural heritage and evaluating the safety of wooden constructions.

ZAHVALA
ACKNOWLEDGEMENTS

Delo je nastalo v okviru interdisciplinarnega doktorskega študijskega programa Bioznanosti, znanstveno področje: les in biokompoziti ter v okviru dela na programih Javne agencije za raziskovalno dejavnost republike Slovenije ARRS, P4-0015 Les in lignocelulozni kompoziti ter P4-0430 Gozdno-lesna veriga in podnebne spremembe: prehod v krožno biogospodarstvo.

VIRI
REFERENCES

Ando, K., Hirashima, Y., Sugihara, M., Hirao, S., & Sasaki, Y. (2006). Microscopic processes of shearing fracture of old wood, examined using the acoustic emission technique. Journal of Wood Science, 52(6), 483–489. DOI: https://doi.org/10.1007/s10086-005-0795-7

Attar-Hassan, G. (1976). The effect of ageing on the mechanical properties of eastern white pine. Bulletin of the Association for Preservation Technology, 8(3), 64. DOI: https://doi.org/10.2307/1493572

Balzano, A., Merela, M., & Čufar, K. (2022). Scanning electron microscopy protocol for studying anatomy of highly degraded waterlogged archaeological wood. Forests, 13(2), 161. DOI: https://doi.org/10.3390/f13020161

Baron, T. (2009). Untersuchungen an ungeschädigten und durch Pilzbefall geschädigten Nadelholzbauteilen mit ausgewählten Prüfverfahren. (Investigations with selected test methods on undamaged softwood constructions and constructions damaged through fungal decay). (In German) Dissertation, Technische Universität Dresden.

Belec, A. (2017). Vpliv staranja na strukturne lastnosti hrasta (Diplomsko delo). Ljubljana: Biotehniška fakulteta, Oddelek za lesarstvo.

Borgin, K., Faix, O., & Schweers, W. (1975a). The effect of aging on lignins of wood. Wood Science and Technology, 9(3), 207–211. DOI: https://doi.org/10.1007/BF00364638

Borgin, K., Parameswaran, N., & Liese, W. (1975b). The effect of aging on the ultrastructure of wood. Wood Science and Technology, 9(2), 87–98. DOI: https://doi.org/10.1007/BF00353388

Buck, R. D. (1952). A Note on the effect of age on the hygroscopic behaviour of wood. Studies in Conservation, 1(1), 39–44. DOI: https://doi.org/10.1179/sic.1952.004

Burmester, A. (1967). Änderung von Festigkeitseigenschaften des Kiefernholzes durch Alterung / Changes in strength properties of pine wood by ageing / Variations des propriétés mécaniques du bois de pin par vieillissement: Mitteilung aus der Bundesanstalt für Materialprüfung (BAM), Berlin-Dahlem. Materials Testing, 9(7), 267–270. DOI: https://doi.org/10.1515/mt-1967-090703

Campanella, L., Tomassetti, M., & Tomellini, R. (1991). Thermoanalysis of ancient, fresh and waterlogged woods. Journal of Thermal Analysis, 37(8), 1923–1932. DOI: https://doi.org/10.1007/BF01912224

Chowdhury, K. A., Preston, R. D., & White, R. K. (1967). Structural changes in some ancient Indian timbers. In: Proceedings of the Royal Society of London. Series B, Biological Sciences, 168(1011), 148–157.

Čufar, K., Gričar, J., Zupančič, M., Koch, G., & Schmitt, U. (2008). Anatomy, cell wall structure and topochemistry of water-logged archaeological wood aged 5,200 and 4,500 years. IAWA Journal, 29(1), 55–68. DOI: https://doi.org/10.1163/22941932-90000170

Čufar, K., & Velušček, A. (2012). Les s koliščarskih naselbin na Ljubljanskem barju in njegov raziskovalni potencial. Les, 64(3/4), 49–56. URL: https://repozitorij.uni-lj.si/IzpisGradiva.php?id=68586

Deppe, H. J., & Rühl, H. (1993). Evaluation of historical construction timber. 1: Density and compression strength. Holz als Roh- und Werkstoff 51: 379–383.

Dremelj, M. (2018). Izbrane fizikalne lastnosti starega hrastovega konstrukcijskega lesa (Magistrsko delo). Ljubljana: Biotehniška fakulteta, Oddelek za lesarstvo.

Ehlbeck, J., & Görlacher, R. (1988). Erste Ergebnisse von Festigkeitsuntersuchungen an altem Konstruktionsholz (First results from investigations of strength on wood from old constructions). Erhalten historisch bedeutsamer Bauwerke. SFB, 315, 235–247.

Ehlbeck, J., & Görlacher, R. (1993). Probleme bei der Beurteilung der Tragfähigkeit von altem Konstruktionsholz (Problems with the evaluation of timber bearing capacity in old constructions). Erhalten historisch bedeutsamer Bauwerke. SFB, 315, 201–208.

Erhardt, D., Mecklenburg, M. F., Tumosa, C. S., & Olstad, T. M. (1996). New versus old wood: differences and similarities in physical, mechanical, and chemical properties. In: Bridgeland J (ed) International council of museums-committee for conservation 11th triennial meeting. James & James, London, pp 903–910.

Fengel, D. (1991). Aging and fossilization of wood and its components. Wood Science and Technology, 25(3), 153–177. DOI: https://doi.org/10.1007/BF00223468

Fengel, D., & Wegener, G. (1989). Wood: chemistry, ultrastructure, reactions. Berlin, New York; Walter de Gruyter.

Froidevaux, J., Volkmer, T., Ganne-Chédeville, C., Gril, J., & Navi, P. (2012). Viscoelastic behaviour of aged and non-aged spruce wood in the radial direction. Wood Material Science and Engineering, 7(1), 1–12. DOI: https://doi.org/10.1080/17480272.2011.629735

Fukada, E. (1965). Piezoelectric effect in wood and other crystalline polymers. In: Proceedings, Second Symposium on Nondestructive Testing of Wood, 143–170.

Ganne-Chédeville, C., Jääskeläinen, A.-S., Froidevaux, J., Hughes, M., & Navi, P. (2012). Natural and artificial ageing of spruce wood as observed by FTIR-ATR and UVRR spectroscopy. Holzforschung, 66(2). DOI: https://doi.org/10.1515/HF.2011.148

García Esteban, L., García Fernández, F., Guindeo Casasús, A., de Palacios de Palacios, P., & Gril, J. (2006). Comparison of the hygroscopic behaviour of 205-year-old and recently cut juvenile wood from *Pinus sylvestris* L. Annals of Forest Science, 63(3), 309–317.

Gawron, J., Szczęsna, M., Zielenkiewicz, T., & Gołofit, T. (2012). Cellulose crystallinity index examination in oak wood originated from antique woodwork. Drewno, 55 (188), 109–114.

Gereke, T., Anheuser, K., Lehmann, E., Kranitz, K., & Niemz, P. (2011). Moisture behaviour of recent and naturally aged wood. Wood Res, 56, 33–42.

Gorišek, Ž. (2009). Les: zgradba in lastnosti: njegova variabilnost in homogenost. Ljubljana: Biotehniška fakulteta, Oddelek za lesarstvo.

Hedges, J. I. (1989). The chemistry of archaeological wood. In: Rowell RM, Barbour RJ (eds) Archaeological wood: properties, chemistry, and preservation. Advances in Chemistry Series 225, American Chemical Society, Washington, 111–140.

Holz, D. (1981). Zum Alterungsverhalten des Werkstoffes Holz – einige Ansichten, Untersuchungen, Ergebnisse (Aging of wood—some aspects, investigations, results). Holztechnologie 22, 80–85.

Horie, H. (2002). Strength deterioration of recycled lumber collected from demolished wooden buildings in Hokkaido. Mokuzai Gakkaishi, 48(4), 280–287.

Hudson-McAulay, K. J. (2016). The structural and mechanical integrity of historic wood [PhD Thesis]. University of Glasgow.

Inagaki, T., Yonenobu, H., & Tsuchikawa, S. (2008). Near-infrared spectroscopic monitoring of the water adsorption/desorption orocess in modern and archaeological wood. Applied Spectroscopy, 62(8), 860–865. DOI: https://doi.org/10.1366/000370208785284312

Kačík, F., Šmíra, P., Kačíková, D., Reinprecht, L., & Nasswettrová, A. (2014). Chemical changes in fir wood from old buildings due to ageing. Cellulose Chemistry and Technology, 48, 79–88.

Kavčič, Ž. (2019). Mehanske lastnosti starega hrastovega konstrukcijskega lesa (Diplomsko delo). Univerza v Ljubljani, Biotehniška fakulteta, Oddelek za lesarstvo.

Kawai, S., Yokoyama, M., Matsuo, M., & Sugiyama, J. (2008). Research on the aging of wood in RISH. Wood Science for Preservation of Cultural Heritage: Mechanical and Biological Factors. Braga, Portugal, 52–56.

Kim, Y. S., & Singh, A. P. (2000). Micromorphological characteristics of wood biodegradation in wet environments: A review. IAWA Journal, 21(2), 135–155. DOI: https://doi.org/10.1163/22941932-90000241

Kohara, J. (1955). Studies on the permanence of wood (X) Colorimetry on the old timbers by the trichromatic colorimeter. Journal of the Japanese Forestry Society, 37(2), 63–66.

Kohara, J., & Okamoto, H. (1955). Studies of Japanese old timbers. The Scientific Reports of the Saikyo University. Agriculture, 7, 9–20.

Kojiro, K., Furuta, Y., Ohkoshi, M., Ishimaru, Y., Yokoyama, M., Sugiyama, J., Kawai, S., Mitsutani, T., Ozaki, H., Sakamoto, M., & Imamura, M. (2008). Changes in micropores in dry wood with elapsed time in the environment. Journal of Wood Science, 54(6), 515–519. DOI: https://doi.org/10.1007/s10086-008-0973-5

Kollmann, F., & Schmidt, E. (1962). Structural derangement and loss in strength of permanently stressed coniferous wood. Holz als Roh- und Werkstoff 20, 333-338.

Kránitz, K. (2014). Effect of natural aging on wood. (PhD), ETH, Zurich. (DISS. ETH No. 21661)

Kránitz, K., Sonderegger, W., Bues, C. T., & Niemz, P. (2016). Effects of aging on wood: A literature review. Wood Science and Technology, 50(1), 7–22. DOI: https://doi.org/10.1007/s00226-015-0766-0

Kurtoglu, A. (1983). The properties of sorption of old spruce timber. Holzforschung und Holzverwertung, 35(6), 125–126.

Lang, A. (2004). Charakterisierung des Altholzaufkommens in Deutschland (Characterisation of the waste wood situation in Germany). Dissertation, Universität Hamburg.

Lissner, K., & Rüg, W. (2004). Ergänzung bzw. Präzisierung der für die Nachweisführung zur Stand-und Tragsicherheit sowie Gebrauchstauglichkeit von Holzkonstruktionen in der Altbausubstanz maßgebenden Abschnitte der DIN 1052: August 2004. Büro Lißner, Ing.-Büro Rug.

Matsuo, M., Yokoyama, M., Umemura, K., Sugiyama, J., Kawai, S., Gril, J., Kubodera, S., Mitsutani, T., Ozaki, H., Sakamoto, M., & Imamura, M. (2011). Aging of wood: Analysis of color changes during natural aging and heat treatment. Holzforschung, 65(3). DOI: https://doi.org/10.1515/hf.2011.040

Narayanamurti, D., Ghosh, S. S., Prasad, B. N., & George, J. (1958). Note on examination of an old timber specimen. Holz Als Roh--Und Werkstoff, 16(7), 245–247.

Narayanamurti, D., Prasad, B. N., & Verma, G. M. (1961). Untersuchungen an alten Hölzern—Dritte Mitteilung: Ein altes Pterocarpus-Holz aus Tirupathi. Holz Als Roh-Und Werkstoff, 19(2), 47–50.

Nier, J. (1994). Experimentelle Festigkeitsuntersuchungen an alten Bauholzern und daraus abgeleitete Erkenntnisse zur Tragfähigkeitsbeurteilung (Experimental investigations of strength on old construction timber and therefrom deduced knowledge for bearing capacity estimation). Dissertation, Technische Hochschule Leipzig.

Noack, D., Schwab, E., & Bartz, A. (1973). Characteristics for a judgment of the sorption and swelling behavior of wood. Wood Science and Technology, *7*(3), 218–236.

Noguchi, T., Obataya, E., & Ando, K. (2011). Effects of ageing on the vibrational properties of akamatsu (Pinus densiflora) wood. Wood Culture and Science, Kyoto, 69.

Obataya, E. (2017). Effects of natural and artificial ageing on the physical and acoustic properties of wood in musical instruments. Journal of Cultural Heritage, 27, S63–S69. DOI: https://doi.org/10.1016/j.culher.2016.02.011

Pearson, C., Wazny, T., Kuniholm, P., Botic, K., Durman, A., & Seufer, K. (2014). Potential for a new multimillennial tree-ring chronology from subfossil Balkan river oaks. Radiocarbon, 56, S51–S59. DOI: https://doi.org/10.2458/azu_rc.56.18342

Pishik, I., Fefilon, V., & Burkovskaya, V. (1971). Chemical composition and chemical properties of new and old wood. Lesnoi J, 14(6), 89–93.

Popescu, C.-M., Dobele, G., Rossinskaja, G., Dizhbite, T., & Vasile, C. (2007). Degradation of lime wood painting supports. Journal of Analytical and Applied Pyrolysis, 79(1–2), 71–77. DOI: https://doi.org/10.1016/j.jaap.2006.12.014

Rede, V., Essert, S., Kocijan, M., & Dubravac, T. (2022). Influence of ageing on abrasion volume loss, density, and structural components of subfossil oak. Applied Sciences, 12(4), 1814. DOI: https://doi.org/10.3390/app12041814

Rug, W., & Seemann, A. (1989). Ermittlung von Festigkeitskennwerten an alten Holzkonstruktionen. Holztechnologie, 30(2), 69–73.

Saito, Y., Shida, S., Ohta, M., Yamamoto, H., Tai, T., Ohmura, W., Makihara, H., Noshiro, S., & Goto, O. (2008). Deterioration character of aged timbers: insect damage and material aging of rafters in a historic building of Fukushoji-temple. Mokuzai Gakkaishi 54: 255–262.

Schulz, H., Bellmann, B., & Wagner, L. (1984). Druckholzanalyse in einem stark verkrümmten Fichtenbrett. Holz Als Roh- und Werkstoff, 42(3), 109–109. DOI: https://doi.org/10.1007/BF02628866

Singh, A., Kim, Y., & Chavan, R. (2019). Relationship of wood cell wall ultrastructure to bacterial degradation of wood. IAWA Journal, 40, 1–26. DOI: https://doi.org/10.1163/22941932-40190250

Stamm, A. J. (1956). Thermal degradation of wood and cellulose. Industrial & Engineering Chemistry, 48(3), 413–417. DOI: https://doi.org/10.1021/ie51398a022

Straže, A., Dremelj, M., Žveplan, E., & Čufar, K. (2018). Spremembe fizikalnih lastnosti hrastovega lesa iz zgodovinskih konstrukcij v življenjski dobi. Les/Wood, 67(1), 5–14. DOI: https://doi.org/10.26614/les-wood.2018.v67n01a01

Sundqvist, B. (2006). Determination of formic-acid and acetic acid concentrations formed during hydrothermal treatment of birch wood and its relation to colour, strength and hardness (B. Sundqvist, O. Karlsson, & U. Westermark, Trans.). Wood Science and Technology, v. 40(7), 549–561. DOI: https://doi.org/10.1007/s00226-006-0071-z

Tomassetti, M., Campanella, L., & Tomellini, R. (1990). Thermogravimetric analysis of ancient and fresh woods. Thermochimica Acta, 170, 51–65. DOI: https://doi.org/10.1016/0040-6031(90)80524-3

Tsuchikawa, S., Yonenobu, H., & Siesler, H. W. (2005). Near-infrared spectroscopic observation of the ageing process in archaeological wood using a deuterium exchange method. Analyst, 130(3), 379–384. DOI: https://doi.org/10.1039/B412759E

Turkulin, H., & Živković, V. (2018). Microtensile testing of wood – influence of material properties, exposure and testing conditions on analysis of photodegradation. Drvna industrija, 69(2), 183–191. DOI: https://doi.org/10.5552/drind.2018.1757

Van Zyl, J. D., Van Wyk, W. J., & Heunis, C. M. (1973). The effect of ageing on the mechanical and chemical properties of wood. In: IUFRO-5 Meeting: Wood in the Service of Man. Pretoria, 2, 1069–1080.

Weimar, H. (2000). Aspekte der stofflichen Charakterisierung von Altholz (Aspects of the material characterisation of aged wood). Msc thesis. Universität Hamburg

Yokoyama, M., Gril, J., Matsuo, M., Yano, H., Sugiyama, J., Clair, B., Kubodera, S., Mistutani, T., Sakamoto, M., Ozaki, H., Imamura, M., & Kawai, S. (2009). Mechanical characteristics of aged Hinoki wood from Japanese historical buildings. Physics and Heritage, 10(7), 601–611. DOI: https://doi.org/10.1016/j.crhy.2009.08.009

Yonenobu, H., & Tsuchikawa, S. (2003). Near-Infrared spectroscopic comparison of antique and modern wood. Applied Spectroscopy, 57(11), 1451–1453. DOI: https://doi.org/10.1366/000370203322554635

Zupanc Lipovec, E., Fajdiga, G., & Humar, M. (2021). Primerjava mehanskih lastnosti recentnega in 400 let starega lesa evropskega macesna. Les/Wood, 70(2), 31-40. DOI: https://doi.org/10.26614/les-wood.2021.v70n02a01

LES/WOOD Vol. 71, No. 2, 67-72
DOI: https://doi.org/10.26614/les-wood.2022.v71n02a06

PROF. DR. PRIMOŽ OVEN – PREJEMNIK ZLATE PLAKETE UNIVERZE V LJUBLJANI

PROF. DR. PRIMOŽ OVEN – RECIPIENT OF THE GOLDEN PLAQUE OF THE UNIVERSITY OF LJUBLJANA

Marko Petrič[1*], Ida Poljanšek[1**]

Izvleček / Abstract

Izvleček: Na Univerzi v Ljubljani (UL) je med 28. novembrom in 2. decembrom 2022 potekal Teden univerze in tudi letos, ob 103. rojstnem dnevu univerze, so bili predstavljeni najodličnejši raziskovalni dosežki, podeljeni častni nazivi, plakete, nagrade in priznanja vsem, ki so pripomogli, da je Univerza v Ljubljani iz leta v leto boljša. Na Oddelku za lesarstvo Biotehniške fakultete UL smo zelo ponosni, da je na slavnostni seji Senata Univerze v Ljubljani 29. 11. 2022 Zlato plaketo prejel tudi naš sodelavec, prof. dr. Primož Oven, vodja Katedre za kemijo lesa in druge lignocelulozne materiale. Prof. Oven je mednarodno uveljavljen raziskovalec in pedagog na področju proučevanja zvez med funkcijami, strukturami, kemizmom in lastnostmi lesa, biorafinacije ter valorizacije lesne biomase s poudarkom na pridobivanju in uporabi nanoceluloze in lesnih ekstraktivov. V akademskem in gospodarskem okolju promovira trajnostno izrabo lesa v krožnem biogospodarstvu in skrbi za ugled UL doma in v tujini.

Ključne besede: Univerza v Ljubljani, Zlata plaketa Univerze, kemija lesa

Abstract: From November 28 to December 2, 2022, the University Week was held at the University of Ljubljana (UL). As in previous years, and on this, the occasion of the 103rd anniversary of the University, the most outstanding research achievements were presented, and honorary degrees, plaques, awards and recognitions were given to all those who have contributed to make the University of Ljubljana better year after year. At the Department of Wood Science and Technology of the Biotechnical Faculty of the University of Ljubljana, we are very proud that at the ceremonial meeting of the Senate of the University of Ljubljana on November 29, 2022, our colleague, the Head of the Chair of Wood Chemistry and Other Lignocellulosic Materials, Prof. Dr. Primož Oven, was also awarded the Golden Plaque. Prof. Oven is an internationally recognised researcher and lecturer in the field of research on the relationships between functions, structures, chemistry and properties of wood, biorefineries and valorisation of woody biomass, with a focus on the extraction and use of nanocellulose and wood extracts. In the academic and business environment, he promotes the sustainable use of wood in the circular bioeconomy and takes care of UL's reputation at home and abroad.

Keywords: University of Ljubljana, Golden Plaque, wood chemistry

Prof. dr. Primož Oven, univ. dipl. inž. les., na Univerzi v Ljubljani deluje vse od leta 1990, ko se je po diplomi (1989) kot mladi raziskovalec zaposlil na Oddelku za lesarstvo Biotehniške fakultete UL. Magistriral je leta 1993 in doktoriral leta 1997. Do leta 2008 je izjemno uspešno kot pedagog in raziskovalec deloval na Katedri za tehnologijo lesa, kjer je bil od leta 2004 do 2008 tudi vodja raziskovalne skupine "Tehnologija lesa«. Leta 2008 pa se je dr. Oven pogumno odločil za zamenjavo svojega ožjega raziskovalnega področja, na katerem je že bil mednarodno uveljavljen znanstvenik. Intenzivno se je začel ukvarjati s kemijo lesa in leta 2008 prešel na Katedro za kemijo lesa in drugih lignoceluloznih materialov, ki jo še vedno vodi.

Kemija lesa je na Oddelku za lesarstvo pedagoška in raziskovalna dejavnost z dolgoletno tradicijo. Prof. Ovnu je na tem temelju z dobro pretehtanimi odločitvami in zavzetim delom uspelo okrog sebe zbrati odlično pedagoško in raziskovalno ekipo, za

[1] Univerza v Ljubljani, Biotehniška fakulteta, Oddelek za lesarstvo
[1] University of Ljubljana, Biotechnical Faculty, Department of Wood Science and Technology
* marko.petric@bf.uni-lj.si
** ida.poljansek@bf.uni-lj.si

področje je navdušil mlajše sodelavce in študente, laboratorije je opremil z najsodobnejšo raziskovalno opremo ter vzpostavil tesne stike z gospodarstvom. S tem je osnoval moderen in mednarodno konkurenčen laboratorij za širše znanstveno področje kemije lesa (Oven, 2022a). Posebno pozornost posveča tudi prenosu in uporabi znanj v prakso, saj je svojo skupino povezal s številnimi raziskovalnimi skupinami na Biotehniški fakulteti, na Kemijskem inštitutu, na Inštitutu za celulozo in papir itd. Povezuje se z gospodarstvom in industrijo, s katerimi prijavlja skupne projekte, kot tudi z različnimi državnimi službami. Tako je pod njegovim vodstvom Oddelek za lesarstvo utrdil svoj status mednarodno uveljavljene in priznane institucije tudi na področju kemije lesa in lignoceluloznih materialov.

Osnovno poslanstvo prof. dr. Primoža Ovna v vlogi rednega profesorja je seveda pedagoška dejavnost. Na Oddelku za lesarstvo UL BF za kemijo lesa navdušuje študente na vseh stopnjah in smereh študija lesarstva v okviru predmetov kot so na primer Kemija lesa, Kemična zgradba lesa, Kemična predelava lesne biomase, Nanofibrilirana celuloza iz lesnih vlaken in še nekaterih drugih predmetov. Predavatelj pa je tudi na Oddelku za gozdarstvo in obnovljive vire BF UL ter na Akademiji za likovno umetnost in oblikovanje UL. Poleg tega je bil od leta 2009 do 2022 koordinator znanstvenega področja Les in biokompoziti na interdisciplinarnem doktorskem študiju Bioznanosti ter vodja Komisije za doktorski študij na Biotehniški fakulteti UL in je član komisije za doktorski študij Univerze v Ljubljani. Kot gostujoči profesor in raziskovalec je v letu 2010/11 deloval na Universität für Bodenkultur (BOKU) na Dunaju. O njegovem pedagoškem ugledu priča dejstvo, da je mentoriral štiri mlade raziskovalce oziroma doktorande in somentoriral dve doktorandki, od katerih je ena prejela nagrado za najboljši doktorat na področju papirništva. Trenutno pa pod njegovim mentorskim vodstvom študij zaključujejo trije doktorandi, pri eni doktorandki, ki je v zadnjem letniku doktorskega študija, pa je somentor. Samo po sebi je umevno, da je bil mentor tudi pri številnih diplomskih delih, od katerih sta bili dve nagrajeni s fakultetno, eno pa z univerzitetno Prešernovo nagrado. V vlogi somentorja je bil pri eni magistrski nalogi, ki je bila nagrajena s fakultetno Prešernovo nagrado.

Seveda tako kvalitetno pedagoško delo v univerzitetnem okolju ne bi bilo možno brez izvrstnega raziskovalnega dela z odličnimi rezultati. Znanstveno težišče raziskav prof. Ovna, ki je rezultiralo v skoraj 100 objavljenih delih, od tega preko 60 v uglednih recenziranih revijah (Bibliografija Primož Oven, 2022), je proučevanje zvez med funkcijami, strukturami in kemizmom ter lastnostmi lesa kot inženirskega materiala in tkiva živih dreves. Proučeval je možnosti uporabe magnetno resonančnega slikanja na širšem področju znanosti o lesu, kar je med drugim omogočilo iznajdbo nove, v soavtorstvu patentirane metode za določanje lesne vlažnosti. V zadnjem obdobju pa je raziskovalno delo usmeril na področje biorafinacije in valorizacije lesne biomase s poudarkom na pridobivanju in razvoju aplikacij ekstraktivov lesa in skorje ter nanofibrilirane celuloze. S svojimi raziskavami in aktivnim vključevanjem v strategije razvoja na področju lignoceluloznih materialov tako na UL kot tudi v družbenem in gospodarskem okolju dr. Oven posega na dandanes izjemno aktualen prehod v krožno gospodarstvo, ki ga s svojimi pedagoškimi in raziskovalnimi izkušnjami in delom aktivno sooblikuje.

V tem kratkem prispevku je nemogoče opisati vse številne aktivnosti prejemnika Zlate plakete Univerze v Ljubljani, prof. dr. Primoža Ovna. Zato naj omenimo le še, da je bil glavni in odgovorni urednik Zbornika za gozdarstvo in lesarstvo v letu 2006 in je tudi član uredniškega odbora te revije, sedaj *Acta Silvae at Ligni*. V letih 2021 in 2022 je gostujoči urednik posebne izdaje *Chemistry and Applications of Lignocellulosic Materials* pri reviji *Forests*, kot nacionalni predstavnik in ekspert je aktivno deloval v komiteju in akcijah COST Evropske unije ter bil vodja različnih raziskovalnih projektov doma in v tujini.

Veseli smo, da imamo na Oddelku za lesarstvo Biotehniške fakultete UL tako odličnega sodelavca, kolego in prijatelja. Iskrene čestitke, Primož!

Slika 1. Rektor Univerze v Ljubljani prof. dr. Gregor Majdič izroča zlato plaketo (Foto: Viljem Vek).
Figure 1. The rector of the University of Ljubljana presents the Golden Plaque (Photo: Viljem Vek).

Prof. Dr. Primož Oven, Univ. B. Sc. Wood Eng. has been working at the University of Ljubljana since 1990, when, after graduation (1989), he was employed as a young researcher at the Department of Wood Science and Technology of the Biotechnical Faculty of the University of Ljubljana. He obtained his master's degree in 1993 and his PhD in 1997. Until 2008, he worked extremely successfully as a lecturer and researcher at the Department of Wood Technology, where he was also the head of the "Wood Technology" research group from 2004 to 2008. In 2008, Dr. Oven courageously decided to change his narrow field of research, in which he was already an internationally recognised scientist. He began to work intensively on wood chemistry and in 2008 moved to the Chair of Chemistry of Wood and Other Lignocellulosic Materials, which he still heads.

Wood chemistry is a pedagogical and research activity with a long tradition at the Department of Wood Science and Technology. On this basis, with well-considered decisions and dedicated work, Dr. Oven has succeeded in gathering around him an excellent teaching and research team, inspiring younger colleagues and students to take up the subject, equipping the laboratories with state-of-the-art research equipment, and establishing close contacts with industry. As a result, he has created a modern and internationally competitive laboratory for the wider scientific field of wood chemistry (Oven, 2022b). He also pays special attention to the transfer and application of knowledge in practice, as he has linked his group with many research groups at the Biotechnical Faculty, the National Institute of Chemistry, the Institute of Pulp and Paper, and others. He is in contact with business and industry, with which he applies for joint projects, as

Slika 2. Prejemnik Zlate plakete Univerze v Ljubljani, prof. dr. Primož Oven (Foto: Katja Kodba in Nebojša Tejić (STA)).

Figure 2. Recipient of the Golden Plaque of the University of Ljubljana, Prof. Dr. Primož Oven (Photo: Katja Kodba and Nebojša Tejić (STA)).

well as with various government agencies. Under his leadership, the Department of Wood Science and Technology has consolidated its status as an internationally established and recognised institution also in the field of wood chemistry and lignocellulosic materials.

The main task of Prof. Dr. Primož Oven as a full professor is, of course, teaching. At the Department of Wood Science and Technology of UL BF he inspires students at all levels and in all programmes of the study of wood science and technology on topics such as wood chemistry, the chemical structure of wood, chemical processing of woody biomass, nanofibrillated cellulose from wood fibres and some other topics. He is also a lecturer at the Department of Forestry and Renewable Resources BF UL and at the Academy of Fine Arts and Design UL. In addition, from 2009 to 2022 he was the coordinator of the scientific area of wood and biocomposites in the interdisciplinary PhD programme in Biosciences and the head of the Commission for Doctoral Studies at the Biotechnical Faculty of UL, and is a member of the Commission for Doctoral Studies of the University of Ljubljana. In 2010/11 he worked as a visiting professor and researcher at the University of Natural Resources and Applied Life Sciences (BOKU) in Vienna. His pedagogical reputation is evidenced by the fact that he has supervised four young researchers or PhD students and co-supervised two female PhD students, one of whom received an award for the best PhD thesis in pulp and paper science. Three doctoral students are currently completing their studies under his supervision, and he is the co-mentor of one doctoral student who is also in the final year of her doctoral studies. It goes without saying that he has also supervised many diploma theses, two of which were awarded the Faculty's and one the University's Prešeren Prize. In the role of co-mentor, he was also involved in a master's thesis that was awarded with the Faculty's Prešeren Prize.

Of course, such high-quality educational work in an academic environment would not be possible without excellent research work with outstanding results. Prof. Oven's scientific research focus, which has resulted in nearly 100 published papers, including more than 60 in prestigious journals (Bibliografija Primož Oven, 2022), is the study of the relationships among the functions, structures, chemistry and properties of wood as an engineering material and the tissues of living trees. He explored the possibilities of using magnetic resonance imaging in the broader field of wood science, which led, among other things, to the invention of a new method for determining wood moisture content, which he helped to develop and patent. In recent years he has focused his research on the field of biorefining and valorisation of woody biomass with emphasis on the extraction and development of the application of wood and bark extracts and nanofibrillated cellulose. Through his research and active involvement in lignocellulosic material development strategies, both at UL and in the broader social and economic spheres, Dr. Oven is involved in today's highly relevant transition to a circular economy, which he is actively shaping through his experience and work in teaching and research.

In this short presentation, it is impossible to describe all the many and varied activities of the recipient of the Golden Plaque of the University of Ljubljana, Prof. Dr. Primož Oven. Therefore, it will only be mentioned that he was the Editor-in-Chief of the *Proceedings of Forestry and Woodworking* in 2006 and is also a member of the Editorial Board of this journal, which is now called *Acta Silvae at Ligni*. In 2021 and 2022, he was the guest editor of the special issue of the *Forest* journal focusing on the chemistry and applications of lignocellulosic materials. As a national representative and expert, he actively participated in the COST committee and COST actions of European Union, and was the leader of several research projects at home and abroad.

We are pleased to have such an excellent co-worker, colleague, and friend at the Department of Wood Science and Technology of University of Ljubljana's Biotechnical Faculty. Sincere congratulations, Primož!

VIRI
REFERENCES

Bibliografija Primož Oven – COBISS, Kooperativni online bibliografski sistem. URL: https://bib.cobiss.net/bibliographies/si/webBiblio/bib201_20221208_123809_11223.html (8. 12. 2022).

Oven, P. (2022a). Katedra za kemijo lesa in drugih lignoceluloznih materialov. V: Matjašec, D., Sepčić, K., Kunej, T. & Brus, R. (ur.), Petinsedemdesetletnica Biotehniške fakultete Univerze v Ljubljani. Ljubljana: Biotehniška fakulteta, 37-39. URL: https://repozitorij.uni-lj.si/IzpisGradiva.php?lang=slv&id=142082 (8. 12. 2022).

Oven, P. (2022b). Chair of chemisty of wood and other lignocellulose materials. In: Matjašec, D., Sepčić, K., Kunej, T. & Brus, R. (eds.), Seventy fifth anniversary of the Biotechnical Faculty University of Ljubljana [na spletu]. Ljubljana: Biotechnical Faculty, 37-39. URL: https://repozitorij.uni-lj.si/IzpisGradiva.php?lang=slv&id=142081 (8. 12. 2022)

Častni naziv Kongresni ambasador Slovenije za leto 2022 je prejel prof. dr. Miha Humar

Honorary title of Congress Ambassador of Slovenia for 2022 awarded to Prof. Dr. Miha Humar

Tina Drolc

V torek, 22. novembra 2022, je Kongresni urad Slovenije ob podpori Slovenske turistične organizacije in Kongresnega urada Turizma Ljubljana že četrtič podelil častne nazive Kongresni ambasador oziroma ambasadorka Slovenije. Časten naziv je prejelo 14 kongresnih ambasadork in ambasadorjev, med njimi je tudi prof. dr. Miha Humar s Katedre za lesne škodljivce, zaščito in modifikacijo lesa Oddelka za lesarstvo Biotehniške fakultete Univerze v Ljubljani. Mag. Petra Stušek, direktorica Turizma Ljubljana, je na podelitvi povedala: »Izjemni posamezniki, ki so danes prejeli naziv Kongresni ambasador, s svojim aktivnim in dolgoletnim delovanjem krepijo pozicijo Slovenije kot enega od središč intelektualnega kapitala, inovativnosti ter trajnostnega in regenerativnega razvoja v širši regiji. Ponosna sem, da večina letošnjih prejemnikov tega častnega naziva deluje v okviru članic Univerze v Ljubljani ali nacionalno pomembnih znanstvenoraziskovalnih, gospodarskih in kulturnih ustanovah s sedežem v našem mestu, kar podpira nadaljnji razvoj Ljubljane kot vodilne slovenske kongresne destinacije.« Zbrane sta nagovorila tudi mag. Maja Pak, direktorica Slovenske turistične organizacije in Fredi Fontanot, v. d. direktorja Kongresnega urada Slovenije. Svečana prireditev je potekala v Stanovski dvorani Ljubljanskega gradu.

V letu 2022 je sedemčlanska komisija, ki so jo sestavljali predstavniki destinacijskih klubov in Kongresnega urada Slovenije, konec oktobra potrdila 14 dobitnikov častnega naziva. Med njimi je bilo največ nominirancev s področja znanstveno-strokovnih kongresov, eden s področja športa in nagrajenka s področja gospodarstva. Med 1štirinajstimi dobitniki častnega naziva Kongresnega ambasadorja Slovenije v letu 2022 je tudi prof. dr. Miha Humar, ki deluje na področju lesarstva, lesnih škodljivcev ter zaščite in modifikacije lesa. Ob prejemu naziva je povedal: »*V zadnjem obdobju, posebej pa v letu 2021 in 2022, smo ob številnih mednarodnih projektih, ki potekajo na fakulteti, organizirali tudi različna mednarodna srečanja, delavnice, izobraževanja in kongrese. Izbirali smo različne lokacije v Sloveniji, v juniju je na Bledu potekalo 53. srečanje Svetovnega združenja za zaščito lesa, ki se ga je udeležilo okoli 200 udeleženk in udeležencev iz 32 držav. Uspel nam je izreden dogodek, tudi v sodelovanju s predstavniki turistične destinacije, ki je navdušila naše udeleženke in udeležence*.«

Slovenski ambasadorski program je podporni steber pri organizaciji znanstveno-strokovnih in drugih poslovnih ter športnih dogodkov. Namen podeljevanja častnih nazivov Kongresni ambasador oziroma ambasadorka Slovenije je privabiti v Slovenijo večje število mednarodnih znanstveno-strokovnih in poslovnih dogodkov, saj z njihovo organizacijo ustvarjamo odlične priložnosti za mreženje, pretok znanja, inovacij in izmenjavo izkušenj ter vzpostavitev dolgoročnih mednarodnih povezav.

On Tuesday, December 22, 2022, the Slovenian Congress Bureau, with the support of the Slovenian Tourist Board and the Ljubljana Convention Bureau of Tourism, awarded the honorary title of Congress Ambassador of Slovenia for the fourth time. Fourteen Congress Ambassadors were awarded the honorary title, including Prof. Dr. Miha Humar from the Department of Wood Pests, Wood Protection and Wood Modification, Department of Wood Science, Faculty of Biotechnology, University of Ljubljana.

As Petra Stušek, director of Ljubljana Tourism, said at the ceremony: "The outstanding personalities who have been awarded the title of Congress Ambassador today strengthen Slovenia's position as one of the centres of intellectual capital, innovation and sustainable and regenerative development in the wider region through their active and long-standing work. I am proud that most of this year's recipients of this honorary title work at the University of Ljubljana, or at nationally significant scientific, research, economic and cultural institutions in our city, which supports the further development of Ljubljana as a leading Slovenian congress destination." The audience was also welcomed by Maja Pak, director of the Slovenian Tourist Board, and Fredi Fontanot, acting director of the Slovenian Convention Bureau. The gala event took place in the Estates Hall of Ljubljana Castle.

A seven-member jury composed of representatives of destination clubs and the Slovenian Convention Bureau confirmed the 14 winners of the honorary title at the end of October. Among them, most of the nominees were from the field of scientific and professional congresses, one from the field of sports and the winner from the field of business. Among the 14 winners of the honorary title of a Congress Ambassador of Slovenia in 2022 is Prof. Dr. Miha Humar, who works in the field of wood science, wood pests and wood protection and modification. He said at the event: "Recently, and especially in 2021 and 2022, in addition to the many international projects taking place at the Faculty, we have organised various international meetings, workshops, trainings and congresses. We have chosen various locations in Slovenia, and in June the 53rd meeting of the World Association for the Protection of Wood was held in Bled, with about 200 participants from 32 countries. We managed to organise an exceptional event, also in cooperation with the representatives of the tourist destination, which impressed the participants."

The Slovenian Ambassador Programme is a mainstay in the organisation of scientific, professional and other business and sports events. The goal of the Slovenian Congress Ambassador or Slovenian Ambassador Honour is to attract a greater number of international scientific, professional and business events to Slovenia, as the organisation of these events creates excellent opportunities for networking, knowledge flow, innovation and the exchange of experience, as well as building long-term international relationships.

Doc. dr. Davor Kržišnik prejemnik Svečane listine za mlade visokošolske učitelje in visokošolske sodelavce UL

Assistant Professor Dr. Davor Kržišnik recipient of the Ceremonial Certificate for Young Higher Education Teachers and Higher Education Associates of the University of Ljubljana

Miha Humar

Doc. dr. Davor Kržišnik je zaposlen na Oddelku za lesarstvo Biotehniške fakultete Univerze v Ljubljani (OL BF UL). Trenutno opravlja delo asistenta in je habilitiran v naziv docenta za področje Znanost o lesu in lignoceluloznih kompozitih ter tehnologije v lesarstvu. Davor Kržišnik je diplomiral leta 2014 na MSc programu Lesarstvo. Že med študijem se je dva semestra usposabljal v tujini na Tuscia University (Università degli Studi della Tuscia) (prof. dr. Mauela Romagnoli), na osnovi česar je objavil tudi izvirni znanstveni članek. Stike s to raziskovalno skupino je ohranil, kar se kaže v raziskovalnem sodelovanju.

Slika 1. Davor Kržišnik je prejel svečano listino za mlade visokošolske učitelje in visokošolske sodelavce Univerze v Ljubljani za leto 2022. Podelil mu jo je rektor Univerze v Ljubljani prof. dr. Gregor Majdič (Foto: Katja Kodba in Nebojša Tejić/STA, 2022)

Figure 1. Davor Kržišnik received the 2022 Ceremonial Certificate for Young Higher Education Teachers and Higher Education Associates from the rector of the University of Ljubljana prof. Dr. Gregor Majdič (Photo: Katja Kodba and Nebojša Tejić/STA, 2022)

V letu 2015 se je Davor Kržišnik zaposlil kot mladi raziskovalec v programski skupini P4-0015 Les in lignocelulozni kompoziti. V okviru doktorskega študija je predstavil povezavo med laboratorijskimi in terenskimi preizkusi pri ocenjevanju funkcionalne in estetske življenjske dobe lesa. Ovrednotil je potencial različnih laboratorijskih testov za namen napovedovanja dinamike vlaženja lesa na prostem. Dokazal je, da se lahko nekateri hitrejši laboratorijski preizkusi uporabijo za napovedovanje dinamike spremembe vlažnosti na prostem. V drugem delu se je posvetil analizi barvnih sprememb lesa na prostem. Večina rezultatov disertacije je bila predstavljena na domačih in mednarodnih konferencah. Disertacija je sestavljena iz desetih znanstvenih člankov, objavljenih v vrhunskih revijah s področja lesarstva. Uspešno delo na področju zaščite lesa je prepoznalo tudi mednarodno društvo za zaščito lesa in Davorju v letu 2019 podelilo nagrado Ron Cockroft award za udeležbo na mednarodni konferenci v Quebecu.

V času zaposlitve se je Davor Kržišnik angažiral pri raziskovalnem delu. Usposobil se je za delo na raznolikih laboratorijsko-eksperimentalnih tehnikah (mikrobiološke tehnike, dinamična sorpcija vodne pare, piknometrija, modifikacija lesa, FTIR, digitalna in konfokalna mikroskopija, terensko delo …), kar se kaže v številnih objavah. Davor Kržišnik je soavtor 30 izvirnih znanstvenih člankov, sodeluje pri prijavi projektov. Zelo pomemben je podatek, da je bil v imenu Biotehniške fakultete uspešen pri prijavi nove programske skupine (P4-0430) pod koordinatorstvom Gozdarskega inštituta. Davor Kržišnik tako koordinira delo te programske skupine na Biotehniški fakulteti. Dela dr. Kržišnika so odmevna, kar se izraža v več kot 200 citatih.

Dr. Davor Kržišnik se zelo vključuje v pedagoško delo katedre. Že kmalu po zaposlitvi je začel z delovnim mentoriranjem diplomantov. Pedagoško delo je nadaljeval z vodenjem vaj pri predmetih na študiju Lesarstva, študiju Biotehnologije in študiju Konzervatorstva na ALUO. Udeležuje se številnih usposabljanj, ki jih organizira UL in ta spoznanja sproti prenaša v pedagoško prakso. Vse to se odraža v odličnih pedagoških ocenah. Dr. Davor Kržišnik je aktiven tudi na strokovnem področju in kot promotor sodeluje pri promociji študija lesarstva v srednjih šolah. Poleg tega dr. Kržišnik sodeluje z Lesarskim grozdom pri uvajanju okoljevarstvenih zahtev v lesno industrijo kot pospeševalec in presojevalec. Vse to je prepričalo strokovno komisijo UL, da dr. Kržišniku podeli ugledno priznanje.

Svečane listine za mlade visokošolske učiteljice in učitelje ter visokošolske sodelavke in sodelavce sta prejeli še dve mladi sodelavki Biotehniške fakultete (Teden univerze, 2022). To sta asist. dr. Meta Sterniša in asist. dr. Katarina Šimunović. Dr. Sterniša je leta 2020 doktorirala na Katedri za biotehnologijo, mikrobiologijo in varnost živil, Oddelka za živilstvo BF, kjer se z raziskovalnim in pedagoškim delom usmerja v živilsko mikrobiologijo, bakterijsko encimsko aktivnost in filmotvornost ter načine preprečevanja kvarnih mikrobioloških procesov. Dr. Šimunović, asistentka na Oddelku za mikrobiologijo, je odlična raziskovalka in predana pedagoginja, ki je ključno in z navdušenjem prispevala k pomembnim raziskovalnim objavam na področju mikrobiologije, prijavi patenta in zagonu start-up podjetja za razvoj in trženje inovacij.

Vsem iskrene čestitke!

Assist. Prof. Dr Davor Kržišnik is employed in the Department of Wood Science and Technology at the Biotechnical Faculty of the University of Ljubljana. He currently works as an assistant and is habilitated as an assistant professor in the field of wood science and lignocellulosic composites and technology in wood science. Davor Kržišnik completed the MSc programme in Wood Science and Technology in 2014. Already during his studies he completed two semesters abroad, at the University of Tuscia (Università degli Studi della Tuscia) (Prof. Dr. Mauela Romagnoli), based on which he also published an original scientific article. He maintained contacts with this research group, which is reflected in his research collaboration.

In 2015, Davor Kržišnik was hired as a young researcher in the P4-0015 Wood and Lignocellulosic Composites programme group. As part of his PhD studies, he presented the link between laboratory and field testing in assessing the functional and aesthetic service life of wood. He evaluated the potential of different laboratory tests to predict the outdoor moisture dynamics of wood. Mr Kržišnik proved that some faster laboratory tests can be used to predict the dynamics of outdoor moisture changes. In the second part, he devoted himself to the analysis of colour changes of wood

Slika 2. Prejemniki Svečane listine za mlade visokošolske učitelje in visokošolske sodelavce Univerze v Ljubljani za leto 2022 iz Biotehniške fakultete: doc. dr. Davor Kržišnik, asist dr. Meta Sterniša in asist. dr. Katarina Šimunović.

Figure 2. Recipients of the 2022 Ceremonial Certificates for Young Higher Education Teachers and Higher Education Associates of the University of Ljubljana from the Biotechnical Faculty: Associate Professor Dr. Davor Kržišnik, Assistant Professor Dr. Meta Sterniša and Assistant Professor Dr. Katarina Šimunović.

outdoors. Most of the results of the dissertation were presented at national and international conferences. The dissertation consists of ten scientific articles published in leading journals in the field of wood research. The successful work in the field of wood preservation was also recognised by the International Association for Wood Protection. in 2019, Davor was awarded the Ron Cockroft Award for participation in an international conference in Quebec.

Dr. Kržišnik was active in research during his employment. He trained in various experimental laboratory techniques (microbiological techniques, dynamic water vapour sorption, pycnometry, wood modification, FTIR, digital and confocal microscopy, and field work, among others), which is reflected in numerous publications. Dr. Kržišnik is the co-author of 30 original scientific articles and participates in the registration of projects. It is very important to mention that he successfully applied for a new programme group (P4-0430) under the coordination of the Forest Institute on behalf of the Faculty of Biotechnology. Davor Kržišnik is thus coordinating the work of this programme group at the Faculty of

Biotechnology. Dr Kržišnik's work is also having an impact on other researchers, as reflected in around 200 citations his publications have already gained.

Dr. Davor Kržišnik is very involved in the department's educational work. Soon after he was hired, he began mentoring graduates. He continued his educational work by leading exercises in the courses in Wood Science and Technology, Wood Engineering, Biotechnology and Conservation at ALUO. Dr. Kržišnik participates in numerous trainings organised by UL and transfers this knowledge into pedagogical practice. All this is reflected in excellent pedagogical evaluations. Dr. Kržišnik is also professionally active, working to promote the study of wood science in secondary schools. In addition, Dr. Kržišnik cooperates with the Wood Industry Cluster in the introduction of environmental protection requirements in the wood industry, as an accelerator and reviewer. All this has convinced the UL Expert Committee that Dr. Kržišnik should receive a prestigious award.

The ceremonial certificates for young university teachers and university assistants of the University of Ljubljana have been received by two more young colleagues of the Biotechnical Faculty. They are Assistant Professor Dr. Meta Sterniša and Assistant Professor. Dr. Katarina Šimunović. Dr. Sterniša received her PhD in 2020 in the Department of Biotechnology, Microbiology and Food Safety, and the Department of Food Science and Technology. Her research and teaching activities focus on food microbiology, bacterial enzyme activity and film formation, and ways to prevent these defective microbiological processes. Dr. Šimunović in the Department of Microbiology is an outstanding researcher and dedicated educator who has enthusiastically contributed to important research publications in the field of microbiology, a patent application, and the creation of a start-up company for the development and commercialisation of research innovations. Congratulations to all certificate awardees.

VIRI / REFERENCES

Foto: Katja Kodba in Nebojša Tejić/STA, Univerza v Ljubljani, Podelitev priznanj strokovnim sodelavkam in sodelavcem Univerze v Ljubljani. URL: UNILJ > Medijsko središče > Foto galerija > Teden Univerze > Teden Univerze 2022 https://www.uni-lj.si/medijsko_sredisce/foto_galerija/teden_univerze/teden_univerze_2022/2022120209064199/ (8. 12. 2022).

Teden Univerze v Ljubljani 2022, Svečana listina za mlade visokošolske učiteljice in učitelje ter visokošolske sodelavke in sodelavce. URL: https://www.uni-lj.si/tedenuniverze/tedenuniverze_2022/svecana_listina_za_mlade_visokosolske_uciteljice_in_ucitelje_ter_visokosolske_sodelavke_in_sodelavce/ (8. 12. 2022).

Priznanje Univerze v Ljubljani skupini strokovnih sodelavk in sodelavcev Biotehniške fakultete

Katarina Čufar

V Tednu univerze v letu 2022 je Univerza v Ljubljani podelila priznanje skupini strokovnih sodelavk in sodelavcev Biotehniške fakultete za pomemben prispevek k izboljšanju delovnih procesov in pozitivni klimi na fakulteti in univerzi.

Skupina strokovnih sodelavk in sodelavcev je priznanje prejela za uvedbo sistema APIS na Biotehniški fakulteti Univerze v Ljubljani. Priznanje so prejeli Darko Klobučar, Ana Kaplan Novak, Polona Hribar, Mateja Bregant Perić, Nataša Miklavčič, Sandra Zafirovič, Jana Trakoštanec, Renata Kovačič, Tomaž Valenčič, Mihael Prosenjak, Petra Žejavac, Jasna Lukan, Urška Iglič, Tadeja Lovšin, Anita Strmole, Jožef Hanč, Tea Kuzman, Maja Kristan Mihičinac, Tadeja Dečman Flis, Tamara Štular, Tina Košnjek, Tomaž Podboj, Anton Zupančič, Mojca Dermastja, Sonja Osolnik, Selma Uršula Muhar in Anja Uršič.

V letu 2019 je Univerza v Ljubljani začela projekt uvajanja enotnega poslovno informacijskega sistema APIS – Sap. Biotehniška fakulteta ga je uspešno začela uporabljati 1. aprila 2021. To je omogočilo prehod na enoten sistem, ki povezuje vse ključne poslovne funkcije in procese Univerze v Ljubljani ter zagotavlja najvišjo stopnjo transparentnosti, zanesljivosti poslovanja in zagotavljanja natančnih in točnih podatkov. Da je uporaba sistema

Slika 1. Prejemnice in prejemniki priznanja strokovnim sodelavkam in sodelavcem na podelitvi v zbornični dvorani Univerze v Ljubljani (Foto: Katja Kodba/STA).

stekla, so zaslužni strokovni sodelavci in sodelavke, ki so sodelovali pri pripravi potrebnih baz podatkov, se učili uporabe modulov novega poslovnoinformacijskega sistema APIS ter učili svoje sodelavce in druge zaposlene na Biotehniški fakulteti Univerze v Ljubljani. V sodelovanju s koordinatorji ključnih uporabnikov so tvorno sodelovali in predlagali številne rešitve, ki so pripomogle k boljšemu delovanju sistema (Teden univerze, 2022).

Sodelavkam in sodelavcem za zasluženo priznanje iskreno čestitamo!

Med prejemniki priznanja je tudi Anton Zupančič, univ. dipl. inž. les. z Oddelka za lesarstvo. Kolega

Slika 2. Anton Zupančič z Oddelka za lesarstvo je s skupino sodelavk in sodelavcev Biotehniške fakultete prejel priznanje, ki jim ga je v Tednu univerze 2022 podelil rektor Univerze v Ljubljani prof. dr. Gregor Majdič (Foto: Katja Kodba/STA).

Zupančič je tajnik in vodja skupnih služb oddelka. Poleg rednih zadolžitev, ki so bile v preteklem obdobju nadpovprečne zaradi uvajanja omenjenega sistema, je Tone nepogrešljiv sodelavec, ki ima velike zasluge za delovanje Oddelka. Nanj se zaposleni na Oddelku dnevno obračamo z najrazličnejšimi vprašanji v zvezi z administrativnim in finančnim poslovanjem, delovanjem stavbe in opreme v učilnicah, uporabo računalniških sistemov in mnogimi drugimi vprašanji, če je njegova številna opravila in zasluge sploh mogoče strniti v tako kratek zapis. Anton Zupančič je tudi tehnični urednik revije Les/Wood z izjemnim znanjem in izkušnjami.

Tone, iskrene čestitke za zasluženo priznanje!

VIRI

Foto: Katja Kodba/STA, Univerza v Ljubljani, Podelitev priznanj strokovnim sodelavkam in sodelavcem Univerze v Ljubljani. URL: UNILJ > Medijsko središče > Foto galerija > Teden Univerze > Teden Univerze 2022 URL: https://www.uni-lj.si/medijsko_sredisce/foto_galerija/teden_univerze/teden_univerze_2022/2022120209300854/ (8. 12. 2022)

Teden Univerze v Ljubljani 2022, Priznanje strokovnim sodelavkam in sodelavcem.

URL: https://www.uni-lj.si/tedenuniverze/tedenuniverze_2022/priznanje_strokovnim_sodelavkam_in_sodelavcem/ (8. 12. 2022)

14. srečanje ALUMNI kluba Oddelka za lesarstvo

14th Meeting of the Alumni Club of the Department of Wood Science and Technology

Katarina Čufar, Boštjan Lesar, Tomaž Kušar, Jure Žigon

Po triletni prekinitvi zaradi epidemije covida-19 se je skupnost alumnov Oddelka za lesarstvo 23. 11. 2022 ponovno zbrala na tradicionalnem srečanju. Tokrat se je na srečanju zbralo okoli 120 bivših študentk in študentov. Udeleženke in udeleženci srečanja so se začeli zbirati že v popoldanskih urah. Poleg uradnega ogleda Oddelka so si vsi najbolj želeli druženja ter se po dolgem času s kolegicami in kolegi pogovoriti, kaj je novega.

Uradni program je bil kot po navadi namenjen predstavitvam novosti na Oddelku in v stroki. Letos ga je popestril nastop mladega čelista Filipa Demšarja. Zaigral je na inštrument, izdelan v Ateljeju Demšar, ki ga vodi njegov oče, priznani goslar in naš alumen Blaž Demšar.

Podrobneje se nam je predstavila skupina diplomantov, ki so diplomirali pred 20 leti. Že kot študenti so bili zelo aktivna in prepoznavna generacija, ki je imela tudi to posebnost, da v letniku ni imela nobene kolegice. Pohvalijo se lahko, da so med njimi številni direktorji in podjetniki, dva doktorja znanosti in en nosilec znanstvenega magisterija. Na letošnjem srečanju so se posebej predstavili mag. Tomaž Kušar, vodja Društva lesarjev Slovenije, univ. dipl. inž. les. Tomaž Vilar iz podjetja DIMPEX, ki je bil glavni sponzor srečanja, in izr. prof. dr. Maks Merela, novi prodekan Oddelka za lesarstvo BF.

Slika 1. Ogledi laboratorijev.
Figure 1. Laboratory tours.

Slika 2. Polna predavalnica in glasba.
Figure 2. Full lecture room and music.

Slika 3. Predstavniki generacije, ki je zaključila študij pred 20 leti.
Figure 3. Representatives of the generation which graduated 20 years ago.

Tomaž Vilar je predstavil podjetje DIMPEX lesnoobdelovalni stroji, ki se ukvarja s prodajo lesnoobdelovalnih strojev priznanih proizvajalcev iz Nemčije, Avstrije, Švice in Češke. Poleg prodaje nudijo vsestransko podporo kupcem, ki vključuje servis in vzdrževanje, rezervne dele, montažo, zagon strojev in usposabljanje za varno delo ter selitev strojev. Podrobneje nam je predstavil prodajni program različnih proizvajalcev kot so HOLZHER, ALTENDORF, KUNDIG, LANGZAUNER, ELKOM, REINBOLD in ADAMIK, s posebnim poudarkom na inovativnih rešitvah, ki omogočajo varno in kakovostno delo.

Raziskovalno delo na Oddelku za lesarstvo so letos predstavile mlade raziskovalke in raziskovalci oz. doktorski študentki in študent. Mlada raziskovalka Eli Keržič je predstavila raziskave, ki proučujejo spremembe odpornosti lesa zaradi izpiranja biološko aktivnih učinkovin in spremembe morfologije površin kot posledice vremenskih vplivov. Raziskave potekajo predvsem v sodelovanju s prof. dr. Miho Humarjem in doc. dr. Viljemom Vekom. Doktorska študentka Urška Osolnik je predstavila raziskovalno delo na Katedri za kemijo lesa, kjer deluje skupaj s

Slika 4. Tomaž Vilar univ. dipl. inž. les. in podjetje DIMPEX–glavni sponzor srečanja.
Figure 4. Tomaž Vilar univ. dipl. ing. and DIMPEX, the main sponsor of the meeting.

Slika 5. Nepogrešljivo druženje.
Figure 5. A much-appreciated get-together.

Slika 6. Milan Pohar, Miran Bajec, Milan Osterman in Janko Stanonik, diplomirani inženirji lesarstva, ki so se na študij lesarstva vpisali v letu 1967/68 in diplomirali pred skoraj 50 leti. Predstavljajo eno najbolj zvestih skupin alumnov in se srečanja udeležijo vsako leto.
Figure 6. Milan Pohar, Miran Bajec, Milan Osterman and Janko Stanonik, wood science and technology engineers who began their studies in 1967/68 and graduated nearly 50 years ago. They represent one of the most loyal groups of alumni, those who attend the reunion every year.

prof. dr. Primožem Ovnom (vodja katedre) ter izr. prof. dr. Ido Poljanšek in doc. dr. Viljemom Vekom.

Uradnemu delu je sledilo neformalno druženje, ki so se ga alumni po treh letih omejitev zaradi pandemije najbolj razveselili. Sponzor in organizatorji so kot vedno poskrbeli za pogostitev, vsi skupaj pa za prijetno vzdušje.

Srečanja so se nekateri udeležili prvič po diplomi, in tako po daljšem času tudi več (deset) let spet videli, kako je danes na “faksu”. Alumni klub ima tudi zelo zveste udeležence, ki nikoli ne manjkajo. Med njimi je skupina alumnov, ki se približujejo 50-letnici diplome.

Slika 7. Leta 2006 so pridobili strokovne nazive in odšli vsak svoji karieri naproti, sedaj, več let kasneje, pa se še vedno radi vračajo nazaj na svoj "faks".
Figure 7. In 2006, they earned their professional degrees and left the faculty to pursue their careers. Now, many years later, they still enjoy returning to their faculty.

Srečanje vedno radi obiščejo tudi mladi udeleženci, ki so diplomirali ali magistrirali pred kratkim, redno pa na srečanje povabimo tudi predstavnike študentov. Tokrat sta nam dva študenta in motivirana tutorja tudi pomagala pri pogostitvi.

Med zelo motivirane alumne, ki redno obiskujejo srečanje, je tudi skupina, ki je visokošolski študij končala okoli leta 2006. Pravijo, da se radi vračajo nazaj na svoj "faks", tudi zato, ker jih nanj in na kolegice ter kolege vežejo lepi spomini.

Srečanje je organiziral klub alumnov Oddelka za lesarstvo Univerze v Ljubljani skupaj z Društvom lesarjev Slovenije. Oddelek in Društvo sta srečanje tudi vsestransko podprla, za kar se iskreno zahvaljujemo. Srečanja so se v velikem številu udeležili kolegice in kolegi Oddelka za lesarstvo, ki so z veliko zagnanostjo prevzeli vlogo organizatorjev. Vsem lepa hvala. Velika zahvala gre tudi sponzorju DIMPEX s Tomažem Vilarjem.

After 3 years of restrictions due to the COVID-19 pandemic, we met again at the traditional, and now 14th, Alumni Club meeting of the Department of Wood Science and Technology, Biotechnical faculty, University of Ljubljana (DWST BF UL). The programme of the meeting included a tour through the department, presentations with a cultural programme – this time performed by a young cello player Filip Demšar, a son of our alumen and respected violin maker Blaž Demšar univ. dipl. ing.

During the official programme, the organisers presented what is new in DWST. The research work was presented by three young researchers, PhD students. Part of the programme was designed by the generation of alumni who graduated 20 years ago. Among them are Tomaž Vilar univ. dipl. ing., representative of the main sponsor DIMPEX, the president of the Slovenian Association of Wood Science and Technology (DLS) mag. Tomaž Kušar, and the current vice dean of DLWS BF UL, Prof. Dr. Maks Merela.

The meeting was organised by the Alumni Club of UL BF DWST and DLS. Both DWST and DLS, supported the meeting in every possible way, for which we would like to express our sincere gratitude. The meeting was well attended by alumni of all generations, who also appreciated the opportunity for an informal face-to-face meeting with colleagues. We thank the DWST staff who enthusiastically took on the role of organisers. A big thanks also goes to the sponsor DIMPEX with Tomaž Vilar. The pictures show that the meeting was a great success.

Poročilo z drugega posveta projektne skupine projekta L4-2623: EKSTRAKTIVI V JELOVIH GRČAH

Viljem Vek, Ida Poljanšek, Primož Oven

V sredo, 15. junija 2022, je v Podjetniškem inkubatorju Kočevje potekal posvet in drugi letni sestanek projektne skupine L4-2623. Posvet z naslovom Ekstraktivi v jelovih grčah je bil organiziran skladno s terminskim planom aktivnosti, ki je definiran v projektni prijavi ARRS-RPROJ-JR/929. Vodja delovnega sklopa WP 7 prof. dr. Primož Oven, ki pokriva področje upravljanja projekta in diseminacije, je sestanek organiziral v sodelovanju z dr. Ido Poljanšek in dr. Viljemom Vekom. Dogodek je del aktivnosti SRIP Mreže za prehod v krožno gospodarstvo, fokusno področje Biomasa in alternativne surovine.

Z aplikativnim projektom z naslovom Pridobivanje ekstraktivov grč in skorje z visoko vsebnostjo polifenolov iz manj izkoriščene biomase bele jelke (L4-2623) raziskujemo načine za optimalno pripravo drevesne biomase za ekstrakcijo ter proučujemo možnosti za učinkovito ekstrakcijo naravnih bioaktivnih spojin iz lesa in skorje bele jelke (*Abies alba*). Projekt financirata Agencija za raziskave in razvoj Republike Slovenije in podjetje Ars Pharmae d. o. o. Gostitelj dogodka je bil g. Aleš Marolt, vodja raziskovalne razvojne skupine Kočevski les. Na posvetu smo aktivno sodelovali Primož Oven, Ida Poljanšek in Viljem Vek kot predstavniki članice Univerze v Ljubljani (Biotehniška fakulteta, Oddelek za lesarstvo), Marko Domazet in Urša Zaloker iz podjetja Ars Pharmae d. o. o. ter Aleš Marolt in Alan Obranovič iz podjetja Kočevski les d. o. o. Seznam vseh udeležencev s kontakti je zajet v SRIP listi prisotnosti. S tokratnim posvetom smo pozornost namenili grčam. Grče v lesu na splošno predstavljajo tehnološke napake, v lesnopredelovali industriji so nezaželene in jih večinoma obravnavamo zgolj kot lesni ostanek. Po drugi strani pa grče predstavljajo bogat vir polifenolov, torej naravnih spojin z visoko tržno vrednostjo. Na posvetu smo izpostavili izbrane lesno biološke in tehnološke vsebine, ki so osnova za pridobivanje ekstraktivov iz grč bele jelke.

Po uvodnem govoru dr. Primoža Ovna so Aleš Marolt ter Marko Domazet in Urška Zaloker predstavili trenutne aktivnosti raziskovalnih skupin Kočevski les in Ars Pharmae. Sledilo je predavanje z naslovom »Nastanek, struktura in kemizem grč pri jelki«, kjer je dr. Oven predstavil fiziološke osnove vej oziroma grč, opisal nastanek veje, definiral grčo, nato je nazorno predstavil kemijske in anatomske značilnosti lesa grč in tako jasno označil tkiva grč, ki predstavljajo relevantno surovino za pridobivanje in ekstrakcijo polifenolov ter s tem vsebinsko odprl novo področje. S predavanjem »Katero od polarnih topil je najbolj primerno za ekstrakcijo jelovih grč?« je dr. Ida Poljanšek predstavila rezultate raziskovalnih aktivnosti, ki so bile v preteklem obdobju opravljene na Oddelku za lesarstvo Biotehniške fakultete. Ti rezultati so jasno pokazali način za učinkovito ekstrakcijo jelove grče, vključno z najprimernejšim načinom za vzorčenje grč, kakšna je ustrezna manipulacija s tkivi jelove grče, kako jelovo grčo ustrezno pripravimo za ekstrakcijo ter katera topila oziroma razmerja med topili so najprimernejša za učinkovito ekstrakcijo jelove grče. V tem sklopu so bili detajlno predstavljeni najprimernejši procesni pogoji, ki zagotavljajo visoke ekstrakcijske donose. Predavanje je zaključila s sklepnim sporočilom, kjer je jasno označila najprimernejši način za pilotno pridobivanje polifenolov iz lesa grč bele jelke. Sledila je predstavitev z naslovom »Vsebnost ekstraktivov v jelovih grčah« z natančnim povzetkom vseh aktivnosti, ki so bile opravljene v času trajanja projekta L4-2623 v preteklem projektnem obdobju, z opisi vseh terenskih akcij, vzorčenj, s katerimi smo odvzeli material, ki je bil vključen v raziskave, vpliva letnega časa na vsebnost ekstraktivov v skorji in grčah bele jelke, ter material, ki bo podal informacijo o vplivu sestave tal na vsebnost ekstraktivov. V tem delu je bil predstavljen seznam in število vseh odvzetih vzorcev. Projektni partnerji so se seznanili z vsemi ključnimi rezultati, ki jasno kažejo na to, katera tkiva živih in mrtvih vej vsebujejo največ ekstraktivov, kakšna je sezonska variabilnost v vsebnosti ekstraktivov v grčah in skorji bele jelke, natančno je bil predstavljen tudi plan raziskovalnega dela na projektu za zadnje projektno obdobje.

Po predavanjih je sledila diskusija o raziskovalnih izzivih, ki projektno skupino še čakajo do izteka aplikativnega projekta L4-2623. Projektna skupina je posvet zaključila s sklepom, da vse raziskovalne aktivnosti potekajo skladno s terminskim planom projekta L4-2623 ter da so bili v drugem projektnem letu doseženi vsi glavni projektni cilji (Spisek časovnih mejnikov je naveden v opisu projekta na internetni strani Biotehniške fakultete: https://www.bf.uni-lj.si/sl/raziskave/raziskovalni-projekti/).

Slika 1. Drugi posvet projektne skupine L4-2623 z naslovom »Ekstraktivi v jelovih grčah« je potekal v konferenčni sobi Podjetniškega inkubatorja Kočevje (foto: Ida Poljanšek in Viljem Vek).

Nova raziskovalna oprema na Oddelku za lesarstvo Biotehniške fakultete Univerze v Ljubljani - Instrument za določanje mikromehanskih lastnosti površin lesa, kompozitov in lesnoobdelovalnih orodij MCT3

Marko Petrič

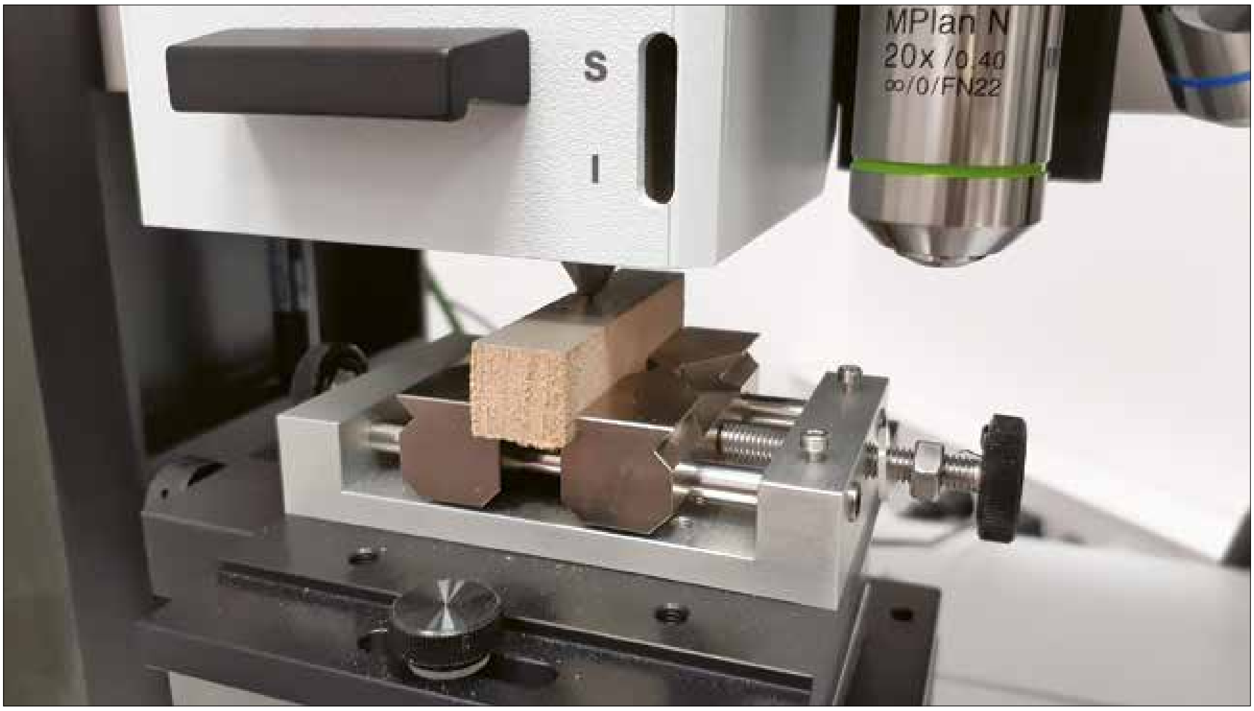
Na Oddelku za lesarstvo Biotehniške fakultete Univerze v Ljubljani smo se pred poletnimi počitnicami leta 2022 razveselili nove pridobitve. Ob polovičnem finančnem prispevku Agencije Republike Slovenije za raziskovalno dejavnost (ARRS) in polovičnih lastnih sredstvih, smo v skupini za obdelavo površin na Katedri za lepljenje, lesne kompozite, obdelavo površin in konstruiranje uspeli pridobiti instrument za določanje mikromehanskih lastnosti površin različnih materialov, MCT3, proizvajalca Anton Paar. Novo opremo smo namestili v novem laboratoriju skupine za površinsko obdelavo, ki je bil prav tako dograjen in opremljen v letu 2022.

Oprema MCT3 sodi v skupino instrumentov, s katerimi merimo mehanske lastnosti površin s karakterizacijskimi tehnikami, imenovanimi instrumentalna indentacija, razenje in tribologija. Z rezultati meritev s takimi instrumenti dobimo odgovore na vprašanja, kot so: Kako elastična je površina? Kako dobro se premaz oprime podlage? Kako odporen je material proti obrabi? ipd.

Instrument MCT3 z diamantno konico različnih geometrij (piramida, stožec, krogla) omogoča mehanske preiskave površin z obremenjevanjem od 50 mN do 30 N z različnimi načini obremenjevanja. Z večcikličnim obremenjevanjem lahko trdoto in modul elastičnosti globinsko profiliramo v tankih plasteh do globine 1000 µm. To pomeni, da je možno določiti gradient merjenih lastnosti v odvisnosti od oddaljenosti od površine. Inštrument je opremljen s svetlobnim mikroskopom, ki omogoča zajem sinhronizirane panoramske slike raze z ostalimi senzorji (preostala globina, sila trenja in akustična emisija). Tehnologija vključuje predskeniranje profila površine (oblika, valovitost in hrapavost) vzorca pred izvedbo testa razenja. To omogoča popravljanje globine indenterja med razenjem (globina penetracije) in po njem (preostala globina) s profilom površine. Na ta način lahko okarakteriziramo elastične, plastične in viskoelastične lastnosti tankih plasti in materialov.

In kakšne bodo možnosti uporabe mikromehanskih preiskav površin z mikroindenterjem MCT3 na Oddelku za lesarstvo za potrebe našega raziskovalnega in pedagoškega dela, za sodelujoče partnerje ter v obliki storitev za partnerje na trgu? MCT3 bo omogočil raziskave površin neobdelanega in na različne načine obdelanega lesa, lesnih kompozitov, lesnoobdelovalnih orodij in drugih trdnih materialov kot so npr. polimeri in polimerni filmi, vključno z lesnimi premazi, samoobnovljivimi premazi, trdimi filmi, ipd. Odpirajo se možnosti raziskav površin arheološkega lesa, modificiranega lesa, lesa, okuženega z glivami, poslikav (premazov) na objektih kulturno zgodovinske dediščine, trdih tankih prevlek na lesnoobdelovalnih strojih, pa tudi kovin, cementnih materialov, in še bi lahko naštevali. Merili bomo predvsem trdoto površin, elastični modul, oprijemno trdnost premaza, odpornost proti razenju in obrabi. V sklopu nove opreme je tudi računalnik za upravljanje naprave z ustrezno programsko opremo za analizo in obdelavo rezultatov merjenja. Omogočeno je mapiranje mehanskih lastnosti mikro-strukturnih elementov ter povezava le-teh z rezultati, pridobljenimi z različnimi drugimi fizikalno-kemijskimi in optičnimi analiznimi tehnikami na makro nivoju.

Slika 1. Mikroindenter MCT3 v novem laboratoriju skupine za površinsko obdelavo (Foto: J. Žigon).



Slika 2. Izvajanje meritve z instrumentom MCT3 (Foto: J. Žigon).