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UVODNIK / EDITORIAL

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Les – naraven material v svetu konkurenčnosti

Les od nekdaj spremlja človeka kot vsestranski material. Danes se v družbeno odgovornih okoljih, kjer postajajo trajnost, obnovljivi viri in ekološka ozaveščenost ključni dejavniki, spet vse bolj uveljavlja, je konkurenčen material ter ključen za doseganje krožnosti.

Les zaradi svojih prednosti izstopa pri pohištvu in notranji opremi, kjer je praktično brez konkurence. Zelo uspešno se uporablja v gradbeništvu, kjer so kot trajnostni material priljubljeni različni lesni kompoziti. Mehanske lastnosti lesa in lesnih kompozitov, kot so visoka trdnost glede na maso oz. gostoto, enostavnost obdelave ter dobre ali celo izjemne izolacijske lastnosti, omogočajo njihovo široko uporabo pri gradnji stanovanjskih in drugih objektov. Les lahko konkurira betonu in jeklu celo pri gradnji najvišjih objektov.

Pomembno mesto, zlasti iz manj kakovostnih surovinskih virov, zaseda v embalažni industriji, kjer vse več podjetij prehaja iz polimerov na lesene ali papirne alternative embaliranja.

Konkurenčnost lesa je nizka na več področjih, kjer lesni kompoziti zaostajajo za kovinami, polimeri in umetnimi kompoziti. V gradnji v ekstremnih pogojih les zaostaja za visokozmogljivimi materiali, kar velja tudi za več področij športne opreme, zlasti zaradi občutljivosti na vlago, UV-žarke in variabilnih lastnosti. V pakirni industriji še vedno prevladuje plastika, zlasti zaradi nižjih stroškov in fleksibilnosti predelave in uporabe. Tako bi lahko lažji in trajnejši lesni materiali nadomestili plastiko v embalaži, medtem ko bi hibridni kompoziti združili estetiko lesa z mehanskimi prednostmi drugih materialov. V zahtevni avtomobilski in letalski industriji ga v primerjavi s kovinami in visokotehnološkimi polimeri omejuje zlasti nekoliko prenizka togost in trdnost, viskoelastični karakter, ter pomanjkanje toplotne in kemične odpornosti.

Omejeno konkurenčnost lesa kot materiala v navedenih področjih lahko v prvi vrsti izboljšamo z raziskavami in razvojem novih izdelkov in rab. Tehnološke izboljšave in inovacije, kot so napredni lesni kompoziti, zaščitni premazi ter kombinacije lesa z drugimi materiali, odpirajo nove rabe. Raziskave in razvoj novih obdelovalnih tehnik, impregnacijskih procesov ter naprednih lesnih in hibridnih kompozitov ponujajo nove priložnosti. Razvoj biološko razgradljivih zaščitnih premazov na primer izboljšuje odpornost lesa na kemijske in mehanske obremenitve.

Na izboljšanje konkurenčnosti lesnih materialov ali izdelkov ključno vplivajo politike, ki spodbujajo trajnost in inovacije, subvencionirajo raziskave in promovirajo obnovljive materiale, tudi s standardizacijo in uvedbo trajnostnih certifikatov. Če hočemo, da bo les ostal vodilni med trajnostnimi materiali prihodnosti, tudi tam, kjer danes še ni konkurenčen, se morajo za to zavzemati industrija, znanost, politika in se povezovati. Poleg tehnoloških rešitev je ključna tudi promocija in izobraževanje ter seznanjanje o prednostih lesa kot trajnostnega materiala.

Vprašanje ostaja: ali lahko znanost, industrija in politike združijo moči, da bi les postal material prihodnosti na vseh področjih? V znanosti in izobraževanju si za dosego tega cilja vsekakor prizadevamo.

Wood has always been a crucial material for humans. Today, in a socially responsible environment where sustainability, renewable resources and environmental awareness are key factors, it is both a commercially competitive material and a key to realizing the circular economy.

Wood has clear advantages in furniture and interior design, but is also very important for the construction industry, where various wood composites play an important role. The mechanical properties of wood and wood composites, such as high strength and favourable relation of weight to density, ease of processing and good or even exceptional insulating properties, mean that they are widely used in the construction of buildings.

Wood of low-grade quality has an important place in the packaging industry, where more and more companies are switching from polymers to packaging made of wood or paper.

However, wood remains less competitive in several areas, where wood composites lag behind metals, polymers and man-made composites. In extreme conditions wood lags behind high-performance materials, as is the case in sports equipment, particularly due to its sensitivity to moisture and UV radiation, as well as the natural variability of wood's properties. Plastics continue to dominate in the packaging industry, mainly due to their lower cost and flexibility in processing and use. However, lighter and more durable wood-based materials could replace plastics in packaging, while hybrid composites could combine the aesthetics of wood with the mechanical advantages of other materials. In the much more demanding automotive and aerospace industries, wood is mainly limited by its slightly too low stiffness and strength, its viscoelastic character and its lack of heat and chemical resistance compared to metals and high-tech polymers.

The limited competitiveness of wood as a material in these areas can be improved primarily through research and development of new products and applications. Technological improvements and innovations, as well as the development of new processing techniques, impregnation processes, advanced wood composites, protective coatings and combinations of wood with other materials, open up the possibility of new applications. For example, the development of biodegradable protective coatings improves the resistance of wood to chemical and mechanical stresses.

Political measures to promote sustainability and innovation, support for research and the promotion of renewable materials, including standardization and the introduction of sustainability certificates, have a decisive influence on improving the competitiveness of wood-based materials or products. Joint efforts of industry, science and politics are necessary if wood is to remain a leading sustainable material of the future, and further expand into areas where it is not yet competitive. In addition to technological solutions, efforts at promoting and raising awareness of the benefits of wood as a sustainable material are also necessary.

The key question is thus whether science, industry and politics can join forces to make wood the material of the future in all areas, and that's something we are certainly working towards in the fields of science and education.

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IZDELAVA VELIKIH GLIVNIH BIOKOMPOZITOV Z NIZKO GOSTOTO

PRODUCTION OF LARGE LOW-DENSITY MYCELIUM COMPOSITES

Nej Bizjak[1], Aleš Straže[1], Davor Kržišnik[1*]

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Izvleček / Abstract

Izvleček: Z naraščajočo težnjo po prehodu na krožno gospodarstvo se povečuje tudi interes po novih trajnostnih materialih. Glivni biokompoziti predstavljajo trajnostno alternativo sintetičnim penam. Za komercializacijo te tehnologije je ključno znanje, kako izdelati večje količine tega materiala z ustreznimi lastnostmi. V okviru eksperimentalnega dela smo izdelali večji glivni biokompozit z nizko gostoto, prostornino 47 litrov in dolžino dveh metrov. Končni glivni biokompozit smo izdelali s trostopenjskim gojenjem micelija; najprej v vrečah za gojenje, nato v dveh večjih modelih, ki smo ju v tretji fazi spojili. Uporabili smo kulturo glive *Ganoderma resinaceum* ter posebej formuliran substrat za doseganje nizke gostote. Končni biokompozit z gostoto 80 kg/m³ je ustrezal ciljnim dimenzijam, ostal brez okužb ter prenesel lažje obremenitve. Glavna pomanjkljivost materiala so bile manjše udrtine na površini, ki so nastale zaradi zračnih žepov v substratu ob prenosu z micelijem preraščenega substrata v modela.

Ključne besede: glive, biokompoziti, materiali iz micelija, micelij

Abstract: As the need for a circular economy grows, so does the need for new sustainable materials. Biocomposites made from fungi are a sustainable alternative to synthetic foams. The key to commercializing this technology is knowing how to produce large quantities of such materials with the appropriate properties. As part of our experimental work, we have produced a larger mycelium biocomposite with a low density, a volume of 47 litres and a length of two metres. The final fungal biocomposite was produced by growing the mycelium in three stages; first in culture bags, then in two larger moulds, which were combined in a third stage. We used a culture of *Ganoderma resinaceum* and a specially formulated substrate to achieve a low density. The final biocomposite with a density of 80 kg/m³ met the target dimensions, remained infection-free and withstood lighter loads. The main disadvantage of the material was the small surface indentations caused by air inclusions in the substrate when the mycelium-laden substrate was transferred to the moulds.

Keywords: fungi, biocomposites, mycelium materials, mycelium

1 UVOD

1 INTRODUCTION

Z naraščajočo težnjo po prehodu na krožno gospodarstvo in zmanjševanjem odvisnosti od fosilnih virov se povečuje potreba po novih trajnostnih materialih. Ena izmed obetavnih rešitev so glivni biokompoziti, ki v zadnjih letih pridobivajo vse večjo pozornost raziskovalcev. Ta naravni material zaradi svoje strukture predstavlja alternativo sintetičnim polimernim penam, kot sta poliuretan in polistiren, za uporabo v različnih aplikacijah, od termoizolacije stavb do embalaže. Tehnologija izkorišča naravno sposobnost micelija, da raste na lignoceluloznih kmetijskih ostankih, kar omogoča izdelavo kompozitov z nizkim okoljskim vplivom in majhnim ogljičnim odtisom, hkrati pa zagotavlja ugodne fizikalne lastnosti, kot so nizka gostota ter zvočna in toplotna izolativnost (Jones et al., 2020). Lastnosti biokompozita se lahko prilagodijo končnemu namenu uporabe. Z izbiro vhodnega substrata, predhodno obdelavo tega ter vrsto glive lahko namreč prilagajamo gostoto, tlačno in upogibno trdnost, trajnost ter druge lastnosti, pomembne za specifično uporabo (Hannef et al., 2017). V materialu micelij funkcionalno deluje kot vezivo, ki delce substrata poveže v enoten porozen material. Micelij sestavljajo med seboj prepletene filamentozne strukture, imenovane hife (Hannef et al., 2017). Hife so sestavljene iz ene ali več podolgovatih glivnih celic, ki so med seboj lahko razdeljene s septami. Celična stena gliv-

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nih celic je sestavljena iz notranje plasti polimera hitina, vmesne plasti glukanov, ki se razlikujejo med vrstami, ter površinske plasti proteinov hidrofobinov (Hannef et al., 2017). Najpogosteje se uporabljajo saprofitske glive iz skupine bele trohnobe, zlasti vrste *Trametes versicolor*, *Pleurotus ostreatus* in *Ganoderma lucidum* (Elsacker et al., 2020). Za glive povzročiteljice bele trohnobe je značilna sposobnost popolne razgradnje lignina skupaj z drugimi prisotnimi polisaharidi (Elsacker et al., 2020). Po razkroju lesa ostane le celuloza, ki ima značilno belo barvo. Poleg gliv bele trohnobe poznamo še glive rjave in mehke trohnobe. Glive rjave trohnobe nimajo peroksidaz, potrebnih za razgradnjo lignina, medtem ko so glive mehke trohnobe v primerjavi z glivami bele trohnobe manj učinkovite pri razkroju lignina, a imajo boljše celulolitične, hemicelulolitične in pektinolitične sposobnosti. Prisotnost gliv mehke trohnobe na razpadajočem lesu se pokaže kot sivkasto obarvanje (Elsacker et al., 2020). Večina uporabljenih substratov za rast micelija vsebuje lignocelulozo. Najpogosteje se uporabljajo kmetijski ostanki kot so slama, luščine žit in ostanki predelave bombaža, industrijske konoplje, koruze, lana ter drugi kmetijsko pomembni rastlinski materiali in lesni stranski proizvodi kot sta žagovina in lesni sekanci (Huang et al., 2024; Yang et al., 2021). Zaradi naraščajoče količine industrijskih ostankov se raziskuje tudi možnost uporabe celuloznih materialov kot so karton, papir, bombažni ostanki in živilski ostanki, kot sta kavna usedlina in pivovarske tropine (Huang et al., 2024). Ne glede na vhodni material se ta najprej ustrezno hidrira, saj je optimalna vlaga ključna za rast glive in se je med samim bioprocesom ne dodaja. Surovinam se navadno doda približno 30 masnih odstotkov vode (Ross, 2016). Navlažen substrat se nato sterilizira, da se odstranijo že prisotni mikroorganizmi, ki bi konkurirali izbrani glivi. Lignocelulozni substrat se nato inokulira z dodatkom pripravljenega glivnega inokuluma. Micelij se lahko pripravi kot inokulum v tekoči kulturi, na zrnih žita ali na hranilnem gojišču v Petrijevi plošči (Elsacker et al., 2020). Inokuliran substrat se nato prenese v kalup z želeno končno obliko. Inkubacija navadno poteka v nadzorovanem okolju z visoko zračno vlažnostjo in temperaturo med 25 in 27 °C (Elsacker et al., 2020). Inkubacija lahko traja od 5 do 42 dni, odvisno od vrste glive, substrata ter želenih lastnosti materiala (Elsacker et al., 2020). Daljša inkubacija ustvari gostejše, manj porozne in termično bolj stabilne kompozite, saj se zapolnijo prostori med vlakni, obenem pa se substrat močneje poveže (Elsacker et al., 2020). Po obdobju rasti se biokompozitni material toplotno obdela, dehidrira in s tem prekine rast glive (Elsacker et al., 2020; Jones et al., 2020). Obdelava poteka pri minimalno 70 °C kar poleg dehidracije materiala zagotovi popolno inaktivacijo oziroma smrt micelija. Inaktivacija zagotovi mikrobiološko stabilnost materiala in onemogoči kakršnokoli nadaljnjo rast ali kontaminacijo izdelkov iz ostalih bioloških materialov kot je leseno pohištvo (Elsacker et al., 2020). Zaradi hitrosti sta najpogosteje uporabljena postopka konvekcijsko komorsko sušenje ter vroče stiskanje biokompozita. Stiskanje zmanjša poroznost, poveča gostoto in obenem dodatno utrdi ter izboljša nekatere mehanske lastnosti materiala (Jones et al., 2020). Glivni biokompoziti iz nizkogostotnih substratov, kot so luščine žit ali slame (59 kg/m^3) (Xing et al., 2018), so po gostoti konkurenčni običajnim sintetičnim penam, kot so polistiren (11−50 kg/m^3) in poliuretan (30−100 kg/m^3) (Jones et al., 2020). Po mehanskih lastnostih so glivni biokompoziti primerljivi polistirenu z natezno trdnostjo med 0,03 in 0,18 MPa, tlačno trdnostjo med 0,17 in 1,1 MPa in upogibno trdnostjo med 0,05 in 0,29 MPa (Jones et al., 2020). Ena od pomanjkljivosti glivnih biokompozitov je absorpcija vode, ki znaša od 40 do 580 masnih odstotkov, kar je bistveno več od 0,03 do 9 masnih odstotkov pri polistirenu (Jones et al., 2020). Kljub očitnim prednostim glivnih biokompozitov se njihovo sprejemanje med potrošniki sooča z dvojnimi merili. Študenti industrijskega oblikovanja, stari med 19 in 24 let, sicer podpirajo uporabo glivnih biokompozitov za izdelavo pohištva, vendar jih sami ne bi uporabili v lastnem domu (Bonenberg et al., 2023). Njihovi zadržki izhajajo iz skrbi, da bi glive lahko še naprej rasle, kar bi lahko povzročilo zdravstvene težave (Bonenberg et al., 2023). Ker so glivni biokompoziti relativno nova tehnologija, so takšni pomisleki zaradi nepoznavanja tehnologije razumljivi. Kljub temu se njihovo sprejemanje povečuje, predvsem zaradi naraščajočega zanimanja za trajnostne in okolju prijazne materiale (Bonenberg et al., 2023).

Cilj raziskave je bil izdelati večji glivni biokompozit. Namen je bil preizkusiti metodologijo za izdelavo večjih količin materiala ter pridobiti vpogled v omejitve in izzive, ki se pojavijo ob prehodu iz laboratorijskega na pilotni raziskovalni nivo. Kot primer aplikacije smo izbrali uporabo tega materiala v sredicah desk za deskanje na valovih. Za ta namen smo določili ciljne lastnosti biokompozita in sicer: prostornino (47 litrov), dolžino (2 metra) in gostoto (med 60 in 100 kg/m³).

2 MATERIALI IN METODE

2 MATERIALS AND METHODS

2.1 PRIPRAVA GLIVNE KULTURE TER SUBSTRATA

2.1 FUNGUS CULTURE AND SUBSTRATE PREPARATION

Uporabili smo tekočo kulturo glive bele trohnobe *Ganoderma resinaceum* (smolena pološčenka) z oznako ZIM L177 (slika 1A). Gliva je bila pridobljena iz zbirke gliv Biotehniške fakultete Univerze v Ljubljani ter je na voljo raziskovalnim ustanovam. Podrobni podatki o izvoru in identifikaciji izolata glive so navedeni v katalogu (Raspor et al., 1995). Kot glavni substrat smo pripravili mešanico, ki je vsebovala 65 masnih odstotkov mlete slame (KGS Krajnc d. o. o. in Oddelek za lesarstvo), 13 masnih odstotkov kokosovih vlaken (Humko ko-ko block, HUMKO d. o. o.), 15 masnih odstotkov pivovarskih tropin (pridobljeno iz pivovarne Laško Union d. o. o.), 5 masnih odstotkov pšenične moke (Mlinotest d. d.) in 2 masna odstotka kavne usedline (BF, Oddelek za lesarstvo). Dvanajst kilogramov mešanice sestavin (slika 1B) smo navlažili z dodatkom 60 masnih % vode. Pripravljen substrat smo nato 3,5 ure sterilizirali z avtoklaviranjem v vrečah za gojenje, pri temperaturi 121 °C in tlaku 150 kPa.

2.2 PRVA STOPNJA PRERAŠČANJA

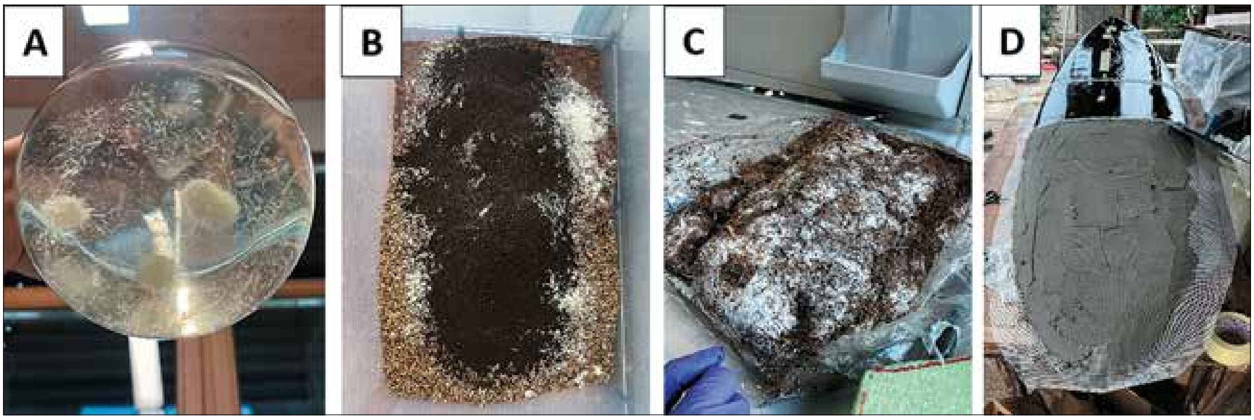
2.2 FIRST STAGE OF GROWTH

Vsako vrečo s substratom smo inokulirali s približno 30 ml tekoče kulture. Preraščanje micelija je nato potekalo v inkubacijski komori pri temperaturi 25 °C in 85 % relativni zračni vlažnosti. Vsake 3 dni smo vreče pregledali za znake rasti micelija ali morebitnih okužb. Po 13 dneh od inokulacije smo ocenili, da je micelij v zadostni meri prerasel substrat, da ga lahko prenesemo v končna modela (slika 1C).

2.3 IZDELAVA MODELOV ZA GOJENJE

2.3 FABRICATION OF GROWTH MOULDS

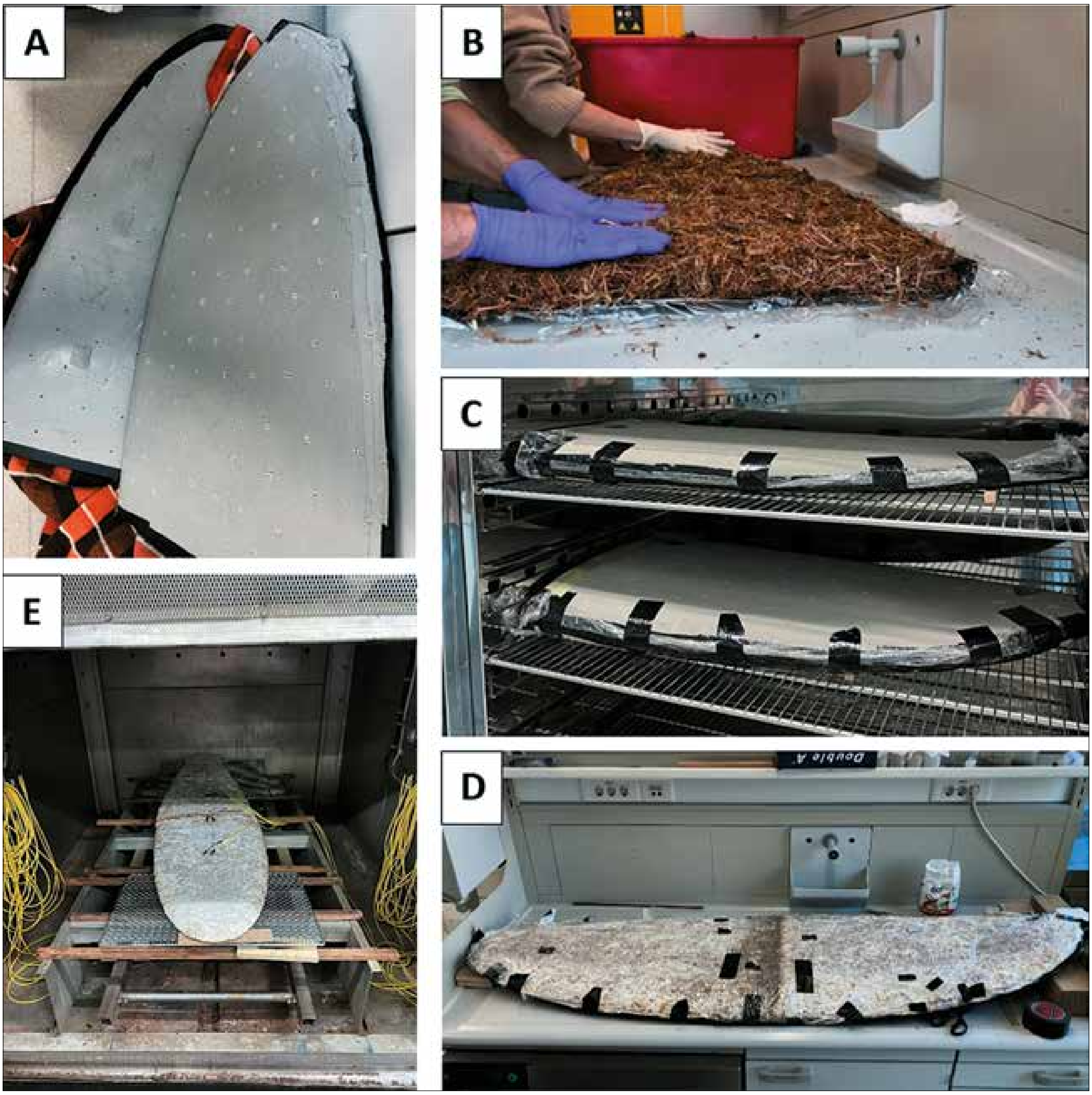
Modela za gojenje smo izdelali kot negativa deske za deskanje na valovih, saj smo želeli, da ima končni glivni kompozit specifično obliko. Desko za deskanje na valovih smo ovili v plastično folijo in na njeno površino petkrat izmenično nanesli plast armirane fasadne mrežice (MERKUR trgovina d.o.o., šifra izdelka: 3380683) ter fasadnega lepila (MERKUR trgovina d.o.o., šifra izdelka: 1819826). Nato smo pustili, da se plasti strdijo pri sobni temperaturi 72 ur (slika 1D). Postopek smo ponovili za spodnjo in vrhnjo površino deske. Med nanosom lepila in mrežice smo dodatno ločili sprednjo in zadnjo polovico, tako da smo na koncu dobili štiri pokrove



Slika 1. Prikaz korakov izdelave glivnega biokompozita: (A) tekoča kultura glive *Ganoderma resinaceum*, (B) mešanica sestavin za substrat, (C) substrat preraščen z micelijem, (D) izdelava modelov za gojenje (Foto: N. Bizjak).

Figure 1. Illustration of the production steps of the mycelium composite: (A) liquid culture of the fungi *Ganoderma resinaceum*, (B) mixture of the ingredients in the substrate, (C) substrate overgrown with mycelium, (D) making of moulds for cultivation (Photo: N. Bizjak).

za dva modela za gojenje: sprednji-vrhnji, sprednji--spodnji, zadnji-vrhnji, zadnji-spodnji. Za ustrezen pretok zraka smo po celotni površini pokrovov zvrtali luknje premera 3 mm na razdalji 5 cm. Na ta način smo naredili sprednji in zadnji model, vsak sestavljen iz spodnjega in vrhnjega pokrova (slika 2A). Skupna prostornina dveh modelov je znašala 47 litrov, dolžina pa 198 cm.



Slika 2. Prikaz korakov izdelave glivnega biokompozita: (A) spodnji in zgornji pokrov enega od modelov za gojenje, (B) prenos z micelijem preraščenega substrata v modela za gojenje, (C) inkubacija obeh zaprtih modelov v komori, (D) spojena biokompozita med fazo preraščanja spoja, (E) sušenje biokompozita brez modelov v konvekcijski komori za sušenje lesa (Foto: N. Bizjak).

Figure 2. Illustration of the production of the mycelium composite: (A) lower and upper covers of one of the cultivation models, (B) transfer of the substrate with mycelium into the cultivation moulds, (C) incubation of the two sealed moulds in the incubation chamber, (D) joined biocomposites during the growth phase, (E) drying of the biocomposite without moulds in the convective kiln drier (Photo: N. Bizjak).

2.4 PRENOS MICELIJA V MODELE
2.4 TRANSFER OF MYCELIUM INTO MOULDS

Pred prenosom z micelijem preraščenega substrata v modele smo pripravili dodaten substrat po prej opisani recepturi. Mešanico substrata in micelija smo najprej nanašali v spodnji pokrov sprednjega modela (slika 2B), po celotni površini brez tlačenja. Nato smo namestili vrhnji pokrov ter stik robov zalepili z lepilnim trakom. Zaprti model smo obrnili navpično in ga stresli, da se je mešanica posedla, nato pa smo z vrhnje odprtine zapolnili model s substratom. Model smo zaprli z vrhnje strani s plastično folijo in ga prenesli v inkubacijsko komoro (slika 2C). Enak postopek smo ponovili za zadnji (repni) model.

2.5 DRUGA STOPNJA PRERAŠČANJA
2.5 SECOND STAGE OF GROWTH

Druga faza preraščanja je potekala pri 25 °C in 85 % relativni zračni vlažnosti. Po 14 dneh smo odprli modela, pregledali stopnjo preraščenosti in morebitne okužbe. Ugotovili smo, da sta modela dovolj preraščena, da ju lahko spojimo.

2.6 SPOJITEV MODELOV
2.6 COUPLING OF MOULDS

Oba modela smo prenesli na laboratorijski pult ter odstranili vrhnja pokrova. Biokompozita smo povezali z 20 cm dolgimi okroglimi lesenimi palicami. Spoj smo zapolnili s slamo in moko ter poškropili z vodo. Da bi ohranili visoko zračno vlažnost, ugodno za rast micelija, smo spojeni del ovili v plastično folijo (slika 2D) in celoten biokompozit dali v plastično vrečo. Po petih dneh se je spoj v celoti zarasel. Odločili smo se, da je rast biokompozita zaključena in je ta pripravljen za sušenje.

2.7 SUŠENJE
2.7 DRYING

Sušenje je potekalo v laboratorijski konvekcijski komori za sušenje lesa. Biokompozit smo namestili na tirno podlogo in ga podprli, da smo ohranili želeno ukrivljeno obliko deske (slika 2E). Na treh točkah po dolžini smo namestili sonde za elektrouporovno merjenje vlage. Postopek sušenja smo spremljali z elektrouporovnim merjenjem vlažnosti biokompozita, in je vključeval naslednje stopnje: segrevanje, glavno fazo sušenja in ohlajanje. Segrevanje je potekalo postopno s hitrostjo 15 °C/h. Glavna faza sušenja se je začela pri nižji temperaturi (40 °C), nato pa se je temperatura s padanjem vlažnosti glivnega biokompozita postopno dvigovala do končne temperature sušenja (70 °C). Sušenje smo zaključili po 10 urah, ko je biokompozit pri 70 °C na vseh merilnih mestih dosegel vlažnost 10 %. Po glavni fazi sušenja smo predvideli še 8-urno fazo ohlajanja biokompozita v zaprti sušilni komori do sobne temperature (20 °C).

2.8 MERJENJE GOSTOTE
2.8 DENSITY MEASUREMENT

Gostoto posušenega glivnega biokompozita smo določili iz razmerja suhe mase in prostornine referenčnega laboratorijskega biokompozita, ki smo ga naredili v Petrijevi plošči s prostornino 0,75 l. V izdelani deski za deskanje gostote glivnega biokompozita nismo določali gravimetrično, zaradi destruktivnosti metode.

3 REZULTATI IN DISKUSIJA
3 RESULTS AND DISCUSSION

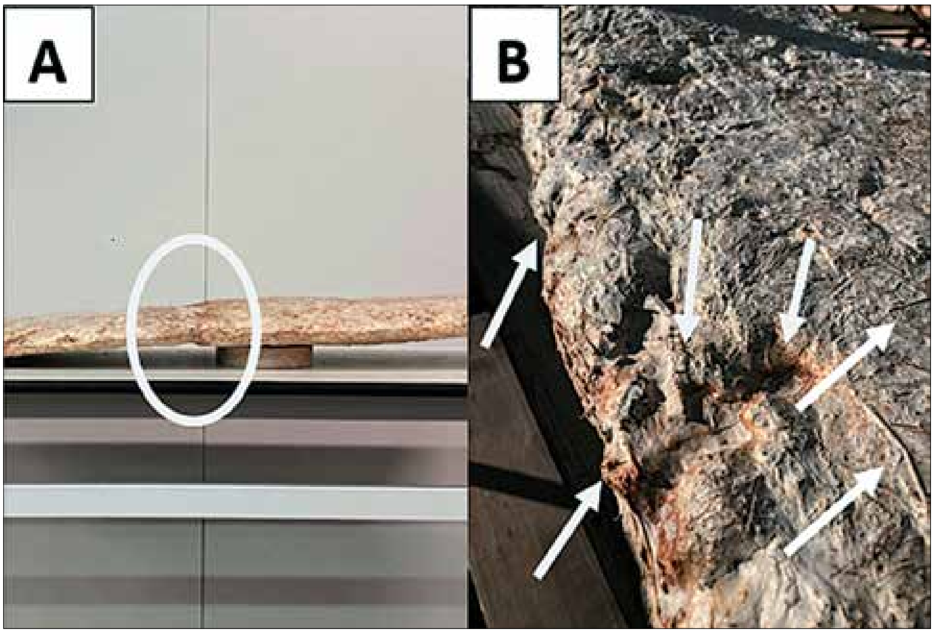
Končni izdelek je dosegel načrtovano dolžino, prostornino in gostoto oz. maso. Uspešno smo izdelali 198 cm dolg glivni biokompozit s prostorni-

Slika 3. Končni glivni biokompozit (Foto: N. Bizjak).
Figure 3. Final fungal biocomposite (Photo: N. Bizjak).

no 47 litrov (slika 3). Celoten biokompozit je ostal neokužen, kar je ključno, saj so okužbe poglavitni razlog za neuspešno izdelavo večjih glivnih biokompozitov. Gostota referenčnega biokompozita je bila 80 kg/m³. Vrednost je višja od nekaterih zabeleženih vrednosti v literaturi (59 kg/m³) (Xing et al., 2018) in višja od gostote polistirena (11–50 kg/m³) (Jones et al., 2020), vendar še vedno sodi med nižje, saj ima večina glivnih biokompozitov gostoto v območju 150 kg/m³ (Jones et al., 2020).

Glavni izziv pri formulaciji substrata in razlog za višjo gostoto od najnižje je prav delež slame v substratu. Xing et al. (2018) so sicer s preraščanjem čiste slame z glivo *Ganoderma resinaceum* izdelali biokompozit z gostoto 59 kg/m³, vendar zgolj s prostornino 0,04 l, pri čemer je preraščanje trajalo 56 dni. Predvidevali smo, da bi čista slama pri tako veliki prostornini lahko povzročila neenakomerno preraščanje, zato smo dodali ostale surovine, ki so sicer negativno vplivale na gostoto, a so zagotovile boljše pogoje za rast. Kokosova vlakna smo dodali za boljšo absorpcijo vode in zaradi njihove vitke oblike, pivovarske tropine, moko ter kavno usedlino pa kot vire enostavnih sladkorjev ter ostalih mikro- in makrohranil (Campos-Vega et al., 2015). Ob podrobnem pregledu površine biokompozita po sušenju smo opazili napake, ki so nastale ob prenosu z micelijem preraščenega substrata v modele. Na površini biokompozita smo opazili lokalno manjša pogreznjena mesta, ki so nastala zaradi neenakomernega posedanja substrata v modelih (slika 4B). Neenakomerno posedanje je vodilo v nastanek zračnih žepov v notranjosti substrata ali na sami površini. Opazili smo tudi, da je na spoju biokompozitov zadnji del tanjši kot sprednji (slika 4A). Razlika je nastala zaradi napake pri nastavitvi vrhnjega pokrova zadnjega dela, ki smo ga preveč stisnili. Tako ugreznjeni deli na površini kot razlika v debelini na spoju predstavljajo težavo za nadaljnje korake obdelave, kot so prekrivanje biokompozita s stekleno volno in epoksi smolo, saj metoda zahteva ravno, enakomerno ukrivljeno površino.

Biokompozit smo zaradi velikosti, namesto v laboratorijskem sušilniku, sušili v konvekcijski komori za sušenje lesa. Za osnovo vodenja postopka smo uporabili blažji program sušenja, primeren za težje sušeče lesne vrste, razdeljen po fazah, s postopnim naraščanjem temperature od začetne 40 °C do končne 70 °C. Glivne biokompozite se suši pri temperaturah med 60 in 110 °C (Arifin & Yusuf, 2013; Islam et al., 2018, 2017; Teixeira et al., 2018), kjer se višje temperature uporablja v kombinaciji s kontaktnim segrevanjem in tlačnim stiskanjem v stiskalnicah. S tem dosežemo propad glive, kar preprečuje rast gob iz končnega izdelka, obenem pa ne poškodujemo micelija, kar je ključno za doseganje ustreznih končnih lastnosti materiala. Elektrouporovno spremljanje vlage v biokompozitu (SIST EN 13183-2: 2003) se je izkazalo kot primerno, saj je omogočalo prilagajanje pogojev sušenja (tempera-



Slika 4. Nepravilnost končnega izdelka: (A) obkrožena razlika v debelini med sprednjim in zadnjim delom, (B) bele puščice označujejo udrtine in grobo površino biokompozita (Foto: N. Bizjak).

Figure 4. Irregularities of the final product: (A) circled difference in thickness between front and back, (B) white arrows indicate depressions and the rough surface of the biocomposite (Photo: N. Bizjak).

tura, zračna vlažnost, hitrost gibanja zraka). S stopnjevanjem pogojev sušenja smo preprečili pojav morebitnih napak sušenja, kot je kolaps, kot posledica velike kapilarne tenzije in notranjih napetosti v materialu. Znano je, da se pri višjih temperaturah sušenja glivni biokompoziti bolj krčijo, predvsem glivni miceliji, poroznost in delež praznih prostorov med micelijem in substratom pa se povečuje (Santos et al., 2021). Vlažnost v materialu je bila ob začetku sušenja 80 %, po 24 urah pa je znašala 10 %. Postopek sušenja je vključeval 8-urno začetno segrevanje ter enako dolgo ohlajanje na koncu postopka sušenja, ki prepreči pokanje in krivljenje materiala, ki bi lahko nastalo zaradi prehitrega ali neenakomernega sušenja in ohlajanja površine ter notranjosti biokompozita. Mehanskih lastnosti (natezna, tlačna in upogibna trdnost) ter ostalih fizikalnih lastnosti, kot sta absorpcija vode in toplotna prevodnost med raziskavo nismo določali, saj smo se osredotočili na samo izdelavo večjega biokompozita. V nadaljnjem delu in raziskavah se bomo osredotočili na znižanje končne gostote biokompozita ter v vrednotenje mehanskih in fizikalnih lastnosti.

4 ZAKLJUČEK
4 CONCLUSIONS

Z eksperimentalnim delom smo izdelali večji glivni biokompozit z želenimi lastnostmi, kar nam je omogočilo vpogled v primernost tehnologije glivnih biokompozitov za komercializacijo in proizvodnjo večjih izdelkov. S sprotnim načrtovanjem in prilagajanjem smo raziskali širok spekter možnih proizvodnih korakov za izdelavo večjih biokompozitov s specifično obliko in materialnimi lastnostmi. Končni postopek izdelave je zajemal tristopenjsko gojenje micelija: najprej v vrečah za gojenje, nato v dveh večjih modelih, ki smo ju v tretji stopnji spojili skupaj, ter končno sušenje v laboratorijski komori za sušenje lesa. Kljub nekaterim nepravilnostim na površini biokompozita predstavlja izdelek uspešen primer uporabe tehnologije glivnih biokompozitov za izdelavo kompozitov večjih dimenzij.

5 POVZETEK
5 SUMMARY

As the need for a circular economy increases, so does the demand for new sustainable materials. Fungal biocomposites are a sustainable alternative to synthetic foams for applications ranging from packaging to building insulation. The technology utilises the mycelium's ability to grow on lignocellulosic agricultural residues to produce biocomposites with similar material properties to synthetic foams. White-rot fungi such as *Trametes versicolor, Pleurotus ostreatus*, and *Ganoderma lucidum* are commonly used due to their ability to digest lignin (Elsacker et al., 2020). The substrates are obtained from lignocellulosic agricultural residues such as straw, grain husks, sawdust, and other by-products from cotton, hemp, and other industrial crops. Increasingly, lignocellulosic by-products from industrial waste, such as cardboard, and food waste such as spent coffee grains and brewer's spent grains, are also being researched as substrates (Huang et al., 2024; Yang et al., 2021). The mycelium acts as an adhesive that binds the substrate particles together to form a uniform, porous material. Understanding how to produce large quantities of these materials is crucial for product development. In our experimental work, we produced a large fungal biocomposite with a low density, a volume of 47 litres and a length of two metres. We used a liquid culture of *Ganoderma resinaceum* labelled ZIM L177 in combination with a specially formulated low-density substrate. The fungal culture comes from the fungal collection of the Biotechnical Faculty, University of Ljubljana, which is available to research institutions on request. Detailed information on the origin and identification of the fungal isolate can be found in the related catalogue (Raspor et al., 1995). The substrate consisted of 65% wheat straw (KGS Krajnc d.o.o. and Department of Wood Science and Technology), 13 % coconut fibre (Humko ko-ko block, HUMKO d.o.o.), 15% brewer's spent grains (Laško Union d.o.o.), 5 % wheat flour (Mlinotest d.d.), and 2% spent coffee grounds (Department of Wood Science and Technology). We added 60% water to the ingredients and autoclaved the substrate in culture bags for 3 hours and 30 minutes at 121 °C and 150 kPa. Each bag received 30 ml of the liquid mycelium culture. We started the growth of the mycelium in culture bags at 25 °C and 85% RH. After 13 days, we transferred the mycelium from the bags into specially prepared growth moulds. After 14 days of incubation, we fused the biocomposites in the two moulds. After 5 days, the biocomposites were

bound together by the mycelium so that we could dry the biocomposite and inactivate the fungus. Due to its size, drying was carried out in a convective kiln drier used for timber drying. We used electrical resistance measurements to determine the moisture content (MC) of the material during the drying process to achieve an MC of 10 %. The drying process lasted 40 hours, with the main drying phase taking place at 70 °C for 24 hours. Through this three-stage growth process, we were able to produce a fungal biocomposite with a density of 80 kg/m³ that met the size specifications, remained free of contamination, and could tolerate lighter loads. Although we did not achieve the lowest density of 59 kg/m³ reported by Xing et al. (2018), we consider 80 kg/m³ to be a success given the large volume of material produced. A lower density could be achieved with a higher proportion of straw in the substrate, but this would increase the risk of contamination. The main drawback of the material was the small surface depressions caused by air pockets in the substrate during the transfer of the mycelium-laden substrate into the moulds.

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KADROVSKE POTREBE IN POTENCIAL IZOBRAŽEVANJA V LESARSTVU

LABOUR DEMAND AND EDUCATION POTENTIAL IN THE WOOD INDUSTRY

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Izvleček / Abstract

Izvleček: Lesna panoga potrebuje izobražen kader z ustreznimi kompetencami, če se želi prilagajati družbenemu in gospodarskemu razvoju, proizvajati izdelke z višjo dodano vrednostjo, uporabljati sodobne tehnologije in uvesti digitalne ter trajnostne poslovne modele. Glavni cilj raziskave je bil analizirati kadrovske potrebe in izobrazbeno strukturo zaposlenih v lesnem sektorju ter ugotoviti potencial izobraževanja v lesarstvu v Sloveniji. V raziskavi smo dokazali povezavo med izobrazbeno strukturo zaposlenih in uspešnostjo panoge, ugotovili pa smo tudi, da se vzporedno s povečevanjem števila zaposlenih v lesarstvu, povečujejo tudi potrebe po kadrih z lesarsko izobrazbo vseh stopenj izobrazbe. Potencial izobraževanja v lesarstvu v Sloveniji je torej velik, pri čemer pa je nujno, da pri razvoju izobraževalnih programov poleg izobraževalnih institucij, ki morajo ponuditi sodobne programe in načine izvedbe, sodeluje tudi gospodarstvo, ki se vključuje v izvajanje in definira potrebe ter poskrbi za promocijo lesarstva in lesarskih poklicev ob podpori države, ki mora poskrbeti predvsem za sistemsko ureditev materialnih in kadrovskih pogojev, ki bodo omogočili kakovostno izobraževanje.

Ključne besede: lesarstvo, kadri, kadrovske potrebe, izobraževanje, poslovna uspešnost, Slovenija

Abstract: To advance the wood sector, which must adapt to social and economic developments, and to manufacture products with higher added value, use modern technologies and introduce digital and sustainable business models in company operations, the wood industry needs an educated staff with appropriate competences. The main objective of the research was thus to analyse the labour demand and educational structure and to identify the potential of education in the wood sector in Slovenia. In the course of the research, we were able to prove a connection between the educational structure of employees and the business success of companies in this sector. We also found that in parallel with the increase in the number of employees in the wood industry, the demand for labour with a wood science and technology education, of all levels, is also increasing. The potential for developing wood science and technology education in Slovenia is therefore great, but it is important that the development of educational programmes involves not only the educational institutions, which must offer modern programmes and implementation methods, but also the business community, which is involved in the implementation of research, defines the needs, and takes care of the promotion of the various branches and professions in the wood sector, with the support of the state, which must above all ensure the systematic creation of material and personnel conditions that enable a high-quality education in this field.

Keywords: wood industry, personnel, labour demand, education, business performance, Slovenia

1 UVOD

1 INTRODUCTION

Sočasno z globalnim družbenim in gospodarskim razvojem se spreminja tudi slovenska lesna industrija. Uvajanje številnih novih digitalnih tehnologij (European Labour Authority, 2022) ob hkratnem stremljenju k podnebni nevtralnosti ponuja veliko novih priložnosti za napredek in širitev tudi lesne panoge. Na njen nadaljnji razvoj vplivajo predvsem temeljni strateški dokumenti Evropske unije kot je Evropa naslednje generacije, iz katere izhajajo iniciative, kot sta Novi evropski Bauhaus (EC, 2021a) in Pripravljeni na 55 (EC, 2021b). Ker je les ključna strateška surovina Slovenije, ima industrija, ki temelji na razpoložljivih naravnih virih kot je les, velik potencial za doseganje ciljev Evropske-

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ga zelenega dogovora (EC, 2019). V zadnjih letih je slovenska lesna industrija tudi zaradi bolj sistemskega pristopa, načrtovanja in finančne podpore s strani države zopet začela dosegati boljše rezultate (MGTŠ, 2023). Veliko je bilo narejenega na področju promocije uporabe slovenskega lesa; SPIRIT Slovenija in Ministrstvo za gospodarski razvoj in tehnologijo (MGRT) že od leta 2013 izvajata vrsto aktivnosti za promocijo slovenskega lesa in lesenih izdelkov doma in v tujini (Spirit Slovenija, 2022). V Slovenski industrijski strategiji 2021–2030, ki je bila sprejeta leta 2021, je bila med pomembne umeščena tudi lesnopredelovalna dejavnost (MGRT, 2021), kar zagotovo predstavlja pomemben mejnik za nadaljnji razvoj panoge. Na podlagi te strategije je bil oblikovan Izvedbeni dokument ukrepov razvoja lesnopredelovalne industrije do leta 2030 (MGRT, 2022), ki je osnova za izvajanje aktivnosti za ustvarjanje ugodnega poslovnega okolja za razvoj in rast panog, povezanih s predelavo in uporabo lesa.

Po raziskavah Evropskega barometra (EBS) je v Sloveniji v zadnjih letih prisotna visoka ozaveščenost prebivalcev o vplivu podnebnih sprememb (ARSO, 2024). Direktorat za lesarstvo, ki deluje v okviru MGTŠ, si z različnimi ukrepi prizadeva povečati gradnjo z lesom in izdelavo lesnih izdelkov z visoko dodano vrednostjo (RS, 2020). Sočasno se podjetja v lesni panogi tudi tehnološko modernizirajo in digitalizirajo svoje poslovanje, kar je nujno za ohranjanje konkurenčnosti, nižanje stroškov in dvig kakovosti. Na primer, na področju gradnje je zelo močan trend digitalizacije procesa gradnje (BIM = building information modeling), uvaja se aditivna proizvodnja (3D tiskanje), strojno učenje, robotika, množični podatki (angl. »big data«), navidezna in razširjena resničnost (VR, AR, MR), na splošno pa podjetja v proizvodne procese uvajajo čedalje več senzorike, proizvajajo pametne izdelke (po načelu Interneta stvari–IoT), pri poslovnem odločanju pa je prisotne vse več umetne inteligence (Asif et al., 2024). Rezultat tega je dodana vrednost na zaposlenega v lesarstvu, ki v povprečju raste že zadnjih 14 let iz cca 20.000 € leta 2010 na dobrih 47.000 € leta 2023 (Valentinčič & Likar, 2024), pri čemer je panoga C16 (Obdelava in predelava lesa, proizvodnja izdelkov iz lesa, plute, slame in protja, razen pohištva) uspešnejša od C31 (Proizvodnja pohištva). Dodana vrednost na zaposlenega je eden pomembnih kazalnikov učinkovitosti proizvodnje, ki se najpogosteje meri s kazalnikoma produktivnosti dela in kapitala. Produktivnost dela je tesno povezana s stopnjo izobrazbe kadra, saj države s precejšnjim deležem zaposlenih z nižjo izobrazbo beležijo nižjo produktivnost dela in nižjo gospodarsko rast kot tiste, kjer so zaposleni visoko usposobljeni (Grzegorzewska & Sedliačiková, 2021). Produktivnost dela v lesni industriji pa je seveda odvisna tudi od stopnje tehnične opremljenosti, uporabljenih tehnologij in inovativnosti, kar je spet vse povezano z usposobljenostjo kadra oz. stopnjo izobrazbe. Kaba et al. (2024) so v svoji raziskavi potrdili, da je nizka stopnja izobrazbe zaposlenih eden izmed zelo pomembnih razlogov za tehnično neučinkovitost lesne industrije. Izobrazba je zelo pomembna tudi pri krepitvi različnih vidikov uspešnosti in pri doseganju višje dodane vrednosti (na zaposlenega (VA/e) kot merilu donosnosti intelektualnega kapitala podjetja (Ngwenya, 2013). Katundu (2021) poudarja pomen izobraževanja pri prispevanju h gospodarski rasti, plačam, dohodkovni neenakosti in družbenem razvoju. Dang et al. (2018) so dokazali, kako lahko konkretna usposabljanja za zaposlene prav tako vodijo do znatnega povečanja učinkovitosti proizvodnje in dodane vrednosti na zaposlenega. Fang (2024) je med preučevanjem razmerja med izobraževanjem zaposlenih ter njihovo produktivnostjo in inovativnostjo ugotovil, da visoko izobraženi zaposleni običajno pomembno vplivajo na produktivnost in rast vrednosti podjetij. Podobno Yang et al. (2019) ugotavljajo, da lahko različni dejavniki, vključno z izobrazbo in sposobnostmi zaposlenih, prispevajo k ustvarjanju dodane vrednosti.

Podjetja za proizvodnjo izdelkov z višjo dodano vrednostjo, rokovanje s sodobnimi tehnologijami in uvajanje sodobnih digitalnih in trajnostnih poslovnih modelov v poslovanje potrebujejo tako sodobno tehnologijo kot izobražen in usposobljen kader z ustreznimi kompetencami. V EU predvsem zaradi hitrega uvajanja novih digitalnih tehnologij primanjkuje alumnov STEM (znanost, tehnologija, inženirstvo in matematika), kamor spadajo tudi poklici s področja lesarstva (European Labour Authority, 2023; EC, 2023b). Prebivalstvo se povsod v Evropi stara (SiStat, 2023; Borzykowski, 2019), povojna generacija se upokojuje, mladih pa ni dovolj, da bi jih nadomestili, čeprav vpis v izobraževalne programe v lesarstvu iz leta v leto malenkost raste (Stopar et al., 2018). Čeprav sodobna lesnopredelovalna industrija ponuja številne karierne priložnosti, poleg poklicev kot so mizar, tesar in tapetnik še vedno primanjkuje tudi lesarskih tehnikov in inženirjev lesarstva (Spirit Slovenija, 2023). V letu 2022 je bil poklic mizarja v večini EU držav med najbolj deficitarnimi (Statista, 2022; ZRSZ, 2024). Na račun zelenega prehoda naj bi bilo na ravni EU do leta 2030 odprtih 1 do 1,25 milijona novih delovnih mest, in sicer v panogah, kjer že sedaj primanjkuje delovne sile (EC, 2023a). Leta 2022 je bilo v EU na različnih področjih gozdarstva in lesne industrije zaposlenih 3,6 milijona ljudi, kar je 1,4 % več kot leta 2012 (EUROSTAT, 2024). V Sloveniji je bilo leta 2022 na področju gozdno lesne verige zaposlenih 18.427 ljudi, od tega 16.207 v lesarstvu: v C16 9935 in v C31 6272 (SiStat, 2024a). V celotni predelovalni dejavnosti smo v letu zabeležili povprečno 5408 prostih delovnih mest, medtem ko je bilo v tem letu zasedenih delovnih mest 200.303 (SiStat, 2024b). Število zaposlenih v lesarstvu v zadnjih letih rahlo raste, medtem ko se število podjetij povečuje še hitreje (predvsem mikro in manjših podjetji), zaradi česar je povprečno število zaposlenih na podjetje v zadnjih 15 letih iz 8,5 padlo na slabih 5 zaposlenih/podjetje (SiStat, 2024a). Podjetja torej postajajo manjša, poslujejo večinoma projektno, ljudje delujejo v timih, zato je posledično manj dela za nekvalificirane delavce oz. se povpraševanje po delavcih z več kompetencami povečuje.

Pomanjkanje ustrezno usposobljenega kadra, ki se v praksi kaže kot velik problem, težko zagotavljamo z uvozom delovne sile, saj se s podobnim problemom srečujejo v celotni Evropski Uniji (European Labour Authority, 2022). Primanjkljaj v določenih poklicih lahko deloma zapolnjujejo migrantski delavci (EC, 2023a; EC, 2023b). Eden izmed problemov pa je tudi, da iskalci zaposlitve pogosto nimajo pravih kompetenc (Yanatma, 2024). Na drugi strani pa se srečujemo z novimi generacijami mladih, ki so za izobraževanje drugače motivirani kot prejšnje generacije, glede dela pa imajo drugačna pričakovanja (Dalheim, 2019a; Dalheim, 2019b). Če torej želimo, da bomo v panogi imeli dovolj ustrezno izobraženega kadra, je treba poleg sprememb na področju gospodarske politike države in uvajanja tehnoloških novosti v poslovanje podjetij povečati in spremeniti tudi izobraževalni potencial na področju lesarstva.

Glavni cilj raziskave je bil opraviti poglobljeno analizo kadrovskih potreb in izobrazbene strukture v lesarstvu ter ugotoviti potencial izobraževanja v lesarstvu v Sloveniji.

2 MATERIALI IN METODE
2 MATERIALS AND METHODS

Podatke o številu razpisanih delovnih mest in o številu razpisanih delovnih mest glede na zahtevano stopnjo izobrazbe v lesarstvu po letih smo pridobili iz Zavoda Republike Slovenije za zaposlovanje (ZRSZ, 2023). Podatki vključujejo vsa prosta delovna mesta, ki so jih razpisala podjetja z glavno dejavnostjo C16 ali C31, in sicer je vključena le prva objava razpisa za posamezno delovno mesto, torej med njimi ni ponovljenih objav, če so jih podjetja po neuspešnem razpisu ponovila. Poudariti moramo tudi, da se je v letu 2013 spremenila metodologija za spremljanje prostih delovnih mest na Zavodu Republike Slovenije za zaposlovanje (ZRSZ), saj je bila odpravljena obvezna prijava prostih delovnih mest pri ZRSZ.

Za identifikacijo potenciala izobraževanja v lesarstvu v Sloveniji smo izvedli kvantitativno analizo. Zanimalo nas je število maturantov in diplomantov oz. število dijakov in študentov v zaključnih letnikih izobraževalnih programov lesarstva (od SOK 3 do SOK 8; SOK = Slovenski okvir kvalifikacij). S tem smo ugotovili število novo izobraženih kadrov v lesarstvu in jih primerjali s številom razpoložljivih delovnih mest v lesarskih podjetjih. Število učečih se vpisanih v zaključne letnike srednješolskih in višješolskih izobraževalnih programov v lesarstvu smo pridobili na Ministrstvu za vzgojo in izobraževanje (MVI, 2023); podatke o številu diplomantov pa smo pridobili iz letnih poročil Biotehniške fakultete (Biotehniška fakulteta, 2024). Podatke smo zbirali za obdobje med 2008 in 2022, saj smo tako zajeli stanje pred veliko gospodarsko krizo leta 2009 in vso dogajanje v letih po njej, vključno s korona krizo leta 2020.

Podatke o številu zaposlenih v lesarstvu v Sloveniji z različnimi stopnjami izobrazbe smo pridobili na portalu Statističnega urada RS (SiStat, 2024a) za obdobje 2008 do 2023; na istem mestu smo pridobili tudi prihodke in dodano vrednost na zaposlenega v panogah C16 in C31. Za preverjanje njihovega medsebojnega vpliva smo uporabili več enostavnih linearnih regresij. Z njihovo pomočjo smo ocenili vpliv neodvisnih spremenljivk (število zaposlenih s primarno, sekundarno in terciarno izobrazbo) na odvisni spremenljivki (prihodke in dodano vrednost na zaposlenega). Vzorec je predstavljal časovno obdobje od 2008 do 2023. Za dodano vrednost na zaposlenega smo vzeli povprečje, medtem ko smo za prihodek in število zaposlenih po izobrazbi upoštevali vsoto vseh podjetij v sektorju.

3 REZULTATI IN RAZPRAVA

3 RESULTS AND DISCUSSION

3.1 ŠTEVILO UČEČIH SE VPISANIH V ZADNJE LETNIKE IZOBRAŽEVALNIH PROGRAMOV V LESARSTVU

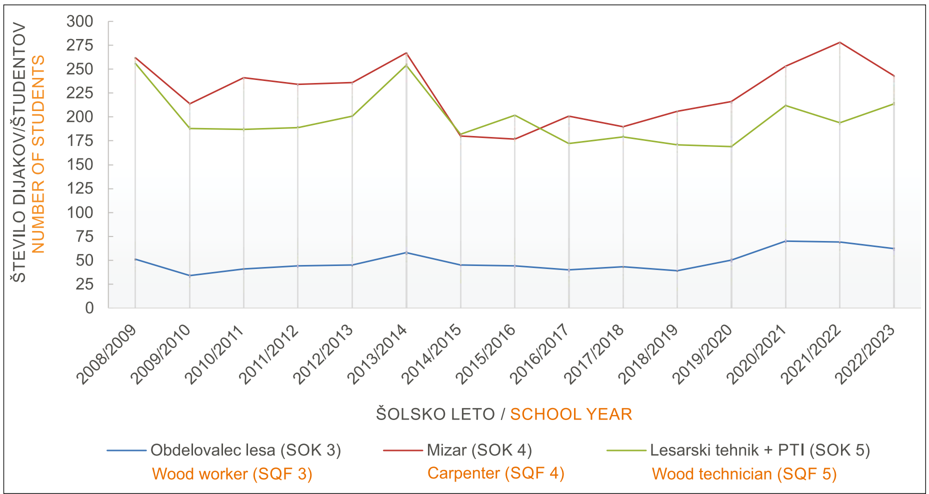
3.1 NUMBER OF STUDENTS ENROLLED IN THE FINAL YEAR OF WOOD SCIENCE AND TECHNOLOGY EDUCATION PROGRAMMES

Najprej nas je zanimalo število učečih se vpisanih v zadnje letnike srednješolskih izobraževalnih programov (slika 1) ter število diplomantov višješolskih in visokošolskih programov (slika 2) v lesarstvu.

V Sloveniji se v srednješolskih izobraževalnih programih za vse profile (obdelovalec lesa, mizar in lesarski tehnik) vsako leto izobrazi skoraj 500 dijakov (povprečje 2008–2022) (slika 1). Ugotovimo lahko, da ta številka od leta 2014, ko je bila najnižja, raste praktično za vse obravnavane profile in je v letu 2022 vsota vseh krepko presegla 500 aktivnih dijakov (brez ponovno vpisanih). Od teh je največ mizarjev (okoli 250), sledijo jim tehniki (okoli 200), najmanj pa je na novo izobraženih obdelovalcev lesa (SOK 3) (okoli 50). Tukaj velja omeniti, da v kategorijo lesarski tehnik uvrščamo tako štiriletni program lesarski tehnik kot tudi lesarski tehnik PTI (PTI = poklicno tehniško izobraževanje, 3+2); razmerje med njima je 40:60 v korist tehnika PTI.

Višješolske izobraževalne programe na leto zaključi okoli 30 diplomantov (slika 2). Študij na 1. stopnji (VSŠ–Visokošolski strokovni študij, UNI – univerzitetni študij) konča okoli 30 diplomantov na leto, na 2. stopnji (magistrski strokovni študij) pa okoli 10, torej imamo na obeh stopnjah skupaj okoli 40 diplomantov na leto (slika 2). (Opomba za sliko 2: podatek za SOK 7 in 8 pri letu 2016 ni relevanten, saj je bilo to leto zadnja možnost za dokončanje študija za stare univerzitetne programe lesarstva in je zato število diplom nesorazmerno visoko; podobno nesorazmerno odstopanje lahko ugotovimo tudi za SOK 6 v letu 2013.)

Če pogledamo skupno, letno izobrazimo okoli 500 mizarjev, lesarskih tehnikov in obdelovalcev lesa, 20–30 inženirjev lesarstva ter okoli 40 diplomiranih inženirjev in magistrov inženirjev lesarstva, torej skupaj skoraj 600 novo izobraženih kadrov s področja lesarstva. Pri tem je potrebno poudariti, da se velik delež dijakov (skoraj polovica), ki zaključijo program mizar, preusmeri v nadaljnje izobraževanje, na program lesarski tehnik PTI, poleg tega veliko lesarskih tehnikov nadaljuje šolanje ali na višji šoli ali na visokošolskem nivoju. Diplomanti 1. stopnje visokošolskega študija pa prav tako v veliko primerih nadaljujejo študij na 2. stopnji študija. Posameznik se torej v tej številki lahko pojavlja večkrat,



Slika 1. Število učečih se vpisanih v zadnje letnike srednješolskih izobraževalnih programov v lesarstvu (vir: Ministrstvo za vzgojo in izobraževanje).

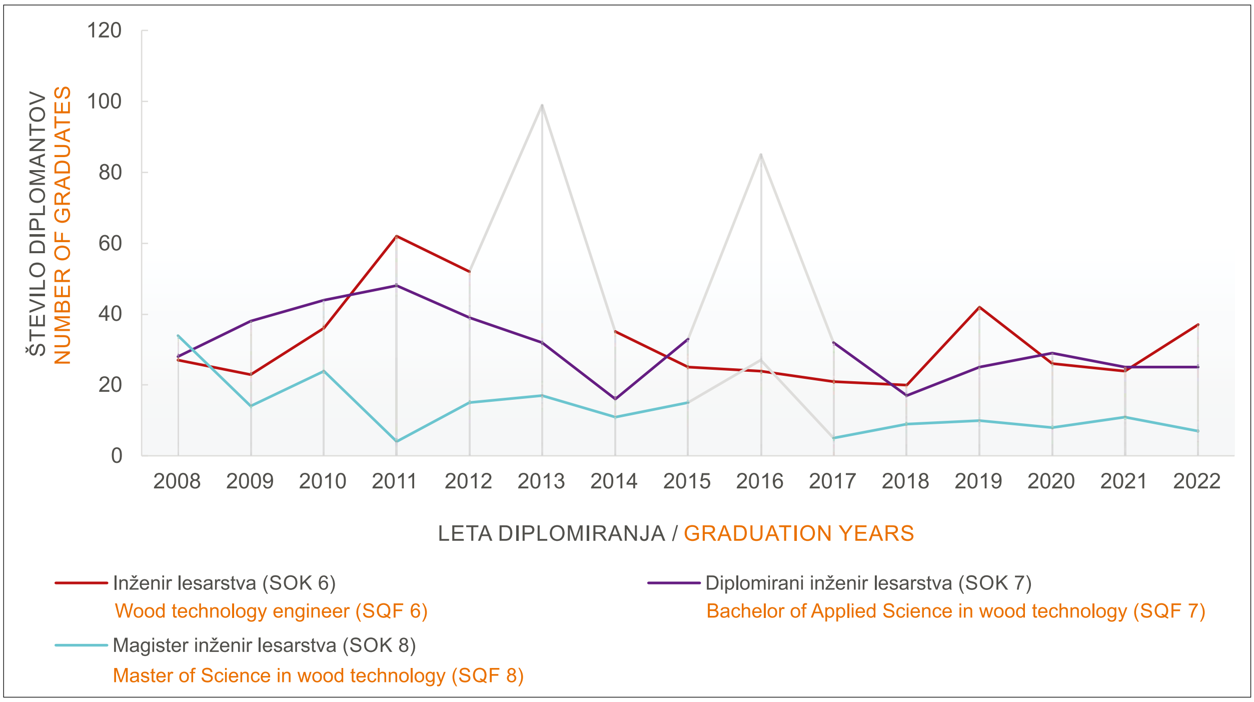
Figure 1. The number of students enrolled in the final years of secondary education programmes in wood science and technology (source: Ministry of Education).

zato je končna številka letno izobraženih kadrov, ki pridejo na trg dela, še precej nižja. Po naših ocenah se ta številka zmanjša za dobrih 30 % (največ na račun zmanjšanja števila mizarjev, ki se preusmerijo na program lesarski tehnik PTI), kar pomeni, da se na trgu dela letno pojavi okoli 400 novo izobraženih kadrov s področja lesarstva.

3.2 ŠTEVILO RAZPISANIH PROSTIH DELOVNIH MEST V LESARSTVU

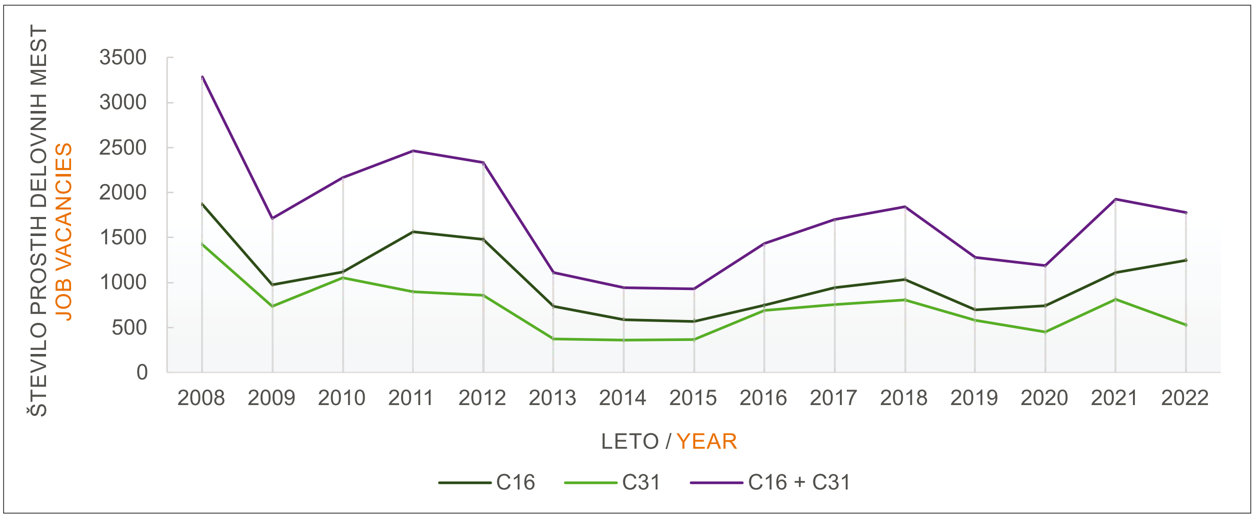
3.2 NUMBER OF JOB VACANCIES IN THE WOOD INDUSTRY

V nadaljevanju nas je zanimalo, kakšna je ponudba prostih delovnih mest v panogi C16 in C31, torej v lesni panogi v celoti (slika 3). Glede na tipe



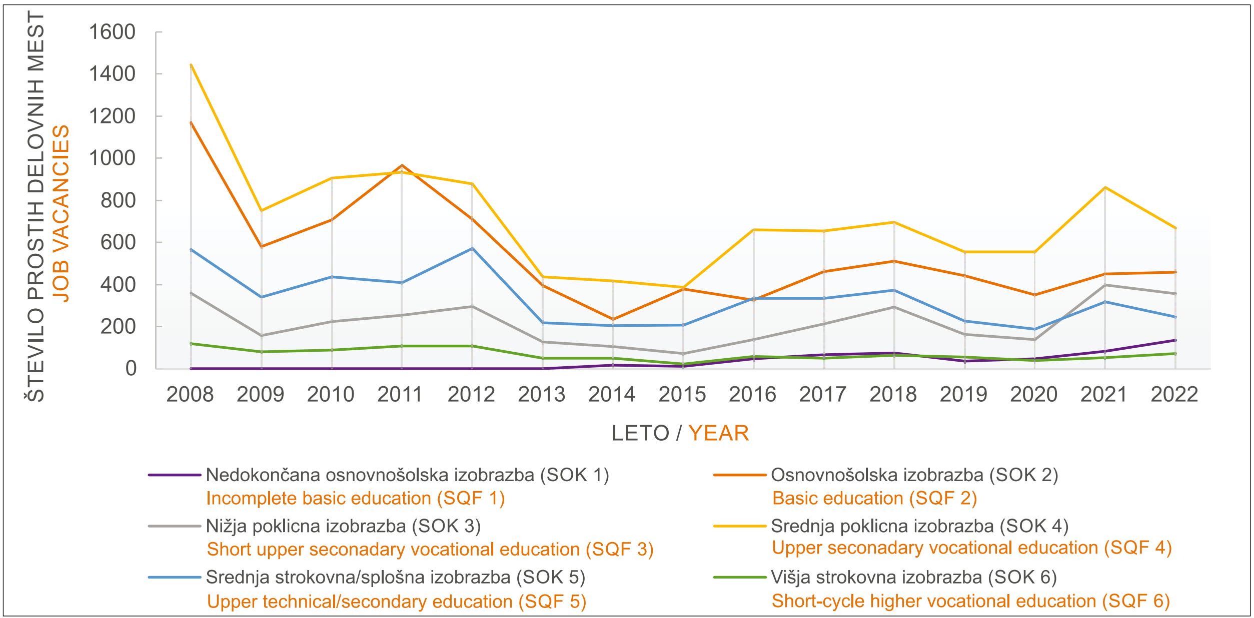
Slika 2. Število diplomantov višješolskih in visokošolskih izobraževalnih programov po letih (vir podatkov: letna poročila Biotehniške fakultete, Univerze v Ljubljani).

Figure 2. Number of graduates from post-secondary and higher education programmes by year (data source: annual reports of the Biotechnical Faculty, University of Ljubljana).



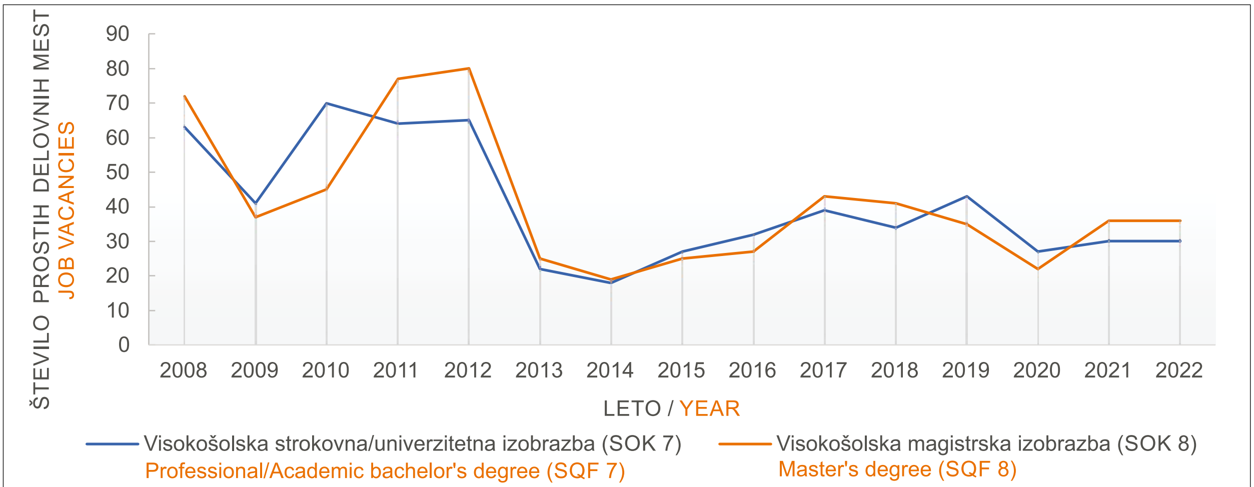
Slika 3. Število vseh razpisanih delovnih mest v panogi C16 in C31 po letih (vir podatkov: ZRSZ, 2023).

Figure 3. The number of all job vacancies in sectors C16 and C31 by year (data source: ZRSZ, 2023).



Slika 4. Število razpisanih delovnih mest glede na zahtevano stopnjo izobrazbe v lesarstvu (skupaj C16 in C31) po letih (do visokošolske izobrazbe) (vir podatkov: ZRSZ, 2023).
Figure 4. Number of job vacancies by the required level of education in the wood sector (C16 and C31) by year (up to higher education) (data source: ZRSZ, 2023).

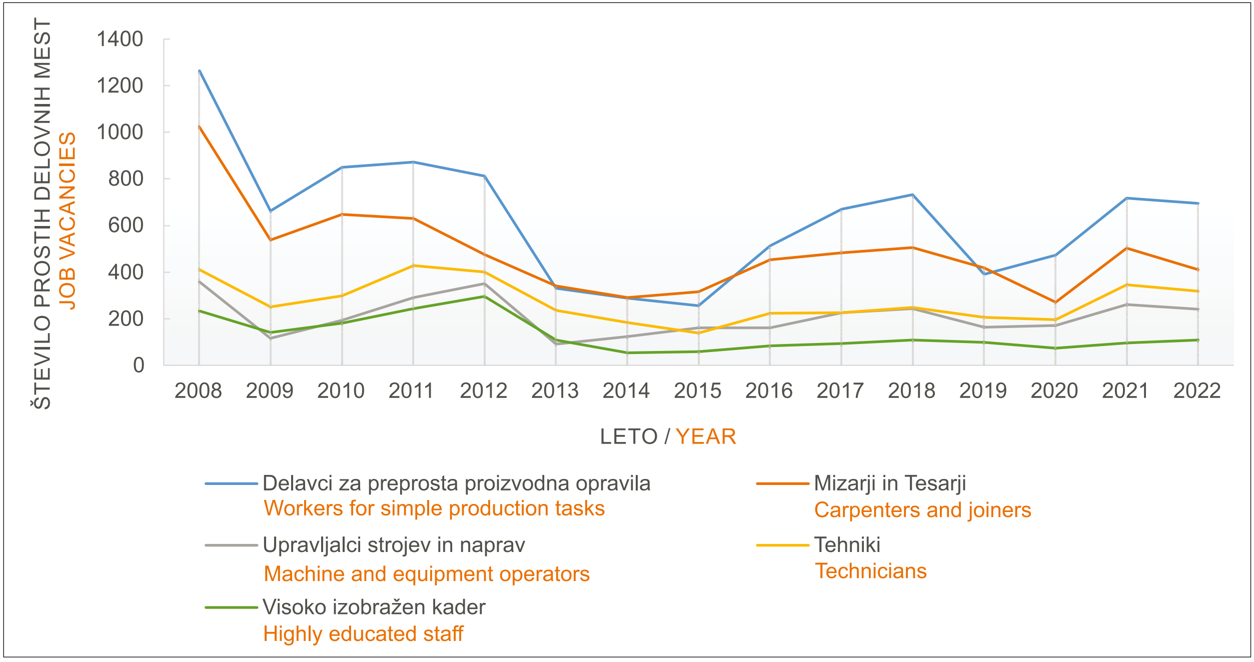
delovnih mest iz teh razpisov lahko ugotovimo, da večino (približno 80 %) prostih delovnih mest lahko izvajajo kadri z lesarsko izobrazbo. Zaključimo torej lahko, da je letni potencial za zaposlitve kadrov z lesarsko izobrazbo okoli 1800 oseb, kar znaša skoraj 4-krat več, kot pa jih trenutno pride iz izobraževalnega sistema. Pri tem bi želeli opozoriti, da se je v letu 2013 spremenila metodologija za spremljanje prostih delovnih mest, odpravljena je bila obvezna prijava prostih delovnih mest na Zavodu Republike Slovenije za zaposlovanje, zaradi česar se je pri njih navidezno zmanjšalo število objavljenih prostih delovnih mest. Zato je pomembno poudariti, da so dejanska prosta delovna mesta v tej panogi od leta 2013 lahko precej višja od tistih, ki jih prikazuje graf na sliki 4. Ugotovimo lahko tudi, da je v panogi C16



Slika 5. Število razpisanih delovnih mest glede na zahtevano stopnjo izobrazbe v panogah C16 in C31 po letih (od visokošolske izobrazbe naprej) (vir podatkov: ZRSZ, 2023).
Figure 5. Number of job vacancies by the required level of education in the wood sector (C16 and C31) by year (from higher education) (data source: ZRSZ, 2023).

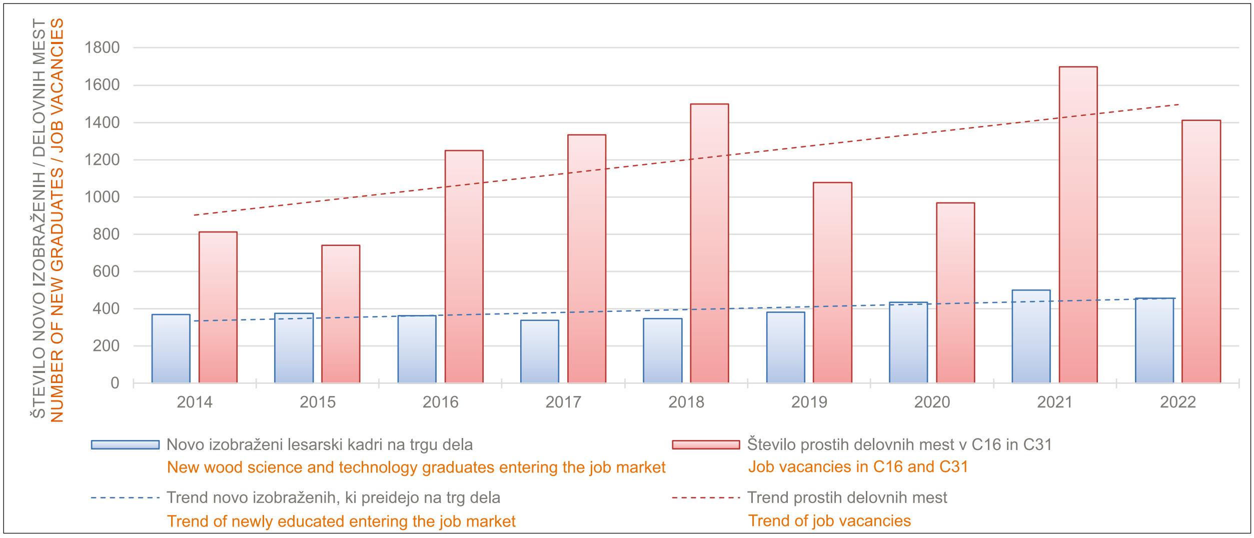
razpisanih delovnih mest v povprečju za 20–25 % več kot v panogi C31.

Zanimalo nas je tudi, katere profile kadrov podjetja najbolj potrebujejo. Ločili smo razpisana prosta delovna mesta glede na zahtevano stopnjo izobrazbe v obeh panogah skupaj. Slika 4 prikazuje število prostih delovnih mest v celotni lesni panogi v Sloveniji do visokošolske izobrazbe, kjer lahko ugotovimo, da je daleč največje število razpisanih mest za srednjo poklicno stopnjo izobrazbe (kamor



Slika 6. Število razpisanih delovnih mest po kategorijah po letih za C16 in C31 skupaj (vir podatkov: ZRSZ, 2023).

Figure 6. Number of job vacancies by category and year for C16 and C31 combined (data source: ZRSZ, 2023).



Slika 7. Primerjava med številom novo izobraženih in prostimi delovnimi mesti v lesarstvu (vir podatkov: MIZŠ, 2023 in ZRSZ, 2023).

Figure 7. Comparison between the number of newly educated individuals and job vacancies in the wood industry (data source: MIZŠ and ZRSZ).

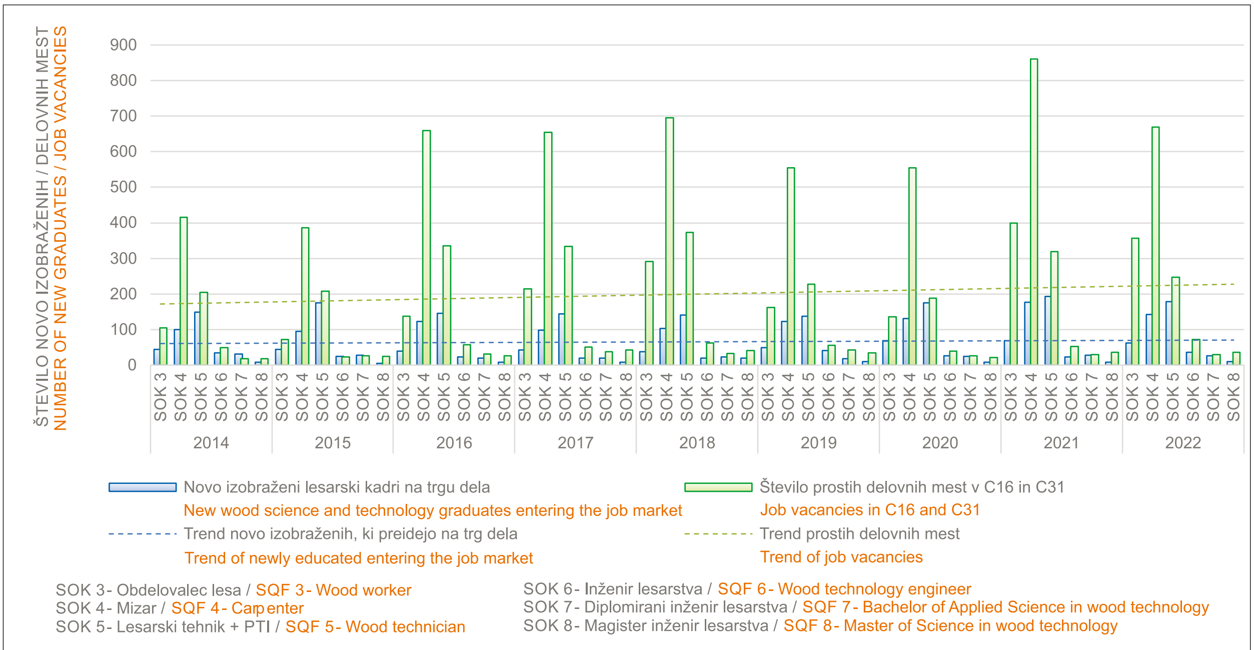
spada tudi mizar), sledijo potrebe po osnovnošolski izobrazbi in tehniški ter nižji poklicni izobrazbi (npr. obdelovalec lesa). Poleg tega se kaže potreba tudi po višje usposobljenem kadru. Leta 2022 je bilo razpisanih kar 72 prostih delovnih mest za strokovnjake z višjo strokovno izobrazbo, kamor spadajo tudi inženirji lesarstva. Zanimivo je, da v zadnjih letih rahlo narašča tudi potreba po kadrih z nedokončano osnovnošolsko izobrazbo, kar pripisujemo pomanjkanju kadra z višjimi stopnjami izobrazbe.

Ugotovimo lahko tudi, da podjetja v lesni panogi iščejo tudi veliko kadra z visokošolsko izobrazbo (slika 5), kjer je povpraševanje po diplomatih 1. in 2. stopnje približno enako in se v zadnjih 10 letih rahlo, a konstantno povečuje.

Podjetja v lesarstvu največ povprašujejo po delavcih za preprosta proizvodna opravila (slika 6). Sledijo mizarji in tesarji ter tehniki. Pričakovano pa je številčno manj povpraševanja po upravljalcih strojev in naprav ter po visoko izobraženem kadru. Če pogledamo ločeno, je v zadnjih 15 letih na trgu dela v panogi C16 največje povpraševanje po upravljalcih lesnoobdelovalnih strojev, upravljalcih procesnih strojev in naprav za predelavo lesa, in pa delavcih za preprosta dela v predelovalni industriji ter tesarjih. V panogi C31 pa je največ povpraševanja po mizarjih, veliko pa tudi po delavcih za preprosta dela v predelovalni industriji in upravljalcih lesnoobdelovalnih strojev. Trend je, podobno kot pri ostalih grafih, do leta 2013 negativen, od tega leta naprej pa v rahlem porastu praktično za vse kategorije delovnih mest.

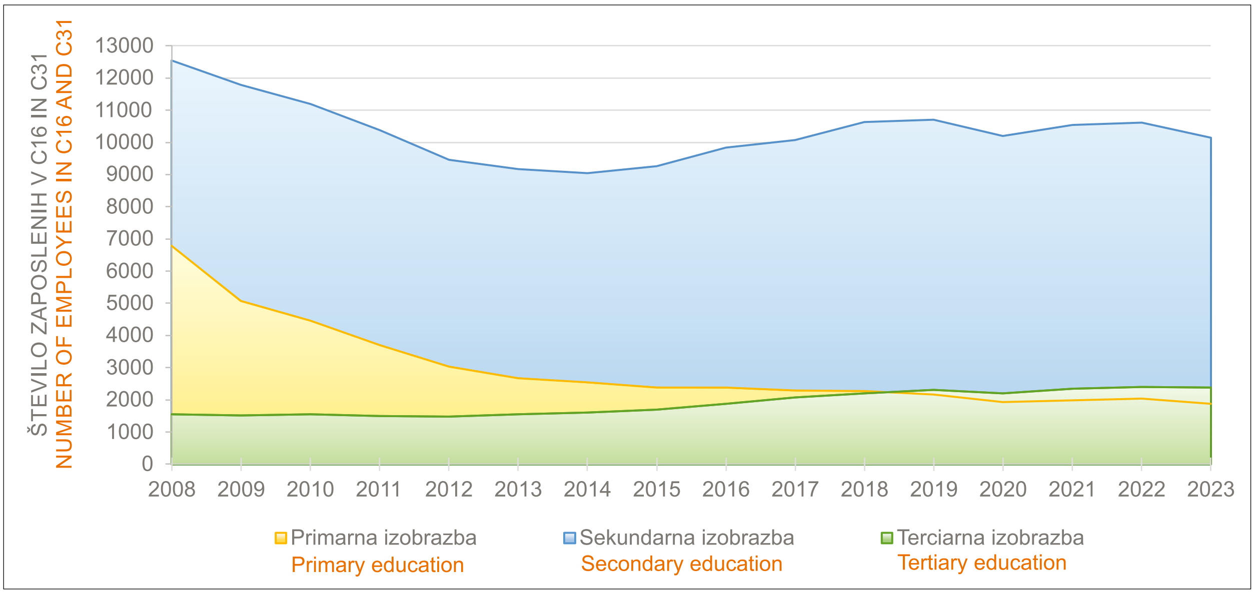
S primerjavo med številom novo izobraženih kadrov v lesarstvu, ki niso nadaljevali svojega izobraževanja, in prostimi delovnimi mesti v slovenski lesni panogi, ki vključuje dejavnosti C16 in C31 (slika 7), lahko ugotovimo, da je dinamika rasti prostih delovnih mest v preučevanem obdobju od leta 2014–2022 precej višja od rasti števila izobraženih v lesarstvu. To v praksi pomeni, da je zaposlitveni potencial v lesarstvu za kadre z lesarsko izobrazbo zelo velik.

Pri razčlenitvi prostih delovnih mest in kadra glede na stopnjo izobrazbe (kjer smo izključili tiste, ki so nadaljevali izobraževanje) ugotavljamo, da v Sloveniji letno vstopi na trg dela približno 400 mladih, od tega dobrih 300 s poklicno izobrazbo s področja lesarstva, kot so obdelovalci lesa, mizarji ali lesarski tehniki; dodatno se trg dela vsako leto obogati s približno 60 inženirji in diplomiranimi inženirji ter 10 magistri lesarstva. Za učinkovito zapolnitev delovnih mest bi bilo potrebno povečati število štu-



Slika 8. Primerjava med številom novo izobraženih in prostimi delovnimi mesti v lesarstvu po stopnji izobrazbe (vir podatkov: MIZŠ, 2023 in ZRSZ, 2023).

Figure 8. Comparison between the number of newly educated individuals and job vacancies in the wood industry by level of education (data source: MIZŠ and ZRSZ).



Slika 9. Število zaposlenih v panogah C16 in C31 po stopnji izobrazbe (vir podatkov: SiStat, 2024a).
Figure 9. Number of employees in sectors C16 and C31 by level of education (data source: SiStat, 2024a).

dentov na vseh stopnjah izobraževanja v lesarstvu (slika 8).

3.3 VPLIV IZOBRAZBENE STRUKTURE ZAPOSLENIH NA UČINKOVITOST PROIZVODNJE
3.3. INFLUENCE OF THE EDUCATIONAL STRUCTURE OF EMPLOYEES ON PRODUCTION EFFICIENCY

Struktura zaposlenih v lesarstvu v Sloveniji glede na stopnjo izobrazbe v zadnjih desetih letih kaže, da število zaposlenih s terciarno izobrazbo raste, število zaposlenih s primarno izobrazbo pada, medtem ko je število zaposlenih s sekundarno izobrazbo približno konstantno (slika 9).

Stanje v lesni panogi se glede izobrazbene strukture izboljšuje v prid višje/visoko izobraženemu kadru, zato smo preverili tudi povezavo števila zaposlenih z različnimi stopnjami izobrazbe na prihodke in dodano vrednost na zaposlenega v panogah C16 in C31. Zanimalo nas je, če tudi za slovensko lesno panogo velja, da višja izobrazba zaposlenih vpliva na povečevanje njihove individualne uspešnosti in posledično na višjo uspešnost poslovanja podjetij. Rezultati več enostavnih linearnih regresij, ki smo jih izvedli na teh podatkih, kažejo naslednje rezultate:

Pri modelih vpliva izobrazbene strukture zaposlenih na dodano vrednost na zaposlenega v panogi smo ugotovili, da ima število zaposlenih s primarno izobrazbo pomemben in statistično značilen vpliv na dodano vrednost na zaposlenega ($p < 0,001$) ter pojasnjuje 60,9 % variance v dodani vrednosti na zaposlenega ($R^2 = 0,609$). F-vrednost znaša 21,804 ($p < 0,001$), koeficient za število zaposlenih s primarno izobrazbo pa znaša -5,046, kar pomeni, da večje število zaposlenih s primarno izobrazbo zmanjšuje dodano vrednost na zaposlenega. Primerjava števila zaposlenih s sekundarno izobrazbo ne pokaže statistično značilnega vpliva na dodano vrednost na zaposlenega ($p = 0,355$), medtem ko ima število zaposlenih s terciarno izobrazbo močan in statistično značilen vpliv na dodano vrednost na zaposlenega ($p < 0,001$) ter pojasnjuje 87,2 % variance v dodani vrednosti na zaposlenega ($R^2 = 0,872$). F-vrednost znaša 95,063 ($p < 0,001$), koeficient za število zaposlenih s terciarno izobrazbo pa znaša 22,662, kar pomeni, da večje število zaposlenih s terciarno izobrazbo zvišuje dodano vrednost na zaposlenega.

Pri modelih vpliva izobrazbene strukture zaposlenih na prihodke sektorja smo ugotovili, da število zaposlenih s primarno izobrazbo ne kaže statistično značilnega vpliva na prihodke ($p = 0,310$) in pojasnjuje le 7,9 % variance v prihodkih ($R^2 = 0,079$). Koeficient za število zaposlenih z osnovnošolsko izobrazbo je negativen in znaša -58,506, vendar ni statistično značilen, saj F-vrednost znaša 1,117 ($p = 0,310$). Prav tako število zaposlenih s sekundarno izobrazbo ne kaže statistično značilnega vpliva na prihodke ($p = 0,286$; $R^2 = 0,087$). Koeficient je pozitiven in znaša 89,203, vendar ni statistično značilen. Ugotovimo lahko, da ima število zaposlenih s terciarno izobrazbo močan in statistično značilen vpliv na prihodke ($p < 0,001$) in pojasnjuje 67,8 % variance v prihodkih ($R^2 = 0,678$). F-vrednost znaša 27,418 ($p < 0,001$), koeficient za število zaposlenih s terciarno izobrazbo pa znaša 643,047, kar pomeni močan pozitiven vpliv na prihodke.

Podjetja se morajo zavedati ključne pomembnosti visoko izobraženega kadra pri zagotavljanju uspešnosti poslovanja. Lesarstvo sicer še vedno uvrščamo med delovno intenzivne panoge z višjo (kratkoročno) potrebo po manj kvalificiranih delavcih, vendar digitalizacija poslovnih procesov in uvajanje konceptov trajnostne proizvodnje spreminja naravo dela tudi v lesnih podjetjih. Naša analiza je namreč pokazala, da ima število zaposlenih s terciarno izobrazbo močan in pozitiven vpliv na dodano vrednost na zaposlenega in prihodke lesnih podjetij, medtem ko število zaposlenih s primarno izobrazbo kaže negativen vpliv na dodano vrednost na zaposlenega. To poudarja, da je vlaganje v višjo izobrazbo ključno za povečanje produktivnosti in finančni uspeh podjetij tudi v lesnem sektorju.

3.4 RAZPRAVA IN PREDLOGI ZA IZBOLJŠANJE STANJA
3.4 DISCUSSION AND PROPOSALS FOR IMPROVEMENT

Vsi ti podatki kažejo na velik potencial izobraževanja v lesarstvu. Število razpisanih delovnih mest, ki jih lahko zapolnijo kadri z lesarsko izobrazbo, je skoraj štirikrat večje od števila tistih, ki so zaključili izobraževanje na področju lesarstva v Sloveniji. Opazen je tudi trend rasti prostih delovnih mest v zadnjih sedmih letih, kar nakazuje na povečanje te vrzeli v bližnji prihodnosti. Za uspešno zapolnitev razpisanih delovnih mest je ključno privabiti več učečih se, da se odločijo za izobraževanje v lesarstvu ter jih hkrati prepričati, da se po izobraževanju v panogi tudi zaposlijo. Kropivšek in Goropečnik (2023) v svoji raziskavi ugotavljata, da lahko to dosežemo z zagotavljanjem ugodnega učnega in delovnega okolja, izvajanjem promocijskih aktivnosti ter ozaveščanjem javnosti o ključni vlogi lesa pri trajnostnem razvoju družbe. Visoka stopnja zaposljivosti in perspektiva panoge zagotovo povečujejo tudi zanimanje za izobraževanje v lesarstvu. Priporočilo za izvajanje promocije je, da se poleg organizacije Spirit vključijo tudi drugi akterji, kot so izobraževalne institucije, združenja v panogi in podjetja. Sodelovanje teh različnih deležnikov bi omogočilo razširitev distribucije oglaševalskih sporočil na številne druge komunikacijske kanale, zlasti tiste, ki jih aktivno uporablja mlajša ciljna populacija. V izvajanju promocije bi nato lahko vključili širši krog deležnikov, na primer, po vzoru organizacije ProHolz v Avstriji, ki uspešno izvaja podobne promocijske dejavnosti. Ključna naloga podjetij je ustvariti delovne pogoje, ki bodo privabili in zadržali izobražene kadre v panogi (tudi s štipendijami). Izobraževalne institucije pa morajo ponuditi sodobne in interaktivne programe, ki bodo pritegnili nove generacije učečih se.

Trenutni izobraževalni programi v lesarstvu so potrebni posodobitve, saj je bila zadnja večja posodobitev v poklicnem izobraževanju izvedena leta 2006, v visokošolskem pa leta 2016. Da bi sledili smernicam družbenega in gospodarskega razvoja, moramo učeče se opremiti tudi z digitalnimi in trajnostnimi kompetencami. Pri prenovi moramo celotno vertikalo izobraževanja v lesarstvu vsebinsko uskladiti, kar bo prispevalo k nadaljnjemu razvoju lesne panoge. Podjetja morajo zagotoviti stimulativno delovno okolje in se (bolj) aktivno vključevati v sam izobraževalni proces, predvsem preko dualnega izobraževanja (v poklicnem izobraževanju) ter projektnega in raziskovalnega dela s študenti (na višješolskem in visokošolskem študiju). Pri poklicnem izobraževanju in inženirskih študijih ima ključno vlogo tudi praktično usposabljanje. V poklicnem izobraževanju v lesarstvu je praktično usposabljanje že prisotno v zadovoljivem obsegu, vendar bi lahko bilo bolj sistematično, individualno in ciljno zasnovano ter bolj skrbno nadzorovano s strani mentorja v šoli. V visokošolskem izobraževanju pa je še vedno prostor za povečanje obsega praktičnega dela. Zaželeno bi bilo, da bi po Sloveniji vzpostavili več sodobno opremljenih prostorov, t.i. ustvarjalnih laboratorijev (Fabrication Laboratory = FabLab), v katerih lahko dijaki, študentje in ostali zainteresirani ustvarjajo brez omejitev. Ena izmed opcij, kako povečati usposobljenost kadrov v lesarstvu, je tudi oblikovanje centra odličnosti za neformalno izobraževanje v lesarstvu, ki je zanimivo predvsem za vseživljenjsko izobraževanje in zagotavlja pomemben ukrep EU pri zagotavljanju prenosa znanja med različnimi deležniki v verigi vrednosti, tudi v lesarstvu (EC, 2020). Takšni centri povezujejo vse ključne deležnike (npr. podjetja, izobraževalne institucije, raziskovalne institucije) in omogočajo hitro prilagajanje in zagotavljanje znanj in spretnosti spreminjajočim se gospodarskim in družbenim potrebam. Na področju visokošolskega izobraževanja so za uvajanje prožnih in vključujočih možnosti učenja in pridobivanja kvalifikacij zelo zanimiva t.i. mikrodokazila (angl. Micro-credential). Tudi Svet Evropske unije je sredi leta 2022 sprejel Priporočilo o evropskem pristopu k mikrodokazilom za vseživljenjsko učenje in zaposljivost, katerega namen je podpreti razvoj, izvajanje in priznavanje mikrodokazil v institucijah, podjetjih, gospodarskih panogah in državah (EC, 2022).

4 ZAKLJUČKI
4 CONCLUSIONS

Zaključimo lahko torej, da se vzporedno s povečevanjem števila zaposlenih v lesarstvu povečujejo tudi potrebe po kadrih z lesarsko izobrazbo z vsemi stopnjami izobrazbe. Če želimo kot panoga dosegati nadaljnjo rast, je poleg podpore države in investicij potrebno zagotoviti dovolj ustrezno izobraženega kadra. Število razpisanih delovnih mest, ki jih lahko zapolnijo kadri z lesarsko izobrazbo, je skoraj štirikrat večje od števila tistih, ki so zaključili izobraževanje na področju lesarstva v Sloveniji. Daleč največje število razpisanih mest je za srednjo poklicno stopnjo izobrazbe (kamor spada tudi mizar), sledijo potrebe po osnovnošolski izobrazbi in tehniški ter nižji poklicni izobrazbi (npr. obdelovalec lesa). Poleg tega se kaže potreba tudi po višje usposobljenem kadru, kjer se povpraševanje po diplomantih 1. in 2. stopnje v zadnjih 10 letih rahlo, a konstantno povečuje. V zadnjih letih je na trgu dela v lesni panogi (C16 in C31) največje povpraševanje po upravljalcih lesnoobdelovalnih strojev, upravljalcih procesnih strojev in naprav za predelavo lesa, in pa delavcih za preprosta dela v predelovalni industriji ter seveda mizarjih in tesarjih. Končna ugotovitev je, da je dinamika rasti prostih delovnih mest v obdobju od leta 2014 do 2022 precej višja od rasti števila izobraženih v lesarstvu, kar v praksi pomeni, da je zaposlitveni potencial v lesarstvu za kadre z lesarsko izobrazbo zelo velik. Zato je nujno, da pri razvoju izobraževalnih programov poleg izobraževalnih institucij, ki morajo ponuditi sodobne programe in načine izvedbe, sodeluje tudi gospodarstvo, ki se vključuje v izvajanje in definira potrebe ter poskrbi za promocijo lesarstva in lesarskih poklicev ob podpori države, ki mora poskrbeti predvsem za sistemsko ureditev materialnih in kadrovskih pogojev, ki bodo omogočili kakovostno izobraževanje. Izziv je torej kompleksen, a z ustreznim pristopom (dokaj enostavno) rešljiv. Za njegovo uspešno rešitev je ključno, da se v izobraževanje v lesarstvu privabi več visoko motiviranih učečih se. To lahko dosežemo s posodobitvami izobraževalnih programov v celotni vertikali v lesarstvu, z zagotavljanjem ugodnega učnega in delovnega okolja, izvajanjem promocijskih aktivnosti, ozaveščanjem javnosti o ključni vlogi lesa pri trajnostnem razvoju družbe in aktivno vključitvijo podjetij v izobraževalni proces. Drugi možni ukrepi zajemajo tudi vzpostavitev več ustvarjalnih laboratorijev (FabLab), oblikovanje centra odličnosti za neformalno izobraževanje v lesarstvu ter uvajanje mikrodokazil na področju visokošolskega izobraževanja.

V raziskavi smo dokazali tudi tesno povezavo med izobrazbeno strukturo zaposlenih in uspešnostjo podjetij (merjeno s prihodki in dodano vrednostjo na zaposlenega), pri čemer ima število zaposlenih s terciarno izobrazbo močan in pozitiven vpliv, število zaposlenih s primarno izobrazbo pa negativen vpliv na uspešnost lesnih podjetij. To dokazuje, da je na dolgi rok vlaganje v višjo izobrazbo ključno za povečanje produktivnosti in finančni uspeh podjetij tudi v lesnem sektorju.

Vloga izobraževanja v lesarstvu je poleg zagotavljanja ustreznih znanj in veščin učečih se zagotoviti tudi dolgoročen gospodarski razvoj družbe in panoge. Poleg specialistov drugih strok so za razvoj lesarstva nujno potrebni ustrezno usposobljeni lesarski kadri, ki med izobraževanjem pridobijo občutek za delo z lesom in vse povezano z njim, hkrati pa pridobijo tudi druge interdisciplinarne kompetence. Slednje imajo tudi širši družbeni pomen, saj omogočajo posameznikom učinkovito delovanje v vsakdanjem življenju ter prispevajo k celostnemu razvoju družbe. Ta raziskava je ena izmed prvih kompleksnejših raziskav na področju izobraževanja v lesarstvu, ki zajema celotno vertikalo, zato je možnosti za njeno nadaljevanje še veliko.

5 POVZETEK
5 SUMMARY

Along with global social and economic developments, the Slovenian wood industry is also changing. The introduction of many new digital technologies while striving for climate neutrality offers many new opportunities for the progress and expansion of the industry. As wood is Slovenia's most important strategic raw material, an industry based on such a readily available natural resource has great potential for achieving the goals of the European Green Deal. This is also reflected in numerous strategic documents at both EU and Slovenian levels. In order to manufacture products with higher added value, to deal with modern technologies and introduce modern digital and sustainable business models in companies, companies need well-trained and qualified employees with the appropriate competences.

Although the modern wood industry offers many career opportunities, there is still a shortage of wood technicians and wood engineers alongside professions such as carpenters, joiners and upholsterers. In practice, the lack of adequately trained personnel is also a major problem at the EU level. Therefore, if we want to have enough well-trained personnel in the industry, in addition to changes in the state's economic policy and the introduction of technological innovations in companies' business processes, we also need to increase/change the educational potential in the field of wood processing. The main objective of the study was to conduct an in-depth analysis of the labour demand and the educational structure in the wood sector and to determine the potential in the field of wood science and technology education in Slovenia. We were also interested in the reciprocal influence of the structure of employees with different levels of education on turnover and value added per employee in the sector. The sample covered the period from 2008 to 2023.

From this, we can conclude that parallel to the increase in the number of employees in the wood industry, the demand for labour with wood science and technology training is also increasing at all educational levels. If the wood sector wants to continue to grow as an industry, it must have sufficient, well-trained personnel in addition to government support and investment. The number of job vacancies in Slovenia that can be filled by personnel with a wood science and technology education is almost four times higher than the number of people who have completed this education. The potential of wood science and technology education in Slovenia is therefore great, but it is important that the development of educational programmes involves not only educational institutions, which must offer modern programmes and implementation methods, but also the business community, which is involved in implementation and defines the related needs, and the state, which provides adequate support for the wood sector and wood professions. The challenge is therefore complex, but (relatively easy) to solve with the right approach. The key to a successful solution lies in attracting more highly motivated learners to wood science and technology education. This can be achieved by updating educational programmes throughout the education chain within wood science and technology education, ensuring a favourable learning and working environment, carrying out promotional activities, raising public awareness of the key role of wood in the sustainable development of society, and actively involving companies in the educational process. Other possible measures include the establishment of several creative laboratories (such as the FabLab project), the creation of a competence centre for non-formal education in woodworking, and the introduction of micro-evidence in the field of higher education.

In this research we also demonstrated a close relationship between the educational structure of employees and the performance of companies (measured by turnover and value added per employee), with the number of employees with higher levels of education having a strong and positive influence on this performance, and the number of employees with primary education having a negative influence. This proves that (in the long run) investment in higher education is the key to increasing the productivity and financial success of companies in the wood sector. The role of education (in wood processing) is not only to provide students with the appropriate knowledge and skills, but also to ensure the long-term economic development of society and the industry. This research is one of the first more complex studies in the field of wood science and technology education that cov-

ers the entire vertical, so there are still many opportunities for further work in this area.

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COMPARISON OF COLOUR PROPERTIES IN AMERICAN WALNUT (*Juglans nigra*) WOOD COATED WITH DIFFERENT SURFACE FINISHES

PRIMERJAVA BARVNIH LASTNOSTI PRI AMERIŠKEM OREHU (*Juglans nigra*), PREMAZANEM Z RAZLIČNIMI POVRŠINSKIMI PREMAZI

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Abstract / Izvleček

Abstract: In this research, the colour characteristics [hue ($h°$) angle, yellow (b^*) colour tone, lightness (L^*), red (a^*) colour tone, chroma (C^*), ΔE^*, ΔL^*, Δa^*, Δb^*, ΔC^*, and ΔH^*] of surfaces treated with three distinct types of coatings [solvent-based yacht varnish, which has high hardness and is highly resistant to water, a waxy varnish formulated for interior and exterior wood coatings, consisting of a mixture of natural oils, waxes, and resins, and matte-glossy, solvent-based, acrylic resin-based stone varnish)] on American walnut (*Juglans nigra* L.) wood were examined and compared. When all types of varnishes are applied to wooden surfaces, decreases in b^*, C^*, $h°$, and L^* values were observed, while increases in a^* values were detected. Reviewing the ΔE^* values, 13.59 was identified for stone, 16.62 for yacht, and 12.40 for waxy varnish. Upon examination of the ΔH^* values, they were determined as 4.72 for stone, 5.06 for yacht, and 3.42 for waxy varnish. The highest values for the parameters L^*, b^*, C^*, and $h°$, and the lowest value for a^*, were determined on the control experimental samples (without any varnish application). In the study, it was observed that the coating types, each with different chemical compositions, yielded different results.

Keywords: Colour, American walnut = *Juglans nigra*, stone varnish, yacht varnish, waxy varnish

Izvleček: Raziskali in primerjali smo barvne značilnosti (barvitost ($h°$), rumeno-modri ton (b^*), svetlost (L^*), rdeče-zeleni ton (a^*), nasičenost (C^*), ΔE^*, ΔL^*, Δa^*, Δb^*, ΔC^*, in ΔH^*) površin lesa ameriškega oreha (*Juglans nigra* L.), obdelanih s tremi različnimi vrstami lakov. Pri uporabi različnih lakov [topilni lak za jahte, ki ima visoko trdoto in je zelo odporen proti vodi; voskast lak, formuliran za notranje in zunanje premaze za les, sestavljen iz zmesi naravnih olj, voskov in smol; mat-sijajni topilni lak na osnovi akrilne smole za površinsko obdelavo kamna] na površinah lesa ameriškega oreha so bile opažene zmanjšane vrednosti b^*, C^*, $h°$ in L^*, medtem ko so bile zaznane povečane vrednosti a^*. Pri pregledu vrednosti ΔE^* smo ugotovili, da je le-ta bila 13,59 pri laku za kamen, 16,62 pri laku za jahte in 12,40 pri voskastem laku. Pri pregledu vrednosti ΔH^* so bile le-te določene kot 4,72 pri laku za kamen, 5,06 pri laku za jahte in 3,42 pri voskastem laku. Najvišje vrednosti parametrov L^*, b^*, C^* in $h°$, ter najnižje vrednosti za parameter a^* so bile ugotovljene na kontrolnih vzorcih (brez nanesenih premazov). V študiji je bilo ugotovljeno, da je raba različnih vrst lakov, ki imajo različno kemično sestavo, privedla do razlik v rezultatih.

Ključne besede: Barva, ameriški oreh = *Juglans nigra*, lak za kamen, lak za jahte, voskast lak

1 INTRODUCTION
1 UVOD

Wood is one of the most common construction materials globally. Thanks to its remarkable mechanical properties relative to its weight, it facilitates the creation of lightweight structures with a high robustness. Its ease of manipulation, as opposed to more labour-intensive materials, renders it a compelling substitute in the field of construction (Niemz et al., 2015).

The unique aesthetic of treated wood holds significant commercial value. Its rich and appealing appearance makes it a sought-after material for upscale furnishings, decorative elements in both residential and commercial settings, and luxury automotive interiors (Marschner et al., 2005).

Varnish is composed of two primary substances: solid matter and solvent. In the case of chemical curing varnishes, the curing process results from

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a chemical reaction between two distinct components within the varnish. Consequently, the reaction time dictates the complete curing duration. Varnishes such as polyester, polyurethane, and synthetic resin belong to this category (Kurtoğlu, 2000).

In the literature, various wood species have been subjected to different types of varnish applications, such as water-based varnish for oriental beech and Scots pine (Pelit, 2007), single and two-component water-based varnishes for iroko, Scots pine, and Anatolian chestnut (Çakıcıer, 2007), polyurethane and synthetic varnishes for oak, chestnut, iroko, and teak (Dalyan, 2010), cellulosic, polyurethane, synthetic, and water-based varnishes for bamboo (Aykaç, 2016), UV varnish for beech, maple, northern red oak, American black walnut, and walnut (Ayata et al., 2018), single and two-component water-based varnishes for Corsican pine, hybrid, Scots pine, and larch (Saygın, 2016), rubberwood, keruing, keranji, meranti, and niové (Çamlıbel & Ayata, 2024), water-based, polyurethane, and acrylic varnishes for Scots pine, sessile oak, and chestnut (Kılıç, 2019), yacht, polyurethane, and epoxy varnishes for limba, chestnut, and sapele (Altıparmak, 2017), synthetic glass lacquer varnish for juniper (Bilgen, 2010), linseed oil, nitrocellulose varnish, water-borne stain, nano-coating for beech (Bohinc et al., 2019), water-based, polyurethane, and synthetic varnishes for beech and Scots pine (Koç, 2023), two-component acrylic modified polyurethane varnish for Scots pine (Yazıcı, 2020), synthetic, cellulosic, polyurethane, and water-based varnishes for elm, Anatolian chestnut, limba, and iroko (Güler, 2010), single and two-component water-based varnishes, as well as two-component solvent-based acrylic and polyurethane varnishes for elm and iroko (Ulay, 2018), polyester, synthetic, polyurethane, and cellulosic varnishes for beech and oak (Sönmez, 1989), water-based and synthetic varnishes for Scots pine, oriental beech, and sessile oak (Özder, 2023), parquet varnish for chestnut, eucalyptus, and Scots pine (Akter et al., 2019), cellulosic, polyurethane, and water-based varnishes for beech (Ceylan, 2016), water-based single-component and synthetic varnishes for European spruce, American elm, alder, and poplar (Gürleyen, 2018), water-based marine varnish for jelutong (Naide et al., 2022), and water-based single and two-component varnishes for Scots pine, beech, and oak (Ayata, 2014), Swedish pine (Ayata & Bal, 2024).

These studies involved conducting a range of tests on wooden surfaces treated with varnish, encompassing assessments such as colour analysis, glossiness measurement, determination of whiteness index, bacterial adhesion, the cigarette test, taber abrasion testing, wetting behaviour examination, scratch resistance evaluation, assessment of surface adhesion strength, pendulum hardness testing, and more. However, it was observed in the literature that UV varnish had been applied to American walnut (*Juglans nigra* L.) wood, while stone, yacht, and waxy varnishes have not yet been used in this way.

This study compares the colour properties of surfaces treated with three different types of coatings applied to American walnut (*Juglans nigra* L.) wood. To briefly describe this tree species, the wood is a type that is quite hard and tightly structured, yet splits easily. It is a diffuse-porous tree with moderately sized pores and a ring-porous structure. Its rays are indistinct, giving it a dull appearance. The specific gravity of air-dried wood averages 0.55 g/cm³ (Şanıvar & Zorlu, 1980). This type of walnut is generally straight-grained, easy to work with tools, and holds well in place. It is heavy, rigid, strong, and has good resistance to shock. Its wood has a suitable structure for natural finishes. Its most significant use is in furniture making. Other important uses include gunstocks, cabinets, and interior decoration. It is used both as solid wood and plywood (Anonymous, 1955). In American walnut wood, the Janka hardness values are 89.38 N/mm² tangentially, 85.53 N/mm² radially, and 101.94 N/mm² on the transverse surface. The air-dried density is measured at 796 kg/m³. Nail-holding resistance is determined as 15.33 N/mm² tangentially, 18.65 N/mm² radially, and 13.92 N/mm² on the transverse surface (Ayata & Bal, 2019).

2 MATERIALS AND METHODS
2 MATERIAL IN METODE

2.1 WOOD MATERIAL
2.1 LES

American black walnut (*Juglans nigra* L.) wood samples were prepared in dimensions of 100 mm x 100 mm x 15 mm. Conditioning treatments were applied to the samples (temperature of (20 ± 29 °C at 65% of relative humidity) (ISO 554, 1976).

2.2 VARNISHES
2.2 LAKI

In the study, three different types of coatings (stone, yacht, and waxy varnish) were used. The varnishes did not contain any paint or pigment, and are briefly described as follows:

a) A solvent-based yacht varnish, characterized by high hardness and high resistance to water (solid content: 50%, containing 60-70% oil alkyd resin, density: 0.87-0.92 g/ml, 2-coat application, coverage: 14-16 m²/lt).

b) A waxy varnish, formulated for interior and exterior wood coatings, consisting of a mixture of natural oils, waxes, and resins (transparent, density: 0.87 g/cm³, coverage: 16-20 m²/lt, initial drying time: 6-8 h, full drying time: 24-48 h, 2-coat application).

c) A stone varnish (matte, solvent-based, acrylic resin-based, density: 0.95 g/cm³, touch dry: 6-8 h, full hardening: at least 24 h, viscosity: 24 seconds, solid content: 27%, two-coat application, 200-250 g/m²).

2.2.3 APPLICATION OF VARNISHES TO WOOD SURFACES
2.2.3 NANOS LAKOV NA POVRŠINE LESA

In the study, the test samples were sanded with 80, 120, and 180 grit sandpapers, and the surfaces were then cleaned with a compressor. A drying time of 24 h was allowed between coats. All coatings were applied to the wood surfaces in two coats using a brush, according to industrial practices.

2.2.4 DETERMINATION OF COLOUR PROPERTIES
2.2.4 DOLOČITEV BARVE

The colour changes in the samples were evaluated using a CS-10 (CHN Spec, China) device, following the ASTM D 2244-3 (2007) standard and employing the CIELAB colour model (Ayata & Ayata, 2024). Assessments were carried out using a CIE 10° standard observer and CIE D65 light source in an 8/d illuminating environment (8°/diffused illumination). Ten measurements were taken from each sample in each group.

The L^* variable indicates lightness or brightness, ranging from 0 (black) to 100 (white). The a^* and b^* variables represent colour coordinates, both of which can vary between -60 and +60. The angle formed between the C^* axis and the a* axis is called the hue ($h°$), which denotes the colour angle. The C^* variable reflects the saturation or chromaticity of the colour. In the CIE-*Lab** colour diagram, the positive and negative signs signify: $+a^*$ for an increase in red, $-a^*$ for an increase in green, $+b^*$ for an increase in yellow, and $-b^*$ for an increase in blue (Konica Minolta, 2014; Mesquita et al., 2023).

The results of total colour differences were determined using the following formulas.

$$C^* = \left[(a^*)^2 + (b^*)^2 \right]^{0.5} \tag{1}$$

$$h^o = arctan\ (b^*/a^*) \tag{2}$$

$$\Delta C^* = \left(C^*_{coated\ sample} - C^*_{control\ sample} \right) \tag{3}$$

$$\Delta a^* = \left(a^*_{coated\ sample} - a^*_{control\ sample} \right) \tag{4}$$

$$\Delta L^* = \left(L^*_{coated\ sample} - L^*_{control\ sample} \right) \tag{5}$$

$$\Delta b^* = \left(b^*_{coated\ sample} - b^*_{control\ sample} \right) \tag{6}$$

$$\Delta H^* = \left[(\Delta E^*)^2 - (\Delta L^*)^2 - (\Delta C^*)^2 \right]^{0.5} \tag{7}$$

$$\Delta E^* = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \right]^{0.5} \tag{8}$$

Visual assessment comparison criteria for ΔE^* colour difference (DIN 5033, 1979) are provided in Table 1.

The definitions of Δa^*, ΔH^*, Δb^*, ΔC^*, and ΔL^* are provided as follows (Lange, 1999):

Δb^*: A positive value indicates that the sample is more yellow or less blueish than the reference, while a negative value indicates that the sample is more blue or less yellowish than the reference.

ΔC^*: Represents the difference in chroma or saturation between the sample and the reference.

Table 1. Comparison criteria for evaluating Δ*E** values (DIN 5033, 1979).
Preglednica 1. Merila za ocenjevanje barvnih razlik Δ*E** (DIN 5033, 1979).

ΔE* values	Visual colour score difference
<0.20	Imperceptible
0.20–0.50	Very weak
0.50–1.50	Weak
1.50–3.00	Noticeable
3.00–6.00	Very noticeable
6.00–12.00	Strong
> 12.00	Very strong

A positive value indicates that the sample is clearer and brighter than the reference, while a negative value indicates that the sample is duller and hazier than the reference.

Δ*L**: A positive value indicates that the sample is lighter than the reference, while a negative value indicates that the sample is darker than the reference.

Δ*H**: Represents the difference in hue or shade between the sample and the reference.

Δ*a**: A positive value indicates that the sample is redder or less greenish than the reference, while a negative value indicates that the sample is greener or less reddish than the reference.

2.5 CALCULATION OF TEST DATA
2.5 OBDELAVA PODATKOV

The standard deviations, mean values, maximum and minimum values, homogeneity groups, variance analyses, and percentage (%) change rates were calculated using a statistical software programme.

3 RESULTS AND DISCUSSION
3 REZULTATI IN RAZPRAVA

Measurement results for total colour differences are shown in Table 2. After analysing the Δ*H** values, it was found that they were 4.72 for stone varnish, 5.06 for yacht varnish, and 3.42 for waxy varnish. Considering the Δ*E** values, 13.59 was determined for stone varnish, 16.62 for yacht varnish, and 12.40 for waxy varnish. When all types of coatings are considered, the Δ*L**, Δ*b**, and Δ*C** values are determined to be negative (respectively: darker than the reference, less yellowish than the reference, and matte, hazier than the reference), while Δ*a** values are found to be positive (more reddish than the reference). According to the colour alteration criteria (DIN 5033, 1979), when compared with the results obtained in this study, it is observed that all types of varnishes provide a "very strong" (> 12.00) colour change (Table 2).

Table 2. Measurement results for total colour differences.
Preglednica 2. Izračuni skupnih barvnih razlik.

Coating Type	ΔL*	Δa*	Δb*	ΔC*	ΔH*	ΔE*	Criteria for Colour (DIN 5033, 1979)
Stone	-12.67	3.39	-3.57	-1.42	4.72	13.59	Very strong (> 12.00)
Yacht	-14.26	0.82	-8.51	-6.89	5.06	16.62	
Waxy	-11.49	2.12	-4.16	-3.19	3.42	12.40	

The results of the variance analyses are presented in Table 3, and these show that the coating type factor was found to be significant in terms of all colour parameters [hue (*h*°) angle, yellow (*b**) colour tone, lightness (*L**), red (*a**) colour tone, and chroma (*C**)] (Table 3).

Measurement results for all colour parameters, obtained using both unvarnished and varnished test samples, are presented in Table 4.

When all varieties of coatings are administered onto wooden surfaces, reductions in the *h*° (stone varnish: 20.30%, yacht varnish: 25.81%, and waxy varnish: 17.24%), *b** (stone varnish: 18.80%, yacht varnish: 44.81%, and waxy varnish: 21.91%), *C** (stone varnish: 6.88%, yacht varnish: 33.38%, and waxy varnish: 15.41%), and *L** (stone varnish: 26.00%, yacht varnish: 29.26%, and waxy varnish: 23.57%) parameters were noted, accompanied by elevations in the *a** (stone varnish: 41.96%, yacht varnish: 10.02%, and waxy varnish: 26.24%) values (Table 4).

At the *L** measurements, the highest result was found in the control sample (without varnish application) (48.74), while the lowest result was observed on samples coated with yacht varnish (34.48). For the *a** value, the lowest result was determined in the control sample (8.08), whereas the highest result was found on experimental samples coated with stone varnish (11.47) (Table 4).

Table 3. Analysis of variance results for colour parameters.
Preglednica 3. Rezultati analize variance za barvne parametre.

Source	Test	Sum of Squares	df	Mean Square	F	Sig.
Coating Type	Lightness (L^*)	1268.062	3	422.687	505.876	0.000*
	Red (a^*) colour tone	66.580	3	22.193	82.517	0.000*
	Yellow (b^*) colour tone	365.242	3	121.747	180.614	0.000*
	Chroma (C^*)	265.835	3	88.612	68.858	0.000*
	Hue ($h°$) angle	1667.291	3	555.764	339.034	0.000*
Error	Lightness (L^*)	30.080	36	0.836		
	Red (a^*) colour tone	9.682	36	0.269		
	Yellow (b^*) colour tone	24.267	36	0.674		
	Chroma (C^*)	46.327	36	1.287		
	Hue ($h°$) angle	59.013	36	1.639		
Total	Lightness (L^*)	62560.853	40			
	Red (a^*) colour tone	3807.728	40			
	Yellow (b^*) colour tone	9307.198	40			
	Chroma (C^*)	12940.946	40			
	Hue ($h°$) angle	128734.696	40			
Corrected Total	Lightness (L^*)	1298.142	39			
	Red (a^*) colour tone	76.263	39			
	Yellow (b^*) colour tone	389.509	39			
	Chroma (C^*)	312.163	39			
	Hue ($h°$) angle	1726.304	39			
For the column α≤0.05: * indicates significance.						

Regarding the b^* parameter, the highest result was obtained in the control samples (18.99), while the lowest result was determined on samples coated with yacht varnish (10.48). For the C^* value, the highest result was identified in the control sample (20.64), whereas the lowest result was obtained on samples coated with yacht varnish (13.75). In terms of the $h°$ parameter, the highest result was observed in the control experimental samples (66.95), while the lowest result was determined on samples coated with yacht varnish (49.67) (Table 4).

In the literature, studies also report that different colour parameters were obtained on the surfaces of wooden materials after varnish was applied to them (Ayata & Bal, 2024; Ayata, 2014; Ayata et al., 2024; **Çamlıbel** & Ayata, 2024; Ulay, 2018).

The current study has fulfilled its purpose, and shown that various outcomes were achieved after applying different surface coatings to the same wooden surfaces. This variation is believed to arise from the different formulations used in preparing the varnishes.

The structural characteristics of varnish layers differ, and the primary factors behind this divergence are the constituents employed during varnish manufacture. Employing varying types and quantities of main binders and supplementary layer-forming agents effectively generates this diversity (Sönmez, 1989).

4 CONCLUSIONS
4 SKLEPI

Examining the ΔE^* values, stone varnish was found to be 13.59, yacht varnish was 16.62, and waxy varnish was 12.40.

The control experimental samples (without any varnish application) exhibited the highest val-

Table 4. Measurement results determined for colour parameters.
Preglednica 4. Izmerjeni rezultati za barvne parametre.

Test	Coating Type	Mean	Change (%)	HG	Standard Deviation	Minimum	Maximum	Coefficient of Variation
Lightness (L^*)	None–Control	48.74	-	A*	1.04	46.34	49.64	2.13
	Stone	36.07	↓26.00	C	0.79	34.94	37.16	2.18
	Yacht	34.48	↓29.26	D**	0.47	33.79	35.21	1.36
	Waxy	37.25	↓23.57	B	1.19	35.60	39.27	3.20
Red (a^*) colour tone	None–Control	8.08	-	D**	0.22	7.53	8.27	2.68
	Stone	11.47	↑41.96	A*	0.87	10.67	12.89	7.57
	Yacht	8.89	↑10.02	C	0.41	7.96	9.52	4.57
	Waxy	10.20	↑26.24	B	0.33	9.78	10.73	3.25
Yellow (b^*) colour tone	None–Control	18.99	-	A*	0.46	17.87	19.54	2.44
	Stone	15.42	↓18.80	B	0.95	14.06	16.69	6.15
	Yacht	10.48	↓44.81	C**	0.55	9.71	11.46	5.27
	Waxy	14.83	↓21.91	B	1.13	13.37	16.96	7.62
Chroma (C^*)	None–Control	20.64	-	A*	0.48	19.40	21.13	2.33
	Stone	19.22	↓6.88	B	1.22	17.65	20.92	6.35
	Yacht	13.75	↓33.38	D**	0.59	12.84	14.90	4.29
	Waxy	17.46	↓15.41	C	1.75	14.74	19.99	10.05
Hue ($h°$) angle	None–Control	66.95	-	A*	0.45	66.36	67.62	0.68
	Stone	53.36	↓20.30	C	1.21	51.63	55.22	2.26
	Yacht	49.67	↓25.81	D**	1.46	47.36	51.68	2.94
	Waxy	55.41	↓17.24	B	1.66	53.08	58.06	3.00

Number of Measurements: 10,
For the Homogeneity Group (*HG*) column: * indicates the highest value, ** indicates the lowest value

ues for the parameters L^*, C^*, b^*, and $h°$, while showcasing the lowest value for the a^* parameter.

When all varieties of coatings are administered onto wooden surfaces, reductions in $h°$, b^*, C^*, and L^* were noted, accompanied by elevations in a^*.

It can be said that the different structural compositions of coating types interact with the wooden material, causing a variety of results.

5 SUMMARY
5 POVZETEK

Ta študija raziskuje in primerja barvne parametre [rdeče-zeleni (a^*) barvni ton, barvitost ($h°$), rumeno-modri (b^*) barvni ton, svetlost (L^*), nasičenost oz. kroma (C^*), Δa^*, Δb^*, ΔE^*, ΔL^*, ΔC^* in ΔH^*] površin, obdelanih s tremi različnimi vrstami lakov [lak za jahte na osnovi topil, ki ima visoko trdoto in je zelo odporen proti vodi; voskast lak, pripravljen za notranje in zunanje premaze na lesu, sestavljen iz zmesi naravnih olj, voskov in smol; topilni mat-sijajni lak za kamen na osnovi akrilnih smol)] na ameriškem orehu (*Juglans nigra* L.).

V študiji je bil uporabljen topilni lak za jahte, za katerega sta značilni visoka trdota in visoka odpornost proti vodi (vsebnost suhe snovi: 50 %, vsebuje 60–70 % oljne alkidne smole, gostota: 0,87–0,92 g/ml, dvoslojni nanos, prekrivnost: 14–16: m²/l).

Uporabljen je bil tudi voskast lak, pripravljen za notranje in zunanje premaze za les, sestavljen iz zmesi naravnih olj, voskov in smol (prozoren, gostota: 0,87 g/cm³, prekrivnost 16–20 m²/l, začetni čas sušenja: 6–8 ur, polni čas sušenja: 24–48 ur, nanos v dveh slojih). V raziskavi je bil uporabljen **še** lak za kamen (dvoslojni nanos, mat–sijaj, na osnovi topil, na osnovi akrilnih smol, gostota: 0,95 g/cm³, prašno suh po 6–8 urah, popolna utrditev po najmanj 24 urah, viskoznost: 24 s, vsebnost suhe snovi: 27 %, nanos v dveh slojih, 200–250 g/m²).

Pri nanosu vseh vrst lakov na površine lesa so se zmanjšale vrednosti h° (lak za kamen: 20,30 %, lak za jahte: 25,81 % in voskast lak: 17,24 %), *b** (lak za kamen: 18,80 %, lak za jahte: 44,81 % in voskast lak: 21,91 %), *C** (lak za kamen: 6 %. 88, lak za jahte: 33,38 % in voskast lak: 15,41 %) in *L** (lak za kamen: 26,00 %, lak za jahte: 29,26 % in voskast lak: 23,57 %), ki so jih spremljala povečanja vrednosti a* (lak za kamen: 41,96 %, lak za jahte: 10,02 % in voskast lak: 26,24 %).

Na podlagi tega preskusa je bilo ugotovljeno, da izbira vrste transparentnega laka pomembno vpliva na vse barvne parametre premazanih površin [barvitost (*h*°), rumeno modri (*b**) barvni ton, svetlost (*L**), rdeče zeleni (*a**) barvni ton in kroma (*C**)].

Kontrolni poskusni vzorci (brez nanosa laka) so imeli najvišje vrednosti parametrov *L**, *b**, *C** in h°, medtem ko so imeli najnižjo vrednost parametra *a**.

Pri merjenju vrednosti *L** je bil najvišji rezultat ugotovljen pri kontrolnem vzorcu (brez nanosa laka) (48,74), najnižji rezultat pa pri vzorcih, premazanih z lakom za jahte (34,48). Pri vrednosti *a** je bil najnižji rezultat določen pri kontrolnem vzorcu (8,08), medtem ko je bil najvišji rezultat ugotovljen pri vzorcih, premazanih z lakom za kamen (11,47). Pri parametru *b** je bil najvišji rezultat dosežen pri kontrolnih vzorcih (18,99), medtem ko je bil najnižji rezultat določen pri vzorcih, premazanih z lakom za jahte (10,48). Pri vrednosti *C** je bil najvišji rezultat določen pri kontrolnem vzorcu (20,64), najnižji rezultat pa pri vzorcih, obdelanih z lakom za jahte (13,75). Pri parametru *h*° je bil najvišji rezultat ugotovljen pri kontrolnih vzorcih (66,95), medtem ko je bil najnižji rezultat določen pri vzorcih, obdelanih z lakom za jahte (49,67).

Pri pregledu vrednosti Δ*E** je bilo ugotovljeno, da je bila vrednost barvne razlike po obdelavi z lakom za kamen 13,59, vrednost pri laku za jahte je bila 16,62, vrednost pri voskastem laku pa 12,40. Po analizi vrednosti Δ*H** je bilo ugotovljeno, da so bile te vrednosti 4,72 za lak za kamen, 5,06 za lak za jahte in 3,42 za voskast lak.

Pri pregledu vpliva vseh vrst lakov na barvo lesa smo ugotovili, da so vrednosti premazanega lesa Δ*L**, Δ*b** in Δ*C** v negativnem območju (natančneje: temnejše, manj rumene in bolj motne, zamegljene od kontrolnega nepremazanega lesa), medtem ko so vrednosti *Δa** pozitivne (kažejo na bolj rdeč odtenek v primerjavi z neobdelanim lesom).

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VPLIV PLAZEMSKE OBDELAVE POVRŠINE LESA NA LEPLJENJE BUKOVINE S POLIURETANSKIM LEPILOM

INFLUENCE OF PLASMA SURFACE TREATMENT ON BONDING OF BEECH WOOD WITH POLYURETHANE ADHESIVE

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Izvleček / Abstract

Izvleček: V raziskavi je bil proučen vpliv plazemske obdelave površine na lepljenje bukovine s konstrukcijskim enokomponentnim poliuretanskim lepilom. Uporabljen je bil les navadne bukve (*Fagus sylvatica* L.) brez obarvanja in les bukve z rdečim srcem, učinkovitost lepilnih spojev pa je bila ovrednotena s testiranjem strižne trdnosti in delaminacije v skladu s standardom SIST EN 14080:2013. Rezultati so pokazali, da je plazemska obdelava izboljšala omočljivost površine, vendar ni prispevala k izboljšanju kakovosti lepilnih spojev. Pri bukovini z rdečim srcem je bila ugotovljena višja stopnja loma po lesu, pri čemer pa so bile strižne trdnosti lepilnega spoja nižje. Z uporabo poliuretanskega lepila pri lepljenju bukovine smo v večini primerov dosegli zahteve standarda glede strižne trdnosti lepilnega spoja, vendar pa lepilni spoji niso dosegli zahtev standarda za delaminacijo lepilnih spojev. Raziskava ni pokazala večjih razlik med lepljenjem bukovine brez obarvanj in bukovine z rdečim srcem.

Ključne besede: Konstrukcijsko lepljenje, les, navadna bukev = *Fagus sylvatica*, rdeče srce, plazemska obdelava površine, poliuretansko lepilo

Abstract: The study investigated the effects of plasma surface treatment on bonding beech wood with structural one-component polyurethane adhesive. The wood used included European beech (*Fagus sylvatica* L.) without discolouration and red-heart beech, and the efficiency of the adhesive joints was evaluated by testing shear strength and delamination according to the SIST EN 14080:2013 standard. The results showed that plasma treatment improved the wettability of the surface but did not contribute to enhancing the quality of the adhesive joints. In the case of red-heart beech, a higher degree of wood failure was observed, while the shear strengths of the adhesive joints were lower. Using polyurethane adhesive for bonding beech wood did not meet the standard requirements for adhesive joint delamination. The study did not show significant differences in bonding between beech wood without discolouration and red-heart beech.

Keywords: structural bonding, wood, European beech = *Fagus sylvatica*, red heart, plasma surface treatment, polyurethane adhesive

1 UVOD
1 INTRODUCTION

Lepljenje lesa je eden ključnih procesov za doseganje polnega potenciala lesa (Ammann, 2015)– tudi kot gradbenega materiala, ki bi pripomogel k zmanjšanju CO_2 izpustov celotnega gradbenega sektorja. V Sloveniji, ki je pogosto predstavljena kot gozdnata dežela, se pričakuje, da bo do leta 2030 vsaka javna zgradba vsebovala vsaj 30 odstotkov lesa oz. lesnih izdelkov. Ta cilj je del širše strategije za povečanje trajnosti gradbenih praks in zmanjšanje okoljskega vpliva gradbenega sektorja (Uradni list Republike Slovenije, 2017).

V Sloveniji večino lesa, ki se uporablja v gradbene namene, predstavljajo iglavci, predvsem smreka. V zadnjih letih v slovenskih gozdovih narašča delež listavcev in je bukev postala najbolj zastopana drevesna vrsta (Zavod za gozdove Slovenije,

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2024). Tradicionalno uporabljena za energetske namene, pohištvo in galanterijske izdelke, ima zaradi dobrih mehanskih lastnosti velik potencial tudi kot konstrukcijski les, kar se v nekaterih primerih že izkazuje v praksi. Po nemškem tehničnem soglasju (Z-9.1-679, 2018) sta tako smrekov/bukov kot bukov lepljeni lamelirani les (GLT–ang. glued laminated timber) odobrena za uporabo v konstrukcijske namene v okviru razreda uporabnosti 1, skladno z EN 1995-1-1. Ena od možnih in morda bolj smotrnih uporab bukovine pa je njena uporaba za nosilne elemente iz lepljenega furnirja t.i. slojnat furnirni les ali LVL (ang. laminated veneer lumber). Razred uporabnosti 1 predvideva uporabo bukovine le v notranjih oz. pokritih prostorih, kjer se ne pričakuje dlje časa trajajoče visoke relativne zračne vlažnosti. Pogoj je predvsem posledica dimenzijske nestabilnosti bukovine ter posledic, ki jih le-ta prinaša za lepilni spoj. Zaradi dimenzijske nestabilnosti ima namreč bukovina precej višje stopnje delaminacije pri standardnih delaminacijskih testih (EN 14080:2013, aneks C), kar za npr. lepljenje s poliuretanskim lepilom (PUR) pogojuje uporabo vodne raztopine predpremaza pred lepljenjem. Uporaba le-tega podaljša čas priprave lepljencev pred stiskanjem, saj je potrebna njegova aktivacija po nanosu (ca 10 min), potreben čas stiskanja pa je podvojen glede na lepljenje brez predpremaza, kar posledično podaljša in podraži tudi proces same izdelave lepljenca (Bamokina Moanda et al., 2022). V preteklosti je bilo izvedenih že več raziskav na temo obdelave površine, ki bi izboljšala lepljenje bukovine brez uporabe predpremaza. Moanda in sodelavci (2022) so preiskovali vpliv t.i. »mikrostrukture«, ki so jo dosegli z uporabo posebnih skobeljnih nožev, vendar so bili rezultati celo slabši od klasične obdelave površine s skobljanjem. Obširno študijo glede različnih obdelav lesa pred lepljenjem so izvedli tudi Kläusler in sodelavci (2014), le-ta je pokazala, da sta t.i. čelno skobljanje (ang. face milling) in brušenje površine rezultirala v večjem deležu loma po lesu lepilnih spojev. Novejša študija (Hänsel et al., 2023) je pokazala podobne rezultate in potrdila prednosti čelnega skobljanja.

Pojav rdečega srca pri bukvi je dokaj pogost, nastanek le-tega pa je v večini primerov posledica mehanskih poškodb drevesa (npr. odlom veje), kar je v primeru vetrolomov in snegolomov neizbežno (Torelli, 2001). Na območju rdečega srca je zaradi otiljenja trahej zmanjšana permeabilnost lesa, kar bi lahko vplivalo na kakovost lepljenja. Na površini diskoloriranega lesa je vrednost pH malenkost višja, vendar lahko to pri procesu lepljenja zanemarimo (Schmidt et al., 2012). Na temo lepljenja tovrstnega lesa je bilo narejenih že nekaj raziskav, npr. Aicher (2006), Ohnesorge (2010) in Schmidt (2010). Fašalek (2019) v svojem delu povzema več raziskav na temo lepljenja neobarvane in diskolorirane bukovine, kjer je v splošnem ugotovljeno, da ima rdeče srce lahko vpliv na večjo stopnjo delaminacije lepilnih spojev, vendar se ob ustrezno daljšem času stiskanja le-ta zmanjša, nasprotno pa je več raziskav potrdilo, da pojavnost rdečega srca ne vpliva na rezultate preskusov strižne trdnosti lepilnih spojev.

Glede na omenjene raziskave različnih obdelav površine bi uporaba plazme v primeru izdelave lepljencev lahko predstavljala praktično rešitev za implementacijo v industriji, saj je učinek plazme takojšen (ni aktivacijskega časa), naprava pa bi lahko bila nameščena neposredno v liniji za skobeljnim strojem. Plazma je delno ali popolnoma ioniziran plin, ki vsebuje ione, elektrone, reaktivne spojine, radikale in fotone. Plazmo lahko ustvarimo z napravami preko termalne ali pa elektromagnetne energije (Fridman, 2008; Gurnett & Bhattacharjee, 2005; Tendero et al., 2006). Tvorjeno plazmo lahko delimo na termične in netermične razelektritve. Pri termičnih razelektritvah so elektroni in drugi plinski delci v termodinamskem ravnovesju, kar pomeni, da imajo vsi delci podobno energijsko porazdelitev. Nasprotno pa so pri netermičnih razelektritvah elektroni nosilci večine energije, medtem ko plinski delci ostajajo pri znatno nižjih energijskih nivojih (Fridman, 2008; Kim, 2004; Kogelschatz, 2003; Samal, 2017). Temperatura netermične plazme lahko zaradi temperaturnega neravnovesja ostane na manj kot 10 °C nad sobno temperaturo in je tako primerna za obdelavo bioloških ter drugih toplotno občutljivih materialov (Fridman, 2008; Kogelschatz, 2003; Shin et al., 2022; Weltmann et al., 2010). Lahko se generira pri podtlaku ali pa pri atmosferskem tlaku (ATNP) (Viöl et al., 2012).

V določenih industrijskih panogah je, zaradi obsega obdelovalnih površin, najbolj uporabna ATNP. Uporablja se predvsem za predpripravo površine, kot npr. čiščenje in razmaščevanje. Plazemsko aktiviran plin ima zelo visoko energijo delcev, ki v stiku s površino omogočajo ter pospešujejo kemijske reakcije. Trki z reaktivnimi delci pa povzročijo migracijo atomov, desorpcijo nečistoč, cepitev kemijskih vezi, polimerizacijo, oksidacijo površine itd. (Blanchard et al., 2009). S plazmo tudi aktiviramo površino, zvišamo njeno hidrofilnost ter omogočimo nastanek kisikovih reaktivnih zvrsti, kot so ozon, hidroksidni ion, vodikov peroksid, hidronijev ion in drugi (Klébert et al., 2022; Thanu et al., 2019).

V atmosferskem tlaku poznamo več načinov generiranja ATNP, med katerimi so najpogostejše razelektritve s korono, dielektrična barierna razelektritev (DBD) in plazemski curek (Cvelbar, 2007). Slednji lahko vključuje različne vrste konfiguracij, kar vpliva na močno razlikovanje med fizičnimi in kemijskimi lastnostmi generirane plazme (Penkov et al., 2015). Plazemski curek zaradi svoje oblike premaguje ovire omejenosti v delovnem prostoru (npr. ukrivljenost površine), slabost take konfiguracije pa je omejitev velikosti površine, ki jo lahko obdelamo (posledica velikosti šobe). V tej študiji smo se odločili za uporabo sistema s plazemskim curkom, ki je podoben plazemski razelektritvi drsnega loka, saj se ta najpogosteje uporablja v različnih industrijah (PlasmaTreat OpenAir).

ATNP je zaradi opisanih lastnosti primerna tudi za predobdelavo lesa (Žigon et al., 2018). Plazma ima pozitivne učinke na omočljivost površine in adhezijo premaznih sredstev in lepil na vodni osnovi (Žigon et al., 2019). Plazma očisti površino lesa ter jo oksidira, kar nakazuje povečana tvorba vezi ogljik-kisik, kot so npr. alkoholi in karboksilne skupine, ter zmanjšanje vezi med ogljikom in vodikom v celulozi, hemicelulozi in ligninu. Prav tako zaradi nastanka radikalov in anionov pride do večje polarnosti površine (Avramidis et al., 2009; Král et al., 2015). Učinkovitost plazemske obdelave se vrednoti z merjenjem stičnega kota med tangento na površino kapljice polarne ali nepolarne tekočine s stično površino. To je zanesljiva in enostavna metoda, ki hitro ovrednoti stanje površine obdelovanca po plazemski obdelavi. Določanje stičnega kota je možno tudi z uporabo lepila namesto vode, kar omogoča natančnejše določanje, kako sestava lepila, vključno z viskoznostjo in kemično sestavo, vpliva na stični kot (Shi & Gardner, 2001). Tovrstne meritve bi lahko opravili tudi s PUR lepilom, vendar bi bilo to zahtevnejše. Hkrati pa ima omočitev pri PUR lepilu manjši vpliv na končno trdnost spoja, saj je glavni mehanizem adhezije te vrste lepil kemična vez. Stični kot je odvisen od proste energije površine ter drugih lastnosti (Gardner et al., 1991).

Predobdelava lesa s plazmo je v prejšnjih študijah pokazala izboljšan oprijem poliuretanskih premazov (npr. Žigon, 2021a; Acda et al., 2012). Za poliuretanska lepila je bilo dokazano, da se po predobdelavi z nizkotlačno (Novák et al., 2015; Safin et al., 2021) in DBD plazmo povečuje oprijem (Žigon et al., 2021b). Izboljšan je tudi oprijem poliuretanskih lepil na plazemsko predobdelanih površinah lesno-plastičnih kompozitov (Nečasová et al., 2019). V nekaterih od teh primerov so bile izboljšave le zanemarljive (Safin et al., 2021). Povod za izvedbo raziskave je bilo pomanjkanje raziskav o vplivu plazemskega curka na kakovost lepilnih spojev s poliuretanskimi lepili.

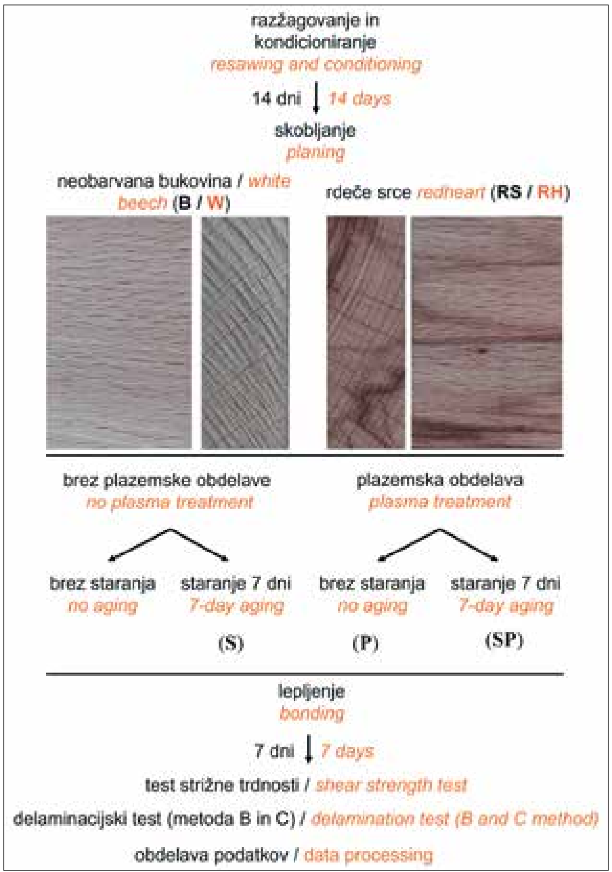
Cilj raziskave je bil proučiti možnosti izboljšanja kakovosti lepilnih spojev pri lepljenju konstrukcijskih lameliranih izdelkov iz bukovine s poliuretanskimi lepili. Pred lepljenjem trdih listavcev je namreč, za zadostitev določenih zahtev glede kakovosti zlepljenosti, potrebna uporaba vodne raztopine predpremaza, ki podaljša čas in poviša stroške izdelave lepljencev. Standard SIST EN 14080:2013 sicer ne določa obvezne uporabe predpremaza, saj je standard namenjen predvsem za lepljene lamelirane izdelke iz lesa iglavcev in topola, kjer uporaba predpremazov ni potrebna. Čeprav ta standard lahko uporabimo za lepljene lamelirane izdelke iz lesa trdih listavcev, pa ne omogoča označevanja takšnih izdelkov z oznako CE. V raziskavi je bila zato proučena uporaba plazemskega curka, ki izboljša omočljivost površine, kar omogoča takojšnjo pripravo na lepljenje. Tehnologija je primerna tudi za posodobitev obstoječe proizvodnje brez večjih predelav.

2 MATERIALI IN METODE
2 MATERIALS AND METHODS

Celoten postopek eksperimenta s ključnimi poudarki je predstavljen na sliki 1.

2.1 PRIPRAVA LEPLJENCEV
2.1 PREPARATION OF SAMPLES

Za izdelavo lepljencev smo uporabili les navadne bukve (*Fagus sylvatica* L.). Iz razpoložljivega materiala smo izbrali deske brez vidnih napak (grče, odklon vlaken, razpoke ipd.) ter razločili tudi med deskami neobarvane bukovine in bukovine z



Slika 1. Shema eksperimenta
Figure 1. Experiment flowchart

rdečim srcem. Za eksperiment smo izbirali deske s tangencialno in polradialno usmeritvijo vlaken na lepljeni površini. Najprej smo deske razžagali na lamele dimenzij 22 mm × 400 mm × 115 mm (debelina × dolžina × širina) nato pa lamele 14 dni kondicionirali v prostoru z normalnimi pogoji (T = 20 ± 2 °C, relativna zračna vlažnost = 65 ± 5 %). Dimenzije lamel smo določili na podlagi dimenzij preizkušancev, predpisanih v SIST EN 14080:2013, ki smo jih v nadaljevanju testirali. Po kondicioniranju smo vse lamele obojestransko poskobljali do končne debeline 20 mm, nato pa polovico lamel plazemsko obdelali s plazemskim pramenom, polovica pa jih je ostala neobdelanih ter pripravljenih na lepljenje. Del s plazmo obdelanih in neobdelanih lamel z debelino 20 mm smo pustili v prostoru z normalno klimo ter jih lepili po 7 dneh od mehanske obdelave površin. Lamele smo med seboj ločili, da sta bili obe ploskvi izpostavljeni zraku (ploskve lamel se niso stikale).

Plazemska obdelava je potekala s Plasmatreat Openair® enoto v podjetju Rogač Plus d. o. o. (Orehova vas, Slovenija). Za obdelavo lamel smo uporabili šobo RD1004 z nastavkom PTF570/1 z D4 izhodom, in generatorjem tipa FG5001 s parametri 250 V, 12,7 A, 21 kHz in PCT 100 %. Šoba je bila od lamel oddaljena 4 mm, hitrost premikanja šobe preko substrata pa je bila 10 m/min. Obdelane lamele smo zapakirali v aluminijasto folijo, saj smo s tem med prevozom zavarovali plazemsko obdelane površine pred nečistočami in zmanjšali deaktivacijo površine. Vrednotenje stičnega kota smo opravili s prenosnim merilnikom BTH Surface Analyst SA 5001. Merjenje stičnega kota je bilo zgolj informativne narave – za potrditev pravilno nastavljenih parametrov in spremljanja učinkovitosti obdelave. Opravljena je bila po ena meritev na serijo, pri čemer je bila le-ta opravljena na mestu, kjer ni bilo vidnih poškodb, grč ipd.

Dan po plazemski obdelavi smo lamele v stiskalnici zlepili s konstrukcijskim enokomponentnim poliuretanskim lepilom (Purbond HB S209, Loctite–Henkel), pri čemer smo upoštevali priporočena navodila proizvajalca lepila in standarda SIST EN 14080:2013. Lamele, ki niso bile plazemsko obdelane, smo lepili takoj po skobljanju. Podatki o karakteristikah lepljenja so podani v preglednici 1. Zlepili smo 12 štirislojnih lepljencev. Te smo 7 dni hranili v prostoru z normalnimi pogoji, nato pa iz njih izžagali preizkušance za strižni in delaminacijski preizkus. Za strižni preizkus smo potrebovali preizkušance dimenzij 100 mm × 48 mm × 48 mm ± 0,5 mm, za delaminacijski preizkus pa 100 mm × 105 mm × 75 mm ± 0,5 mm (debelina × dolžina × širina). Iz vsakega lepljenca smo izdelali po 4 strižne in po 2 delaminacijska preizkušanca.

2.2 TEST STRIŽNE TRDNOSTI
2.2 SHEAR STRENGTH TEST

Testiranje strižne trdnosti lepilnih spojev (opredeljeno v aneksu D standarda SIST EN 14080:2013) je potekalo na računalniško podprtem testirnem stroju Z100 (Zwick/Roell, Ulm, Nemčija). Vsak spoj na izbranih preizkušancih smo obremenili in v programu odčitali silo, potrebno za porušitev spoja ter vizualno ocenili delež loma po lesu na 10 % natančno (0, 10, 20 … 90, 100 %). Po eksperimentu je sledila statistična analiza pridobljenih podatkov.

Preglednica 1. Parametri lepljenja bukovih lamel s poliuretanskim lepilom.
Table 1. Bonding parameters of beech lamellae with polyurethane adhesive.

Lepilo / Adhesive	1C-PUR, HB S209, Loctite
Ročni nanos lepila / Manual adhesive application quantity	160 g/m² (enostranski nanos / one side application)
Tlak stiskanja / Press pressure	1 MPa
Pogoji stiskanja / Press conditions	23 °C, 53 % RZV / RH
Čas stiskanja / Pressing time	120 min

2.3 DELAMINACIJA LEPILNIH SPOJEV
2.3 DELAMINATION OF THE ADHESIVE JOINTS

Delaminacijski test smo izvedli v skladu s standardom SIST EN 14080:2013, aneks C. Standard predpisuje tri različne metode/režime impregnacije in sušenja (A, B in C). Pri izvedenem eksperimentu smo uporabili metodi B in C. Vsem metodam je skupna vakuumsko–tlačna impregnacija preizkušancev v vodi, kateri sledi sušenje v sušilni komori.

Preizkušance smo postavili v impregnacijsko komoro ter z distančniki iz HDPE mreže omogočili, da je destilirana voda prišla do vseh površin preizkušancev. Najprej smo vzpostavili podtlak, ki iz celic izsesa zrak in tako omogoči boljši tok vode v lumen celic, nato pa nadtlak, ki omogoči polnjenje celic z vodo. Po impregnaciji smo preizkušance sušili v sušilni komori pri predpisani temperaturi, vlažnosti in hitrosti gibanja zraka. Pri sušenju smo preizkušance razmaknili in čela obrnili vzporedno s tokom zraka ter s tem zagotovili enakomerno sušenje. Ko je masa preizkušancev dosegla 110 % začetne mase, smo izmerili stopnjo delaminacije posameznih spojev. Ocenitev delaminacije smo izvedli neposredno po sušenju na preizkušancih. Pred in po delaminaciji smo preizkušance optično prebrali z namiznim optičnim bralnikom. Po eksperimentu je sledila statistična analiza pridobljenih podatkov.

2.3.1 Delaminacijski test – metoda B
2.3.1 Delamination test – method B

Preizkušance smo stehtali in izmerili dolžino spojev, nato pa smo jih potopili v korito z destilirano vodo in ga vstavili v tlačno komoro. Najprej smo preizkušance 30 minut izpostavili podtlaku med 70 in 85 kPa, nato pa vzpostavili nadtlak med 500 in 600 kPa za 2 uri. Po impregnaciji smo preizkušance sušili pri temperaturi zraka 65–75 °C z relativno zračno vlažnostjo 8–10 % in hitrostjo zraka 2,5 m/s, med 10 in 15 ur oziroma tako dolgo, da je njihova masa dosegla 110 % začetne mase.

2.3.2. Delaminacijski test – metoda C
2.3.2 Delamination test – method C

Preizkušance smo stehtali in izmerili dolžino spojev, nato pa smo jih potopili v korito z destilirano vodo, ki smo ga vstavili v tlačno komoro. Najprej smo preizkušance 30 minut izpostavili podtlaku med 70 in 85 kPa, nato pa vzpostavili nadtlak med 500 in 600 kPa za 2 uri. Sledil je ponoven cikel podtlaka in nadtlaka. Po impregnaciji smo preizkušance sušili 90 ur pri temperaturi zraka 25–30 °C z relativno zračno vlažnostjo 25–35 % in hitrostjo zraka 2,5 m/s.

3 REZULTATI IN DISKUSIJA
3 RESULTS AND DISCUSSION

Testirali in med seboj primerjali smo štiri različne metode obdelave površine pred lepljenjem. Obdelave smo primerjali tudi med obema tipoma bukovine. Testirali smo vpliv lepljenja na sveže skobljanem lesu (kontrola), en teden starem skobljanem lesu (staran), plazemsko obdelanem lesu, ki smo ga lepili en dan po obdelavi (plazma) ter en teden po obdelavi s plazmo (starana plazma). Način plazemske obdelave smo izbrali glede na velikost izmerjenega stičnega kota. Preglednica 2 prikazuje stični kot v različnih časovnih intervalih: takoj po plazemski obdelavi, 24 ur ter 7 dni po obdelavi. Kontaktne kote so izmerili v podjetju v različnih časovnih intervalih na referenčnih lamelah. Pred vsakim merjenjem stičnega kota so bile lamele odvite iz aluminijaste folije (enako kot pred lepljenjem). Opazimo lahko, da je vrednost stičnega kota pred obdelavo višja pri neobarvani bukovini, po obdelavi s plazmo pa sta vrednosti stičnega kota znatno manjši in dokaj podobni. Iz podatkov lahko opazimo postopno povečevanje stičnega kota po enem in sedmih dneh po obdelavi. Nižje vrednosti stičnega kota predstavljajo boljšo omočljivost površine. Predpostavljamo, da se vrednost stičnega kota te-

Preglednica 2. Stični koti (CA) kapljice vode na bukovi lameli pred in po plazemski obdelavi (PO).
Table 2. Contact angle (CA) of water drop on beech lamellae surface before and after plasma treatment (PT).

CA	pred PO / before PT	po PO / after PT	24 ur po PO / 24h after PT	7 dni po PO / 7 days after PT
B / W	71°	25°	38°	45°
RS / RH	52°	29°	35°	49°

stnih lamel spreminja enako kot vrednost stičnega kota na lamelah, ki smo jih imeli shranjene v prostoru z normalnimi pogoji.

Pred merjenjem stičnega kota smo gravimetrično določili vlažnost ter gostoto lesa. Rezultati so prikazani v preglednici 3.

3.1 STRIŽNA TRDNOST LEPILNEGA SPOJA
3.1 SHEAR STRENGTH OF ADHESIVE JOINT

Analiza podatkov testa strižne trdnosti lepilnega spoja je pokazala, da plazemska obdelava ni imela vpliva na kakovost lepljenja. Sprva smo primerjali dosežene strižne trdnosti lepilnih spojev vseh štirih metod predobdelave lamel znotraj tipa bukovine.

Preglednica 3. Povprečna vlažnost in gostota lamel neobarvane bukve (B) in bukovih lamel z rdečim srcem (RS) s standardno napako.
Table 3. Average moisture content and density of normal "white" beech (W) and red heart (RH) beech wood lamellae with standard deviation.

CA	Vlažnost / moisture content [%]	Gostota / density [kg/m³]
B / W	11,0 ± 0,6	732 ± 45
RS / RH	13,1 ± 0,1	691 ± 10

Rezultati so prikazani v preglednici 4, kjer vidimo, da med povprečnimi strižnimi trdnostmi ni statistično signifikantnih razlik znotraj skupine (tip bukovine), kar je potrdil tudi test enosmerna ANOVA (n= 8–16, P > 0,05).

Sledila je primerjava metod predobdelav po parih, kjer smo primerjali kako predobdelave vplivajo na lepljenje testiranih tipov bukovine. Izvedena statistična analiza za primerjavo parov je bil Studentov t-test. Iz rezultatov v preglednici 4 opazimo, da metoda predobdelave površine nima statistično značilnega vpliva na vrsto bukovine (n = 8–16, P > 0,05). Plazemska obdelava ni pripomogla k boljšemu lepljenju, prav tako tudi en teden star skobljan

Preglednica 4. Rezultati testa strižnih trdnosti s povprečnimi vrednostmi in standardno napako (SE) z dodanimi rezultati enosmerne ANOVA (eA) za metode predobdelave znotraj tipa bukovine, skupnim Studentovim t-testom (Stt sk.) za primerjavo vseh metod znotraj tipa bukovine med neobarvano bukovino (B) in bukovino z rdečim srcem (RS) ter Studentov t-test (Stt) za primerjavo metode predobdelave med tipoma bukovine. (*) P < 0,05
Table 4. Results of the shear strength test with added results of one-way ANOVA (eA) for pre-treatment methods within beech wood type, combined Student's t-test (Stt comb.) for comparison of all methods within beech wood type between white (W) and red heart (RH) beech wood, and Student's t-test (Stt) for comparison of pre-treatment methods between beech wood types. (*) P < 0.05

	Kontrola / control (n= 16)		**Plazma / plasma (n= 16)**		**Staranje / aged (n= 8)**		**Starana plazma / aged plasma (n= 8)**		***P* (eA)**	**Post Hoc Tukey test**	***P* (Stt sk.)**
	povp./ mean [MPa]	SE [MPa]	povp./ mean [MPa]	SE [MPa]	povp./ mean [MPa]	SE [MPa]	povp. / mean [MPa]	SE [MPa]			
B / W	**13,74**	0,297	**13,40**	0,295	**13,44**	0,528	**13,01**	0,402	> 0,05	-	0,0067*
RS / RH	**12,97**	0,285	**12,91**	0,267	**12,51**	0,282	**12,71**	0,209	> 0,05	-	
P (Stt)	> 0,05		> 0,05		> 0,05		> 0,05				

les nima slabših lepilnih sposobnosti od sveže skobljanega lesa.

Večina lepilnih spojev pri vseh načinih predobdelave pri obeh tipih bukovine dosega zadostno strižno trdnost, ki jo narekuje standard SIST EN 14080:2013, kjer je navedeno, da mora povprečna strižna trdnost lepilnih spojev (ob ustreznem odstotku loma po lesu) po enem tednu pri sobnih pogojih dosegati vsaj 6 N/mm² (= 6 MPa). Dobljene vrednosti strižne trdnosti so pričakovano višje, kot v primeru iglavcev, in primerljive z vrednostmi, ki jih je dosegel Pecman (2016) – 13,5 do 13,9 MPa, vendar nižje od vrednosti, ki jih je dosegel Luedtke (2015) – 19,6 do 22,3 MPa. Rezultati strižne trdnosti lepilnega spoja so grafično predstavljeni na sliki 2.

3.2 OCENA LOMA PO LESU PO TESTU STRIŽNE TRDNOSTI

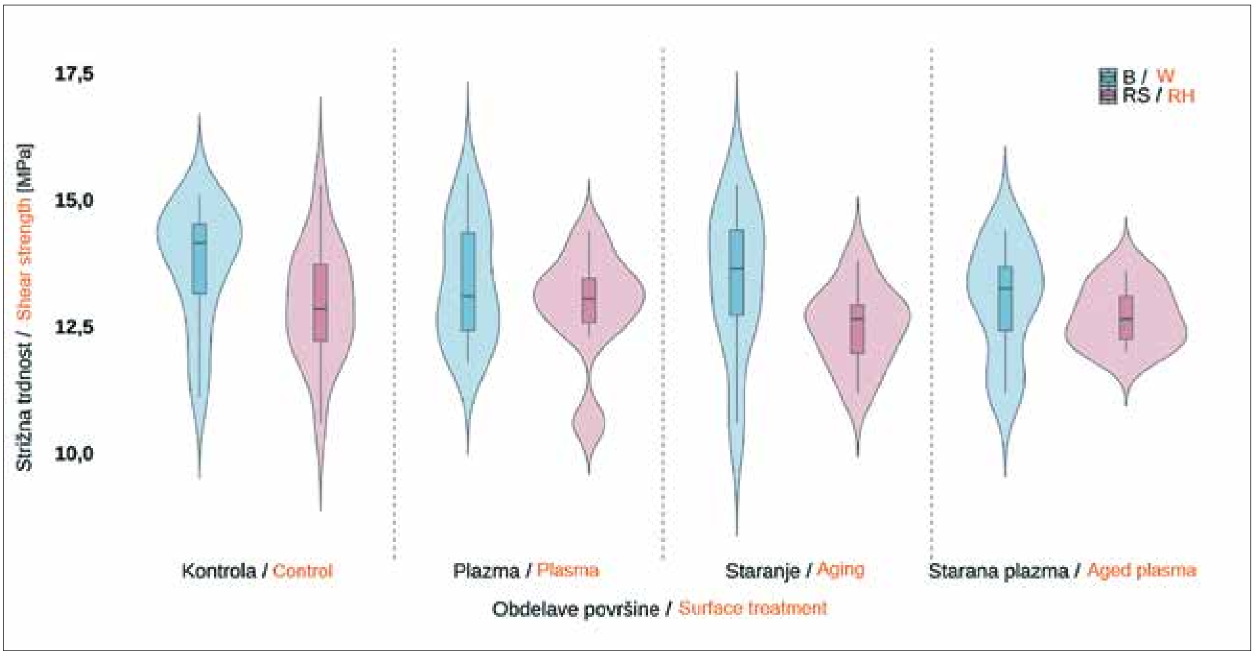
3.2 EVALUATION OF PERCENTAGE OF WOOD FAILURE AFTER SHEAR STRENGTH TEST

Lom po lesu je bil ocenjen neposredno po strižnem testu spoja. Ocenjevali smo ga vizualno z opazovanjem in zaokroževali na deset procentov natančno. V preglednici 5 so strnjeni rezultati loma po lesu, kjer smo z enosmernim ANOVA testom primerjali metode predobdelave znotraj tipa bukovine. Opazimo, da znotraj tipa bukovine ni statistično značilne razlike med metodami predobdelave ($n = 8–16$, $P > 0,05$), Studentov t-test vseh metod znotraj tipa bukovine pa je pokazal, da je med njima statistično značilna razlika ($n = 48$, $P = 4.31e^{-9}$). Na podlagi tega lahko zaključimo, da ima bukovina z rdečim srcem višje deleže loma po lesu kot neobarvana bukovina.

Razlike med metodami predobdelave je pokazal tudi parni test med tipoma bukovine, kjer je statistična značilna razlika pri vseh metodah predobdelave.

Če primerjamo strižno trdnost in lom po lesu rdečega srca (slika 3, zgoraj), en rezultat pade pod mejo standarda EN 14080:2013, en pa je mejen, vendar le-ta ustreza predlogu zahtev, ki jih za listavce predlagata Aicher in Ohnesorge (2011). Pri rezultatih neobarvane bukovine (slika 3, spodaj) opazimo, da 9 rezultatov ne pride v okvir zahtev standarda, vendar pa so le-ti na meji predloga zahtev, 10 rezultatov pa je na meji zahtev standarda.

Ugotovili smo, da je odstotek loma po lesu višji pri preizkušancih iz rdečega srca v primerjavi s preizkušanci iz neobarvane bukovine. Nasprotno pa vrednosti strižne trdnosti, ki so manjše za približno 1 MPa, kažejo na to, da je strižna trdnost



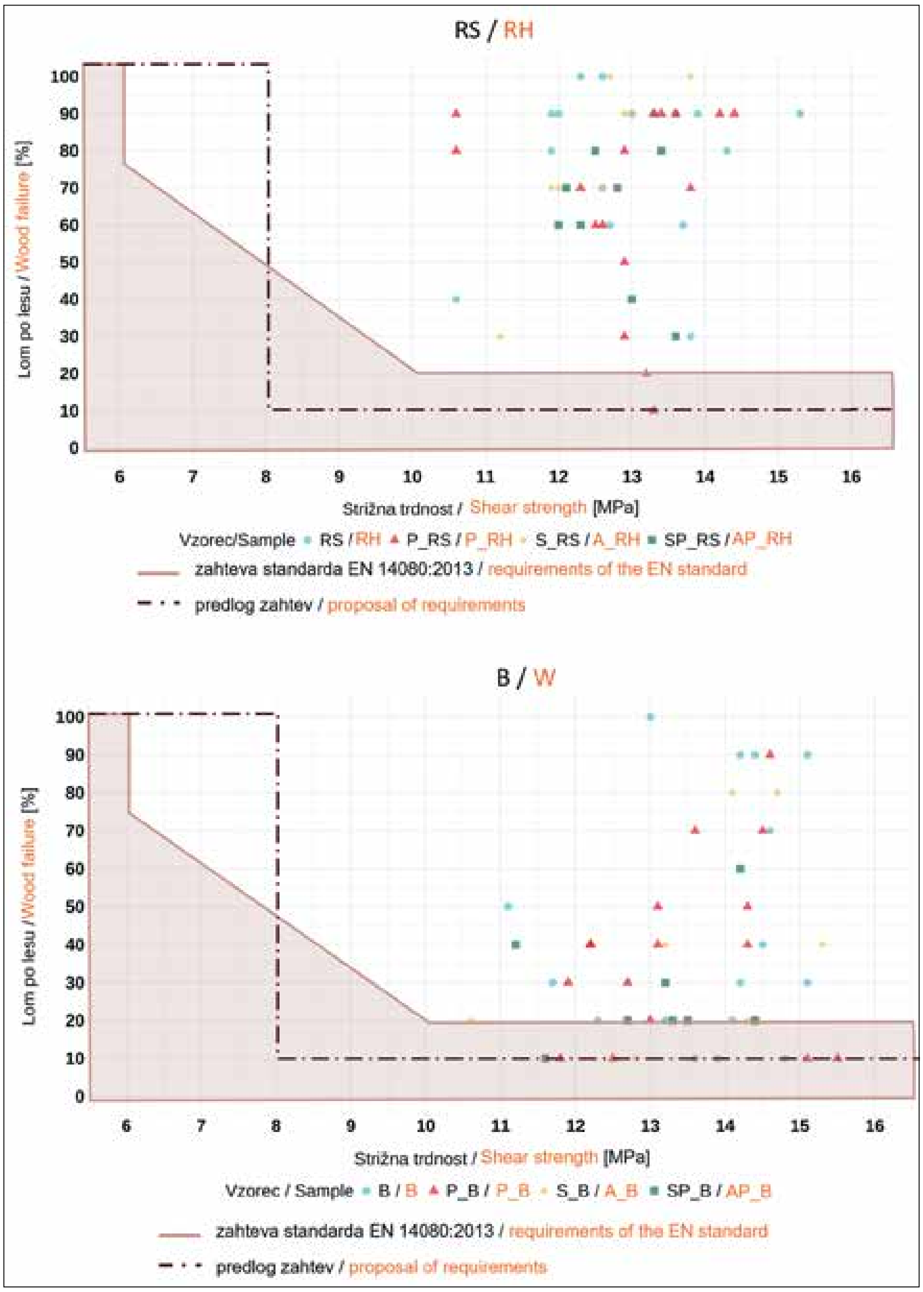
Slika 2. Vrednosti strižne trdnosti po skupinah (kontrola, plazemska obdelava, staranje, starana plazma) za neobarvano bukev (B) in rdeče srce (RS).

Figure 2. Shear strength values by groups (control, plasma treatment, aging, aged plasma) for white beech (W) and red heart (RH).

bukovine z rdečim srcem nižja od strižne trdnosti neobarvane bukovine. Slednje bi lahko potrdili ali ovrgli s strižnim preizkusom lesa. V našem primeru bi lahko vzrok za nižjo strižno trdnost iskali v nekoliko višji vlažnosti lesa z rdečim srcem, kar se običajno kaže v nižji tlačni trdnosti lesa (Fu et al., 2021). Vlažnost lesa smo sicer določali iz odrezkov po končnem razžagovanju lamel, kar pomeni, da so lahko bili preizkušanci ob testu že uravnovešeni na enako vlažnost. Razlog za manjše vrednosti strižne trdnosti bi lahko bila tudi nižja gostota lesa rdečega srca (preglednica 3). Poleg lastnosti lesa pa bi na rezultate lahko vplivala tudi orientiranost lamel.

3.3 DELAMINACIJA LEPILNIH SPOJEV
3.3 DELAMINATION OF ADHESIVE JOINTS

Rezultati delaminacije lepilnih spojev so zbrani v preglednici 6. Najprej smo eksperiment izvedli po metodi B v skladu s standardom EN 14080:2013. Med seboj smo primerjali metode predobdelave znotraj tipa bukovine (preglednica 6). Ugotovili



Slika 3. Soodvisnost posameznih meritev strižne trdnosti in loma po lesu za neobarvano bukovino in rdeče srce, skupaj z okvirjem standarda EN 14080:2013 (polna črta) in predlogom zahtev Aicherja in Ohnesorgeja (črtkana črta). B- neobarvana, RS – rdeče srce, P-plazma, S – starana, SP – starana plazma.

Figure 3. Correlation of individual measurements of shear strength and wood fracture for white beechwood and red heartwood, along with the framework of the EN 14080:2013 standard (solid line) and the proposed requirements by Aicher and Ohnesorge (dashed line). B–white, RS–red heartwood, P–plasma, A–aged, AP–aged plasma.

Preglednica 5. Rezultati loma po lesu po strižnem testu z dodanimi rezultati enosmerne ANOVA (eA) za metode predobdelave znotraj tipa bukovine, skupnim Studentovim t-testom (Stt sk.) za primerjavo vseh metod znotraj tipa bukovine med neobarvano (B) in bukovino z rdečim srcem (RS) ter Studentov t-test (Stt) za primerjavo metode predobdelave med tipoma bukovine. (*) P < 0,05, (***) P > 0,001

Table 5. Results for wood failure in percentage terms after the shear strength test with added results of one-way ANOVA (eA) for pre-treatment methods within the beech wood type, combined Student's t-test (Stt comb.) for comparison of all methods within the beech wood type between white (W) and red heart (RH) beech wood, and Student's t-test (Stt) for comparison of pre-treatment methods between beech wood types. (*) P < 0.05, (**) P > 0.001

	Kontrola / control (n= 16)		**Plazma / plasma (n= 16)**		**Staranje / aged (n= 8)**		**Starana plazma / aged plasma (n= 8)**		***P* (eA)**	**Post Hoc Tukey test**	***P* (Stt sk.)**
	povp. / mean [%]	SE [%]	povp./ mean [%]	SE [%]	povp./ mean [%]	SE [%]	povp. / mean [%]	SE [%]			
B / W	**44,4**	8,2	**38,1**	6,0	**37,5**	10,1	**27,5**	5,6	> 0,05	-	$4{,}31e^{-9}$ ***
RS / RH	**78,1**	5,2	**66,9**	6,7	**77,5**	8,2	**61,3**	6,4	> 0,05	-	
P (Stt)	0,0015*		0,0032*		0,0083*		0,0014*				

smo, da med metodami predobdelave pri neobarvani bukovini ni razlik (Kruskal-Wallisov test, n = 2–4, P > 0,05), pri rdečem srcu pa zaznamo statistično značilno razliko med metodami (P = 0,036). Največjo stopnjo delaminacije so imeli preizkušanci, katerih lamele so bile obdelane s plazmo, najmanjšo pa vzorci, pri katerih je med lepljenjem in skobljanjem minil en teden (Post Hoc Dunnov test).

Na podlagi rezultatov iz metode B smo se odločili, da izvedemo tudi metodo C istega standarda. Iz rezultatov v preglednici 6 opazimo, da se ne razlikujejo bistveno od rezultatov metode B. Znotraj metod predobdelave pri neobarvani bukovini ni statistično značilnih razlik, so pa znotraj rdečega srca. Statistična analiza je bila opravljena po Kruskal-Wallisovem testu, pri rdečem srcu pa dodatno še po Post Hoc Dunnovem testu. Dodatno je bil opravljen še t-test, kjer smo med seboj primerjali vrednosti delaminacije po metodi B in C. Statistično značilna razlika (P = 0,012) je le za kontrolo neobarvane bukovine, kjer je delaminacija nižja pri metodi C, v primerjavi z metodo B. Drugje test ni pokazal statistično značilne razlike.

Standard SIST EN 14080 predpisuje, da je skupna delaminacija lepilnih spojev za metodo B maksimalno 4 oz. 8 %, za metodo C pa 10 %. Vsi naši preizkušanci so izkazovali bistveno večjo delaminacijo in niso zadostili zahtevam standarda. Razlog za preveliko delaminacijo bi lahko bila usmeritev vlaken med dvema zlepljenima lamelama (po standardu so to tangencialne lamele) in s tem povezano generiranje visokih napetosti med testom delaminacije. Orientacijo lahko opazujemo na sliki 4, kjer je opazna tudi delaminacija po sušenju. Večina lamel RS je bila bolj radialno orientiranih, kar bi lahko botrovalo k večji stopnji delaminacije. Nekaj lamel pri neobarvani bukovini je bilo povsem tangencialnih (slika 4a), kjer pa opazimo, da imata zgornji in spodnji lepilni spoj precej večjo stopnjo delaminacije kot srednja dva, kljub uporabi tangencialnih lamel. Glede na podatke iz literature (preglednica 7), so stopnje delaminacije v našem primeru večje. V literaturi smo iskali samo rezultate testov, kjer je bilo uporabljeno Purbond lepilo (lepilo proizvajalca Loctite–Henkel).

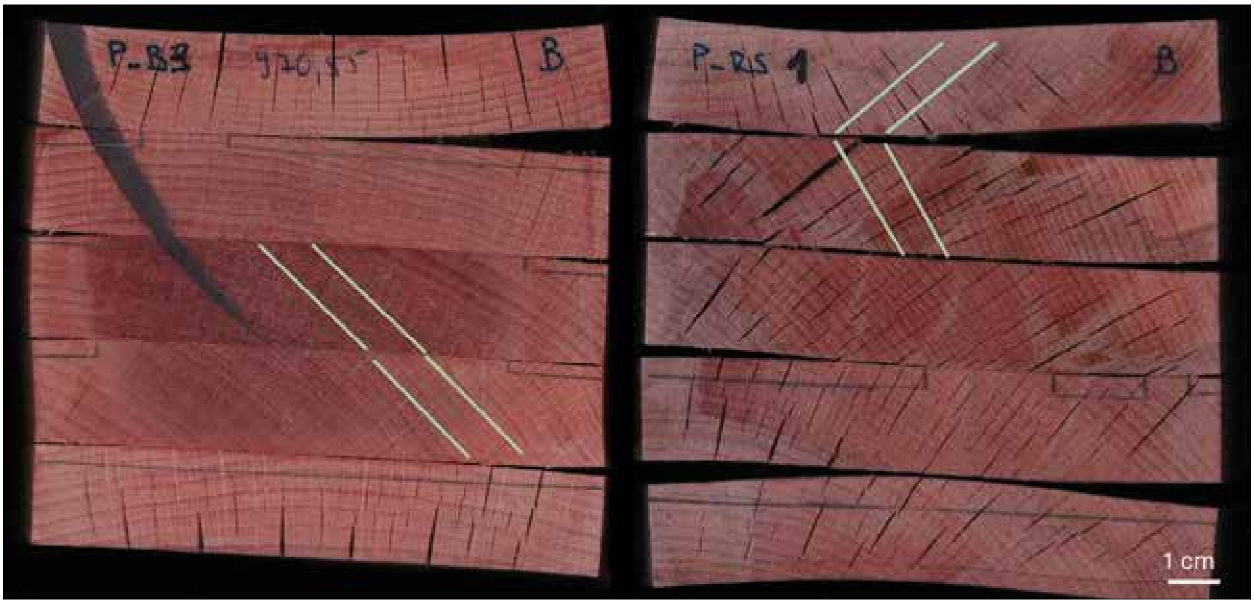
4 ZAKLJUČEK
4 CONCLUSIONS

Pri testu strižne trdnosti lepilnih spojev smo pri bukovini z rdečim srcem zaznali večji delež loma po lesu, vendar je bila strižna trdnost teh spojev nižja kot pri neobarvani bukovini.

Obdelava s plazmo je prispevala k znižanju stičnega kota – plazma izboljša omočitev površine, kar

Preglednica 6. Rezultati delaminacije lepilnih spojev po metodi B in C po standardu EN 14080:2013 z dodanimi rezultati Kruskal-Wallisovega testa (KW) za metode predobdelave znotraj tipa bukovine, Post Hoc Dunnovega testa za podatke, kjer je P < 0,05, ter Studentovega t-testa (Stt) za primerjavo metode predobdelave med tipoma bukovine (B – dela, RS – rdeče srce). (*) P < 0,05
Table 6. Results of the delamination of adhesive joints according to Methods B and C of the EN 14080:2013 standard, with additional results from the Kruskal-Wallis test (KW) for pre-treatment methods within the beech wood type, post-hoc Dunn's test for data where P < 0.05, and Student's t-test (Stt) for comparing the pre-treatment method between the beech wood types (W – white beech, RH – red heart beech). (*) P < 0.05

	Kontrola / control (n= 4)		Plazma / plasma (n= 4)		Staranje / aged (n= 2)		Starana plazma / aged plasma (n= 2)		*P* (KW)	Post Hoc Dunn test
Met. B	povp./ mean [%]	SE [%]	povp./ mean [%]	SE [%]	povp./ mean [%]	SE [%]	povp./ mean [%]	SE [%]		
B / W	**88,6**	5,58	**91,3**	7,24	**71,2**	8,99	**79,7**	7,63	> 0,05	-
RS /RH	**57,9**	5,59	**87,94**	3,31	**47,65**	6,46	**86,7**	1,42	0,036*	P ≥ SP ≥ K > S
P (Stt)	> 0,05		> 0,05		> 0,05		> 0,05			
Met. C	povp./ mean [%]	SE [%]	povp./ mean [%]	SE [%]	povp./ mean [%]	SE [%]	povp./ mean [%]	SE [%]		
B / W	**82,1**	3,79	**84,1**	4,65	**50,3**	5,96	**91,7**	2,54	> 0,05	-
RS / RH	**77,1**	3,30	**95,1**	1,57	**73,1**	2,59	**91,7**	0,35	0,028*	P ≥ SP ≥ K > S
P (Stt)	> 0,05		> 0,05		> 0,05		> 0,05			



Slika 4. Preizkušanca po delaminacijskem testu z vidnim potekom branik (zelene črte).
Figure 4. Test specimen after the delamination test. Green lines indicate the direction of the growth rings.

Preglednica 7. Delaminacija lepilnih spojev bukovih nosilcev, lepljenih s Purbond lepili brez uporabe predpremaza.
Table 7. Delamination of adhesive joints in beech joints bonded with Purbond adhesive without the use of a primer.

Avtor, uporabljeno lepilo / Author, adhesive used	Delaminacija / delamination (%)
(Luedtke et al., 2015), HB S109	metoda B normalen čas stiskanja: 62, 66 podvojen čas stiskanja: 40, 50
(Bamokina Moanda et al., 2022), HB S109	metoda B med 30 in 50 za skobljano površino, nad 60 za mikrostrukturirano površino
(Pecman et al., 2016), HB S209	metoda A:71, metoda B:62, metoda C:52

pa ni imelo vpliva na kvalitetnejše lepljenje s PUR lepilom.

Enotedensko staranje lepilne površine ni negativno vplivalo na rezultate strižnega preizkusa. Starana površina je imela nepričakovano boljše rezultate delaminacije. Upoštevati je potrebno, da smo za delaminacijo uporabili le 2 preizkušanca starane površine in je zato rezultat v okviru statistične variabilnosti lastnosti lesa.

Stopnje delaminacije po postopkih B in C se le malenkost razlikujejo, po obeh metodah pa ne dosegamo vrednosti, ki jih določa standard SIST EN 14080:2013.

Glede na to, da je uporaba plazme dokazano koristna v aplikacijah, kjer se uporabljajo vodotopni premazi ter lepila, ki vsebujejo vodo, bi bilo smiselno izvesti podoben eksperiment s konstrukcijskim melamin-urea-formaldehidnim (MUF) lepilom, kjer bi imela boljša omočitev verjetno večji vpliv na kakovost lepljenja.

5 POVZETEK
5 SUMMARY

This study explores the effects of plasma surface treatment on the bonding of European beech (*Fagus sylvatica*) wood with structural one-component polyurethane (PUR) adhesive. A focus is placed on two types of beech: non-discoloured beech and red-heart beech, the latter known for its distinct colouration in the central part of a stem. The research aimed to assess the effectiveness of plasma treatment on these woods, with shear strength and delamination tests performed in accordance with the related standards. The use of wood as a construction material is increasingly favoured due to its potential to reduce CO_2 emissions. In Slovenia, beech has become the predominant tree species in forests, though Norway spruce (*Picea abies*) is commonly used in construction nowadays. While beech is often used for furniture and energy purposes, its mechanical properties suggest it has potential as a structural material. However, beech's tendency to swell and shrink with changes in moisture more than the commonly used spruce creates challenges for adhesive bonding, often resulting in higher delamination, particularly when polyurethane adhesives are applied. Plasma treatment is considered a possible solution, offering immediate surface activation without the delays associated with traditional priming processes. Lamellae of non-discoloured and discoloured beech wood were conditioned, planed and then treated with a plasma jet system in the study. Plasma treatment is recognized as enhancing the surface properties of materials, including wood, by increasing wettability — a critical factor for effective bonding. Following plasma treatment, the lamellae were bonded with PUR adhesive, and the adhesive joints were tested for shear strength and resistance to delamination. Additionally, the effects of surface aging were explored by bonding some lamellae one week after treatment. The results indicated that while the plasma treatment improved the wettability of the wood surfaces, as evidenced by a reduced contact angle of water droplets, this improvement did not result in better bonding performance with PUR adhesive. Shear strength tests showed no significant enhancement in the adhesive joints, regardless of whether the wood had undergone plasma treatment. Interestingly, a higher wood failure percentage was demonstrated by red-heart beech in shear tests, but with lower overall shear strengths compared to common beech. The aging of treated surfaces for a week did not negatively affect shear strength, suggesting that plasma treatment's effects on surface chemistry are relatively stable over short periods. Delamination testing revealed that none of the samples met the standard

requirements, which specify maximum allowable delamination rates for adhesively bonded wood joints. Particularly high delamination rates were observed in plasma-treated samples of red-heart beech, even exceeding those of untreated samples in some instances. This suggests that while plasma treatment can modify surface properties to make them more receptive to adhesives, it does not necessarily guarantee improved long-term bonding performance, especially with PUR adhesives. Increased moisture content likely contributed to the lower shear strength observed in red-heart beech joints, underscoring the need for longer conditioning prior to adhesive bonding processes. The study's results indicate that although plasma treatment is beneficial for increasing wettability, it may not sufficiently address the bonding challenges associated with beech wood when using PUR adhesives. Ultimately, it is suggested by the research that exploring alternative adhesives, such as melamine-urea-formaldehyde (MUF), might yield better results, since these water containing adhesives could potentially benefit more from the improved surface wettability provided by plasma treatment. Additionally, the orientation of wood grain appears to influence delamination outcomes, as variations in lamella alignment could affect stress distribution and failure modes during testing. The nuanced interactions between wood surface treatments and adhesives are underscored by this study, emphasizing the importance of tailored bonding strategies to suit the specific properties of wood species like beech. Future work should aim to refine plasma treatment protocols and test different adhesive formulations, potentially paving the way to achieving durable and reliable bonds in beech wood applications, especially in structural uses where adhesive performance is critical. Understanding these dynamics will be essential in advancing the use of wood as a sustainable construction material, in line with broader environmental goals.

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PHYSICAL AND MECHANICAL PROPERTIES OF THE STEM AND BRANCH WOOD OF WEST AFRICAN EBONY (*Diospyros mespiliformis*)

FIZIKALNE IN MEHANSKE LASTNOSTI LESA DEBLA IN VEJ ZAHODNOAFRIŠKE EBENOVINE (*Diospyros mespiliformis*)

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Abstract / Izvleček

Abstract: This study examines the physical and mechanical properties of the sapwood and heartwood of the stem and branch wood of the West African ebony (*Diospyros mespiliformis*) to determine if the branch wood can be used for various products. Three mature *Diospyros mespiliformis* trees with stem diameters at breast height ranging from 50 to 65cm and branch diameters from 25 to 40 cm were purposively selected and felled. Wood samples were prepared to the exact sizes in accordance to the chosen standards, tested, and analysed. The results showed that wood density was insignificantly higher in the stem wood (551 kg/m³) than the branch wood (513 kg/m³). Radially, the heartwood had higher density than the sapwood for both stem wood and branch wood. The Modulus of Elasticity (MOE) was higher in the branch part (7066 MPa) than stem part (1903 MPa), and the sapwood recorded higher MOE for both stem wood and branch wood. Moreover, the Modulus of Rupture (MOR) had a similar result, with the stem part showing a higher average MOR (61 MPa) than the branch part (52 MPa), the sapwood had higher values as compared to its corresponding heartwood. The same trend was observed for the compression strength as well as Janka hardness. In general, it was shown that the branch wood could equally perform well when used as a supplement to the stem wood.

Keywords: *Diospyros mespiliformis* = West African ebony, stem, branch, heartwood, sapwood, physical properties, mechanical properties

Izvleček: V študiji obravnavamo fizikalne in mehanske lastnosti beljave in jedrovine lesa debla in vej zahodnoafriške ebenovine (*Diospyros mespiliformis*), da bi ugotovili, ali se lahko les vej uporablja za različne izdelke. V ta namen so bila izbrana in posekana tri zrela drevesa ebenovine s premerom debel v prsni višini 50–65 cm in premerom vej 25–40 cm. Vzorci lesa so bili pripravljeni in analizirani v skladu z izbranimi standardi. Rezultati so pokazali, da je bila gostota lesa višja v lesu debla (551 kg/m³) kot v vejah (513 kg/m³). Jedrovina je imela višjo gostoto kot beljava tako v deblu kot v vejah. Modul elastičnosti (MOE) je bil višji v vejah (7066 MPa) kot v deblu (1903 MPa), beljava je imela višji MOE, tako v vejah kot tudi v deblu. Poleg tega je upogibna trdnost (MOR) v deblu znašala 61 MPa in v vejah 52 MPa, beljava pa je imela višje vrednosti kot jedrovina. Enak trend je bil opažen za tlačno trdnost in trdoto po Janki. Na splošno je les debla nekoliko boljši in se manj krči kot les vej, vendar razlike niso bile statistično značilne, kar nakazuje, da bi lahko veje uporabljali kot dodatek lesu debla.

Ključne besede: *Diospyros mespiliformis* = zahodnoafriška ebenovina, deblo, veje, jedrovina, beljava, fizikalne lastnosti, mehanske lastnosti

1 INTRODUCTION
1 UVOD

The need for environmental sustainability and the demand for durable materials in the furniture and construction industries has sparked growing interest among academics, policymakers, NGOs, and development practitioners in the use and explora-

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tion of lesser-known wood species for various uses (Acheampong et al., 2024; Tampori et al., 2024). Among the species of interest is the West African ebony *Diospyros mespiliformis* with substantial ecological and economic potential in both developed and developing countries (PROTA4U, 2024).

The International Union for Conservation of Nature (IUCN, 2022) reported that the global market for *Diospyros crassiflora* (ebony) wood is valued at approximately US$200 million annually. In Ghana, the economic contribution of forests and woods is significant, with the timber and logging industry contributing about US$1.19 billion to the Gross Domestic Product (GDP) in 2020 (Statista, 2023). This economic growth and the need to sustainably manage forest resources could further be accelerated given the potential of ebony branch wood.

Ghana is home to several species of *Diospyros* (commonly known as ebony), with *Diospyros crassiflora,* African ebony, being one of the most notable species. African ebony is highly sought after for its dense, black heartwood, used in high-end products such as musical instruments (e.g., piano keys, guitar fingerboards), sculptures, and luxury furniture. Historically, it has been one of the most valuable export woods from Ghana, contributing significantly to the development of the timber industry. The rarity and quality of African ebony make it a prized material on international markets. Due to over-exploitation, however the availability of African ebony in Ghana has diminished, leading to stricter regulations on its harvesting, and the International Union for Conservation of Nature (IUCN) Red List thus classifies *Diospyros* as vulnerable, largely because of unsustainable logging and habitat loss. As such, sustainable logging practices, including the encouragement of plantations and reduced illegal logging, are being promoted to protect ebony populations.

Diospyros mespiliformis is found across Sub-Saharan Africa, from Senegal in the west to Sudan and South Africa in the east and south. It is widely distributed in savanna woodlands and riparian zones (InsideWood, 2024). *Diospyros mespiliformis* is drought resistant, enabling the trees to thrive in the Savannah ecological zone of Ghana. Its wood is used locally for construction, furniture, tool handles, and firewood. The heartwood is black or dark brown, while the sapwood tends to be lighter. The distinct separation between heartwood and sapwood is a notable characteristic, with more variation in colour and grain patterns. The wood of *Diospyros mespiliformis* is similar to that of *Diospyros crassiflora,* but the wood properties may greatly vary among the species and geographical origin (CIRAD, 2024).

Wood, as defined by Rosenkilde (2002), is a versatile material made up of cellulose, lignin, and hemicelluloses, forming a natural composite that is both strong and flexible. Technically, the term "wood" encompasses all parts of the tree, including the branches, stem, and roots (Yisa et al., 2021). Each tree part possesses unique characteristics that can influence its suitability for various applications by woodworkers and industry. For instance, Tarelkin et al. (2019) emphasize that these unique properties can vary not only between different species but also within different parts of a single tree. The ebony tree, renowned for its dense, dark heartwood, is particularly prized for high-end applications such as furniture, musical instruments, and ornamental objects. Despite this, the specific potential of its stem and branch wood for such uses remains largely under-explored and poorly documented. This gap in knowledge highlights the need for detailed research into the properties of these parts of the tree. This study aims to contribute to knowledge on the properties of the stem and branch of the ebony as a valuable alternative wood source for the timber industry in Ghana.

The utilization of branch wood has been suggested as a viable solution to reduce the pressure on stem wood in the timber industry. Dadzie et al. (2015) argues that a thorough examination of the physical and mechanical properties of tree branches could reveal their potential for wood utilization and will alleviate the pressure on stem wood. In their study, Dadzie et al. (2015) concluded that the stem and branch of mahogany possess similar durability, although the stem is more durable than the branch. This indicates that branch wood could offer substantial volumetric potential for various uses, contributing to the effectiveness of forest management (Moreira et al., 2022). Furthermore, Gurau et al. (2008) suggested that if the characteristics of branch wood are well understood, then it can be employed in new, value-added products, which will reduce the pressure on the stem wood.

This study aims to determine some selected physical and mechanical properties of the stem and branch wood of *Diospyros mespiliformis* to propose the appropriate use of its parts. This is because properties such as the density, moisture content, volumetric shrinkage, modulus of elasticity, modulus of rupture, compressive strength, shear parallel to grain and Janka hardness determine the suitability of wood for either structural use or other purposes.

2 MATERIALS AND METHODS
2 MATERIALI IN METODE
2.1 SAMPLE PREPARATION
2.1 PRIPRAVA VZORCEV

Three *Diospyros mespiliformis* trees were carefully selected from the natural forest reserve in East Gonja District, located at latitude 9.0153745 N, longitude 0.4532919 E in Ghana. The trees were selected based on specific criteria to ensure samples of adequate quality. The selection process, guided by BS ISO 3129:2019, focused on trees that exhibited straight stems, a substantial diameter, and minimal defects or fire damage. The chosen ebony trees were felled with a chain saw with a height of about 13 meters, with the stem's diameter measured around 50 to 65 cm. This stem was then divided into three segments and sawed into beams of 75 mm × 250 mm dimensions, separating the heartwood from the sapwood while discarding the juvenile wood and lumber with wane defects. The branches of the trees were also processed with precision. They were cut 300 mm from the joint to avoid knots, and their diameters were recorded around 25 to 40 cm. These branches were similarly sawed into beams, distinguishing heartwood from sapwood despite unclear differences. To prevent moisture loss, all beams both from the stem and branches were placed in a sack and tightly covered to prevent moisture loss. Subsequently, the prepared samples were transported to the Council for Scientific and Industrial Research (FORIG).

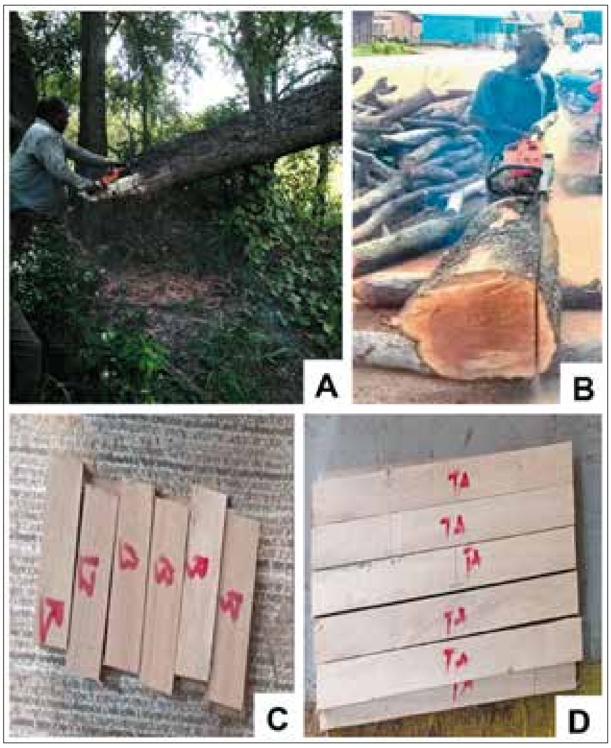

Figure 1. West African ebony (*Diospyros mespiliformis*) wood used for the study: (A) stem wood (B) branch wood (C) heartwood (D) sapwood.

Slika 1. Les zahodnoafriške ebenovine (*Diospyros mespiliformis*), uporabljen za študijo: (A) les debla, (B) les vej, (C) jedrovina, (D) beljava.

Kumasi for further processing following BS373 (1957) standard specifications. At FORIG, the samples underwent a series of physical and mechanical property tests. The equipment used for these physical property tests included a digital electronic scale, electronic vernier caliper, desiccator, beaker, and oven. The mechanical tests, including bending, compressive, shear, and Janka hardness tests, were conducted using an Instron Universal Testing Machine. The laboratory results were analysed using descriptive statistics to provide mean values, standard deviations, and graphical representations. To examine the relationships and variations among the properties of the ebony wood, inferential statistical methods, including Analysis of Variance (ANOVA), were employed. This analysis aimed to uncover patterns, trends, and the extent of variation in the physical and mechanical properties of the ebony wood.

2.2 PHYSICAL PROPERTIES OF STEM AND BRANCH WOOD
2.2 FIZIKALNE LASTNOSTI LESA DEBLA IN VEJ
2.2.1 Basic density
2.2.1 Osnovna gostota

The ebony stem wood and branch wood samples were cut from the sapwood and heartwood for determination of the moisture content. In conformity with the guidelines specified in BS373 (1957) the samples were sawn into precise 20 mm × 20 mm strips, which were then cross-cut into 20 × 20 × 20 mm cubes, yielding a total of 80 samples. The samples were then oven-dried at 103 ± 2 **°C** for 24 hours and the oven-dry mass was recorded by the electronic scale. The same samples were put in a rubber bag and soaked in water for 24 hours to define the maximum volume by means of the immersion method using a container with graduation marks filled with water. The basic density based on the oven-dry mass and the maximum (swollen) volume was obtained according to the following formula:

$$\rho = \frac{m_0}{V_{max}} \quad (1)$$

where:
ρ = basic density
m_0 = oven-dry mass
V_{max} = volume in wet state (V_{max} = Length × Breadth × Height)

2.2.2 Moisture Content (MC)
2.2.2 Vlažnost lesa (MC)

The ebony stem wood and branch wood samples were cut from the sapwood and the heartwood for the moisture content determination in conformity with the guidelines specified in 2016 ASTM D4442–16. The samples were sawn into 20 mm × 20 mm strips, which were then cross-cut into 20 × 20 × 20 mm cubes, yielding a total of 80 samples. The green weight was taken with an electronic scale and recorded, and the samples were then oven-dried in the oven at a temperature of 103 ± 2°C to obtain the oven-dry weight. The moisture content (MC) was calculated as shown in formula (2):

$$MC = \frac{W1 - W2}{W2} X(100) \quad (2)$$

where:
MC = moisture content
W1 = green weight
W2 = oven dry weight

2.2.3 Volumetric shrinkage
2.2.3 Prostorninsko krčenje

The samples were cut and sanded to remove any whiskers, achieving the required dimensions of 20 mm × 20mm × 100mm according to BS 373 standards. Subsequently, the longitudinal, radial, and tangential dimensions of the samples were marked with unique marks for easy identification. The longitudinal, radial, and tangential dimensions were measured and documented using an electronic digital vernier caliper. The samples were then placed at room temperature for 24 hours to assess shrinkage and dimensional stability. After this period, the weight of each sample was recorded using the electronic scale, and the dimensions in the longitudinal, radial, and tangential directions were measured and documented with the digital vernier caliper. Finally, the samples were placed in an oven set to a temperature of 103 ± 2 °C for 24 hours, after which they were placed in a desiccator to prevent uptake of moisture before the oven-dry dimensions were measured with the electronic digital vernier caliper (3).

$$VS = \frac{GV - OV}{GV} X100\% \quad (3)$$

where:
VS = volumetric shrinkage
GV = green volume
OV = oven dry volume

2.3 MECHANICAL PROPERTIES
2.3 MEHANSKE LASTNOSTI

The test specimens were prepared in accordance with the sizes and orientations specified by British Standard BS 373 for the testing of the selected mechanical properties. Samples were taken from the stem and branch parts of the trees taking into consideration the radial sections (sapwood and heartwood). The specimens were conditioned to reach the 12% moisture content after being air-dried to a respectable amount of moisture content, and they were then kept for testing in a controlled laboratory.

2.3.1 Bending test (Modulus of Elasticity and Modulus of Rupture)
2.3.1 Upogibni test (modul elastičnosti in upogibna trdnost)

Tests with regard to the static bending parallel to the grain (modulus of elasticity and modulus of rupture) were carried out using an Instron Universal Testing Machine equipped with a three-point bending (central loading) system. For testing, 80 samples with the dimensions 20 × 20 × 300 mm in accordance to BS 373 (1957) were used. At a pace of 6.5 mm/min, the machine automatically applied the load. Every 0.1 N interval, the device recorded the force exerted and associated deflection. This rate of loading was maintained until the test item failed. The computer portion of the Instron Universal Testing Machine used for the MOE recorded the maximum load at failure as well as its maximum load limit proportionality. The testing lasted 90 ± 30 seconds.

The modulus of elasticity, MOE, was computed as:

$$MOE = \frac{P_1 L^2}{4\Delta_1 A^2} \quad (4)$$

where:
MOE = Young's modulus, i.e. modulus of elasticity (N/mm²)
P_1 = load applied at the limit of proportionality (N)
A = area of cross-section of beam normal to direction of load (mm²)
Δ_1 = deflection at mid-length at limit of proportionality (mm)
L = distance between supports (mm)

The highest load a wood sample can withstand before breaking is known as the modulus of rupture. A test approach identical to that described for MOE was employed to determine the MOR.

The modulus of rupture R, is calculated as:

$$R = \frac{3PL}{2bd^2} \quad (5)$$

where:
R = modulus of rupture (N/mm²)
P = maximum load applied at the midpoint of the sample (N)
L = distance between supports (mm)
b = breadth of test piece (mm)
d = depth of the test sample (mm)

2.3.2 Compression parallel to grain
2.3.2 Tlak vzporedno z aksialnimi elementi

Compression according to BS 373 (1957) was tested with the Instron Universal Testing Machine. We tested 80 samples made up of stem sapwood and heartwood as well as branch sapwood and heartwood samples. The test duration was 90 ± 30 seconds. Resistance was measured using the parallel-to-longitudinal grain technique (BS 373, 1957). Utilizing the 20 mm standard, the sample's sizes were 20 × 20 × 600 mm. Every sample was looked over to make sure the rectangular test sample was parallel to the axis and the test device was constructed using the right materials. The plates containing the test component were set parallel to each other. The maximum compressive load was calculated according to the following formula:

$$C = \frac{P}{A} \quad (6)$$

where:
C = Maximum compressive load (N/mm²)
P = Maximum load (N)
A = Cross sectional area of sample (mm²)

2.3.3 Shear parallel to grain
2.3.3 Strig vzporedno z vlakni

The shear test parallel to grain was conducted in accordance with BS 373 (1957), which stipulates that the sample sizes should be a 50 × 50 × 50 mm cube. The Instron Universal Testing Machine's 100 kN load cell capacity was used to analyse 20 samples of the sapwood and heartwood as well as stem and branch. With the load applied, the crosshead moved at a constant speed of 0.635 mm/min. The shearing direction and the longitudinal direction of the grain were parallel. Every sample was loaded up until the point of failure. The load at which a failure occurred was automatically recorded by the Instron Universal Testing Machine. The test took 90 ± 30 seconds to complete, and the results were obtained with the following formula:

$$S = \frac{P}{A} \quad (7)$$

where:
S = Shear (N/mm²)
P = Maximum load (N)
A = Area in shear (mm²)

2.3.4 Janka hardness
2.3.4 Trdota po Janki

The test was conducted in accordance with BS 373 (1957). For the purpose of the hardness test, 80 specimens were cut from branch and stem sapwood and heartwood into 50 mm × 50 mm × 150 mm tangentially, longitudinal and radially. The Instron Universal Testing Machine's hardness test fixture was applied to a total of 20 sapwood and heartwood samples for each category. The fixture is made out of a steel ball with a diameter of 11.3 ± 2.5 mm located on one side of the iron bar. When the force is applied, the steel ball or bar's hemispherical end enters the test piece. The force needed to press the steel ball's hemispherical head into the specimen to a depth of 5.6 mm, or equal to the steel ball's radius, was recorded, and the failure load was automatically calculated by the Instron machine.

2.3.5 Data Analysis
2.3.5 Analiza podatkov

Analysis of variance (ANOVA) was used to compare the results for the stem and branch portions and to determine whether there was a significant difference between them. The statistical tool used for the analyses was the SPSS programme.

3 RESULTS AND DISCUSSION
3 REZULTATI IN RAZPRAVA
3.1 BASIC DENSITY AND MOISTURE CONTENT
3.1 OSNOVNA GOSTOTA IN VLAŽNOST

The basic density of the ebony tree parts (stem and branch wood) is presented in Figure 2. According to the results, the basic density of ebony wood varies significantly between stem and branch samples. The average density of the stem wood stands at 550.81 kg/m³ compared to 513.35 kg/m³ for branch wood. This result is in line with Marasigan et al. (2022) and Zhao et al. (2018), but is contrary to the findings of Dadzie et al. (2016). The higher density found in stem wood than branch wood could be attributed to the higher level of extractives present in the former. Furthermore, the age-related maturity of the stem over the branch may be the cause of the observed variance in the densities of the stem and branches. Zhao et al. (2018) showed that the average density of stem wood was higher at 0.59 g/cm³, compared to the branch wood of *Populus ussuriensis Kom* with a density of 0.50 g/cm³.

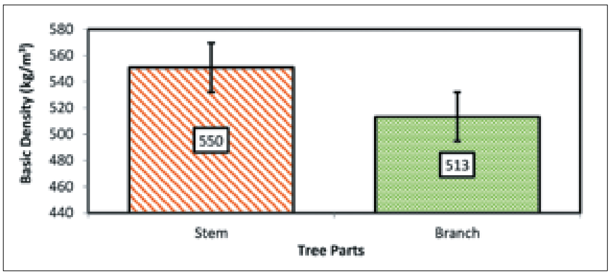

Figure 2. Average basic density of stem and branch wood of the ebony tree.

Slika 2. Povprečna osnovna gostota lesa debla in vej ebenovine.

Table 1. Physical properties, basic density and moisture content, after felling, of sapwood and heartwood of stem and branch wood of ebony (*Diospyros mespiliformis*); the values are average ± standard deviation.

Preglednica 1. Fizikalne lastnosti, osnovna gostota in lesna vlažnost beljave in jedrovine debla in vej ebenovine (*Diospyros mespiliformis*) po poseku; vrednosti predstavljajo povprečje ± standardno deviacijo.

Tree Part	*Tree Section*	*Basic Density (kg/m³)*	*Moisture Content (%)*
Stem	Sapwood	562.57± (12.86)	69.51± (2.21)
	Heartwood	539.04± (10.37)	77.91± (3.39)
Branch	Sapwood	531.96± (12.04)	79.43± (2.69)
	Heartwood	494.74± (13.93)	90.11± (3.91)

The analysis of the physical properties of the ebony wood samples revealed variations in the density and moisture content as shown in Figure 2 and Table 1. An analysis of variance (ANOVA) between the physical properties (density and moisture content) and the tree parts (stem and branch) and sections (heartwood / sapwood) (Table 2) showed that the tree part (TP – stem or the branch) and tree sections (TS – sapwood or heartwood) both have a statistically significant effect on the physical properties of the ebony wood at a 5% level. Specifically, 36.6% of the observed variation in the basic density and 24.7% of the variation in the moisture level of the wood can be attributed to the TP, meaning that the properties of the stem or the branch are statis-

Table 2. ANOVA for physical properties of ebony wood; TP (tree part, stem or branch), TS (tree section, sapwood or heartwood).
** = significant at $p < 0.05$, ns = not significant
Preglednica 2. ANOVA za fizikalne lastnosti, osnovno gostoto in vlažnost lesa ebenovine; TP (del drevesa, deblo ali veja), TS (sekcija, beljava ali jedrovina).
** = statistično značilno pri $p < 0,05$, ns = ni značilno

		Basic Density			Moisture Content		
Source	Df	F-value	P-value	Var. (%)	F-value	P-value	Var. (%)
Tree Part (TP)	1	43.935	0.001**	36.6	24.950	0.001**	24.7
Tree Section (TS)	1	28.902	0.001**	27.6	18.586	0.001**	19.6
TP × TS	1	1.467	0.229ns	1.9	264	0.609ns	0.3

tically significant. Similarly, the TS contribute 27.6% to the variation in basic density and 19.6% to the variation in moisture content.

The results show that the interaction effect between the tree part and tree section (TP × TS) has no significant influence on the basic density and moisture content of the ebony wood. The level of variability for the basic density stands at 1.9% while the moisture content could only be varied by 0.3%.

The average green moisture content of the stem (heartwood and sapwood) after felling was 73.71%, while that of the branch wood was 84.77%. The higher moisture content observed in the branch wood is in agreement with the findings of Siau (1984). This earlier study attributed this trend to the fact that branch wood tends to have more active xylem vessels, which contribute to a higher water content compared to the stem wood. Similarly, Desch and Dinwoodie (1996) found that branches tend to have a higher proportion of sapwood compared to heartwood. Sapwood is responsible for water and nutrient transport, and typically has a higher moisture content than heartwood, which is drier and more mature. Marasigan et al. (2022) further indicated in their study that the moisture content of branch wood of Falcata *[Falcataria moluccana (Miq.) Barneby & J.W. Grimes]* ranged from 163% to 262%, while the range for stem wood was 163% to 243%. This is contrary to the findings of White (2018), who revealed that high-density wood of ebony has a lower moisture content than other wood types.

3.2 SHRINKAGE OF WOOD
3.2 KRČENJE LESA

The shrinkage of the wood of different parts of ebony varies among the different directions of the stem and branch wood (Figure 3). The longitudinal shrinkage is minimal for both stem (0.75%) and branch (0.92%) wood. Low longitudinal shrinkage of stem and brand wood is ascribed to the orientation of the axial cells in the wood. Similar results have been reported in the literature for 12 cloned of three poplar hybrid crosses, *Populus deltoides*,

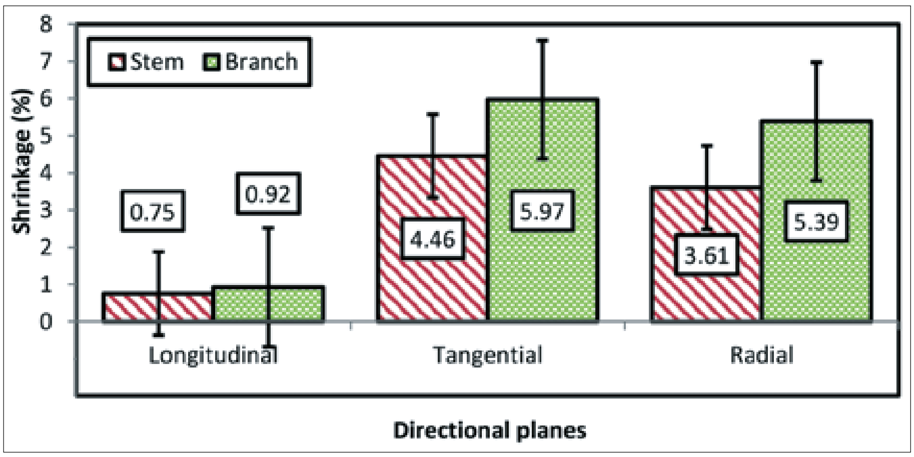

Figure 3. Average longitudinal, tangential and radial shrinkage (± standard deviation) of ebony stem and branch wood.
Slika 3. Povprečno vzdolžno, radialno in tangencialno krčenje (± standardni odklon) za les debla in vej ebenovine.

Table 3. Shrinkage of stem and branchwood of sapwood and heartwood of ebony.
Preglednica 3. Krčenje beljave in jedrovine v lesu debla in vej ebenovine.

Tree Part	Tree Section	Longitudinal Shrinkage (%)	Tangential Shrinkage (%)	Radial Shrinkage (%)
Stem	Sapwood	0.73 ± 0.14	4.05 ± 1.25	3.33 ± 0.79
	Heartwood	0.77 ± 0.39	4.87 ± 1.90	3.89 ± 1.53
Branch	Sapwood	0.85 ± 0.22	5.27 ± 1.08	4.37 ± 0.43
	Heartwood	0.99 ± 0.43	6.67 ± 0.90	6.40 ± 1.42

as investigated by Pliura (2005), and in wood from natural forest by Wang et al. (2008). In contrast, Saranpää (1994) reported an increase in the longitudinal shrinkage of the stem wood. However, this result is contrary to the findings of Topaloglu and Erisir (2018), which showed an increase in the longitudinal shrinkage and swelling of oriental beech (*Fagus orientalis*) and Caucasian fir (*Abies nordmanniana*) trees. The results further revealed that the tangential shrinkage was the highest for both stem and branch wood, at 4.46% and 5.97%, respectively. This also suggests greater susceptibility to dimensional changes in the tangential direction, particularly in branch wood. The radial shrinkage is unusually high, with the stem shrinkage of 3.61% and the branch of 5.39%, which is below the fibre saturation point of about 25%. The shrinkage properties of the stem and branch sections (sapwood and heartwood) were also measured across the three directions (Table 3).

Table 4. ANOVA for shrinkage properties of ebony tree parts; TP (tree part, stem or branch), TS (tree section, sapwood or heartwood), PD (plane direction).
P-value ** = significant at p < 0.05, ns = not significant
Preglednica 4. ANOVA za lastnosti krčenja delov drevesa ebenovine; TP (del drevesa, deblo ali veja), TS (sekcija, beljava ali jedrovina), PD (smer krčenja). P- vrednost ** = značilna pri p < 0.05, ns = ni značilna

		Shrinkage		
Source	df	F-value	P-value	Var. (%)
Tree Part (TP)	1	61.948	0.001**	24.4
Tree Section (TS)	1	32.302	0.001**	14.4
Plane Direction (PD)	2	343.683	0.001**	78.2
TP × TS	1	6.024	0.015**	3.0
TP × PD	2	11.550	0.001**	10.7
TS × PD	2	6.563	0.002**	6.4
TP × TS × PD	2	1.856	0.159ns	1.9

The analysis of variance showed that the Tree Part (TP), Tree Section (TS), and Plane Direction (PD), along with their interactions, were statistically significant but exerted different levels of influence on the shrinkage properties of wood samples. The significant influence (78%) and the statistical relationships of the plane direction (PD) on the shrinkage properties means that the direction in which the wood shrinks – longitudinal, tangential or radial – plays a crucial role in determining the shrinkage properties of the wood.

Additionally, the Tree Part (TP) significantly affects the shrinkage properties of the wood, accounting for 24.4% of the variance in the shrinkage properties of the stem and branch, with stem wood showing less shrinkage compared to branch wood. Moreover, the interactions between the TP and TS significantly affect the shrinkage properties of the ebony wood. The TP **×** TS interaction explains 3% of the variation in the shrinkage properties at the dimensional planes, while the TP × PD interaction accounts for 10.7% of the variance. This implies that the shrinkage differences between stem and branch wood are not uniform across different planes.

The TS × PD interaction also has a significant effect and accounts for 6.4% of the variance in the shrinkage properties of the ebony wood. Conversely, it became evident that the three-way interaction (TP × TS × PD) does not have significant statistical relationships with the shrinkage properties of ebony wood. This suggests that while two-way interactions are important, the combined effect of all three factors does not have a statistically significant relationship with the shrinkage properties of wood.

Table 5. Mechanical properties of ebony tree parts, stem and branch sapwood and heartwood; bending strength parallel to grain, MOE – modulus of elasticity and MOR – modulus of rupture; COM – compression strength parallel to grain, shear strength and hardness after Janka. The values shown are the averages ± standard deviation.

Preglednica 5. Mehanske lastnosti delov drevesa ebenovine, beljave in jedrovine debla in vej; upogibna trdnost vzporedno z vlakni, MOE–modul elastičnosti in MOR – upogibna trdnost; COM–tlačna trdnost vzporedno z vlakni, strižna trdnost in trdota po Janki. Prikazane so srednje vrednosti ± standardna deviacija.

Tree Height	Tree Portion	MOE (MPa)	MOR (MPa)	COM (MPa)	Shear (MPa)	Hardness (kN)
Stem	Sapwood	8416 ± 457.41	64.86 ± 2.04	46.99 ± 2.07	15.02 ± 1.83	4.01 ± 0.01
	Heartwood	7390.4 ± 464.59	56.48 ± 2.31	40.28 ± 1.49	14.01 ± 1.23	4.01 ± 0.01
Branch	Sapwood	7283.3 ± 326.87	54.03 ± 2.17	37.98 ± 1.68	13.74 ± 1.06	4.01 ± 0.01
	Heartwood	6848.3 ± 426.08	49.14 ± 1.03	36.86 ± 1.27	14.01 ± 1.16	4.01 ± 0.01

Table 6. ANOVA for mechanical properties: bending strength parallel to grain, MOE – modulus of elasticity and MOR – modulus of rupture, and COM – compression strength parallel to grain, of ebony tree parts (TP) – stem or branch, and tree section (TS) sapwood or heartwood.

P-value ** = significant at p < 0.05, ns = not significant

Preglednica 6. ANOVA za mehanske lastnosti: upogibna trdnost vzporedno z vlakni, MOE – modul elastičnosti in MOR – upogibna trdnost; COM – tlačna trdnost vzporedno z vlakni delov drevesa ebenovine (TP) – deblo ali veje in sekcije (TS) beljava ali jedrovina.

P- vrednost ** = značilna pri p < 0.05, ns = ni značilna

		MOE			MOR			Compression		
Source	df	F-value	P-value	Var. (%)	F-value	P-value	Var. (%)	F-value	P-value	Var. (%)
Tree Part (TP)	1	7.809	0.007**	9.3	30.906	0.001**	28.9	207.027	0.001**	73.1
Tree Section (TS)	1	5.939	0.017**	7.2	16.547	0.001**	17.8	82.323	0.001**	52
TP × TS	1	0.971	0.328ns	1.3	1.138	0.289ns	1.5	41.913	0.001**	35.5

Table 7. ANOVA for mechanical properties: shear strength and hardness after Janka, of ebony tree parts (TP)–stem or branch, and tree section (TS) sapwood or heartwood.

Preglednica 7. ANOVA za mehanske lastnosti: strižna trdnost in trdota delov drevesa ebenovine (TP) po Janki – deblo ali veje in sekcije (TS) beljave ali jedrovine.

		Shear			Hardness		
Source	df	F-value	P-value	Var. (%)	F-value	P-value	Var. (%)
Tree Part (TP)	1	3.530	0.064 ns	4.4	1.526	0.220 ns	2
Tree Section (TS)	1	1.193	0.278 ns	1.5	2.242	0.138 ns	2.9
TP × TS	1	3.553	0.063 ns	4.5	0.561	0.456 ns	0.7

3.3 MECHANICAL PROPERTIES
3.3 MEHANSKE LASTNOSTI

Overview of mechanical properties, bending test (Modulus of Elasticity and Modulus of Rupture) and compression parallel to grain, shear and hardness of different tree parts of ebony are shown in Table 5. The ANOVA results are shown in Tables 6 and 7.

3.3.1 Bending–Modulus of elasticity
3.3.1 Upogib–modul elastičnosti

The mean values for the Modulus of Elasticity (MOE) of the ebony for the stem is 1903.2 MPa and for the branch 7065.8 MPa (Table 5). The substantial difference between the stem and branch MOE values is probably due to differences in their anatomical structure and density. According to the results in Table 5, the mean MOE was higher in the sapwood at 8416 MPa and lower in the branch heartwood at 6848.3 MPa.

3.3.2 Bending–Modulus of rupture
3.3.2 Upogibna trdnost

The higher MOR at the stem sapwood could be attributed to the greater resistance to elastic deformation under load. Additionally, the average MOR was also higher in stem sapwood at 64.86 MPa and lowest in branch heartwood at 49.14 MPa, indicating that stem sapwood can withstand greater stress before failure. Table 6 shows the ANOVA results, in which the tree part and tree section significantly affect the Modulus of Elasticity, at a 5% significance level. The level of variability is 9.3% and 7.2%, respectively, and this could be explained by the tree part and tree section. The mean values for the Modulus of Rupture (MOR) (Table 5), provide insights into the wood's bending strength, i.e. ability to resist breaking under stress. There is a notable difference in the MOR between the stem and branch. The average MOR for the stem part is 60.67 MPa and for the 51.58 MPa. The disparity suggests that the stem, with its higher MOR, is structurally stronger and more resilient to bending and breaking forces.

3.3.3 Compression strength parallel to the grain
3.3.3 Tlačna trdnost vzporedno z vlakni

The compression strength parallel to the grain demonstrates distinct variations between different parts of the tree (Table 5). The average compression strength for the stem is significantly higher at 43.64 MPa than the compression strength of 37.42 MPa for the branch wood. Furthermore, it became evident that the compression strength was greatest in stem sapwood (46.99 MPa), showing superior performance under compressive loads compared to other sections. The high compression strength of the stem could be attributed to its denser and more uniform wood structure, which improves its ability to bear loads. Density is the key physical characteristic that determines the compression strength of a wood sample, with a significant correlation observed between these two properties (Gindl & Teischinger, 2002). In the current study, the highest compressive strength parallel to the grain of the stem wood is precisely related to the higher basic density of the stem compared to the branch wood.

3.3.4 Shear Strength Parallel to Grain
3.3.4 Strižna trdnost vzporedno z vlakni

The results for the shear strength of the stem and branch (Table 5) reveal that the former has a slightly higher shear strength than the latter. The results further show fewer variations in shear strength among the sections, with stem sapwood at 15.02 MPa and branch sapwood at 13.74 MPa.

Specifically, the stem has an average shear strength of 14.51 MPa and the branch wood 13.88 MPa. Nonetheless, the branch still maintains a relatively high shear strength. Table 7 (ANOVA) further reveals that the Tree Part (TP) factor was statistically significant at 5% (p-value of 0.064), accounting for 4.4% of the total variance in shear strength. Moreover, the TS has no significant impact on shear strength, but contributes about 1.5% to its variance. Furthermore, TP × TS has a significant effect on the shear strength (p-value of 0.063), with a 4.5% contribution to the variance.

3.3.5 Janka Hardness
3.3.5 Trdota po Janki

The mean values for the hardness of the ebony tree parts (Table 5) show that there is no difference in the mean average hardness (4.01 kN) between the stem and branch parts. Moreover, the hardness was the same across all stem and branch wood sections at 4.01 kN. This suggests uniform surface resistance to indentation between the stem and branch wood of ebony.

However, the ANOVA results reveal that there are variations between the hardness of the stem and branch wood of ebony and their differences are significant (Table 7). This means that the stem and branch wood of ebony are different from each other.

4 CONCLUSIONS
4 SKLEPI

This study investigated the physical and mechanical properties of three *Diospyros mespiliformis* trees, i.e. stems and branch wood. An experimental research design was employed to carry out the study and ANOVA was used to examine the properties and account for the statistical influence between the properties and tree parts. The findings indicated that stem wood has superior mechanical properties to branch wood, as demonstrated by its higher basic density (550.81 kg/m³). Cross-sectional analysis of the stem and branch wood parts revealed that the sapwood and heartwood have the highest densities, at 562.57 kg/m³ and 539.04 kg/m³, respectively. This suggests that the stem wood is structurally stronger than the branch wood. The findings also showed that the branch wood has minimal longitudinal shrinkage, but at the tangential and radial planes of the wood the branch wood has the highest shrinkage properties, highlighting the significant role of plane direction on the shrinkage properties of the ebony wood.

The Modulus of Elasticity (MOE) for the branch wood is significantly higher (7065.8 MPa) compared to that of the stem part (1903.2 MPa), indicating greater stiffness associated with the branch wood. Notwithstanding this, the evidence suggests that the stem parts have the highest Modulus of Rupture (60.67 MPa), compression strength parallel to the grain (43.64 MPa) and slightly higher shear strength (14.51 MP), suggesting that the stem wood has greater resistance to breaking, and ability to withstand axial loads and shear forces. Regarding the hardness level of the stem and branch wood, both stem and branch parts exhibited the same hardness level, at 4.01 kN. The variability in properties between the stem wood and branch wood could be as a result of the age-related difference between the stem and branch wood. Moreover, the branch wood has a higher percentage of earlywood with wider lumens, therefore leading to higher dimensional instability. The results from this study are in line with those in the literature, which revealed that stem wood has better performance compared with branch wood, although this difference is statistically insignificant, suggesting that the branch wood could be used as a supplement to the stem wood.

5 SUMMARY
5 POVZETEK

Lesna industrija ima izjemno vrednost za gospodarsko rast ter prispeva k ustvarjanju delovnih mest v Gani. Vendar pa je izčrpavanje lesnih zalog povzročilo potrebo po iskanju alternativnih virov lesa za industrijsko predelavo. Ti razlogi so privedli do iskanja alternativnih materialov na osnovi lesa za izdelke z dodano vrednostjo. Rod *Diospyros*, kamor spadajo številne ebenovine, je zastopan z različnimi vrstami, ki uspevajo po vsej Gani. Afriška ebenovina *Diospyros crassiflora* je ena izmed najbolj zaželenih zaradi svoje posebej cenjene črne jedrovine. *Diospyros crassiflora* spada med vrste rodu Diospyros, ki veljajo za ogrožene zaradi prekomernega izkoriščanja njihovega dragocenega trdega lesa. *Diospyros crassiflora* je na rdečem seznamu IUCN navedena kot ranljiva zaradi izgube habitata in neodgovorne sečnje.

Po drugi strani je manj znana zahodnoafriška ebenovina *Diospyros mespiliformis* razširjena po vsej podsaharski Afriki, od Senegala na zahodu do Sudana in Južne Afrike na vzhodu in jugu. V veliki meri jo najdemo v obrežnih območjih in savanskih gozdovih. Ker je odporna na sušo, dobro uspeva v naravnem območju Savannah v Gani. Domačini uporabljajo njen les za kurjavo, ročaje za orodje, pohištvo in gradnjo. Medtem ko je beljava običajno svetlejša, je jedrovina večinoma črna ali temno rjava. Ta študija preučuje fizikalne in mehanske lastnosti beljave in jedrovine lesa debla in vej ebenovine (*Diospyros mespiliformis*), da bi ugotovili, ali se lahko les vej uporablja za različne izdelke. V ta namen so bila izbrana in posekana tri zrela drevesa ebenovine s premerom debel v prsni višini 50–65 cm in premerom vej 25–40 cm. Vzorci lesa so bili pripravljeni na ustrezne velikosti v skladu z izbranimi standardi, testirani in analizirani na fizikalne (gostota, lesna vlažnost in prostorninsko krčenje) in mehanske lastnosti (modul elastičnosti, tlačna in strižna trdnost vzporedno z vlakni ter trdota po Janki). Analiza variance je bila uporabljena za preverjanje statistične značilnosti razlik med lastnostmi lesa različnih delov drevesa. Rezultati so pokazali, da je bila gostota lesa višja v lesu debla (551 kg/m³) kot v vejah (513 kg/m³) za vse primerke, uporabljene v študiji. Na prečnem prerezu je imela jedrovina višjo gostoto lesa kot beljava, tako pri lesu debla kot pri lesu vej. Vendar pa sta bila lesna vlažnost in prostorninsko krčenje relativno višja v lesu vej kot v lesu debla, beljava pa je imela višjo vlažnost in prostorninsko krčenje, kar velja tako za les debla kot za les vej, vendar razlike niso statistično značilne. Modul elastičnosti (MOE) je bil višji v lesu vej (7066 MPa) kot v lesu debla (1903 MPa) in beljava je imela višji MOE, kar velja tako za les debla kot za les vej. Poleg tega je bila upogibna trdnost (MOR) za les debla povprečno višja (61 MPa) kot v lesu vej (52 MPa), beljava pa je imela višje vrednosti v primerjavi z jedrovino. Enak trend je bil opažen za tlačno trdnost in trdoto po Janki. Na splošno je imel les debla nekoliko boljše lastnosti in manjše krčenje v primerjavi z lesom vej, vendar razlike niso bile statistično značilne. To nakazuje, da bi lahko les vej uspešno uporabljali.

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ASSESSING CLIMATE-GROWTH RELATIONSHIPS WITH DAILY AND MONTHLY OBSERVATIONAL AND GRIDDED METEOROLOGICAL DATA

PRIMERJAVA KORELACIJ ŠIRIN BRANIK Z DNEVNIMI IN MESEČNIMI IZMERJENIMI IN MODELIRANIMI METEOROLOŠKIMI PODATKI

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Abstract / Izvleček

Abstract: We compared climate-growth relationships by correlating tree-ring variation with daily and monthly meteorological data obtained from the stations of the Slovenian Environment Agency (ARSO) and modelled data from the SLOCLIM database. Tree-ring width series for analyses were obtained from previously collected European beech (*Fagus sylvatica*) tree-ring data from 30 sites all over Slovenia. Climate-growth correlations were calculated to evaluate whether daily meteorological data exhibits stronger correlations than monthly data. We also compared the maximum correlation coefficients using meteorological station data and gridded SLOCLIM data. The analysis was conducted using the *dendroTools* R package, incorporating data on daily and monthly average air temperatures and precipitation sums from the period 1960–2018. Our findings revealed significantly higher maximum correlation coefficients for daily data compared to monthly data, underscoring the importance of using daily data, particularly for precipitation. However, no significant difference was observed between maximum correlation coefficients using the meteorological station and modelled data, and the difference did not change significantly with increasing altitude.

Keywords: observational data, gridded data, tree rings, correlation analysis, dendroclimatology

Izvleček: V raziskavi smo primerjali korelacije med širinami branik in dnevnimi oziroma mesečnimi meteorološkimi podatki, pridobljenimi iz meteoroloških postaj (ARSO) ali iz modelirane baze SLOCLIM. Uporabili smo podatke o dnevnih in mesečnih povprečnih temperaturah zraka in vsotah padavin za obdobje 1960–2018. V analize smo vključili 30 kronologij širin branik navadne bukve (*Fagus sylvatica*) iz celotne Slovenije. Raziskali smo tudi, kako na korelacije vpliva uporaba podatkov iz meteoroloških postaj ali iz baze SLOCLIM. Naše ugotovitve so pokazale značilno višje maksimalne korelacijske koeficiente, ko smo uporabili dnevne meteorološke podatke, kot če smo uporabili mesečne. Glede na to je priporočljiva uporaba dnevnih podatkov v dendroklimatoloških analizah, zlasti pri padavinah. Pri primerjavi korelacij s podatki iz meteoroloških postaj in modeliranimi podatki nismo ugotovili statistično značilnih razlik. Razlike med uporabo dnevnih in mesečnih podatkov ter podatkov iz dveh baz se z nadmorsko višino rastišč bukve niso značilno spreminjale.

Ključne besede: meteorološki podatki, modelirani podatki, branike, korelacijska analiza, dendroklimatologija

1 INTRODUCTION
1 UVOD

The use of meteorological data to explain variations in tree-ring widths has long been a cornerstone of dendrochronology, with traditional analyses relying on monthly data. However, over the past decade, authors have begun to emphasize the importance of daily data (Beck et al., 2013; Liang et al., 2013; Pritzkow et al., 2014), which has led to the increasing use of daily meteorological datasets (Castagneri et al., 2015; Kaczka et al., 2017). Daily data better captures weather hazards which last several days such as heatwaves, heavy rainfall events or sudden frost, which significantly affect the formation of tree rings. These effects can remain obscured in monthly averages. This is espe-

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cially relevant for precipitation data, which has an unpredictable occurrence pattern with low autocorrelation. Daily meteorological data also have a stronger relation to phenological phases (Kaczka et al., 2017), as the growth of a tree is not confined to the first and last day of a calendar month (Nagavciuc et al., 2019). Recently, a study by Jevšenak (2019) examined the question of the importance of using daily data in tree-ring analysis, and reported that the correlation coefficients calculated using the daily data compared to monthly data are on average by 0.076 higher for precipitation and 0.060 for air temperature data. However, these differences were generally not statistically significant, although still important with regard to capturing stronger climate signals.

Gridded meteorological series with daily resolution are less common and not available in all regions worldwide. However, high resolution gridded climate datasets have already been developed regionally, e.g. for Spain (Serrano-Notivoli et al., 2017, 2019), Norway (Lussana et al., 2018), Africa (Chaney et al., 2014) and certain large areas, e.g. E-OBS, ERA5, CHELSA, and the Berkeley Earth climate dataset. E-OBS is a commonly used daily gridded land-only observational dataset covering Europe, with a spatial resolution of 0.1° x 0.1° and 0.25° x 0.25° (Haylock et al., 2008). ERA5 is a global climate reanalysis dataset providing hourly estimates of atmospheric, land-surface and sea-state parameters from 1940, with a spatial resolution of 0.25° x 0.25° (or 0.1° for ERA5-Land) (Copernicus Climate Change Service, 2023). CHELSA is also global downscaled climate dataset with climate layers for various time periods and variables and a spatial resolution of 1 km (Karger et al., 2017). The Berkeley Earth climate dataset provides high-resolution land and ocean time series data and gridded temperature data from 1850 (Rohde & Hausfather, 2019). These datasets provide meteorological data for evenly spaced locations across a defined area, overcoming the limitations of station-based datasets, which are sometimes incomplete and have low spatial resolution.

In Slovenia, the Slovenian Environment Agency (ARSO) provides nationwide daily meteorological data collected from meteorological stations, with the earliest records dating back to 1850 (Nadbath, 2015). The distribution of these stations is uneven, with a higher density found in urban areas and at lower altitudes, while more forested regions have limited coverage. In recent years, there has been a significant decline in the number of traditional meteorological stations with observers, while the number of automatic meteorological stations has increased (Nadbath, 2015). All the data is being regularly validated and is publicly available. Although such data is of great value, there are still some downsides. For example, the data provided by the stations is of varying length and often partly incomplete. Moreover, many stations have been relocated in the past, resulting in altitudinal variations and corresponding climate discrepancies. However, these issues have been resolved through the homogenization of temperature and precipitation data, which can be obtained upon request. For dendrochronological studies, access to a comprehensive and consistent dataset is essential to ensure accurate climate reconstructions or climate-related dendroecological investigations. The SLOCLIM – Slovenian Modelled Climate Database was created (Škrk et al., 2021) to address these challenges, using available measurement data from ARSO, incorporating latitude, longitude, altitude and distance from the coast. Generalized linear mixed models (GLMMs) and generalized linear models (GLMs) were applied in the calculation process. The dataset has a spatial resolution of 1 x 1 km and contains daily data on maximum and minimum air temperatures, as well as precipitation amounts for the period 1950-2018. It offers modelled local meteorological data, ensuring continuous coverage without missing values.

The aim of this study was to evaluate whether daily meteorological data better explains the climate-growth relationship compared to monthly data, as daily data offers more precise weather information and is less constrained by temporal averaging. Our first hypothesis was that daily meteorological data will yield significantly stronger climate-growth correlations than monthly data, and differences will be greater for precipitation data. To test this, we employed selected sites from a Slovenian tree-ring database of European beech (*Fagus sylvatica*) (Čufar et al., 2008a; Dolar et al., 2023), the predominant tree species in Slovenia, comprising approximately 33% of the country's wood stock (Skudnik et al., 2021). The extensive coverage of tree-ring data from beech across Slovenia also provides a robust foundation for our analysis.

Additionally, we sought to compare data derived from traditional meteorological stations with that obtained from a gridded dataset, i.e. SLOCLIM, which feature higher spatial resolution and more comprehensive data. We hypothesized that gridded meteorological data for a given site explain the influence of weather conditions on the variation of tree-ring widths better than the commonly used data from meteorological stations (Hypothesis 2). Notably, there is a lack of studies that have systematically compared data from meteorological stations with gridded datasets in the context of dendrochronological research. This comparison is critical for understanding how different data sources influence dendrochronological analysis.

We further hypothesized that at higher altitudes the differences in maximum correlation coefficients between gridded and observational meteorological data, as well as between daily and monthly data, would be more pronounced (Hypothesis 3). This is attributed to the shorter growing season at higher altitudes, making daily data more significant than monthly data. Additionally, meteorological stations are predominantly located at lower altitudes, with fewer stations at higher altitudes, and we thus expected that the altitudinal correction of meteorological data should reveal stronger climate-growth effects.

2 MATERIALS AND METHODS
2 MATERIALI IN METODE
2.1 TREE-RING CHRONOLOGIES
2.1 KRONOLOGIJE ŠIRIN BRANIK

Tree-ring data of selected European beech (*Fagus sylvatica*) sites in Slovenia from the collection of the Department of Wood Science and Technology, Biotechnical Faculty, University of Ljubljana (Čufar et al., 2008a; Dolar et al., 2023) were used in this study. The data contains raw tree-ring measurements from 30 sites across Slovenia with altitudes ranging between 230 and 1330 m a.s.l. (Figure 1, Table 1). Sites are located in three different climatic zones: Subcontinental, Subalpine, and Sub-Mediterranean. For each site, we calculated first-order autocorrelation (AR1), Gleichläufigkeit coefficient (%GLK) and mean interseries correlation (rbar) (Table 2). AR1 represents the impact of growth from the previous to the current year (Fritts, 1976). High positive values close to 1 indicate strong positive

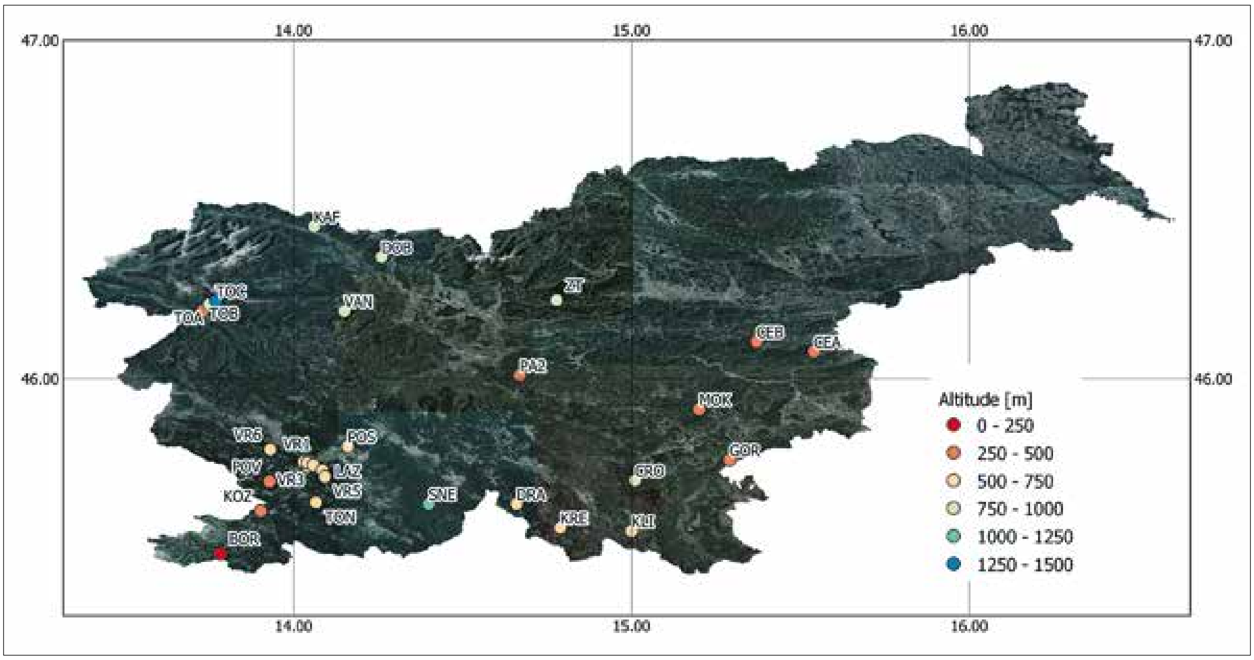

Figure 1. Selected European beech (*Fagus sylvatica*) sites for tree-ring analyses in Slovenia with respective altitudes in metres above sea level.

Slika 1. Izbrane lokacije s kronologijami širin branik navadne bukve (*Fagus sylvatica*) in njihove nadmorske višine.

Table 1. Basic site information for chronologies: altitude (m a.s.l.) (ALT), latitude (LAT), longitude (LON), ARSO nearest meteorological station (ARSO MS), mean annual air temperature (TAVG), annual precipitation sum (PCP). ARSO – data from Slovenian Environment Agency; SLOCLIM (Škrk et al., 2021). Meteorological data is calculated for the period 1960-2018.
Preglednica 1. Osnovni podatki o rastiščih: nadmorska višina (m) (ALT), zemljepisna širina (LAT), zemljepisna dolžina (LON), kronologiji najbližja ARSO meteorološka postaja (ARSO MS), povprečna letna temperatura zraka (TAVG), letna količina padavin (PCP). ARSO – podatki Agencije Republike Slovenije za okolje; SLOCLIM (Škrk et al., 2021). Meteorološki podatki so izračunani za obdobje 1960–2018.

Code / Oznaka	ALT	LAT	LON	ARSO MS	TAVG (ARSO) [°C]	PCP (ARSO) [mm]	TAVG (SLOCLIM) [°C]	PCP (SLOCLIM) [mm]
CEA	450	46.1	15.5	BIZELJSKO	10.4	1031	10.2	955
CEB	450	46.1	15.4	MALKOVEC	10.4	1126	9.5	1033
CRO	1000	45.7	15.0	KOČEVJE	8.8	1502	8.5	1331
DOB	1000	46.4	14.3	BRNIK–LETA-LIŠČE	9.0	1344	9.0	1515
DRA	750	45.6	14.7	BABNO POLJE	6.5	1688	7.9	1569
GOR	450	45.8	15.3	MALKOVEC	10.4	1126	7.9	1293
KAF	950	46.5	14.1	KREDARICA	-1.1	2025	6.8	1656
KLI	531	45.6	15.0	KOČEVJE	8.8	1502	9.2	1373
KRE	568	45.6	14.8	KOČEVJE	8.8	1502	8.3	1524
MOK	400	45.9	15.2	MALKOVEC	10.4	1126	9.6	1068
PA2	380	46.0	14.7	LJUBLJANA–BEŽIGRAD	10.6	1390	9.6	1215
POS	640	45.8	14.2	POSTOJNA	9.1	1557	9.6	1449
SNE	1100	45.6	14.4	BABNO POLJE	6.5	1688	7.3	1709
TOA	355	46.2	13.7	KREDARICA	-1.1	2025	11.0	1991
TOB	821	46.2	13.8	KREDARICA	-1.1	2025	8.2	2015
TOC	1328	46.2	13.8	KREDARICA	-1.1	2025	7.0	2010
VAN	1000	46.2	14.2	VOJSKO	6.6	2379	7.9	1879
KOZ	380	45.6	13.9	GODNJE	11.3	1411	11.1	1167
LAZ	650	45.7	14.1	POSTOJNA	9.1	1557	9.3	1382
POT	690	45.7	14.0	POSTOJNA	9.1	1557	9.2	1401
POV	500	45.7	13.9	GODNJE	11.3	1411	10.7	1236
TON	590	45.6	14.1	POSTOJNA	9.1	1557	9.8	1269
VR1	570	45.8	14.0	POSTOJNA	9.1	1557	10.0	1353
VR2	615	45.8	14.0	POSTOJNA	9.1	1557	9.5	1383
VR3	690	45.7	14.1	POSTOJNA	9.1	1557	9.4	1395
VR4	638	45.7	14.1	POSTOJNA	9.1	1557	9.3	1382
VR5	650	45.7	14.1	POSTOJNA	9.1	1557	8.9	1404
VR6	515	45.8	13.9	GODNJE	11.3	1411	10.3	1398
ZT1	900	46.2	14.8	KRVAVEC	3.6	1476	6.8	1207
BOR	230	45.5	13.8	GODNJE	11.3	1411	12.0	1148

Table 2. Basic characteristics of the tree-ring width chronologies of European beech: first-order autocorrelation (AR1), Gleichläufigkeit coefficient (%GLK), mean interseries correlation (rbar).

Preglednica 2. Osnovni podatki o izbranih kronologijah navadne bukve: avtokorelacija prve stopnje (AR1), koeficient ujemanja Gleichläufigkeit (% GLK), drseča korelacija med zaporedji širin branik kronologije (rbar).

Code / Oznaka	Number of trees / Število dreves	First year / Prvo leto	Last year / Končno leto	%GLK	rbar	AR1
BOR	13	1939	2022	0.75	0.43	0.62
CEA	5	1840	2001	0.69	0.45	0.82
CEB	4	1883	2001	0.66	0.30	0.74
CRO	6	1831	2004	0.69	0.47	0.70
DOB	12	1840	2013	0.63	0.33	0.72
DRA	7	1752	2004	0.67	0.38	0.75
GOR	11	1830	2005	0.65	0.33	0.73
KAF	7	1859	2010	0.63	0.30	0.83
KLI	6	1845	2004	0.69	0.48	0.62
KOZ	13	1935	2022	0.69	0.28	0.68
KRE	7	1775	2004	0.61	0.29	0.80
LAZ	17	1921	2020	0.66	0.45	0.50
MOK	27	1854	2007	0.64	0.34	0.65
PA2	7	1911	2020	0.65	0.33	0.68
POS	8	1840	2007	0.63	0.24	0.74
POT	18	1886	2020	0.66	0.44	0.72
POV	13	1919	2022	0.69	0.37	0.67
SNE	24	1844	2008	0.60	0.25	0.72
TOA	7	1880	2001	0.70	0.29	0.76
TOB	4	1924	2001	0.77	0.43	0.74
TOC	10	1731	2001	0.66	0.32	0.74
TON	7	1911	2021	0.62	0.19	0.73
VAN	16	1927	2016	0.58	0.17	0.80
VR1	7	1914	2014	0.71	0.47	0.51
VR2	4	1928	2014	0.74	0.47	0.72
VR3	5	1927	2014	0.66	0.36	0.77
VR4	4	1889	2014	0.64	0.18	0.76
VR5	5	1872	2015	0.66	0.32	0.70
VR6	4	1910	2014	0.67	0.39	0.75
ZT1	10	1896	2021	0.68	0.43	0.68

autocorrelation, reflecting stronger lag effects related to previous tree-ring growth. GLK is a non-parametric measure of growth similarity when comparing two tree-ring series (Speer, 2010). GLK can reach a maximum of 100, indicating a complete agreement between two series, while values above 60 are usually considered to indicate good agreement (Geijer et al., 2024). Rbar represents the average correlation between individual tree-ring chronologies within each site (Cook & Kairiukstis, 2013), where higher values represent a stronger underlying common signal. The raw tree-ring data was detrended using the *detrend()* function from the dplR package, using a spline with a 50% frequency cutoff response at 32 years (Popa et al., 2024). We used pre-whitening to remove biological trends and temporal autocorrelation from each tree-ring width series. Finally, we built 30 site chronologies by robust bi-weight averaging of individual detrended tree-ring width series, used in subsequent analyses.

2.2 METEOROLOGICAL DATA

2.2 METEOROLOŠKI PODATKI

For each site, daily and monthly meteorological data was extracted based on the shortest distance between the site and the location of meteorological stations or grid points. For the modelled meteorological data, the SLOCLIM database was used (Škrk et al., 2021) for the period 1960-2018, extracting daily maximum (TMAX) and minimum air temperature (TMIN), and daily precipitation (PCP). The same daily data (TMAX, TMIN, PCP) were extracted from the Slovenian Environment Agency's observational database (ARSO, 2024), considering only the nearest meteorological stations that have a complete dataset for the period from 1960 to 2018. The period from 1960 to 2018 was chosen because it offers comprehensive meteorological data coverage from both ARSO and SLOCLIM. The mean air temperature (T) was calculated as the average of the maximum and minimum temperature. The differences in monthly values between ARSO and SLOCLIM datasets for both temperature and precipitation were also computed.

As shown in Figure 2, the average distance from the chronology site to the nearest meteorological station provided by the Slovenian Environment Agency (ARSO) was 15044 m (± 6405.2 m), whereas

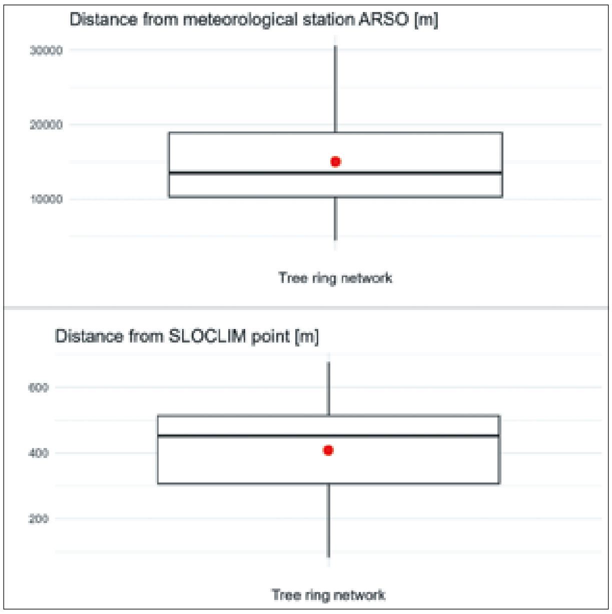

Figure 2. The boxplots of distances between site chronologies and the nearest meteorological station (ARSO) or gridded point (SLOCLIM). The red dots represent the average distance.
Slika 2. Okvir z ročaji za razdalje med lokacijami kronologij in najbližjo meteorološko postajo (ARSO) ali točko na mreži modeliranih podatkov (SLOCLIM). Rdeči piki predstavljata povprečno razdaljo.

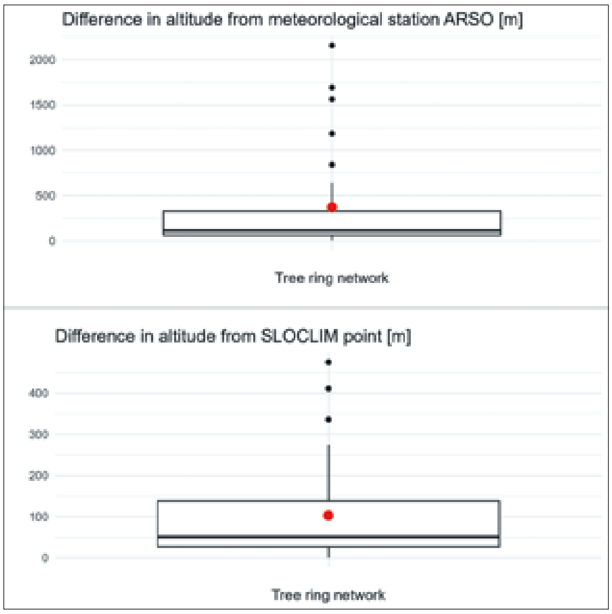

Figure 3. Difference between the altitude of the chronology site and the altitude of the ARSO meteorological station or gridded point (SLOCLIM). The red dots represent the average distance.
Slika 3. Okvir z ročaji za razlike med nadmorskimi višinami lokacij kronologij in nadmorskimi višinami najbližjih meteoroloških postaj (ARSO) ali točke na mreži modeliranih podatkov (SLOCLIM). Rdeči piki predstavljata povprečno razliko.

the average distance to the modelled climate data from SLOCLIM was only 409 m (± 141.6 m). This indicates the often-discussed inadequate spatial coverage of meteorological datasets in contrast to gridded datasets, underscoring their limited ability to accurately represent local climate conditions (e.g. Škrk et al., 2021).

The average difference between the altitude of a chronology site and the altitude of the nearest meteorological station was 370 m (± 559.1 m), while the average difference with regard to the altitude of SLOCLIM point was 103 m (± 122.2 m) (Figure 3).

2.3 STATISTICAL ANALYSES
2.3 STATISTIČNA ANALIZA

Climate-growth relationships were calculated using the *daily_response()* function for daily meteorological data and *monthly_response()* for monthly data from the dendroTools R package (Jevšenak & Levanič, 2018). Both functions work by sliding moving windows with variable lengths and calculating the correlation coefficient between the aggregated meteorological data of interest and the selected tree-ring chronology. We performed these calculations for the growing season, spanning from March to September to cover the entire period of cambial production, which for European beech in Slovenia mainly starts in April and ends in August (Čufar et al., 2008b; Prislan et al., 2013, 2019). This time frame was chosen because it is presumed that climate has the greatest influence on growth during this period. For each site, the highest absolute Pearson correlation coefficient was extracted and used for the comparison, calculated separately for mean air temperatures and precipitation sums, and for meteorological observational ARSO and gridded SLOCLIM datasets. Pairwise statistical significance was assessed using the Wilcoxon-rank sum test (Wilcoxon, 1992).

To test whether meteorological daily data exhibit significantly higher correlations with variations in tree-ring widths than monthly data, we compared daily and monthly data correlations with tree-ring widths for both meteorological stations (ARSO) and the gridded dataset (SLOCLIM), with separate calculations for precipitation and air temperature (Hypothesis 1). To test whether modelled meteorological data for a given site better explain the influence of climate conditions on tree-ring width variation than the commonly used meteorological station data, we compared ARSO and SLOCLIM data for daily and monthly air temperature and precipitation (Hypothesis 2). Furthermore, this study aimed to investigate whether altitude has an influence on the magnitude of the difference in the maximum correlation coefficient between data from meteorological stations and gridded datasets. We also sought to determine if altitude impacts the magnitude of the difference in maximum correlation coefficients between monthly and daily data (Hypothesis 3). To address the altitude effects, we first calculated differences between daily and monthly correlations with tree-ring data and also differences between SLOCLIM and ARSO correlations with tree-ring data (separately for temperature and precipitation variables), and afterwards fitted linear models where these differences are regressed as a function of altitude.

3 RESULTS AND DISCUSSION

3 REZULTATI IN DISKUSIJA

When comparing climate-growth relationships using daily and monthly meteorological data, the results show significantly higher maximum correlation coefficients between tree-ring data and meteorological data, if daily data of SLOCLIM or ARSO is used compared to monthly data for both the temperature and precipitation variables (Figure 4). The mean absolute maximum correlation coefficient with daily temperature was 0.30 for both ARSO and SLOCLIM (Figure 4). For daily precipitation, it was 0.44 for ARSO and 0.43 for SLOCLIM. For the monthly data, the absolute maximum correlation coefficient for temperature was 0.22 for ARSO and 0.21 for SLOCLIM, while for precipitation it was 0.34 for both ARSO and SLOCLIM. The correlations for temperature data were on average lower than the correlations in a study by Jevšenak (2019), where they were 0.47 for daily data and 0.41 for monthly data. Similarly, they were lower for precipitation data. However, the data in Jevšenak (2019) mainly included conifers (82%), which are known to be generally more sensitive to the climate. The advantage of using daily data applies especially for precipitation, which was also confirmed in the aforementioned study. This is due to the higher autocorrelation of temperatures compared to precipitation, and therefore the relative position of time windows for temperature is less important. The stronger correlation between daily meteorological data and tree-ring proxies, compared to monthly data, was also confirmed in a study by Nagavciuc et al. (2019).

The comparative analysis revealed no significant differences between daily and monthly data for SLOCLIM and ARSO data for either temperature or precipitation variables (Figure 4). Although the SLOCLIM database was developed on the basis of data from ARSO meteorological stations across Slovenia (considering also altitude, latitude, longitude and distance to the coast), the result remains surprising. Given SLOCLIM's higher spatial resolution, it was expected to more accurately reflect local climate conditions and their influence on tree-ring variations.

Furthermore, the analysis of monthly temperature and precipitation differences between the ARSO and SLOCLIM databases revealed that the medians of the differences are consistently close to zero throughout the year (Figure 5). Nevertheless, in certain months (July to October), ARSO recorded lower temperature values than SLOCLIM in some years, suggesting occasional discrepancies during these months which could explain the lack of significant differences between ARSO and SLOCLIM meteorological data in climate-growth analysis.

Linear regression was applied to describe the statistical relationship between altitude and differences in absolute maximum climate-growth correlations between gridded data and meteorological station data, as well as between daily and monthly data. The results indicate that none of the dependent variables are significantly influenced by altitude (Table 3, Figure 6).

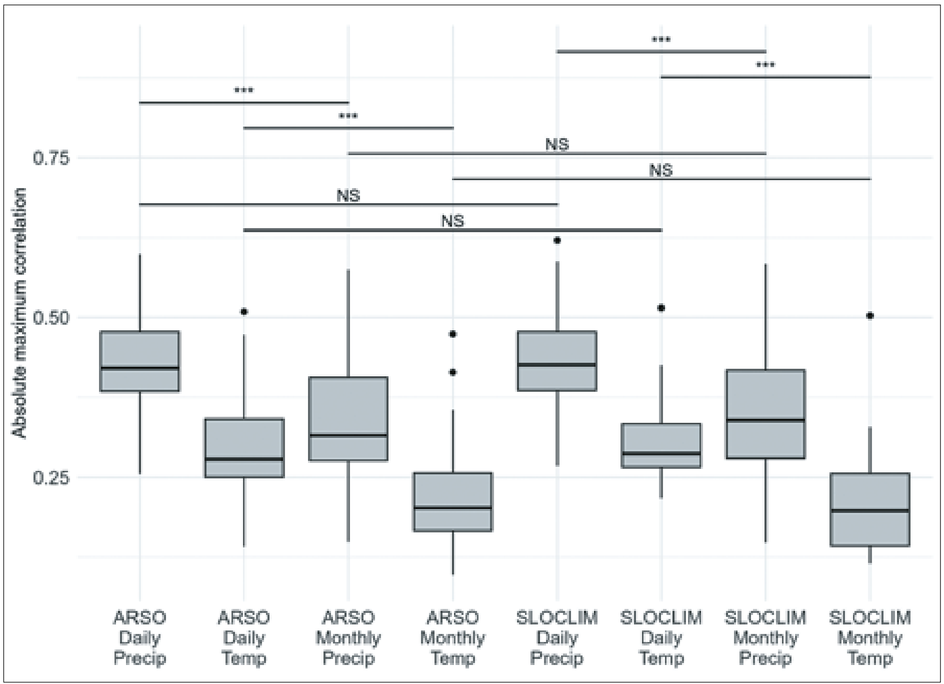

Figure 4. Boxplots of absolute maximum correlation coefficients, calculated between tree-ring data and daily or monthly meteorological data, calculated separately for gridded data (SLOCLIM) and data from meteorological stations (ARSO). Horizontal lines indicate statistical significance of pairwise comparisons. Significance levels: NS not significant at p >0.05; significant: *(0.01 < p ≤ 0.05); **(0.001 < p ≤ 0.01); ***(p ≤ 0.001).

Slika 4. Okvirji z ročaji za prikaz vrednosti absolutnih maksimalnih korelacijskih koeficientov, izračunani med širinami branik in dnevnimi oziroma mesečnimi meteorološkimi podatki, ki so pridobljeni iz modelirane baze SLOCLIM ali iz meteoroloških postaj (ARSO). Ravne črte predstavljajo statistično značilnost pri parnih primerjavah. Stopnje značilnosti: NS ni značilno pri p >0.05; značilno: *(0.01 < p ≤ 0.05); **(0.001 < p ≤ 0.01); ***(p ≤ 0.001).

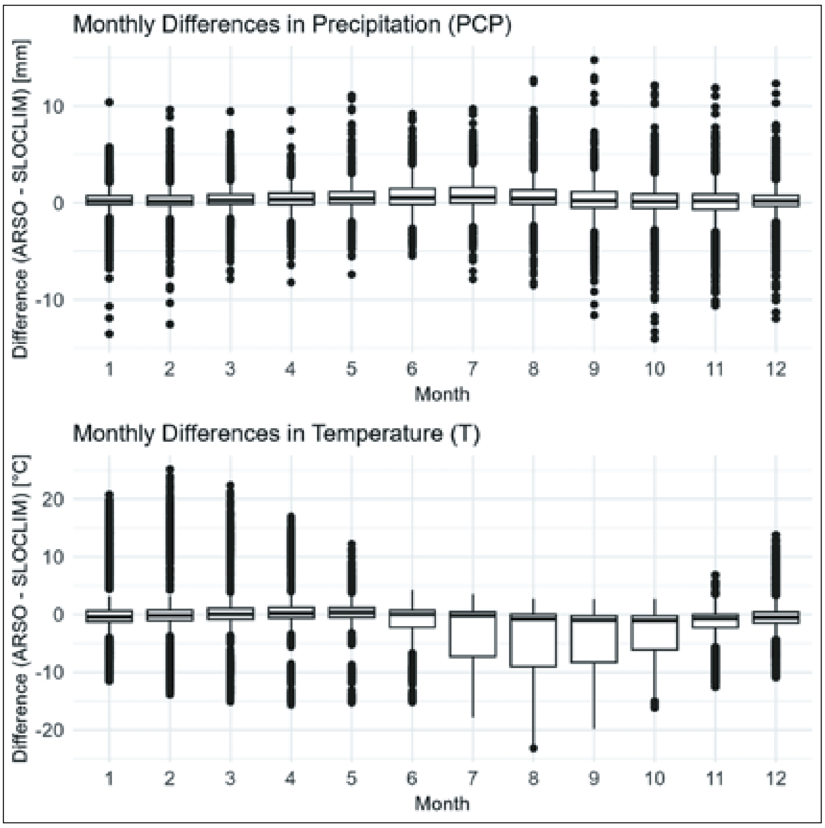

Figure 5. Boxplots of monthly differences between ARSO and SLOCLIM datasets for precipitation (PCP) and temperature (T). The difference is calculated as ARSO – SLOCLIM for the period 1960-2018.

Slika 5. Okvirji z ročaji za prikaz razlik v mesečnih vrednostih med meteorološkimi podatki SLOCLIM ali ARSO za padavine in povprečne temperature. Razlika je izračunana kot ARSO – SLOCLIM v obdobju 1960–2018.

Table 3. The results of the linear regression analyses for the relationship between altitude (independent variable) and the difference (Diff) in absolute maximum correlation coefficient between tree-ring data and meteorological data when observational data (ARSO) versus gridded data (SLOCLIM) is used for temperature (T) and precipitation (PCP), as well as difference in daily and monthly meteorological data from ARSO or SLOCLIM (dependent variables). The table presents the beta coefficient (β), standard error (SE), t-value, p-value, and the coefficient of determination (R^2).

Preglednica 3. Rezultati linearne regresije, kjer je neodvisna spremenljivka nadmorska višina, odvisne spremenljivke pa so razlike v maksimalnih korelacijskih koeficientih med širinami branik in dnevnimi oziroma mesečnimi meteorološkimi podatki ter podatki iz meteoroloških postaj (ARSO) ali baze SLOCLIM za temperature (T) in padavine (PCP). Beta – koeficient β, standardna napaka (SE), t-vrednost, p-vrednost in koeficient determinacije (R^2).

Dependent Variable / Odvisna spremenljivka	Beta (β)	SE	t-value	p-value	R^2
Diff between ARSO and SLOCLIM in daily T	0.000	0.000	0.418	0.679	0.006
Diff between ARSO and SLOCLIM in daily PCP	0.000	0.000	0.543	0.591	0.010
Diff between ARSO and SLOCLIM in monthly T	0.000	0.000	0.339	0.738	0.004
Diff between ARSO and SLOCLIM in monthly PCP	0.000	0.000	0.160	0.874	0.001
Diff between daily and monthly data in ARSO T	0.000	0.000	-1.156	0.258	0.046
Diff between daily and monthly data in SLOCLIM T	0.000	0.000	-1.105	0.279	0.042
Diff between daily and monthly data in ARSO PCP	0.000	0.000	0.768	0.449	0.021
Diff between daily and monthly data in SLOCLIM PCP	0.000	0.000	0.352	0.728	0.004

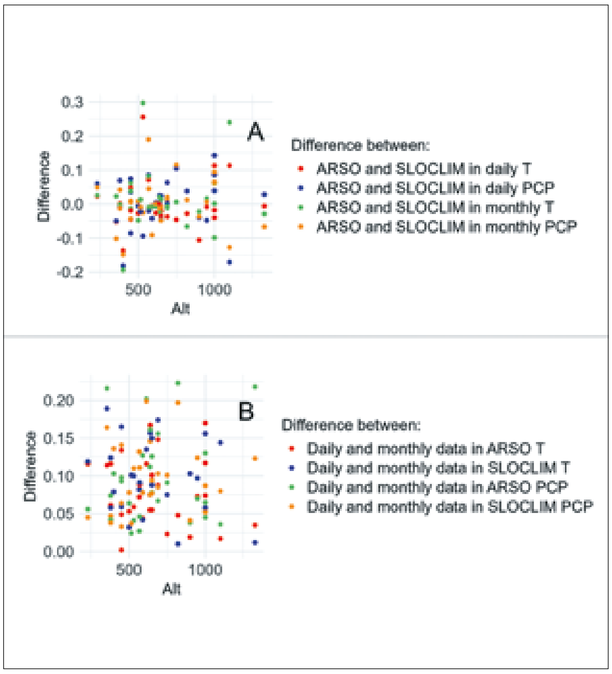

Figure 6. Difference in absolute maximum correlation coefficient between tree-ring data and meteorological data when observational data (ARSO) versus gridded data (SLOCLIM) is used for temperature (T) and precipitation (PCP) regarding altitude (A). Difference in maximum correlation coefficient between tree-ring data and meteorological data when daily versus monthly data is used from ARSO and SLOCLIM regarding altitude (B). Altitude (x-axis) refers to the elevation of the specific site.

Slika 6. Razlike v maksimalnih korelacijskih koeficientih med širinami branik in meteorološkimi podatki, glede na to, ali uporabimo podatke iz meteoroloških postaj (ARSO) ali modelirane podatke (SLOCLIM) pri temperaturah (T) in padavinah (PCP) glede na nadmorsko višino (A), ter ali uporabimo dnevne ali mesečne meteorološke podatke (B) glede na nadmorsko višino. Nadmorska višina (x os) se nanaša na nadmorsko višino posameznega rastišča.

4 CONCLUSIONS
4 ZAKLJUČEK

In this study we compared the climate-growth relationship of European beech from selected sites in Slovenia, based on newly compiled tree-ring chronologies (with the recommended detrending procedure) and meteorological data from the meteorological stations of the Slovenian Environment Agency (ARSO) and gridded data from the SLOCLIM database. Our results show that daily meteorological data provided a significantly higher maximum correlation coefficients with tree-ring data compared to monthly data, which underlines the advisability of using daily data (if available) over monthly data in dendrochronological analyses. This advantage is particularly pronounced for precipitation, and agrees with results reported by other studies. Hypothesis 1 is thus supported.

Using these particular tree-ring data and the statistical approach, no statistically significant difference was found in correlations between tree-ring data and the meteorological data from meteorological stations and the gridded data from SLOCLIM, with a high spatial resolution. This confirms that the observations from ARSO, which were also used to interpolate SLOCLIM database, adequately reflect the actual climate variability in Slovenia as already discussed by Škrk et al. (2021). Boxplots of the differences in monthly meteorological data between the ARSO and SLOCLIM databases revealed that both datasets report similar values for precipitation and temperature, indicating that the datasets are largely consistent. We thus reject Hypothesis 2.

The advantage of using daily data over monthly data applies to both lower and higher altitudes. However, the difference in absolute maximum climate-growth correlations between daily or monthly data does not significantly vary with altitude. Furthermore, the difference between gridded and observational meteorological data remains fairly constant across different altitudes. As such, Hypothesis 3 is not supported.

These results suggest the importance of further studies with a larger tree-ring network, possibly also including other tree species to gain a more comprehensive understanding of the benefits of daily and gridded meteorological data, particularly in regions with sparse meteorological station coverage, such as forested areas and higher altitudes, and in cases with many gaps in meteorological data. High spatial resolution of meteorological data is also crucial for the calibration of process models. When interpreting the climate-growth relationships, it should also be considered that the tree-ring width integrates the effect of climatic and other ecological influences, and that these reactions recorded in the tree-ring width cannot simply be described by the selected climate data alone.

5 SUMMARY
5 POVZETEK

V dendrokronoloških študijah se za analizo vpliva podnebnih dejavnikov na variiranje širin branik tradicionalno uporabljajo mesečni meteorološki podatki. V mesečnih povprečjih pa pogosto ostanejo prezrti ekstremni vremenski dogodki, ki pomembno vplivajo na rast dreves in se v zadnjem času zaradi podnebnih sprememb pojavljajo pogosteje. Zato se v zadnjih letih vedno bolj poudarja pomen uporabe dnevnih meteoroloških podatkov (Beck et al., 2013; Jevšenak, 2019; Liang et al., 2013; Pritzkow et al., 2014), ki lažje zajamejo tudi različne fenološke faze, ki jih beležimo v dnevnih intervalih.

Ker meteorološke postaje, ki beležijo dnevne podatke, običajno niso gosto in enakomerno razporejene po prostoru, so bile razvite različne interpolirane in/ali modelirane podatkovne baze, ki nudijo tudi dnevne meteorološke podatke z visoko prostorsko ločljivostjo, tako na evropski (E-OBS) kot tudi svetovni ravni (CHELSA, ERA5). V Sloveniji imamo v okviru Agencije Republike Slovenije za okolje (ARSO) dobro razvito mrežo meteoroloških postaj. Število klasičnih postaj z opazovalci v zadnjih letih sicer upada, veča pa se število samodejnih postaj (Nadbath, 2015). Gostota teh postaj je manjša na gozdnatih in višje ležečih predelih, lokacije postaj pa so bile v preteklosti tudi večkrat spremenjene. Da bi zagotovili meteorološke podatke z visoko časovno in prostorsko ločljivostjo, je bila razvita modelirana baza SLOCLIM (Škrk et al., 2021), ki smo jo uporabili tudi v tej raziskavi.

Glavni cilj raziskave je bil preučiti, ali dnevni podatki bolje pojasnijo vpliv podnebnih razmer na variiranje širin branik kot doslej običajno uporabljeni mesečni podatki (hipoteza 1). Poleg tega smo želeli preveriti tudi, ali se korelacijski koeficienti med širinami branik in meteorološkimi podatki razlikujejo, če uporabimo podatke iz meteoroloških postaj ali iz baze SLOCLIM (hipoteza 2). Zanimalo nas je še, ali se te razlike značilno spreminjajo z nadmorsko višino (hipoteza 3).

Uporabili smo 30 na novo sestavljenih kronologij navadne bukve (*Fagus sylvatica* L.) iz celotne Slovenije z razponom nadmorskih višin med 230 in 1330 metri. Izračunali smo maksimalne absolutne korelacijske koeficiente med širinami branik in dnevnimi oziroma mesečnimi meteorološkimi po-

datki iz meteoroloških postaj ARSO ali baze SLOCLIM. Meteorološka postaja ARSO ali točka na mreži SLOCLIM je bila izbrana glede na oddaljenost od lokacije kronologije, pri čemer smo upoštevali najkrajšo razdaljo. Pri analizah smo uporabili knjižnico dendroTools (Jevšenak & Levanič, 2018) s funkcijama *daily_response*() za dnevne meteorološke podatke in *monthly_response*() za mesečne podatke. Analize so vključevale povprečne temperature zraka ter količino padavin za obdobje od 1960 do 2018.

Rezultati so pokazali, da so maksimalni korelacijski koeficienti med širinami branik in meteorološkimi podatki statistično značilno višji, če uporabimo dnevne, kot pa če uporabimo mesečne podatke. To potrjuje smiselnost uporabe dnevnih podatkov v dendroklimatoloških analizah. Korelacijski koeficienti so bili višji tako pri temperaturah kot pri padavinah. Uporabo dnevnih podatkov še posebej priporočamo pri korelacijah širin branik s padavinami, kar je pokazal tudi Jevšenak (2019). Temperaturni podatki imajo namreč veliko stopnjo avtokorelacije, ki je padavine nimajo. Hipotezo 1 smo torej potrdili. V primerjavi z raziskavo, kjer so bili vključeni predvsem iglavci (Jevšenak, 2019), so bili maksimalni korelacijski koeficienti v naši študiji z bukvijo nekoliko nižji, verjeto zato, ker so iglavci na splošno občutljivejši na podnebne razmere.

Čeprav je bila povprečna oddaljenost meteorološke postaje ARSO od lokacije s kronologijo približno 15 km, točke SLOCLIM, ki temeljijo na podatkih več okoliških postaj, pa le okoli 409 m, rezultati niso potrdili statistično značilnih razlik v maksimalnih korelacijskih koeficientih med širinami branik in meteorološkimi podatki iz dveh različnih baz podatkov. Tudi analize razlik v mesečnih meteoroloških podatkih so pokazale, da ni večjih razlik med bazama tako pri padavinah kot temperaturah. Hipotezo 2 smo zato zavrnili.

Z višanjem nadmorske višine se razlike med korelacijami s širinami branik glede na to, ali smo uporabili dnevne ali mesečne podatke, tako pri temperaturah kot tudi padavinah niso statistično značilno spreminjale. Prav tako se z višanjem nadmorske višine niso značilno spreminjale razlike v korelacijah s kronologijami med bazama. Predvidevamo, da je med razlogi za to manjše število proučenih kronologij z višjih nadmorskih višin, kjer bi pomanjkanje meteoroloških postaj lahko privedlo do večjih razlik. Hipotezo 3 smo prav tako zavrnili.

Naši rezultati so potrdili pomembnost izbire načina izračuna korelacijskih koeficientov. Delno smo potrdili ugotovitve predhodnih študij, pokazali pa tudi, da so merjeni meteorološki podatki, čeprav oddaljeni od lokacij rastišč v Sloveniji, še vedno zanesljiv vir za zajem variabilnosti podnebja kot dejavnika pri rasti bukve. Rezultati so pokazali neznačilen vpliv nadmorske višine na razlike v korelacijah.

V prihodnjih raziskavah bi lahko analize razširili s širšim naborom kronologij bukve in drugih drevesnih vrst ter tako pridobili še celovitejše razumevanje pomena uporabe meteoroloških podatkov z visoko prostorsko in časovno ločljivostjo, še posebej na območjih, kjer je meteoroloških postaj malo, npr. v gozdnatih in višje ležečih predelih. Kljub temu je potrebno poudariti, da na širino branik vplivajo tudi ekološki in drugi individualni dejavniki in zato variacij med širinami branik ni možno pojasniti izključno z izbranimi meteorološkimi podatki.

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THE ŠPICA PILE-DWELLING SITE – ANALYSES OF ARCHAEOLOGICAL WOOD

KOLIŠČARSKA NASELBINA ŠPICA – RAZISKAVE ARHEOLOŠKEGA LESA

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Abstract / Izvleček

Abstract: We present the investigation of wood discovered during the 2009/2010 archaeological excavations at the prehistoric pile-dwelling settlement of Špica in Ljubljansko barje, Slovenia. The results include data on wood identification, dendrochronological dating and the spatial distribution of the piles. We focussed on smaller sections of the site and dated oak and ash piles with the reference chronologies of the pile-dwelling settlements of Založnica and Parte spanning the period 2659 – 2366 BC. Based on the established dates of tree felling, we identified several construction activities between 2522 and 2406 BC. Due to the time span of the available reference chronologies, it was not possible to date the wood eventually felled before or after 2659 – 2366 BC. The analyses of the wood together with earlier analyses of archaeological artefacts allow a better understanding of the chronological framework of the Špica site, although this study could not exploit the entire research potential of the excavated archaeological wood.

Keywords: Ljubljansko barje, Špica pile-dwelling, Late Copper Age, 3rd millennium BC, archaeological wood, dendrochronology

Izvleček: Predstavljamo raziskavo lesa, odkritega med arheološkimi izkopavanji 2009/2010 na prazgodovinski koliščarski naselbini Špica na Ljubljanskem barju v Sloveniji. Raziskave so v glavnem vključevale identifikacijo lesa, dendrokronološko datiranje in prostorsko razporeditev kolov. Osredotočili smo se na manjše dele najdišča in datirali hrastove in jesenove kole z referenčnimi kronologijami koliščarskih naselbin Založnica in Parte, za obdobje 2659–2366 pr. Kr. Na podlagi ugotovljenih datumov poseka dreves smo identificirali več faz gradbenih aktivnosti med leti 2522 in 2406 pr. Kr. Zaradi časovnega razpona razpoložljivih referenčnih kronologij ni bilo mogoče datirati lesa, ki je bil morda posekan pred letom 2659 ali po letu 2366 pr. Kr. Analize lesa skupaj s predhodnimi analizami arheoloških najdb omogočajo boljše razumevanje kronološkega okvira obstoja kolišča Špica, čeprav v študiji nismo uspeli izkoristiti celotnega potenciala zbranega arheološkega lesa.

Ključne besede: Ljubljansko barje, kolišče Špica, pozna bakrena doba, tretje tisočletje pr. Kr., arheološki les, dendrokronologija

1 INTRODUCTION

1 UVOD

The archaeological site Špica is located in the northern part of the Ljubljansko barje area in central Slovenia in the city of Ljubljana, on the right bank of the river Ljubljanica (Figure 1). The site is bordered to the south by the Ljubljanica River and to the east by the Gruber Canal, which was built at the end of the 18th century to speed up the drainage of excess water from the Ljubljanica. The results of the research of the archaeological finds from Špica funded by the ARIS postdoctoral project "Exchange and mobility dynamics at Ljubljansko barje: Late Copper age pile-dwelling Špica in Ljubljana" indicated that the majority of the finds originate from the middle of the 3rd millennium BC. However, the

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analyses of the archaeological wood from Špica has not yet been presented.

The first mention of the Špica site is dated back to the end of the 19th century, when numerous finds came to light as a result of the repeated regulation of the Ljubljanica river. In the first half of the 20th century multiple discoveries, such as copper, stone, bone and pottery finds, were made in the vicinity of the Špica site. Included in the discoveries were artefacts resembling those known from Dežman's pile-dwellings near Ig, which were discovered and researched by Dragotin Dežman between 1875 and 1877 (Šinkovec, 1995; Šinkovec, 2012; Gaspari, 2012; Leghissa, 2021). In 2009, in the light of the planned renovation of the Špica area, preliminary archaeological investigations were therefore carried out to determine the archaeological potential of the site by drilling core holes in the wider area of Špica park and along the Ljubljanica River and Gruber Canal (Novšak et al., 2009). The results confirmed the existence of pile-dwelling settlement

Figure 1. Location of the Špica site in the city of Ljubljana (source: https://gis.arso.gov.si/atlasokolja; map: E. Leghissa).

Slika 1. Lokacija najdišča Špica v Ljubljani (vir: https://gis.arso.gov.si/atlasokolja; zemljevid: E. Leghissa).

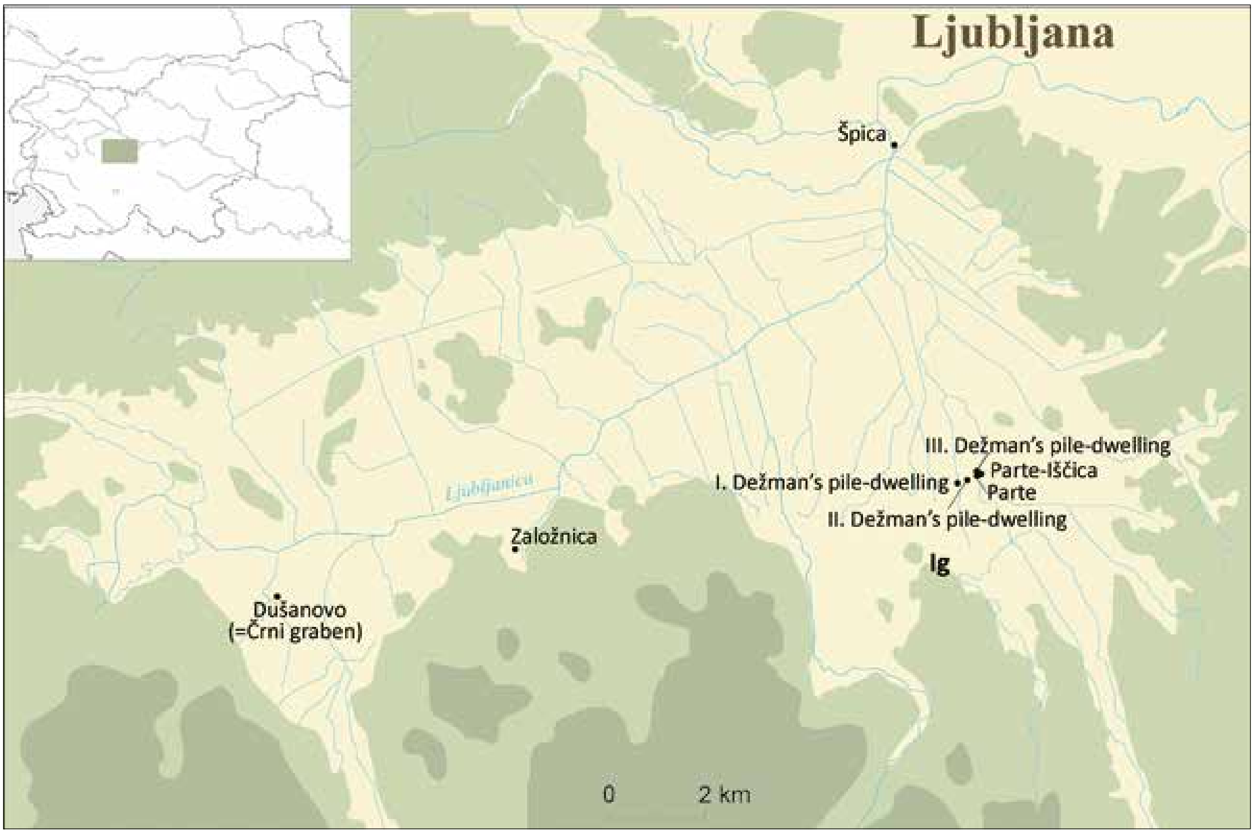

Figure 2. Distribution of the first half and the middle of the 3rd millennium BC pile dwellings in the Ljubljansko barje area, Slovenia. Map: E. Leghissa.

Slika 2. Razporeditev koliščarskih naselbin iz prve polovice in sredine 3. tisočletja pr. Kr. na območju Ljubljanskega barja. Zemljevid: E. Leghissa.

structures. On the basis of the results, rescue archaeological investigations took place in 2009 and 2010 in the area of the planned work of arranging the Špica area and the banks of Gruberjevo nabrežje. The archaeological investigation uncovered a small part of a pile-dwelling settlement, with well-preserved remains of wooden architecture and numerous finds from the Late Copper Age, i.e. most likely from the middle of the 3rd millennium BC (Klasinc et al., 2010; Šinkovec, 2012; Jančar, 2016). The majority of the finds consist of numerous pottery vessels and other objects, comparable to those found at contemporaneous sites in the Ljubljansko barje, such as Parte, II. Dežman's, Založnica and Dušanovo pile-dwellings, which are attributed to the newly defined Ljubljana culture (Figure 2) (Leghissa, 2021; Leghissa, 2024).

2 MATERIALS AND METHODS

2 MATERIALI IN METODE

2.1 ARCHAEOLOGICAL INVESTIGATIONS OF ŠPICA PILE DWELLING IN 2009-2010

2.1 ARHEOLOŠKE RAZISKAVE KOLIŠČARSKEGA NASELJA ŠPICA V LETIH 2009/2010

The archaeological investigation, conducted under the supervision of the Museum and Galleries of Ljubljana and the Institute for the Protection of Cultural Heritage, OE Ljubljana, was carried out by the company Tica Sistem.

The excavations only covered certain areas of Špica, which were then the subject of a planned restoration of this section of the riverbank (see the excavation field borders marked in Figure 6). A total area of almost 750 m² was investigated, of which 463 m² were completely excavated down to the cultural layer, while 284 m² remained untouched. Based on archaeological drillings from 2009, archaeological excavations and geological research, it was found that in prehistoric times a stream ran in the place of today's Gruber Canal, which flowed into a lake and transported material from Grajski grič and Golovec. In the vicinity of today's Ljubljanica, lake sediments were found during archaeological investigations that indicate a lake on whose shores a pile-dwelling settlement was built.

The oldest geological layer is represented by the marl layer (in Slovene *polžarica*), within which laminae of sand are found, indicating the action of flowing water, most likely associated with periodic floods of the aforementioned stream and lake. In some areas, the upper part of the marl layer is oxidized, suggesting that parts of the layer were occasionally exposed to air, indicating dry conditions and exposure to oxidation. Above the geological base was documented the cultural layer. Geological and palynological research at the Špica site (Andrič et al., 2017) has shown that a large part of the stratigraphic sequence, deposited between 18,000 and 2,500 BC – that is, between the marl layer and the cultural layer – has eroded. The late glacial and early/middle Holocene sediment is thus missing and was presumably removed by fluvial processes. The cultural layer thickens from south to north, or from the beds of the Ljubljanica River and the Gruber Canal toward the interior. Within the cultural layer, particularly at its top, there is a large quantity of finds and stones. The material is predominantly composed of pottery and bone fragments. Most of the ceramic finds are highly fragmented with rounded edges, indicating horizontal displacement of the material within the pile-dwelling settlement area due to water movement. The cultural layer is thickest in trench 1001/1, located in the central western part of the investigated area. At this location, the number of wooden remains, both vertical and horizontal piles, was the greatest, likely contributing to the preservation of the most finds between the wooden piles. Based on comparisons, the finds most likely date to the mid-3rd millennium BC, corresponding to the Late Copper Age. This area of the site also contains the most stones/rock fragments, most of which originate from the southern edge of the marshland. The cultural layer was overlain by gyttja/layers of organic mud, marking the phase following the abandonment of the pile-dwelling settlement, characterized by the marshification and drying of the lake. The layers of gyttja were in some areas covered by other layers of alluvial origin, formed during later prehistoric periods and the Roman era. The youngest layers date to the Early Modern period and more recent times, which in some areas have reached down to the level of the geological layers (Figure 3) (Klasinc et al., 2010).

Figure 3. View of the layers in section P 1008 at Špica pile dwelling excavation: at the bottom the marl layer is visible, directly overlain by the cultural layer (dark brown layer). The layers between the loess and the cultural layer were most likely removed by fluvial processes (see Andrič et al. 2017). The cultural layer is covered by organic mud / gyttja (light brown layer), followed by floodplain sediments (grey layers), and in the upper part, modern-age deposits and alluvium (yellowish layer) are visible. The section also shows wooden elements and larger stones at the interface between the cultural layer and the gyttja. View towards the northeast. Photo: G. Babič; source: Museums and Galleries of Ljubljana (after Klasinc et al., 2010, Fig. 6).

Slika 3. Pogled na plasti v prerezu P 1008 pri izkopu kolišča Špica: na dnu je vidna polžarica (svetlo siva plast), na kateri leži direktno kulturna plast (temno rjava plast). Plasti med polžarico in kulturno plastjo so bile erodirane najverjetneje zaradi delovanja vode (glej Andrič et al., 2017). Kulturna plast je prekrita z organskim blatom/gyttjjo (svetlo rjava plast). Sledijo poplavni sedimenti (sive plasti) in v zgornjem delu novoveški sedimenti in naplavine (rumenkasta plast). Na prerezu so vidni tudi leseni elementi in večji kamni na stiku med kulturno plastjo in gyttjo. Pogled proti severovzhodu. Fotografija: G. Babič; vir: Muzeji in galerije mesta Ljubljane (po Klasinc et al., 2010, slika 6).

2.2 WOODEN REMAINS, DISCOVERED DURING ARCHAEOLOGICAL INVESTIGATIONS IN 2009/2010

2.2 LESENI OSTANKI, ODKRITI MED ARHEOLOŠKIMI RAZISKAVAMI V LETIH 2009/2010

The wood discovered during archaeological excavations at the Špica site was typologically classified into usable objects (such as parts of spindles and axe shafts), tree remnants (branches, twigs, and weaving remains that formed house walls), and construction or building elements. The latter were the most numerous and were used in the construction of the dwellings or various other structures in the prehistoric pile-dwelling settlement (Figure 4). The total number of identified wooden elements (hereafter referred to as LE after the Slovene term *Lesni Element*) amounts to 2,737. For dendrochronological research and wood species identification, 2,528 LE samples of construction and building elements were collected. Among the discovered LE, the majority are vertical LE (93%), while only 7% were horizontal. Most wooden piles were documented at the level of cultural layers, with some being identified within the gyttja, and only exceptionally in the alluvial deposits above the gyttja. The preservation of LE was, in some places, very poor (especially in areas near the Ljubljanica River). At the level of the marl layer a significant number of posts was discovered, representing fully weathered piles.

More than 60% of all discovered LE were processed in various ways. Some were split on one or both sides, sometimes even on multiple sides. A significant number of LE were sharpened to a point, with some of these also being flattened into planks. Some of the processed piles had burnt tips, indicating that fire was also used by the pile-dwellers in processing wood.

All wooden elements (LE) were numbered during the excavations and documented both descriptively and spatially using a total station. For most of them, samples were taken for dendrochronological analysis. These samples were approximately 20 cm long, typically taken from the lower, better-preserved part of the pile. In rare cases, samples could not be taken due to poor preservation of the pile. After the sampling in the field, the waterlogged samples were sealed in airtight polyethylene bags and transported to the Chair of Wood Science at the Department of Wood Science and Technology, Biotechnical Faculty, University of Ljubljana for wood analyses. Research work was done in the Wood Anatomy and Dendrochronology Laboratory.

Figure 4. Densely hammered upright wooden piles found at two locations of the Špica pile-dwelling site during excavations in 2009/2010. Photo: G. Babič; source: Museums and Galleries of Ljubljana.
Slika 4. Gosto zabiti pokončni leseni koli, najdeni na dveh mestih na kolišču Špica med izkopavanji v letih 2009/2010. Fotografija. G. Babič; vir: Muzeji in galerije mesta Ljubljane.

2.3 WOOD IDENTIFICATION AND DENDROCHRONOLOGY
2.3 IDENTIFIKACIJA LESA IN DENDROKRONOLOGIJA

In 2009 the Chair of Wood Science received 238 samples of piles, followed by a further 2,214 in 2010. All 2,452 wood samples collected over two years were processed according to the standard methodology developed during work on other excavations at Ljubljansko barje under the direction of Anton Velušček (e.g. Čufar et al., 2022; Velušček & Čufar, 2025). The wood was processed as follows:

- surface preparation of cross-sections of 2,452 wood samples,
- macroscopic identification of the wood species,
- preparation of microscopic sections (transverse, radial and tangential) for microscopic wood identification when macroscopic identification was not possible,
- counting the tree rings, measuring the diameters and recording the main characteristics of all samples,
- measurement of tree-ring widths for samples of oak (*Quercus* sp., QUSP), ash (*Fraxinus* sp., FRSP), beech (*Fagus sylvatica*, FASY) and silver fir (*Abies alba*, ABAL) containing ≥45 tree rings,
- cross-dating and attempting to construct tree-ring chronologies of the site and dendrochronologically date the tree-ring series of individual piles using the reference chronologies of Založnica and Parte pile dwellings of the Ljubljansko barje,
- creation of a table with all the important information for each of the samples.

After the wood analyses were completed, the water-saturated samples were vacuum-sealed and stored in airtight polyethylene bags in a cool storage room at the Department of Wood Science and Technology.

2.4 MAPS OF PILE DISTRIBUTION REGARDING WOOD CHARACTERISTICS
2.4 PRIPRAVA NAČRTOV RAZPOREDITVE KOLOV GLEDE NA ZNAČILNOSTI LESA

The individual piles were recorded during the excavation using a total station, which was locked into an absolute coordinate system in use at the time: the Yugoslavia Reduced Gauss-Krüger Transverse Mercator D48. The estimated precision of the measurements falls well within ±0.05 metres. Although the coordinate system is now obsolete, we did not reproject the data for two reasons. First, due to the scale, reprojecting the data would not yield any benefit for our analysis. Second, minor errors could be introduced by this process.

We imported the field data into Golden Software Surfer 8 to map the points. Subsequently, the data was further processed in ArcGIS Desktop 9.3.1 (the analysis was conducted in 2011-2012) to calculate Kernel Density Estimation (KDE). KDE is a method that provides valuable insights into the intensity and concentration of point data, such as archaeological sites or features. It creates a smooth, continuous surface by placing a kernel function at each point in the dataset and summing these functions to generate a density surface. The kernel function determines the shape and size of the area of influence around each point. Commonly used kernel functions include Gaussian, Epanechnikov, and Uniform kernels. The bandwidth parameter controls the size of the kernel and influences the degree of smoothing applied to the data (e.g., Baxter et al., 1997; Bonnier et al., 2019; Lozić & Štular, 2024).

We empirically determined that a 1 m bandwidth and the "kernel densities" parameter are the most appropriate for our application. We calculated the total kernel density estimations for all piles, as well as separately for oak (QUSP) and ash (FRSP) piles.

3 RESULTS AND DISCUSSION

3 REZULTATI IN RAZPRAVA

3.1 WOOD IDENTIFICATION AND DENDROCHRONOLOGY

3.1 IDENTIFIKACIJA LESA IN DENDROKRONOLOGIJA

Analyses of 2,452 samples of construction and building elements helped us to identify 13 wood species or genera (Table 1). The most common species/genera were ash with 1,460 samples (60%) and oak with 509 (21%). Furthermore, beech (4%), maple (3%), hornbeam (3%), willow (3%), elder (2%), silver fir (1%), and hazel (1%) accounted for 1 to 4%, while poplar, rowan, elm, and birch occurred only sporadically. In 1.6% of the samples, the wood species / genera could not be determined because the wood had deteriorated too much. The selection and proportion of wood species, especially the highest share of ash and oak, is consistent with the situation at the Ljubljansko barje pile-dwelling sites, where ash and oak usually predominate, but have different proportions from site to site (e.g., Čufar & Velušček, 2012; Jančar, 2016; Čufar et al., 2022; Out et al., 2022, 2023).

The wood was collected to carry out dendrochronological dating. Oak and ash are best suited for this purpose. The samples contained 45 or more tree rings and were dendrochronologically analysed for 85 (27%) of the oak samples and 394 (17%) of the ash ones (Table 2). Additionally, we measured nine (8%) of the beech and nine (31%) of the silver fir samples which could not be cross-dated. The ash piles were predominantly 4 to 12 cm in diameter, while the oak piles were generally larger (Figure 5). In other sites, the oaks with diameters of 20 cm or more were usually split lengthwise before being used as piles (e.g., Oat et al., 2023; Čufar et al., 2022). However, at the Špica site there were only 36 split oaks (7%) and only 11 (2%) of these were dendrochronologically analysed.t

Before we started to cross-date the tree-ring series of the dendrochronologically measured samples we created maps showing the distribution and arrangement of piles from different wood species to identify potential structures to be dated.

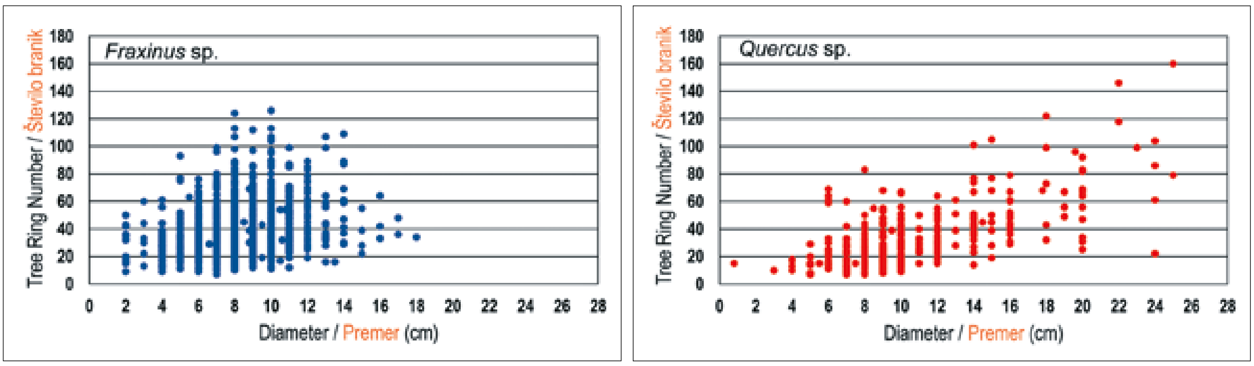

Figure 5. Ash (*Fraxinus* sp.) and oak (*Quercus* sp.) from the Špica pile-dwelling site: number of tree rings vs. diameter.

Slika 5. Jesen (*Fraxinus* sp.) in hrast (*Quercus* sp.) s kolišča Špica: število branik in premeri.

Table 1. Wood species of 2,452 samples of piles and other construction elements collected at the Špica pile-dwelling site.
Preglednica 1. Lesne vrste 2452 vzorcev kolov in drugih konstrukcijskih elementov, zbranih na kolišču Špica.

	Scientific name Latinsko ime	Code Koda	English name Angleško ime	Slovenian name Slovensko ime	Number Število	% %
1	*Fraxinus* sp.	FRSP	ash	jesen	1460	59.5
2	*Quercus* sp.	QUSP	oak	hrast	509	20.8
3	*Fagus sylvatica*	FASY	beech	bukev	110	4.5
4	*Acer* sp.	ACSP	maple	javor	77	3.1
5	*Carpinus betulus*	CPBE	hornbeam	beli gaber	75	3.1
6	*Salix* sp.	SASP	willow	vrba	62	2.5
7	*Alnus glutinosa*	ALGL	elder	jelša	50	2.0
8	*Abies alba*	ABAL	silver fir	jelka	29	1.2
9	*Corylus avellana*	COAV	hazel	leska	21	0.9
10	*Populus* sp.	POSP	poplar	topol	12	0.5
11	*Sorbus torminalis*	SOTE	rowan	brek	3	0.1
12	*Ulmus* sp.	ULSP	elm	brest	3	0.1
13	*Betula* sp.	BEPE	birch	breza	1	<0.1
14		INID	not identified	neidentificiran	40	1.6
				SUM	2452	

Table 2. Ash (*Fraxinus* sp.) and oak (*Quercus* sp.) from the Špica pile-dwelling site: total number of samples, average (minimum, maximum) number of tree rings, average (minimum, maximum) diameter and number of dendrochronologically analysed samples of each species.
Preglednica 2. Jesen (*Fraxinus* sp.) in hrast (*Quercus* sp.) s kolišča Špica: skupno število vzorcev, povprečno (najmanjše, največje) število branik, povprečni (najmanjši, največji) premer in število dendrokronološko analiziranih vzorcev posamezne vrste.

	Total number of samples Skupno število vzorcev	Number of tree rings Average (Min.-Max.) Število branik Povprečje (min.-maks.)	Diameter (cm) Premer (cm)	Dendrocronologically analysed samples Št. dendrokronološko analiziranih vzorcev
Fraxinus sp.	1460	40 (7-126)	8 (2-18)	394 (27%)
Quercus sp.	509	33 (7-160)	11 (1-25)	85 (17%)

3.2 DISTRIBUTION OF THE WOOD FINDS ON THE ARCHAEOLOGICAL SITE

3.2 RAZPORED LESENIH NAJDB NA ARHEOLOŠKEM NAJDIŠČU

The remains of the predominant ash wood were evenly distributed over the entire excavation site, while the oak was found only in certain places (Figure 6). Other wood species (marked in yellow in Figure 6) are distributed throughout the site and often intermixed with ash. The distribution of piles on the site is important with regard to aiding dendrochronological dating and its interpretation, especially if the archaeological constructions were built and rebuilt in different phases and different time periods, as is often the case (e.g., Čufar & Velušček, 2003; Velušček & Čufar, 2004).

The distribution of piles at Špica in certain sections of the excavation field indicates parallel lines running in a NE-SW direction, similar to those found at other pile dwellings on the Ljubljansko barje. However, the dense arrangement of piles in some parts (Figures 4, 7) of the excavated Špica

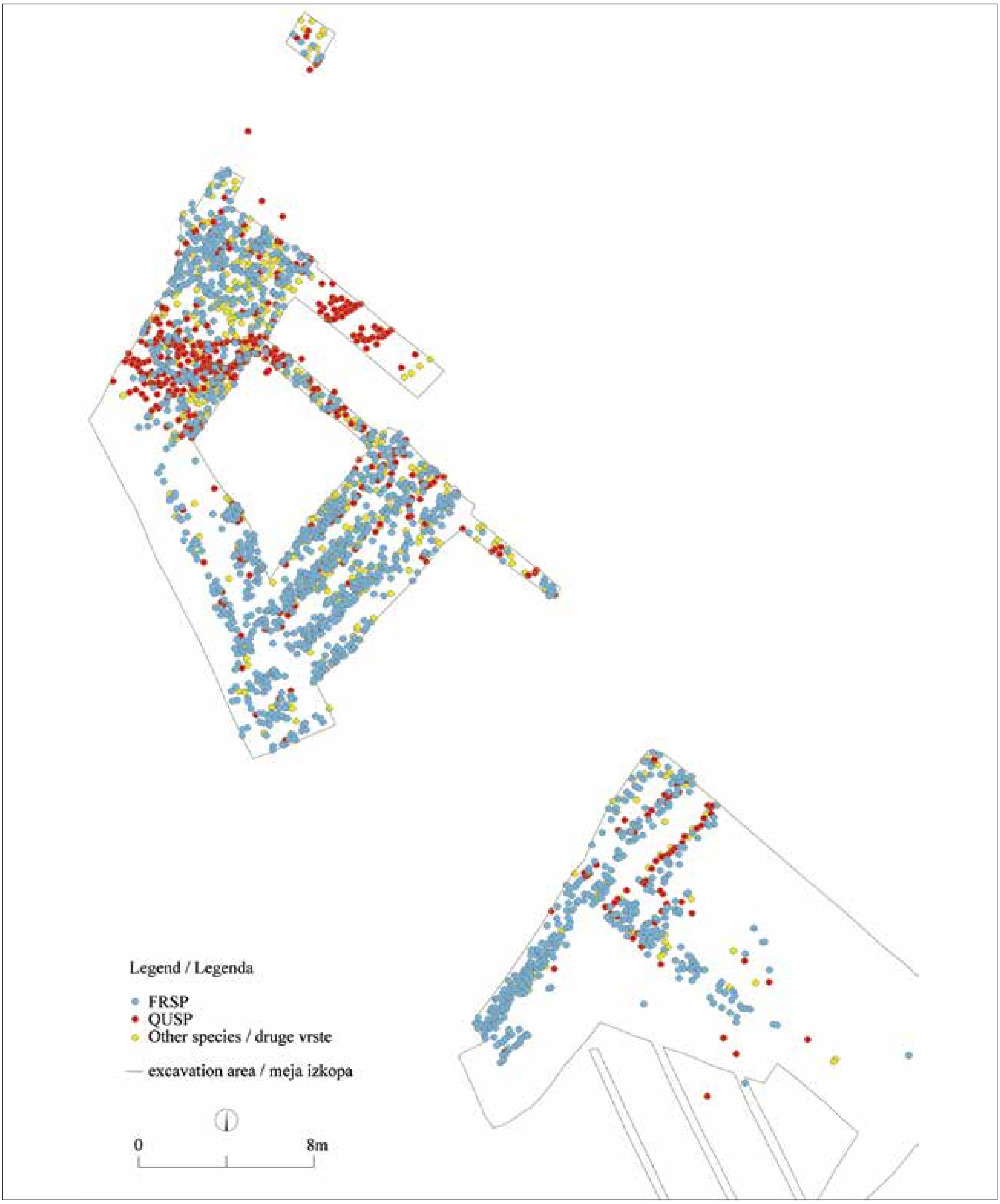

Figure 6. Distribution of 2,452 piles and other construction elements of different tree species on the ground plan of the Špica pile-dwelling site. Both the vertical piles (93% of all samples) and the horizontal elements (7%) are marked with points. FRSP – ash (*Fraxinus* sp.), QUSP – oak (*Quercus* sp.). Map: B. Štular.
Slika 6. Razpored 2452 kolov in drugih konstrukcijskih elementov iz lesa različnih drevesnih vrst na tlorisu kolišča Špica. Vertikalni koli (93 % elementov) in horizontalni elementi (7 %) so označeni s pikami. FRSP–jesen (*Fraxinus* sp.), QUSP–hrast (*Quercus* sp.). Zemljevid: B. Štular.

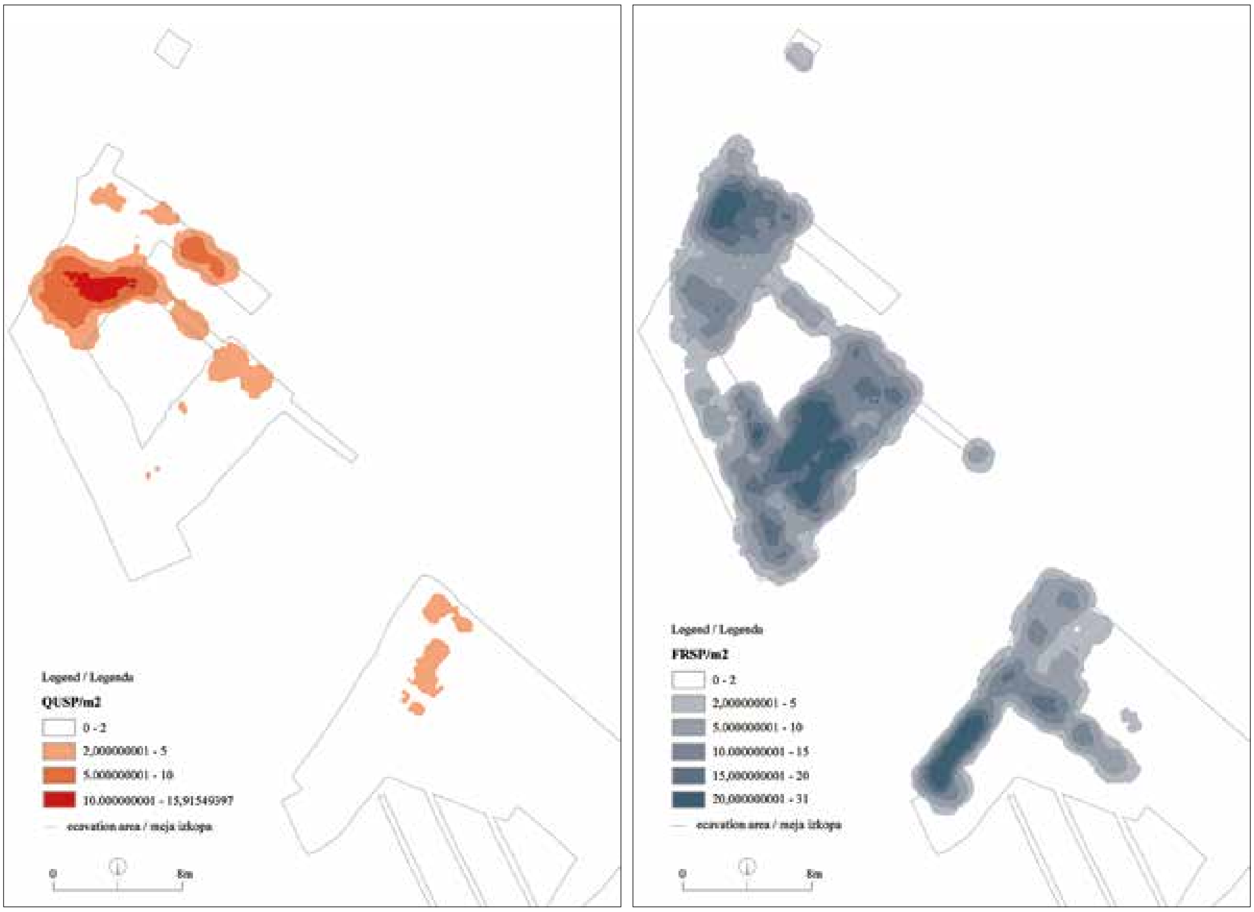

Figure 7. Density of oak (QUSP) piles (left) and ash (FRSP) piles (right) at the Špica pile-dwelling site. Map: B. Štular.

Slika 7. Gostota hrastovih (QUSP) kolov (leva slika) in jesenovih kolov (FRSP) (desno) na kolišču Špica. Načrt: B. Štular.

differs slightly from the pile density discovered at, for example, the Parte, Parte-Iščica, Založnica, and Dušanovo pile dwellings (Čufar et al., 1997; 1999; Čufar & Velušček, 2003). It appears that the piles at Špica were placed more densely than those at the Parte pile dwelling, for example (Harej, 1978, 1981-1982, 1987; see also Leghissa, 2017, Fig.13). This suggests that there were presumably more repairs of the constructions on this site, as indicated by the numerous piles placed next to one another, or the ones which were damaged when the pile dwellers were driving new piles into the ground (Figure 8) as previously discussed by Jančar (2016). Fluctuating water levels may have played an important role in this, as indicated by some horizontally lying wooden piles and discussed by Jančar (2016), particularly in the western part of the area that has been explored, and this issue deserves additional analysis. Different construction phases are also assumed, based on the different typology regarding diameter, form and processing marks on the piles. Another possible explanation for the dense arrangement of piles is that the structure may not have been a dwelling, but rather a different type of construction, such as a palisade, dock or similar facility.

3.3 DENDROCHRONOLOGY

3.3 DENDROKRONOLOGIJA

Since much of the pottery and other archaeological objects are similar to those from the mid-3rd millennium BC pile dwellings of Založnica and Parte, for which we have overlapping oak and ash reference chronologies spanning the period 2659 – 2366 BC (Figure 9) (Čufar et al., 2022). The oak chronology of Založnica ZALQUSP1 was dated to an end date of 2417 ± 18 cal BC on the basis of several

Figure 8. Example of wooden piles, tightly driven next to each other on the Špica pile-dwelling site; the upper oak pile LE877 was pounded later than the lower ash pile LE878 (left), and some of the different diameters and forms of wood samples analysed in the laboratory (right). Photo: (left) G. Babič; source: Museums and Galleries of Ljubljana, (right) L. Krže.

Slika 8. Primer lesenega kola, tesno zabitega ob drugem kolu, na kolišču Špica; zgornji hrastov kol je bil zabit kasneje kot spodnji jesenov kol (levo) in različna tipologija vzorcev, pripravljenih za raziskave v laboratoriju (desno). Fotografija: (levo) G. Babič; vir: Muzeji in galerije mesta Ljubljane, (desno) L. Krže.

C14-dated samples and the wiggle-matching method. The other oak and ash chronologies (Figure 9) were dendrochronologically dated with ZALQUSP1. It should be noted that the chronologies given can be used for dating wood from the period they cover, but not for dating wood (if present at the site) from younger or older periods outside this time span.

To find out whether the wooden structures from Špica can be dated with the available chronologies, we have attempted to cross-date the tree-ring series of all oak and ash samples to create one or more local chronologies for Špica based on the overlapping series (e.g. Čufar et al., 2015). The local chronology usually includes and dates all elements with overlapping tree-ring series where the same date of tree felling indicates the same construction phase. This approach did not work in Špica, and we were unable to reconstruct ground plans of objects (houses), as was possible in Parte Iščica, for example (Velušček et al., 2000).

However, it was possible to date some individual piles with the given reference chronologies. For this purpose, we randomly selected specific areas (trenches and quadrants) (Figure 10, Table 3) and attempted to date all dendrochronologically analysed piles in each area. Finally, the individual piles shown in Figures 10, 11 and 12 were dendrochronologically dated. After checking whether the wood samples contained the outer tree-ring below the bark (waney edge), we obtained seven felling dates of individual piles or pile groups distributed throughout the archaeological site (Figure 10). Their felling dates (the position of end dates on the chronologies ZALFRSP1 and ZALQUSP1) were between 2522 and 2406 ±18 cal BC. The dendro-

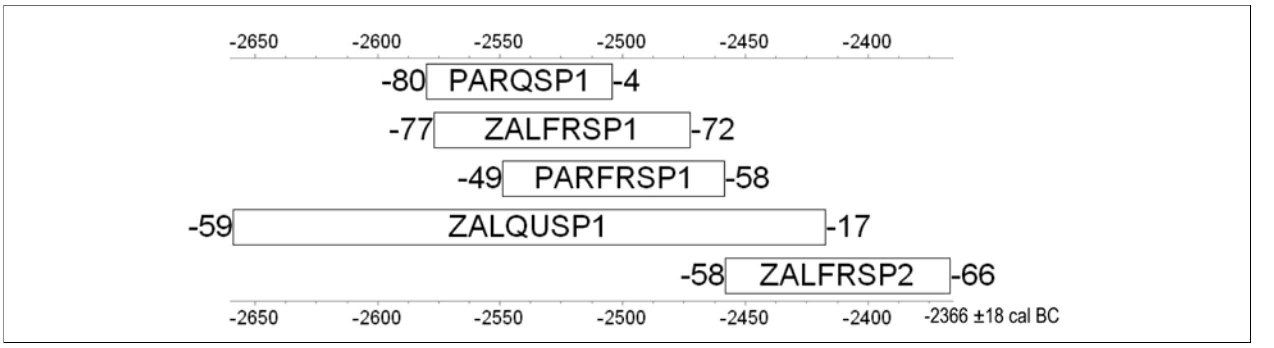

Figure 9. Time spans of the chronologies of oak (QUSP) and ash (FRSP) from the pile-dwelling settlements of Parte (PAR) and Založnica (ZAL) dated by C14 and wiggle-matching methods and spanning the period of 2659 – 2366 BC.

Slika 9. Razponi kronologij hrasta (QUSP) in jesena (FRSP) s koliščarskih naselbin Parte (PAR) in Založnica v obdobju 2659–2366 pr. Kr. datiranih s pomočjo radiokarbonske metode in metode wiggle-matching.

chronologically defined difference between the earliest and the latest end date was 116 years.

The details of the units in Figure 10 enabled us to verify the locations of the dendrochronologically measured ash (FRSP) and oak (QUSP) wood elements and to distinguish them from the elements of other species and unmeasured oak and ash elements. The situation in the units was very different.

Unit A contained oak, ash and other species but only one ash-wood element could be dated to an end date of 2456 BC. Unit B contained mainly oak elements (Figure 10). Two of them could be dated to 2454 BC. Unit C contained ash, oak and other wood species. Two ash elements were dated to 2483 BC. Unit D also contained ash, oak and other wood species, and the density of the piles was lower. Two ash piles located close to each other were dated, one to 2481 BC and another to 2515 BC. They belonged to two phases of construction, 34 years apart (Figure 11).

In unit E, the density of the wooden elements was high. Ash wood predominated, but most elements were not measured as they contained too few tree rings. Two ash samples were dendrochronologically dated with the end year of 2522 BC and thus represented the oldest dated elements. The other undated piles contained relatively few tree rings and numerous growth anomalies. They probably belong to different construction phases (Figure 12). In unit F in the immediate vicinity, we were able to identify four oak elements arranged in a row. All of them had the same felling date of 2406 BC and represent the youngest dated construction. The ash piles in their immediate vicinity could not be dated.

The detailed investigation provided us with felling dates for 14 wooden elements, which made it possible to recognize at least four periods of building activities with the following end dates: around 2522 BC (unit E, D), around 2483 BC (unit D, C), around 2456 BC (units A, B) and around 2406 BC (unit F). The closely spaced end dates (e.g. 2456 and 2454) indicate a particular building activity (and intensive logging) over a number of years,

Table 3. Areas of dendrochronological analyses (A – F) marked in Figure 10 and the corresponding surveyed trenches and quadrants documented during the 2009/2010 excavations.

Preglednica 3. Območja dendrokronoloških analiz (A – F), označena na Sliki 10 ter pripadajoče raziskane sonde in kvadranti, dokumentirani med izkopavanji v letih 2009/2010.

Dendrochronologically investigated units / Območja dendrokronoloških raziskav	Trench / Sonda	Quadrant / Kvadrant
A	1001/1	AR28, AR29
B	1001/2	AO28, AO29, AN29, AN30
C	1001/3	AN28, AN29
D	1005	AM30, AL30, AL31
E	1006	AH30, AI30, AI31
F	1006	AI31, AI32, AH32

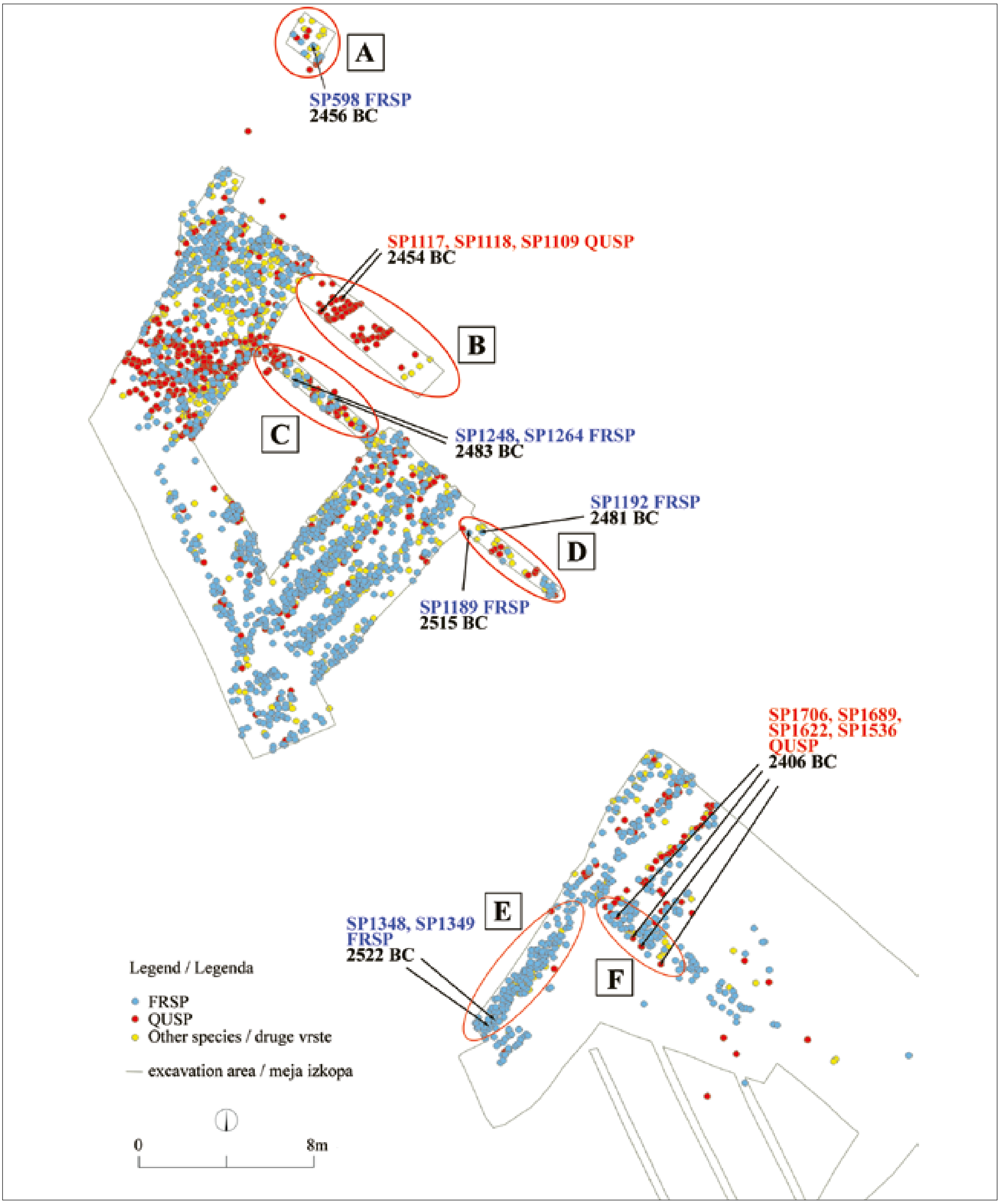

Figure 10. Dendrochronologically analysed units A, B, C, D, E, F of the Špica pile-dwelling site. The arrows point to the locations of the dated piles (SP*) of ash FRSP (*Fraxinus* sp.) and oak QUSP (*Quercus* sp) and the felling dates. Map: B. Štular and K. Čufar.

Slika 10. Dendrokronološka raziskava enot A, B, C, D, E, F na kolišču Špica. Puščice kažejo mesta datiranih kolov (SP*) jesena FRSP (*Fraxinus* sp.) in hrasta QUSP (*Quercus* sp.) in datumi poseka lesa pr. Kr. Zemljevid: B. Štular in K. Čufar.

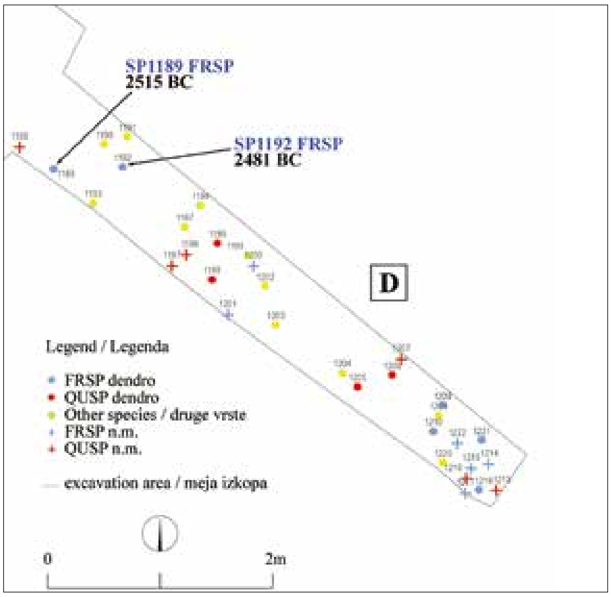

Figure 11. Dendrochronological analysis of unit D: dendrochronologically examined and dated ash FRSP and oak QUSP Legend, dendro – dendrochronologically measured, n.m. – not measured, for excavated units see Table 3. Map: B. Štular and K. Čufar.

Slika 11. Dendrokronološko raziskano območje D: vzorci jesena FRSP in hrasta QUSP. Legenda, dendro – dendrokronološko merjeni, n.m. – nemerjeni, other species–druge lesne vrste, za izkopane enote prim. preglednica 3. Zemljevid: B. Štular in K. Čufar.

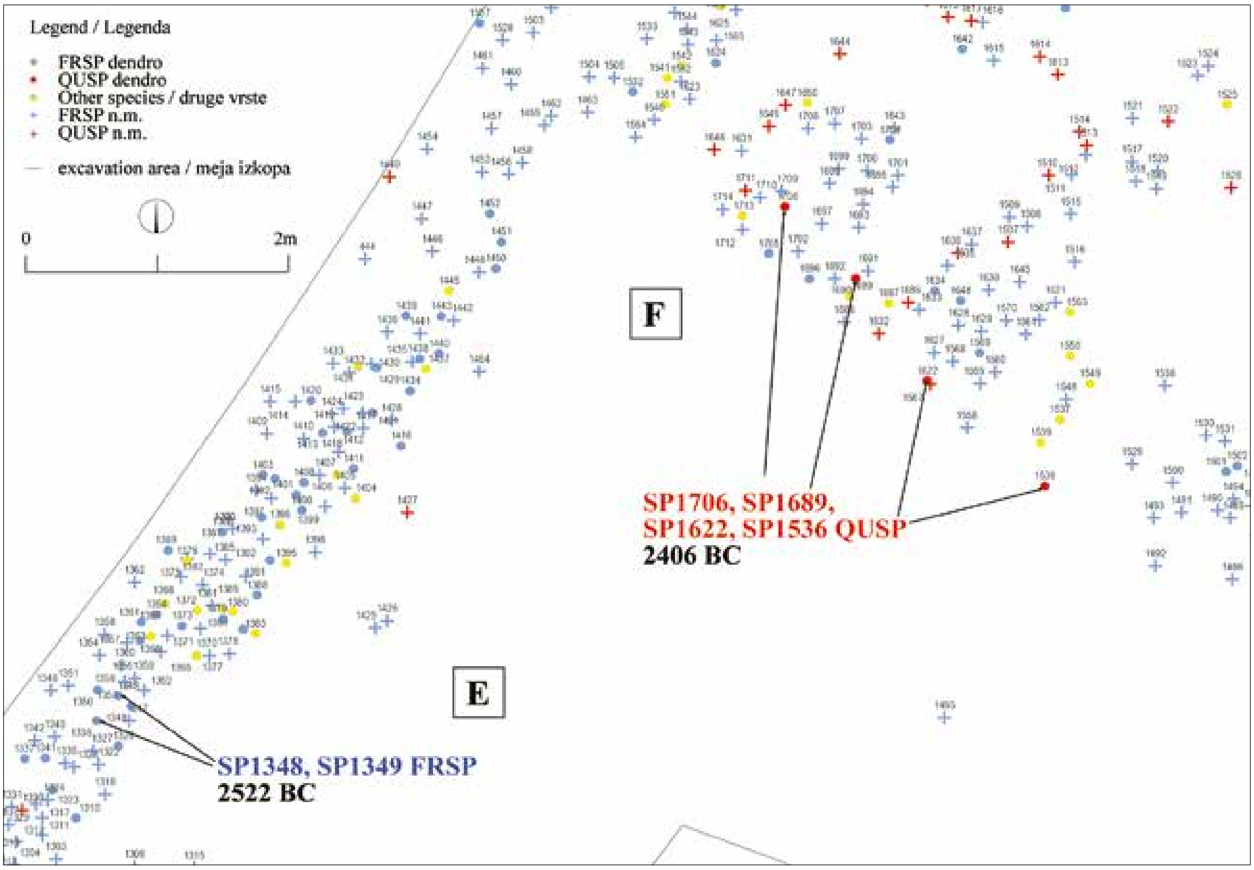

Figure 12. Dendrochronologically analysed units E with two dated ash FRSP elements and F with four dated oak QUSP piles in the row (red dots) with an end date of 2406 cal BC, while the ash FRSP piles (blue dots) could not be dated. Map: B. Štular and K. Čufar Map: B. Štular and K. Čufar.

Slika 12. Dendrokronološko raziskano območje E z dvema FRSP koloma in območje F (sonda 1006) s 4 datiranimi hrastovimi QUSP koli, postavljenimi v vrsti (rdeče pike) z datumom zadnje branike 2406 kal. pr. Kr., medtem ko jesenovih FRSP kolov (modre pike) nismo mogli datirati. Zemljevid: B. Štular, dopolnila K. Čufar.

which is consistent with the results of other sites on the Ljubljansko barje. Slightly deviating end dates may also be a result of missing external parts of the wooden elements, which were caused by the processing of wood or decay over time.

Felling activities between 2522 and 2406 BC, i.e. a period of 116 years, seem to represent one of the longest documented time spans for felling activities in Ljubljansko barje. One of the longest construction periods documented in Ljubljansko barje so far was that of the Založnica pile-dwelling site, where the period of settlement of 80-90 years (Velušček & Čufar, 2003) has been extended to about 140 years due to the recent precise radiocarbon wiggle-matching dates for ZALFRSP2 chronology (Figure 9). However, most of the other sites on Ljubljansko barje seemed to indicate felling activities for a shorter period, e.g. 60 years or only two decades or even less (Velušček & Čufar, 2014) which could appear also due to relatively small excavation areas. The long construction period documented in Špica is consistent with the relatively large excavation area and large number of piles discovered. The results indicate that the buildings were probably repaired and restored, and that several phases of settlement in the same area are also likely.

The results presented here show that so far only relatively few wood samples have been dated and that this study could not utilize the full research potential of the wood from Špica. Future research should thus aim to carry out the dendrochronological dating of more wooden elements. In addition, radiocarbon and wiggle-matching analyses should be used to support the dating of the wood, which was presumably felled outside the time span of the reference chronologies.

4 CONCLUSIONS
4 ZAKLJUČKI

Analyses of the archaeological wood in the Špica pile-dwelling settlement showed that ash was the most common type of wood, followed by oak. Ash was also predominant in other pile-dwelling settlements of the Ljubljansko barje that existed in the 3rd millennium BC, at Parte-Iščica, Parte, Založnica and Dušanovo (e.g. Velušček et al., 2000). Ash was distributed over the entire area studied, while oak was mainly found in the north-western part (trench 1006). Other tree species were beech, maple, hornbeam, willow, alder, silver fir and hazel. The latter tree species were also found in other pile-dwelling sites in the Ljubljansko barje.

For the dendrochronological analyses, the reference chronologies of the Parte and Založnica pile-dwelling sites were used, as the pottery material found there is most comparable to that from Špica. The oak and ash chronologies from Založnica and Parte were dated using C14 and wiggle matching with an accuracy of ±18 years. They cover the period 2659 – 2366 ±18 cal BC and make it possible to date the wood that grew or was felled in the middle of the 3rd millennium BC over a period of about 300 years. With the available chronologies, it was not possible to determine whether some piles date from younger or older periods outside the 300-year time span, as there are no dated chronologies for the periods immediately before or after 2659 – 2366 BC.

The dendrochronological analyses have confirmed the contemporaneity of Špica with the Parte and Založnica sites, which are archaeologically defined within the framework of the Ljubljana culture (for the latter, see Leghissa, 2021 and the literature cited there). In particular, the finds from the second Dežman pile-dwelling settlement near Ig are also attributed to this culture (Leghissa, 2017, 2021).

Dendrochronological analyses in selected parts of the Špica excavating area indicate a timeframe of felling activity between 2522 and 2406 BC, covering a period of 116 years between the earliest and latest felling dates. This period appears to represent one of the longest documented time spans of felling activity at a site (Špica), but we cannot confirm whether the area was occupied in one or more phases of settlement of the same area.

The study of the wood complements and clarifies the results of recent investigations of the pottery and other archaeological finds from Špica (Leghissa, 2024), although we were only able to date a small number of wooden elements. Therefore, we can conclude that further research is recommended to exploit the full research potential of the excavated archaeological wood.

5 SUMMARY

5 POVZETEK

Ostanki koliščarske naselbine Špica se nahajajo v Ljubljani na desnem bregu reke Ljubljanice (slika 1). Območje predstavlja severni del Ljubljanskega barja (slika 2). Na jugu meji na reko Ljubljanico, na vzhodu pa na Gruberjev prekop, ki je bil zgrajen konec 18. stoletja. Prve omembe najdišča Špica segajo v konec 19. stoletja, ko so zaradi večkratne regulacije Ljubljanice prišle na dan številne najdbe. V prvi polovici 20. stoletja je bilo v okolici najdišča Špica odkritih več najdb, kot so bakrene, kamnite, koščene in keramične najdbe. Leta 2009 so bile ob načrtovani prenovi območja Špice opravljene raziskave, s katerimi je bil ugotovljen arheološki potencial najdišča (Novšak et al., 2009). Rezultati so potrdili obstoj koliščarskih naselbinskih struktur. Na podlagi teh rezultatov so v letih 2009 in 2010 potekale zaščitne arheološke raziskave na območju načrtovanih del ureditve območja Špice in bregov Gruberjevega prekopa. Te arheološke raziskave so odkrile del koliščarske naselbine z dobro ohranjenimi ostanki lesene arhitekture in številnimi najdbami iz pozne bakrene dobe, tj. najverjetneje iz sredine 3. tisočletja pr. Kr. (Klasinc et al., 2010; Šinkovec, 2012). Med najdbami so številne keramične posode in drugi predmeti, ki so primerljivi s keramičnim repertoarjem ljubljanske kulture in zastopane na drugih sočasnih najdiščih na Ljubljanskem barju, kot so Parte, Dežmanova kolišča, Založnica in Dušanovo (Leghissa, 2021; Leghissa, 2024).

Arheološke raziskave v letih 2009 in 2010 je pod nadzorom Muzeja in galerij mesta Ljubljane in Zavoda za varstvo kulturne dediščine, OE Ljubljana, izvedlo podjetje Tica Sistem. Izkopavanja so zajela le določena območja Špice, ki so bila nato predmet načrtovane obnove tega dela nabrežja. Raziskana je bila skupna površina skoraj 750 m², od tega je bilo 463 m² v celoti izkopanih do kulturne plasti, 284 m² pa je ostalo nedotaknjenih. Arheološke najdbe so bile najbolj celovito raziskane v okviru podoktorskega projekta Elene Leghissa z naslovom »Dinamike izmenjave in mobilnosti na Ljubljanskem barju: pozno bakrenodobno kolišče Špica v Ljubljani«. V okviru analize in ovrednotenja stratigrafske slike in keramičnih najdb s Špice je bilo ugotovljeno, da sodi kolišče Špica v okvir na novo definirane ljubljanske kulture, v kateri se odražajo še elementi tradicije predhodne vučedolske kulture in vplivi kultur vrvičaste keramike in zvončastih čaš (Leghissa, 2021; Leghissa, 2024 in Leghissa, v pripravi).

Les, odkrit med arheološkimi izkopavanji na najdišču Špica, je bil tipološko razvrščen na uporabne predmete (kot so deli vreten in nasadov sekir), ostanke dreves (veje, vejice in ostanki pletiv, ki so tvorili stene hiš) ter gradbene oziroma stavbne elemente (sliki 3, 4). Slednji so bili najštevilčnejši in so predstavljali ostanke predvsem v tla zabitih kolov bivališč ali različnih drugih struktur v prazgodovinski koliščarski naselbini. Skupaj so identificirali 2737 lesenih elementov, v tej študiji pa smo opravili identifikacijo lesa in dendrokronološke raziskave 2528 vzorcev lesa elementov, med katerimi so prevladovali vertikalni v zemljo zabiti koli (93 %), le 7 % pa je bilo horizontalnih elementov. Večina lesenih elementov je bila dokumentirana na ravni kulturnih plasti, nekaj jih je bilo identificiranih znotraj gmote in le izjemoma v naplavinah nad gmoto. Ohranjenost lesa je bila ponekod zelo slaba (zlasti na območjih v bližini reke Ljubljanice). Na nivoju marmorne plasti je bilo odkrito precej lesa, ki predstavlja v celoti obdelane kole.

Več kot 60 % vseh odkritih lesenih elementov je bilo obdelanih na različne načine. Nekateri so bili celi, več jih je bilo razcepljenih ali obdelanih v tramove. Precejšnje število lesenih elementov je imelo obdelane konice za zabijanje v tla, nekateri pa so bili cepljeni v deske. Nekateri obdelani elementi so imeli ožgane konice, kar kaže na to, da so prebivalci koliščarske naselbine pri obdelavi lesa uporabljali tudi ožiganje.

Vsi leseni elementi so bili med izkopavanji oštevilčeni ter opisno in prostorsko dokumentirani s pomočjo tahimetra. Iz večine od njih so bili odvzeti vzorci za dendrokronološko analizo. Ti vzorci so bili večinoma približno 20 cm debeli koluti in so bili običajno odvzeti s spodnjega, bolje ohranjenega dela kola. V redkih primerih zaradi slabe ohranjenosti kola vzorcev ni bilo mogoče odvzeti. Po vzorčenju na terenu v letih 2009 in 2010 so bili z vodo napojeni vzorci shranjeni v neprepustnih polietilenskih vrečkah in prepeljani na Oddelek za lesarstvo Biotehniške fakultete Univerze v Ljubljani za analizo lesa na Katedri za tehnologijo lesa–Laboratoriju za anatomijo in dendrokronologijo.

Vseh 2452 vzorcev lesa je bilo obdelanih po standardni metodologiji, ki so jo razvili pri delu na drugih izkopavanjih na Ljubljanskem barju v obdobju 1994–2024 pod vodstvom Antona Veluščka (npr. Čufar & Velušček, 2004, 2025; Velušček, 2004; Čufar et al., 2022). Raziskava je potekala v naslednjih korakih:

- površinska priprava prečnih prerezov 2452 vzorcev lesa,
- makroskopska identifikacija lesnih vrst,
- priprava mikroskopskih preparatov (prečnih, radialnih in tangencialnih prerezov) za mikroskopsko identifikacijo lesa, če makroskopska identifikacija ni bila mogoča,
- štetje branik, merjenje premerov in beleženje glavnih značilnosti posameznih vzorcev,
- merjenje širine branik za vzorce hrasta (*Quercus* sp., QUSP), jesena (*Fraxinus* sp., FRSP), navadne bukve (*Fagus sylvatica*, FASY) in navadne jelke (*Abies alba*, ABAL), ki so vsebovali ≥45 branik (497 vzorcev),
- sinhroniziranje zaporedij širin branik in dendrokronološko datiranje z referenčnimi kronologijami Oddelka za lesarstvo BF UL za Ljubljansko barje,
- izdelava preglednice rezultatov z vsemi pomembnimi podatki za vsak vzorec.

Po končanih analizah lesa so bili z vodo napojeni vzorci v vakuumsko zaprtih polietilenskih vrečkah shranjeni v hladnem prostoru s konstantno temperaturo okoli 13 °C na Oddelku za lesarstvo.

Analiziranih 2452 vzorcev je pripadalo 13 lesnim vrstam ali rodovom (preglednica 1). Najpogostejša rodova sta bila jesen (*Fraxinus* sp.), 1460 (60 %) vzorcev in hrast (*Quercus* sp.), 509 (21 %) vzorcev. Ostale dokaj dobro zastopane vrste lesa so bile: navadna bukev (*Fagus sylvatica*) (4 %), javor (*Acer* sp.) (3 %), beli gaber (*Carpinus betulus*) (3 %), vrba (3 %) (*Salix* sp.), črna jelša (*Alnus glutionosa*) (2 %), navadna jelka (*Abies alba*) (1 %) in navadna leska (*Crylus avellana*) (1 %). Ostale vrste, topol (*Populus* sp.), jerebika (*Sorbus* sp.), brest (*Ulmus* sp.) in breza (*Betula* sp.) so se pojavile le občasno (Preglednica 1). Pri 1,6 % vzorcev ni bilo mogoče določiti lesne vrste/rodu, ker je bil les preveč poškodovan. Izbor in delež lesnih vrst se ujemata s stanjem na drugih koliščih na Ljubljanskem barju, kjer običajno prevladujeta jesen in hrast, ki pa imata od kolišča do kolišča različen delež (npr. Čufar & Velušček, 2012; Čufar et al., 2022; Out et al., 2022; 2023).

Les je bil raziskan z namenom dendrokronološkega datiranja in s tem določitve oz. potrditve starosti kolišča Špica. Za dendrokronološke raziskave kolišč imata največji pomen hrast in jesen ter tudi bukev in jelka s 45 ali več branikami. Glede na to smo dendrokronološko raziskali 85 vzorcev hrasta in 394 vzorcev jesena ter le po 9 vzorcev bukve in jelke (preglednica 1, 2) in se v nadaljevanju posvetili predvsem jesenovim in hrastovim elementom. Premer jesenovih kolov je bil večinoma od 4 do 12 cm, medtem ko so bili premeri hrastovih kolov na splošno nekoliko večji (preglednica 2, slika 5).

Lega kolov različnih vrst na načrtu kolišča kaže, da so jesen in druge drevesne vrste dokaj enakomerno razporejene po območju, hrast pa je prisoten samo v določenih delih kolišča. Hkrati smo ugotovili, da gostota v tla zabitih kolov po površini kolišča variira (slike 6, 7). Tam, kjer je bila gostota kolov največja, so že na terenu opazili, da so med uporabo utrjevali konstrukcije z naknadno zabitimi koli (slika 8). Poudariti moramo tudi, da načrti, ki smo jih pripravili, ne razlikujejo vertikalnih kolov, ki so prevladovali, in morebitnih horizontalno ležečih elementov.

Ker je bil velik del arheoloških najdb (keramike) podoben tistim s koliščarskih naselij Parte in Založnica iz sredine 3. tisočletja pr. Kr. (slika 9), smo kronologije teh kolišč s časovnim razponom 2659–2366 pr. Kr. uporabili za datiranje lesa s Špice (npr. Čufar et al., 2022). Omenjene kronologije so bile datirane s pomočjo radiokarbonske metode in metode wiggle-matching z natančnostjo ± 18 let. Za datiranje vzorcev s Špice smo kot običajno skušali najprej sinhronizirati zaporedja širin branik vzorcev posameznih vrst, da bi sestavili eno ali več lokalnih kronologij za kolišče Špica. Ker ta pristop ni dal zadovoljivih rezultatov, smo v naslednjem koraku na načrtu kolišča določili 6 območij (A, B, C, D, E, F) (slika 10), kjer smo pregledali vse dendrokronološko izmerjene lesene elemente, ki smo jih skušali datirati z referenčnimi kronologijami. Ta pristop je bil uspešen in je omogočil datiranje več kot 14 lesenih elementov, razporejenih po celotnem arheološkem najdišču (slika 10). Najmlajši datirani koli iz lesa jesena se nahajajo na območju F, najstarejši pa na območju E (sliki 10 in 13).

Podrobna raziskava nam je omogočila, da smo prepoznali vsaj štiri obdobja gradbenih aktivnosti z naslednjimi končnimi datumi: okoli 2522 pr. Kr. (enota E, D), okoli 2483 pr. Kr. (enota D, C), okoli 2456 pr. Kr. (enoti A, B) in okoli 2406 pr. Kr. (enota F). Razlike v datacijah, ki znašajo le nekaj let (npr. 2456 in 2454), nakazujejo isto gradbeno fazo, ki je kot običajno trajala več let, kar je skladno z rezultati drugih najdišč na Ljubljanskem barju. Nekoliko različni končni datumi so lahko tudi posledica manjkajočih zunanjih delov lesenih elementov (manjkajoča ena ali več branik pod skorjo), zaradi obdelave, obrabe ali razkroja lesa.

Zaradi časovnega razpona razpoložljivih referenčnih kronologij smo lahko ugotovili samo datume poseka lesa oz. postavitve konstrukcij znotraj obdobja 2659–2366 pr. Kr., lesa, morebiti posekanega pred ali po omenjenem obdobju, pa na ta način nismo mogli prepoznati oz. datirati, ker za obdobje neposredno pred letom 2659 in po letu 2366 pr. Kr. nimamo referenčnih kronologij.

Izbor lesnih vrst na kolišču Špica, kjer je najpogostejša vrsta jesenovina in nato hrastovina, je podoben kot na koliščih iz 3. tisočletja pr. Kr., Parte-Iščica, Parte, Založnica in Dušanovo (npr. Velušček et al., 2000; Čufar & Velušček, 2012, 2025; Čufar et al., 2022).

Dendrokronološke analize na Špici so potrdile kronološko sočasnost s kolišči Parte in Založnica, ki sta opredeljeni v okvir ljubljanske kulture (Leghissa, 2021 in tam citirana literatura). V okvir slednje kulture so opredeljene tudi najdbe, predvsem z drugega Dežmanovega kolišča pri Igu (Leghissa, 2017, 2021). Zaenkrat so dendrokronološke analize na izbranih delih raziskanega območja Špice pokazale, da so gradbene aktivnosti zaznane v časovnem okvirju med leti 2522 in 2406 pr. Kr., kar zajame obdobje 116 let med posekom najstarejšega in najmlajšega datiranega kola. Tak časovni razpon predstavlja enega najdaljših dokumentiranih časovnih razponov gradbenih posegov na kolišču na Ljubljanskem barju. Do sedaj je bilo najdaljše dokumentirano obdobje gradbenih aktivnosti zabeleženo na kolišču Založnica, kjer je znašalo približno 80–90 let (Velušček & Čufar, 2003), vendar najnovejše datiranje kronologije ZALFRSP2 nakazuje daljši, to je 140 let dolg razpon gradbenih aktivnosti (slika 9). Na večini drugih kolišč so zabeležili gradbene aktivnosti v krajšem obdobju, npr. 60 ali 20 let ali manj, kar je lahko tudi posledica relativno majhnega raziskanega območja (Velušček & Čufar, 2014). Dolgo obdobje gradbenih aktivnosti na Špici lahko nakazuje tudi popravila ali obstoj več poselitvenih faz istega območja, kar smo zabeležili tudi na terenu (slika 8). Glede na to, da je bilo izkopno polje na Špici razmeroma veliko, tudi to povečuje verjetnost za najdbo kolov iz daljšega časovnega obdobja.

Predstavljene raziskave lesa dopolnjujejo in pojasnjujejo ugotovitve nedavnih raziskav keramike in drugih arheoloških najdb s Špice (Leghissa, 2024 in v pripravi), čeprav moramo poudariti, da naša študija še zdaleč ni izkoristila celotnega raziskovalnega potenciala arheološkega lesa s Špice.

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IN MEMORIAM PIETER BAAS, 1944-2024

IN MEMORIAM PIETER BAAS, 1944-2024

Katarina Čufar*, Angela Balzano

UDK članka: 929Baas P.:630*8

Abstract / Izvleček

Izvleček: Mednarodna skupnost za anatomijo lesa žaluje, ker nas je zapustil prof. dr. Pieter Baas (28. april 1944–29. april 2024) iz Nizozemske. Bil je ključna osebnost Mednarodnega združenja lesnih anatomov (IAWA) in desetletja urednik revije IAWA Journal. Več kot štiri desetletja je izjemno prispeval k razvoju anatomije lesa. S svojim življenjem, delom in izjemnimi osebnostnimi lastnostmi je prispeval k rasti in povezanosti svetovne skupnosti IAWA.

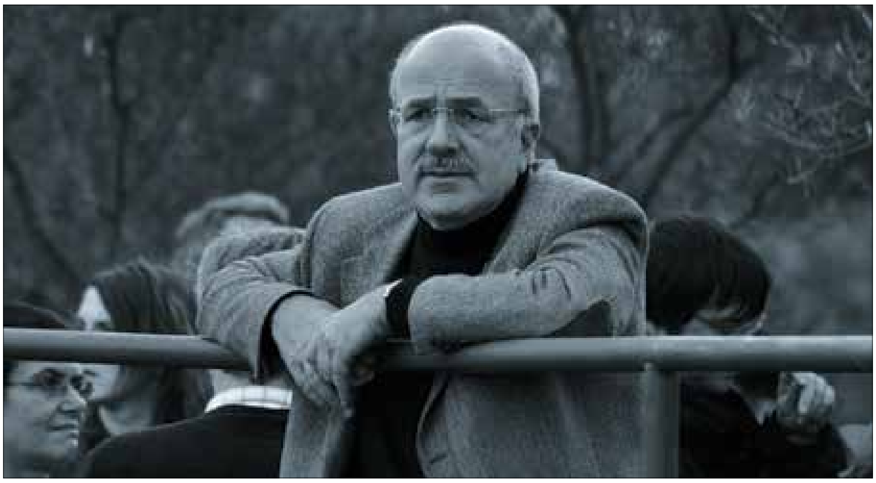
Ključne besede: Pieter Baas, in memoriam, anatomija lesa, IAWA = International Association of Wood Anatomists, IAWA Journal

Abstract: The international wood anatomy community mourns the loss of Prof. Dr Pieter Baas (28 April 1944–29 April 2024) from the Netherlands. He was a key figure in the International Association of Wood Anatomists (IAWA) and editor of the *IAWA Journal* for decades. He made an outstanding contribution to the development of wood anatomy and wood science for more than four decades. His life, work and outstanding personal qualities have contributed to the growth and connection of the worldwide wood anatomy community.

Keywords: Pieter Baas, in memoriam, wood anatomy, IAWA = International Association of Wood Anatomists, *IAWA Journal*

Mednarodno skupnost za anatomijo lesa je pretresla vest, da nas je za vedno zapustil prof. dr. Pieter Baas (28. april 1944–29. april 2024) (slika 1). Več kot štiri desetletja je bil ključna osebnost in je izjemno prispeval k razvoju anatomije in znanosti o lesu, pa tudi anatomije rastlin in gozdarstva. Njegovo življenjsko pot, delo in izjemne osebnostne lastnosti so opisali njegovi najbližji sodelavci in sodelavke (Van Welzen et al., 2024; Wheeler et al., 2024), posvečena pa mu bo tudi posebna številka revije IAWA Journal v letu 2025.

Pieter Baas se je rodil na Nizozemskem ter študiral biologijo na Univerzi Leiden, kjer je diplomiral leta 1965 in magistriral leta 1969. Za anatomijo lesa se je začel specializirati že med dodiplomskim študijem (Van Welzen et al., 2024). Po magisteriju se je leta 1969 zaposlil kot lesni anatom v nacionalnem herbariju Rijksherbarium, ki je spadal pod Univerzo Leiden. Leta 1975 je doktoriral in leta 1987 postal izredni profesor sistematične anatomije rastlin. Leta 1991 je postal znanstveni direktor ustanove Rijksherbarium in profesor sistematične botanike.



Slika 1. Pieter Baas na ekskurziji v okviru srečanja ISWS, Montpellier, Francija, 2004 (Foto: dovoljenje Peter Gasson).
Figure 1. Pieter Baas on a conference tour of the ISWS meeting in Montpellier, France, 2004 (Photo: courtesy Peter Gasson).

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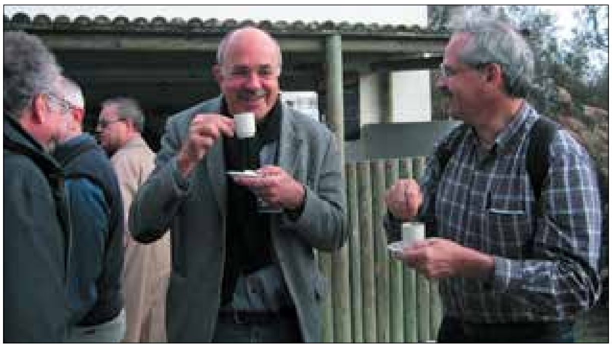
Od leta 1993 se je moral boriti za ohranitev herbarija in lesne zbirke, saj so ju želeli ukiniti. Pieter Baas je dosegel, da so leta 1999 zbirko vključili v novoustanovljeni Nacionalni herbarij Nizozemske (NHN) in postal prvi direktor ustanove. Pripomogel je, da je nastal današnji Center za biotsko raznovrstnost Naturalis v Leidnu. Pieter Baas se je upokojil leta 2005. Kot zaslužni profesor je ostal predan znanosti. Ostal je znanstveno dejaven na širokem področju anatomije lesa in povezan z mednarodno skupnostjo, ki je po njegovi zaslugi ves čas rasla in postala zelo povezana (Van Welzen et al., 2024; Wheeler et al., 2024).

Pomen dela Pietra Baasa je razviden iz njegove obsežne bibliografije in številnih prestižnih nagrad in priznanj (Van Welzen et al., 2024; SCOPUS, 2024), veličine njegovih zaslug pa sploh ni mogoče izmeriti. Pieter Baas je v društvu IAWA, ki so ga ustanovili že leta 1931, deloval od leta 1976. Med leti 1976 in 1981 je bil izvršni sekretar IAWA. Od 1980 do 2019 je bil glavni urednik revije, ki je v preteklosti izhajala pod različnimi imeni, med drugim IAWA Bulletin new series in od leta 1993 IAWA Journal (Baas & Wheeler, 2019). IAWA Journal je vodilna znanstvena revija na področju anatomije lesa, ki je z urednikom Pietrom Baasom nenehno pridobivala na kakovosti. Tehnično brezhibno jo je desetletja urejala Emma van Nieuwkoop (1933–2022) (Wheeler et al. 2004; IAWA, 2004).

Pieter Baas je bil najbolj prepoznavna osebnost društva IAWA in največji zagovornik mednarodnega sodelovanja. Sodeloval je pri organizaciji konferenc IAWA ali sekcij IAWA v okviru velikih simpozijev po vsem svetu (slika 2). Posebnost vseh IAWA konferenc so bile legendarne družabne ure (social hours), ki so udeležencem formalnih konferenc omogočile neformalne stike (slika 3). Prav zaradi izjemnih osebnostnih lastnosti, družabnosti in karizme je Pieter pripomogel, da je na njih vedno vladalo dobro razpoloženje in da so se vsi počutili sprejete. Mednarodna skupnost za anatomijo lesa je zato postala kot velika družina, kjer so nastajali skupni projekti in objave ter trajna prijateljstva. Pieter je običajno imel nagovore in bil zadolžen za zahvale organizatorjem, pri čemer smo vedno občudovali njegovo izjemno angleščino. Velikodušno je spodbujal mlade znanstvenice in znanstvenike, sprejemal nove člane IAWA, prodajal revije IAWA in se pogovarjal z vsemi. Imel je izjemen spomin za



Slika 2. Pieter Baas s kolegi na ekskurziji v Camargue v Provansi v okviru simpozija ISWS International Symposium on Wood Sciences, Montpellier 2004.
Figure 2. Pieter Baas and colleagues on a field trip to Camargue, Provence, as part of the ISWS International Symposium on Wood Sciences, Montpellier 2004.

obraze in imena. S svojim delovanjem je vzpostavil model, kako voditi svetovno društvo in kako poskrbeti, da se ljudje med seboj spoznajo, drug drugega sprejemajo in resnično sodelujejo.

Izjemne podpore smo bili deležni tudi znanstvenice in znanstveniki iz Slovenije, ki smo se kakorkoli ukvarjali z anatomijo lesa. V letu 1983 sta se prof. dr. Niko Torelli in Katarina Čufar udeležila simpozija IAWA IUFRO Wood Anatomy Meeting v Hamburgu (Ter Welle, 1983) ter tam spoznala Pietra Baasa in vse takratne evropske vodilne znanstvenice in znanstvenike na področju anatomije lesa. Torelli in Čufar sta se takrat vpisala v društvo IAWA in začela prejemati tiskano verzijo revije IAWA Bulletin n.s. ter kasneje IAWA Journal. V času brez interneta je revija z znanstvenimi članki in ključnimi obvestili o dogodkih in članstvu bila skupaj s konferencami ključna za vzdrževanje stika s stroko in člani IAWA. Pieter Baas je dvakrat obiskal Oddelek za lesarstvo BF UL v Ljubljani, najprej za uskladitev priprave in nato kot soorganizator IAWA in IUFRO S 5.01 simpozija na 18. svetovnem kongresu IUFRO, ki so ga leta 1986 organizirali v Cankarjevem domu v Ljubljani. Simpozij je imel naslov »The effects of environmental pollution on wood structure and quality«. Takrat je znanstvena skupnost ugotovila, da za proučevanje propadanja drevja zaradi sprememb okolja potrebujemo več znanja o fiziologiji drevja, kar je vplivalo tudi na kasnejši razvoj in usmeritev raziskav na Oddelku za lesarstvo. Po simpoziju v Ljubljani so organizirali tudi tradicionalni IAWA meeting in družabni dogodek, kjer sta bila lokalna organizatorja Torelli in Čufar (Shortle, 1986). Pieter Baas je nato z nami ostal v osebnih in seveda profesionalnih stikih. Z društvom IAWA so se kasneje povezali vsi, ki so delovali (in delujejo) na področju anatomije lesa, Primož Oven, Jožica Gričar, Maks Merela, Peter Prislan, Angela Balzano in drugi. Niko Torelli, Katarina Čufar, Jožica Gričar in Angela Balzano so v reviji IAWA Bulletin n.s. oz. IAWA Journal objavili svoj prvi znanstveni članek s faktorjem vpliva (Scopus, 2024), revija pa je še vedno zelo pomembna za objavo njihovih del. Pieter Baas je bil kot urednik v stiku z avtorji v vseh fazah od oddaje prispevka do objave. Znanstvenice in znanstveniki iz Slovenije so sodelovali tudi v uredniških odborih ter kot recenzentke in recenzenti, srečevali smo se tudi v okviru COST akcije STREeSS in drugih dogodkov.

Angela Balzano in Maks Merela sta se srečala s Pietrom Baasom tudi na konferenci »From Forests to Heritage« aprila 2022 v Amsterdamu. Skupaj so bili med nepozabnim izletom z ladjico po amsterdamskih kanalih. Medtem ko je Pieter Baas užival v svojih priljubljenih »bitterballen« in kozarcu vina, je kolegicam in kolegom na poseben način predstavil Amsterdam ter z njimi delil smeh in zgodbe (slika 4).

Pieter Baas je bil aktiven znanstvenik do konca. Kljub bolezni je bil skupaj z Yafang Yinom in Veronico de Micco soorganizator simpozija IAWA z naslovom "The Contribution of Wood in Forests: From Wood Dynamics to Trait Diversity and Carbon Gains" v okviru XX. mednarodnega botaničnega kongresa v Madridu. Žal se Pieter Baas kongresa v juniju 2024 ni mogel več udeležiti, s čimer je na dogodku in na področju, ki ga je tako strastno promoviral, ostala globoka praznina.

Kot so sporočili, je na svoj 80. rojstni dan z velikim veseljem prebiral e-poštna voščila prijateljic in prijateljev z vsega sveta. Na ta sporočila izjemoma nismo prejeli odgovorov, saj je že naslednji dan prispela vest, da se je za vedno poslovil.

Vsi, ki smo imeli srečo, da smo ga osebno poznali, se ga bodo spominjali kot navdihujoče osebnosti s čudovitim smislom za humor. Pogrešali bomo njegovo elegantno angleščino, njegovo izjemno znanje in neukrotljivega duha, njegove talente, pa tudi skromnost in prijaznost.

The wood anatomy community is mourning the loss of Prof. Dr Pieter Baas (28 April 1944 – 29 April 2024) (Figure 1) who passed away in Leiden, the Netherlands, just one day after he celebrated his 80th birthday. For more than four decades he was a key personality in the field of wood anatomy. He has made an outstanding contribution to the development of wood and plant anatomy, wood science, and forestry. His work has been recognized nationally and internationally. He was a key figure in the International Society of Wood Anatomy, IAWA, in which he was active since 1976. He was executive secretary and for many years editor of the *IAWA Journal*. His life, work and outstanding personal qualities have been described by those closest to him (Van Welzen et al., 2024; Wheeler et al., 2024), and a special issue of the *IAWA Journal* will be dedicated to him in 2025.

Pieter Baas, born in the Netherlands, studied biology at Leiden University, and obtained Bachelor and Master of Science degrees in 1965 and 1969, respectively. During his master's work he started to specialize in wood anatomy (Van Welzen et al., 2024). He received a scholarship to visit the Royal Botanic Gardens Kew in London, and became very skilled in the English language, which we all admired. After his MS degree in 1969 he started to work as wood anatomist at the Rijksherbarium (National Herbarium) which was a part of Leiden University. In 1975 he received a PhD and in 1987 he became an Extraordinary Professor of Systematic Plant Anatomy at the same university. In 1991 he became scientific director of the Rijksherbarium and professor of systematic botany at Leiden University. Starting in 1993, he engaged in a six-year struggle to preserve the herbarium and wood collection. In 1999 the Rijksherbarium and the herbaria of Utrecht University and Wageningen University were merged to form the National Herbarium of the Netherlands (NHN), with Pieter as its first director. Later Pieter began discussions of merging all biodiversity collections in the Netherlands, resulting in today's Naturalis Biodiversity Center in Leiden. In 2000 he became a member of the Royal Netherlands Academy of Arts and Sciences. He was elected a fellow of the International Academy of Wood Science and a corresponding member of the Botanical Society of America. In 2023, he won the Linnean Medal of the Linnean Society of London, and he became a Knight in the Order of the Netherlands Lion in 2005. Although Pieter official retired on 1 April 2005 and became a professor emeritus, he remained scientifically active in wood anatomical research (Van Welzen et al., 2024; Wheeler et al, 2024). He continued his work as an editor and never stopped providing advice to anybody who asked for it. He remained active and involved in wood anatomical projects until almost his last day. He has greatly contributed to the field of wood anatomy, and left us an impressive bibliography (e.g., Scopus, 2024).

Pieter Baas was especially known to international community as the Executive Secretary of IAWA between 1976 – 1981. From 1980 -2019 he ran the *IAWA Bulletin New Series,* later the *IAWA Journal* (Baas & Wheeler, 2019) as editor in tight cooperation with Emma van Nieuwkoop (1933–2022), desk editor in the Rijksherbarium (Wheeler et al., 2024; IAWA, 2024).

As the key person at the IAWA he was the greatest advocate of international collaboration. He was involved in the organization of IAWA conferences or IAWA sessions as a part of large symposia all over the world (Figure 2). They were always accompanied by IAWA social events where Pieter's personal qualities, friendliness and charisma always contributed to their success. He was the one making toasts and thanking the organizers, generously encouraging young scientists, welcoming new IAWA members, selling IAWA publications and chatting with everyone (Figure 3). In this way he established a model of how to run a worldwide society and how to make sure that the people involved know each other and really cooperate.

All scientists from Slovenia who deal with wood anatomy came into contact with Pieter Baas and the IAWA. In 1983, Prof. Dr Niko Torelli and Katarina Čufar attended the IAWA IUFRO Wood Anatomy Meeting in Hamburg and met Pieter and all the leading European scientists in the field of wood anatomy at that time (Ter Welle, 1983). Torelli and Čufar became members of the IAWA and began receiving the printed version of the *IAWA Bulletin, New Series*, and later the *IAWA Journal*. In the pre-internet era, the *IAWA Journal* with its scientific articles and important announcements on events and membership, together with the conferences, was crucial for enabling Slovenian scientists to stay in touch with the profession and other IAWA members. Pieter visited the Department of Wood Science and Technology at the Biotechnical Faculty of the University of Ljubljana (DWST BF UL) twice. The first visit was to prepare and the second to execute the IAWA and IUFRO S 5.01 Symposium at the 18th IUFRO World Congress held in Ljubljana, then still part of Yugoslavia, in September 1986. The symposium was entitled "The Effects of Environmental Pollution on Wood Structure and Quality", and Peter helped to organise the IAWA satellite meeting and social hour, with Torelli and Čufar as local organisers (Shortle, 1986). Shortle reports that the members sat in silence during the IAWA business meeting. However, a miraculous change came over the members and their guests once the social hour began after the formal meeting. Once the anatomists began loosening themselves with fine wines and building up their carbohydrate and protein reserves with fruits and cheeses, they broke their silence, and a good time was had by all in attendance.

Afterwards, Pieter remained in personal and, of course, professional contact with the scientists from Slovenia. All those who worked in the field of wood anatomy in Ljubljana – Primož Oven, Jožica Gričar, Maks Merela, Peter Prislan, Angela Balzano

Slika 3. Pieter Baas, Manuela Romagnoli (levo) in Katarina Čufar (desno) na gala večerji konference International symposium on wood structure in plant biology and ecology, April 2013, Neapelj, Italija, v okviru COST akcije STREeSS.
Figure 3. Pieter Baas, Manuela Romagnoli (left) and Katarina Čufar (right) at the Gala Dinner of the International Symposium on Wood Structure in Plant Biology and Ecology, 17-20 April 2013, Napoli, Italy in the framework of the COST Action STREeSS.

and others – were committed to the IAWA. Katarina Čufar, Jožica Gričar and Angela Balzano published their first scientific articles with an impact factor in the *IAWA Journal* (e.g. Scopus, 2024) which remains a distinguished journal in their resumes. As editor, Peter was in contact with the authors at all stages of the process, from submission to publication. The scientists from Ljubljana also participated in editorial boards and as reviewers and met Pieter regularly as part of the COST Action STREeSS.

Angela Balzano and Maks Merela also met Pieter Baas at the "From Forests to Heritage" conference in Amsterdam in April 2022. They went on an unforgettable boat trip together on the canals of Amsterdam (Figure 4). While Pieter enjoyed his favourite *bitterballen* and a glass of wine, he introduced his colleagues to Amsterdam in a special way and shared laughs and stories with them.

Pieter was an active scientist until the end. Despite his illness, he co-organized with Yafang Yin and Veronica de Micco the IAWA Symposium "The Contribution of Wood in Forests: From Wood Dynamics to Trait Diversity and Carbon Gains" for the XX International Botanical Congress in Madrid. Unfortunately, he was unable to attend the congress, which took place in June 2024, leaving a deep void at the event and in the field that he so passionately promoted throughout his career.

On his 80th birthday, he was delighted to receive email greetings from his wood anatomy friends from all over the world. This year, however, we did not receive an email with his thanks, but instead the very next day we received the news that we had lost him forever.

All of us who were fortunate enough to know Peter personally will remember him as an inspiring personality with a wonderful sense of humour. We will miss his extraordinary knowledge, his spirit, talents, elegance and kindness. Pieter Baas will be remembered and missed by us all.

VIRI
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Slika 4. Pieter Baas (desno zadaj), Paolo Cherubini, Elisabeth Wächter (levo) in Angela Balzano (desno) med vožnjo po kanalih Amsterdama v okviru konference »From Forests to Heritage« aprila 2022.

Figure 4. Pieter Baas (right), Paolo Cherubini, Elisabeth Wächter (left) and Angela Balzano (right) during a ride through the canals of Amsterdam as part of the "From Forests to Heritage" conference in April 2022.

Poletna šola 2024 v Clausthalu

Summer school 2024 in Clausthal

Marko Petrič[1*], Sergej Medved[1], Matic Jančar[1], Enej Lipovec Zupanc[1], Matevž Vrhovec[1], Anže Zajc[1], Primož Zore[1]

Izvleček: Pet študentov in profesorja Oddelka za lesarstvo Biotehniške fakultete na Univerzi v Ljubljani so se konec septembra 2024 udeležili poletne šole v Nemčiji. To je bila že 5. poletna šola, ki jo Oddelek organizira v sodelovanju s Tehniško univerzo Clausthal v kraju Clausthal-Zellerfeld v Nemčiji. Tema poletne šole so vmesne faze na lignoceluloznih materialih. Slovenski in nemški študentje so izdelovali frizbije iz kompozitnih materialov po lastni zamisli (materiali, struktura). Nemški gostitelji so udeležencem teden popestrili z ekskurzijo v rudarski muzej in na jezero Oderteich. Teden v tujini je sklenil turnir v metu novo izdelanih frizbijev. Poletna šola se je ponovno izkazala za izvrstno priložnost za izmenjavo znanja in sklepanje novih prijateljstev.

Ključne besede: poletna šola, Nemčija, Clausthal-Zellerfeld, Oddelek za lesarstvo, TU Clausthal, lignocelulozni kompoziti, frizbi, ekskurzija

Abstract: Five students and two professors from the Department of Wood Science and Technology of the Biotechnical Faculty at University of Ljubljana attended a summer school in Germany at the end of September 2024. This was the 5th summer school organized by the Department in collaboration with the Technical University of Clausthal in Clausthal-Zellerfeld, Germany. The title of the summer school was "Interphases of Biobased-Lignocellulosic Materials". Slovenian and German students made frisbees using composite materials of their own design (materials, structure). The German hosts enriched the week for the participants with an excursion to the mining museum and the Oderteich pond. The week abroad was concluded with a competition throwing the newly made frisbees. The summer school again proved to be a great opportunity for the exchange of knowledge and making new friends.

Keywords: summer school, Germany, Clausthal-Zellerfeld, Department of Wood Science and Technology, TU Clausthal, lignocellulose composites, frisbee, excursion

1 UVOD
1 INTRODUCTION

Oddelek za lesarstvo Biotehniške fakultete Univerze v Ljubljani (kratko OL BF UL) in Tehnische Universität Clausthal iz Nemčije tradicionalno organizirata slovensko-nemško poletno šolo »Vmesne faze na lignoceluloznih materialih«. Šola poteka v mesecu septembru izmenoma, enkrat v Nemčiji, drugič na naši univerzi v Ljubljani. Vendar je bilo zaporedje lokacij v preteklosti zaradi covida in finančnih pogojev moteno. Eno od večjih težav pri organizaciji poletne šole vedno predstavljajo sredstva za pokritje stroškov. Letos smo za izvedbo šole uspeli pridobiti sredstva na internem razpisu Mednarodne poletne šole UL 2024, ki se izvaja v okviru RSF (razvojni steber financiranja). Tako smo poletno šolo lahko uspešno izvedli tudi letos, v predzadnjem tednu septembra. Delavnico je vodil prof. dr. Leif Steuernagel s profesorjema dr. Markom Petričem in dr. Sergejem Medvedom (OL BF UL) ter petimi slovenskimi študenti 1. letnika magistrskega študija lesarstva (soavtorji tega prispevka) ter štirimi nemškimi študenti. Vsem je poletna šola zagotovila nepozaben teden inovativnega, praktičnega raziskovalnega dela. Zahvaliti se moramo tudi sodelavcem Inštituta v Clausthalu, ki so pomagali pri izvedbi delavnice: mag. Carrie Schulz, mag. Silvia Imrich, mag. Fabian

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Že 5. poletna šola zapovrstjo se je pričela v nedeljo, 15. 9. 2024, pred Oddelkom za lesarstvo v Ljubljani, od koder so se študentje in profesorja v zgodnjih jutranjih urah odpeljali proti Nemčiji. Po 12 urah vožnje so prispeli v Clausthal-Zellerfeld, kjer so jih sprejeli in pogostili predstavniki Tehniške univerze Clausthal.

The University of Ljubljana, Biotechnical Faculty (Department of Wood Science and Technology) and the Technical University Clausthal, Germany, traditionally organize a Slovenian-German Summer School – "Interphases on Biobased-Lignocellulosic Materials". The school takes place alternately in September, once in Germany, and the other time in Slovenia. However, this sequence of venues has been interrupted in the past due to COVID and financial conditions. One of the biggest difficulties in organizing a summer school is always financing the costs. This year, we were able to obtain funding for the summer school through the internal call for proposals "International Summer Schools UL 2024", which is organized under the RSF (the pillar of development funding). As a result, we were able to successfully hold the summer school again this year in the penultimate week of September. The workshop was led by Prof. Dr. Leif Steuernagel, and together with Prof. Dr. Marko Petrič and Prof. Dr. Sergej Medved (UL BF) he offered five Slovenian students (we are co-authors of this paper together with M. Petrič and S. Medved) of the first year MSc in Wood Science and Technology and four German students an unforgettable week of innovative, hands-on research. We would also like to thank the colleagues at the Institute who helped organize the workshop. Carrie Schulz, MSc. Silvia Imrich, MSc. Fabian Hartkopf, MSc. Cedric Tschentscher, Markus Lenk, Petra Dröttboom and Dipl.-Ing. Martin Novotny.

The 5th Summer School began on Sunday, September 15, 2024, in front of the Department of Wood Science and Technology in Ljubljana, where the students and professors left for Germany in the early hours of the morning. After a 12-hour drive, they arrived in Clausthal-Zellerfeld, where they were welcomed and hosted by representatives of the Technical University Clausthal.

2 CLAUSTHAL-ZELLERFELD IN TAMKAJŠNJA UNIVERZA

2 CLAUSTHAL-ZELLERFELD AND THEIR UNIVERSITY

Clausthal-Zellerfeld (slika 1) se nahaja v severni Nemčiji v zvezni državi Spodnja Saška. Leži v jugozahodnem delu hribovja Harz, na 560 m nadmorske višine. Najbližje veliko mesto je okoli 100 kilometrov oddaljeni Hannover na severu. Mesto je nastalo s postopnim zbližanjem in zlitjem dveh naselij, katerih začetki segajo v 16. stoletje. Razvijalo se je hkrati z uspešno rudarsko dejavnostjo v okolici, ki je leta 1775 sprožila tudi ustanovitev Tehniške univerze v Clausthalu. Danes ima mesto 15000 prebivalcev, velik del živosti pa kot središče inovativnosti in razvoja zagotavlja prav univerza (Harz Tourism Association, 2024).

Slednja bo prihodnje leto praznovala 250-letnico ustanovitve. Sestavljajo jo 3 fakultete s kar 33 oddelki – učijo vse od znanosti o materialih, ekonomike, do računalništva in strojništva. Univerzo obiskuje prek 3000 študentov (kar 40 % mednarodnih), katerim se posveča okoli 1100 zaposlenih. Poudarek dajejo krožnemu gospodarstvu, trajnosti in učinkoviti rabi virov. Glavna področja raziskav zajemajo sisteme trajnostne energije, oskrbo s surovinami in trajnostnimi materiali ter digitalizacijo za razvoj zelene družbe. Svoj doseg povečujejo s tesnim sodelovanjem z mnogimi podjetji (TU Clausthal, 2024).

Slika 1. Študentje so se dobro seznanili s središčem mesta Clausthal (foto: M. Jančar).
Figure 1. The students explored Clausthal city centre (photo: M. Jančar).

Clausthal-Zellerfeld (Figure 1) is located in northern Germany in the federal state of Lower Saxony. It lies in the south-western part of the Harz Mountains at 560 m above sea level. The nearest major city is Hannover, about 100 kilometres to the north. The town was formed by the gradual merging of two settlements whose origins date back to the 16th century. It developed in parallel with the flourishing mining industry in the area, which also led to the founding of the Technical University of Clausthal in 1775. Today, the town has a population of some 15,000 and the university is an important part of its vibrant life as a centre for innovation and development (Harz Tourism Association, 2024).

The university celebrates its 250th anniversary next year. It consists of three faculties with 33 departments teaching everything from materials science and economics to computer science and mechanical engineering. The university has over 3,000 students (40% of whom come from abroad) and around 1,100 employees. The focus is on the circular economy, sustainability and resource efficiency. The main research areas include sustainable energy systems, the supply of raw materials and sustainable materials as well as digitalization for the development of a green society. Close cooperation with many companies increases its reach (TU Clausthal, 2024).

3 PROJEKT KOMPOZITNI FRIZBI
3 THE COMPOSITE FISBEE PROJECT

Cilj tokratne šole sta bila snovanje in izdelava kompozitnega frizbija. Ta naj bi bil sestavljen iz dveh različnih naravno-polimernih kompozitnih materialov, kar je spodbujalo interdisciplinarno razmišljanje in povezovanje.

Prvi dan po prihodu v Clausthal sta poletno šolo s predavanji na temo polimernih in lignoceluloznih materialov otvorila profesorja Steuernagel in Medved. Na daljavo je prek videoklica študentom delil znanje tudi prof. dr. Milan Šernek, ki je govoril o tehnologiji lepljenja. Za tem so se študentje razdelili v tri skupine in brez odlašanja pričeli z razvojem svojih frizbijev.

Skupina A, ki so jo sestavljali Matic Jančar, Nicolas Uzunhan in Shaoqin Ruan, si je zamislila frizbi

Slika 2. Prvi frizbi se je oprijel kalupa (foto: P. Zore).
Figure 2. The first frisbee got stuck to the mould (photo: P. Zore).

iz mešanice smrekovega žaganja in polipropilena ter lanenih vlaken in polibutilena. Skupina B, ki so jo sestavljali Primož Zore, Enej Lipovec Zupanc in Valentin Heinmüller, se je odločila za komercialna kompozitna materiala Lifocork UV in JELU WPC. V zadnji skupini C pa so Anže Zajc, Matevž Vrhovec in Jafaar Naciri preizkušali kombinacijo smrekovine in polipropilena v različnih razmerjih v spodnji in zgornji plasti.

Po idejni zasnovi so se študentje takoj lotili praktičnega dela. V izjemno dobro opremljeni in urejeni delavnici Inštituta so najprej pripravili poskusne vzorce izbranih materialov. Na teh so preverili mehanske lastnosti zamišljenih kombinacij in po potrebi prilagodili deleže različnih komponent. Preverjali so upogibno in udarno trdnost svojih kompozitov.

Ko so bili zadovoljni z rezultati, so se lotili izdelave frizbijev. Prvi dve skupini sta se odločili za takojšnje vroče stiskanje v kalupu, tretja pa za dvostopenjski pristop – najprej ekstruzijo posamezne plasti in šele nato oblikovanje v kalupu.

Tretji dan je skupina B kot prva pogumno stisnila svoj frizbi in naletela na težave pri odstranjevanju iz kalupa (slika 2). Čeprav je prvi frizbi pri tem razpadel, jih to ni ustavilo. Prilagodili so kalup in predlagali uporabo povoščenega papirja za lažje odstranjevanje. Spodrsljaje in odkritja so skupine odprto delile med seboj in se tako podpirale in spodbujale.

The aim of this year's school was to design and create a composite frisbee. This was to be composed of two different natural-polymer composite materials, which encouraged interdisciplinary thinking and networking.

On the first day after their arrival in Clausthal, Professors Steuernagel and Medved opened the summer school with lectures on polymer and lignocellulosic materials. Prof. Dr. Milan Šernek also shared his knowledge with the students via video call and spoke about bonding technology. The students then split into three groups and immediately began developing their frisbees.

Group A, consisting of Matic Jančar, Nicolas Uzunhan and Shaoqin Ruan, developed a frisbee made from a mixture of spruce sawdust and polypropylene on one side and flax fibres and polybutylene on the other. Group B, consisting of Primož Zore, Enej Lipovec Zupanc and Valentin Heinmüller, opted for commercially available composite materials, Lifocork UV and JELU WPC. In the last group, C, Anže Zajc, Matevž Vrhovec and Jafaar Naciri tested a combination of pine wood and polypropylene in different proportions in the bottom and top layers.

After the conceptual design, the students got straight down to practical work. First, they produced test samples of the selected materials in the institute's well-equipped and well-organized workshop. Using these, they were able to check the mechanical properties of the combinations they had designed and, if necessary, adjust the proportions of the various components. They tested the bending and impact strength of their composite materials.

Once they were satisfied with the results, they started to make the frisbees themselves. The first two groups opted for immediate hot pressing in a mould, while the third group chose a two-step approach – first extruding each layer and then forming it in a mould.

On the third day, Group B was the first to boldly press their frisbee, and had difficulty releasing it from the mould (Figure 2). Although the first frisbee fell apart, this did not stop them. They adjusted the mould and suggested using wax paper to make it easier to remove. Accidents and discoveries were openly shared between the groups to support and encourage each other.

4 EKSKURZIJA V RUDNIK SAMSON IN JEZERO ODERTEICH

4 THE EXCURSION TO THE SAMSON MINE AND ODERTEICH POND

Gostitelji so Slovencem popestrili bivanje v Nemčiji z ekskurzijo v rudniški muzej v kraju Sankt Andreasberg, ki leži 15 kilometrov jugovzhodno od Clausthal-Zellerfelda. Muzej je postavljen na rudniku Samson, enem od mnogih v hribovju Harz.

Rov Samson so pričeli kopati v 16. stoletju. Obratoval je vse do leta 1910, dosegel pa je globino kar 840 metrov. Glavna ruda, ki so jo pridobivali, je bilo srebro. Rudnik je še posebej zanimiv, ker je v njem ohranjena in delujoča pomična lestev iz leta 1837. Gre za zgodnjo alternativo dvigalu, kar je rudarjem omogočalo mnogo hitrejše potovanje v globine in nazaj na površje kot po klasičnih lestvah (slika 3). Celoten sistem je bil gnan z vodo, ki je prihajala iz akumulacijskih jezer na višjih legah. V muzeju je danes postavljena delujoča replika enega največjih vodnih koles, premera kar 12 metrov. Kolo je izdelano iz smrekovine in hrastovine. Kljub temu da rudnik ne obratuje več, pa se še danes izkorišča moč vode, ki priteka vanj. V glavnem jašku je namreč na globini 190 m postavljena hidroelektrarna.

Po ogledu jaška, pomične lestve in vodnega kolesa je skupina rudnik zapustila po krajšem rovu. Za tem so si ogledali še razstavo v sosednji stavbi, ki je prikazala življenje rudarjev in njihovih družin skozi čas.

Po končanem obisku muzeja so se odpeljali do bližnjega akumulacijskega jezera Oderteich (slika 4), okoli katerega je speljana lepa pohodna pot. Skupina se je sprehodila ob jezeru in se čudila nekaterim pohodnikom, ki so se opogumili in celo zaplavali v njem.

Med potjo na ekskurzijo in nazaj je bilo presenetljivo videti obseg škode, ki jo je na tamkajšnjih pretežno smrekovih gozdovih povzročil lubadar. Ker celotno območje spada pod narodni park Harz, napadenih dreves ne odstranjujejo. Posledica je na tisoče posušenih dreves, do koder seže oko.

Po vrnitvi v Clausthal je dan sklenila proslava rojstnega dne profesorja Petriča, ki je vse udeležence povabil na večerno druženje ob pšeničnih in ječmenovih napitkih.

Slika 3. Model pomične lestve, star toliko kot sama naprava. Na njem so se novi rudarji učili uporabe tega nenavadnega dvigala (foto: M. Jančar).
Figure 3. A model of the man engine, as old as the machine itself. It was used to teach new miners how to use this unusual lift (photo: M. Jančar).

Slika 4. Favna jezera Oderteich (foto: M. Jančar).
Figure 4. The fauna of lake Oderteich (photo: M. Jančar).

On Wednesday afternoon, the hosts invited the Slovenians on an excursion to the mining museum in Sankt Andreasberg, 15 kilometres southeast of Clausthal-Zellerfeld. The museum is located in the Samson mine, one of many in the Harz Mountains.

The Samson mine was first utilized in the 16th century. It was in operation until 1910 and reached a depth of 840 metres. It was mainly silver that was mined. The mine is particularly interesting because it houses a preserved and functioning sliding ladder from 1837. This was an early alternative to the elevator, allowing miners to reach the depths and back to the surface much faster than the conventional ladder (Figure 3). The entire system was powered by water from the higher reservoirs. A working replica of one of the largest water wheels with a diameter of 12 metres is on display in the museum today. The wheel is made of pine and oak wood. Although the mine is no longer in operation, the power of the water flowing into the mine is still being harnessed. There is a hydroelectric power station in the main shaft at a depth of 190 metres.

After visiting the shaft, the moving ladder and the water wheel, the group left the mine through a short tunnel. They then visited the exhibition in the adjacent building, which showed the life of the miners and their families over the course of time.

After the museum visit, the group drove to the nearby Oderteich pond (Figure 4), around which there is a beautiful hiking trail. The group walked along the lake and were amazed at some of the hikers who dared to swim in it.

On the way there and back it was surprising to see the extent of the damage caused by the bark beetle in the local, predominantly spruce forests. As the entire area is part of the Harz National Park, the infested trees are not removed. The result is thousands of dead trees as far as the eye can see.

After returning to Clausthal, the day was rounded off with a birthday party for Professor Petrič, who hosted an evening of wheat and barley drinks.

5 ZAKLJUČNI TURNIR IN VRNITEV DOMOV
5 THE FINAL TOURNAMENT AND THE RETURN HOME

V četrtek so študentje nadaljevali z izdelavo frizbijev. Z novim pristopom so vsem trem skupinam izdelki dobro uspeli. Za tem so pripravili predstavitve svojih projektov, ki so jih naslednje jutro predstavili ostalim prisotnim. Proti večeru so si udeleženci ogledali tradicionalni sejem, ki se v Clausthalu poleti odvija vsak teden.

V petek je nastopil pomemben zaključek – praktično testiranje frizbijev. Le-to je potekalo na bližnjem travniku, kjer so se skupine pomerile v dolžini meta svojih mojstrovin. Vsak član je metal enkrat, pri čemer je nekaterim rahlo ponagajal veter. V vlogo sodnika se je postavil profesor Steuernagel, ki je skupne razdalje izmeril z nitjo. Uvrstitev skupin se je nato določila glede na mase pridobljenih klopk. Najdlje so metali v skupini B, za tem v C in naposled v A. Ali je na rezultat bolj vplivala masa posameznega rekvizita, ali sposobnost metalca, je težko opredeliti, vsekakor pa so se vsi frizbiji dobro odrezali z vidika trdnosti in obstojnosti.

Po končanem turnirju so profesorji uradno sklenili poletno šolo z izmenjavo simboličnih daril in podelitvijo priznanj o udeležbi študentom. Zvečer je sledil še poslovilni piknik, ki ga je za vse organiziral profesor Steuernagel. Po slovesu od nemških gostiteljev so se študentje še zadnjič sprehodili po mestu in prijetno preživeli preostali del dneva.

V soboto, 21. 9. 2024, je slovenska delegacija rano odrinila proti domu. Zahvaljujoč vztrajnemu šoferju so že popoldne prispeli nazaj v Ljubljano. Teden je minil, kot bi trenil in tako študentje kot profesorja so bili s poletno šolo zelo zadovoljni. Odprava v Nemčijo je poleg novih znanj in izkušenj s področja polimernih in lignoceluloznih kompozitov udeležencem razširila obzorja in omogočila nova poznanstva.

On Thursday, we continued with making the frisbees. All three groups did well with a new approach. The students then presented their projects, which they then showed to the rest of the audience the next morning. Towards the evening, the participants visited the traditional fair that takes place every week in Clausthal during the summer.

On Friday, an important final event took place – a practical test of the frisbees. This took place in a nearby meadow, where the groups competed in the throwing distance of their masterpieces. Each member threw once, with some of them being slightly hindered by the wind. Professor Steuernagel acted as referee, measuring the total distance with a rope. The ranking of the groups was then determined based on the results of this. The longest throws were made in group B, followed by C and finally A. Whether the weight of the individual frisbee or the skill of the thrower had more influence on the result is difficult to determine, but in any case all frisbees performed well in terms of strength and durability.

After the tournament, the professors officially closed the summer school by exchanging symbolic gifts and presenting the students with certificates of participation. In the evening, a farewell picnic was organized by Prof. Steuernagel. After saying goodbye to their German hosts, the students took a final walk through the city and made the most of the rest of the day.

On Saturday, September 21, 2024, the Slovenian delegation left for home early in the morning. Thanks to a determined driver, they arrived back in Ljubljana in the afternoon. The week flew by and both the students and the professors were very satisfied with the summer school. In addition to the new knowledge and experience that was gained in the field of polymer and lignocellulose composites, the trip to Germany broadened the participants' horizons in general and enabled them to make new friends and acquaintances.

ZAHVALA
ACKNOWLEDGEMENT

Zahvaljujemo se Univerzi v Ljubljani (UL) za odobritev sredstev v okviru RSF ukrepa »Razvoj in krepitev sodelovanja v okviru transnacionalnih medinstitucionalnih učnih skupnostih« (B.II.3). Za podporo pri finančni izvedbi projekta in poročanju se zahvaljujemo Renati Kovačič in Juretu Letonja z Biotehniške fakultete, za pomoč pri organizaciji prevoza pa Urški Kovačič z Oddelka za lesarstvo.

We would like to thank the University of Ljubljana (UL) for providing funding under the RSF Action "Developing and strengthening cooperation in transnational inter-institutional learning communities" (B.II.3). We would also like to thank Ms Renata Kovačič and Mr Jure Letonja from the Biotechnical Faculty for their support in the financial implementation of the project and reporting, and Ms Urška Kovačič from the Department of Wood Science and Technology for her help in organizing the transport.

VIRI
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67. mednarodni kongres SWST 2024 v organizaciji InnoRenew CoE in Univerze na Primorskem

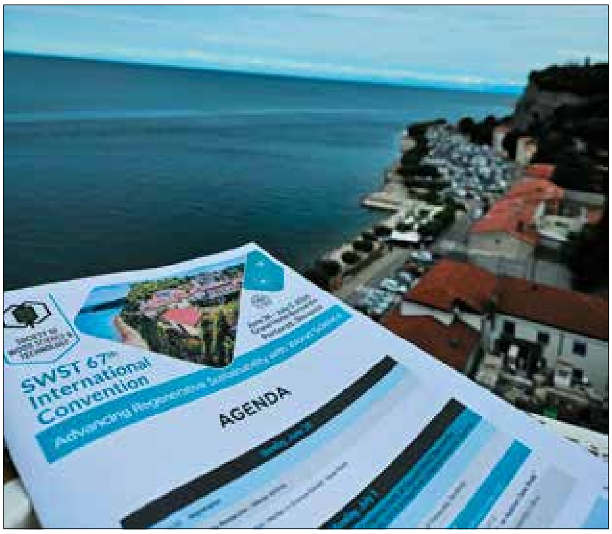
67th SWST International Convention 2024 with local hosts InnoRenew CoE and the University of Primorska

Lea Primožič[1*]

67. mednarodni kongres Združenja za znanost o lesu in tehnologijo lesa SWST (The Society of Wood Science & Technology), ki je potekal od 30. junija do 5. julija 2024 v kongresnem centru hotela Bernardin v Portorožu, sta uspešno gostila raziskovalni inštitut InnoRenew CoE in Univerza na Primorskem.

Letošnji kongres je potekal pod geslom »Pospeševanje regenerativne trajnosti z znanostjo o lesu«, in je v Sloveniji združil več kot 190 raziskovalk in raziskovalcev ter predstavnic in predstavnikov industrije iz različnih koncev sveta.

Kongres se je tradicionalno začel s sprejemno slovesnostjo že v nedeljo, kjer so tudi uradno odprli potujočo razstavo »Women in Science«. Ta je namenjena praznovanju žensk v znanosti.



Slika 1. 67. Kongres SWST 2024, ki je potekal v kongresnem centru hotela Bernardin v Portorožu, je imel bogat program.

Figure 1. The 67th SWST International Convention (2024) was organized at the Bernardin Hotel Congress Centre in Portorož, Slovenia, had an outreach programme.

Dr. Andreja Kutnar, direktorica InnoRenew CoE, je bila osrednja govorka na kongresu. V svojem predavanju se je dotaknila teme o prihodnosti za znanost o lesu.

V štirih dneh kongresa se je zvrstilo več kot 170 predstavitev, kjer so raziskovalke in raziskovalci predstavili najnovejša dognanja in spoznanja glede inovacij v gozdarskem sektorju, znanosti o lesu, nove uporabe lesa v grajenem okolju, pozitivnih okoljskih učinkih z uporabo lesa, o trajnosti, novih pristopih k izobraževanju v lesnem sektorju, prihodnosti za inženirske žive materiale ter o socialno-ekonomskih učinkih trajnostnih praks na področju lesa.

Na kongresu je bilo tudi najavljeno, da je dr. Matthew Schwarzkopf, raziskovalec v InnoRenew CoE, postal podpredsednik društva SWST. Ob najavi je povedal: »Počaščen sem, da sem bil izbran za ta položaj. V združenju sodelujem že od študentskih let in zelo cenim, kaj lahko to združenje ponudi tako mladim kot uveljavljenim raziskovalkam in raziskovalcem. Veselim se, da bom zdaj lahko služil in vračal nazaj ter tako zagotovil, da bodo lahko tudi drugi še naprej imeli koristi od tega odličnega združenja!«

Organizatorji so pripravili tudi okroglo mizo in pogovor z urednikoma knjige Handbook of Wood Science and Technology, izdane pri založbi Springer. Urednika Peter Niemz in Alfred Teischinger sta predstavila knjigo in posebej izpostavila pomen poenotenja izrazoslovja na področju znanosti o lesu, kar je pomembno tudi za nadaljnji razvoj te vede.

Poleg drugih aktivnosti je bil poseben del konference namenjen predstavitvi Mednarodne akademije znanosti o lesu (International Academy of Wood Science, IAWS). Ta je organizirala posebno sekcijo s predavanji, IAWS pa je organiziral tudi

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Slika 2. Dr. Andreja Kutnar, direktorica InnoRenew CoE, kot osrednja govorka na kongresu.
Figure 2. Dr. Andreja Kutnar, InnoRenew CoE director as a Keynote Speaker at the congress.

družabno uro s pogostitvijo. V okviru konference je bil pripravljen tudi bogat spremljevalni program, ki je vključeval aktivnosti za mlade raziskovalke in raziskovalce ter mentorice in mentorje, poslovno srečanje SWST in podelitev nagrad ter slavnostno večerjo.

Kongres je bil pomembna priložnost za izmenjavo znanja in za obogatitev našega razumevanja in uporabe lesa kot ključnega naravnega vira ter za vzpostavljanje novih povezav in spodbujanje inovacij na področju lesarstva in tehnologije lesa. Organizatorji so kongres zaključili z vabilom k udeležbi na naslednjem kongresu, ki bo v letu 2025 potekal v ZDA.

The 67th International Convention of the Society of Wood Science & Technology (SWST) was successfully hosted by the InnoRenew CoE research institute and the University of Primorska at the Bernardin Hotel Congress Centre in Portorož, Slovenia, from 30 June 2024 to 5 July 2024.

The theme of this year's congress was "Advancing regenerative sustainability with wood science". It brought together more than 190 researchers, academics and industry representatives from around the world.

The congress began with the traditional welcoming ceremony on Sunday, during which the travelling exhibition "Women in Science" was officially opened. It is dedicated to honouring exceptional women in wood science.

Dr Andreja Kutnar, InnoRenew CoE director, was the keynote speaker at the congress. In her presentation entitled "Where is wood science going?", she addressed the future of wood science.

Over the four days of the congress, more than 170 presentations were given by researchers on the latest developments in forest innovation, wood science, new uses of wood in the built environment, positive environmental impacts of wood use, sustainability, new approaches to education in the wood sector, the future of living engineering materials and the socio-economic impact of sustainable practices in the wood sector.

It was also announced that Dr Matthew Schwarzkopf, an InnoRenew CoE researcher, would be the new Vice President of SWST. He said: "I am honoured to have been selected for this position. I have been involved in SWST since I was a student

Slika 3. Potujoča razstava "Ženske v znanosti", in predstavitve ambasadork znanosti o lesu.
Figure 3. Travelling exhibition "Women in Science" presenting women ambassadors of wood science.

Slika 4. Skupinska slika in gala večerja ob zaključku kongresa.
Figure 4. Group photo and gala dinner at the end of the congress.

and really appreciate what SWST has to offer both young and established researchers. I look forward to serving the organization and giving back so that others can benefit from this great association."

The hosts also organized a roundtable and discussion with the editors of the *Handbook of Wood Science and Technology*, published by Springer. Peter Niemz and Alfred Teischinger presented the book and emphasized the importance of standardizing terminology for the further development of wood science and technology.

Among other activities, a special session was dedicated to introducing the International Academy of Wood Science (IAWS), with a special lecture session and a social hour with a banquet organized by the IAWS.

The conference also included a rich social programme, including activities for young researchers and mentors, a SWST business session with awards ceremony and a gala dinner.

The convention was an important opportunity to share knowledge and enrich our understanding and utilization of wood as an important natural resource, make new connections and promote innovation in the field of wood science and technology. The organizers concluded the congress with an invitation to participate in the next convention, which will take place in the USA in 2025. •

67. mednarodni kongres SWST 2024 in Oddelek za lesarstvo BF UL

67th SWST International Convention 2024 and the Department of Wood Science and Technology BF UL

Katarina Čufar[1], Manja Kitek Kuzman[1*], Milan Šernek[1]

67. mednarodne konvencije SWST v Portorožu, od 30. junija do 5. julija 2024, so se udeležili tudi sodelavke in sodelavci ter alumne in alumni Oddelka za lesarstvo Biotehniške fakultete Univerze v Ljubljani (OL BF UL).

Pri organizaciji dogodka sta bila vključena tudi prof. dr. Manja Kitek Kuzman in prof. dr. Milan Šernek, ki sta dolgoletna člana društva Society of Wood Science & Technology (SWST). Prof. dr. Manja Kitek Kuzman je bila v letu 2023 tudi prejemnica priznanja »Women ambassador«, ki ga SWST podeljuje za promocijo dela žensk v znanosti o lesu. Prejmejo ga izjemne posameznice, ki uspešno in aktivno zastopajo znanstveno področje lesarstva. SWST je mednarodno priznana organizacija znanstvenic in znanstvenikov s področja gozdno-lesnega sektorja.

Prof. dr. Katarina Čufar se je konference udeležila kot predstavnica prestižne Mednarodne akademije znanosti o lesu (International Academy of Wood Science, IAWS), ki je organizirala posebno sekcijo s predavanji. Katarina Čufar je imela vabljeno predavanje v okviru te sekcije.

Posebej zanimive so bile posterske predstavitve in predavanja doktorskih študentk in študentov, ki so izkoristili izjemno priložnost srečati se s kolegicami in kolegi iz celega sveta. Oddelek za lesarstvo so zastopale tri mlade raziskovalke, Meta Pivk, Neja Bizjak Štrus in Katarina Remic. Poleg tega sta svoje delo predstavila tudi Ana Pršlja in Andrej Fašalek, ki sta alumna Oddelka za lesarstvo, kjer sta nedavno magistrirala. Oba sta trenutno na doktorskem študiju na univerzi BOKU (Universität für Bodenkultur) na Dunaju.

Nenazadnje naj omenimo, da so alumne in alumni Oddelka za lesarstvo predstavili svoje delo na konferenci SWST kot zaposleni na raziskovalnem inštitutu InnoRenew CoE in na Univerzi na Primorskem. Najbolj prepoznavna med njimi je prof. dr. Andreja Kutnar, direktorica InnoRenew CoE in glavna slovenska organizatorka konference SWST, ki je diplomirala in doktorirala na Oddelku za lesarstvo, na SWST konferenci pa je imela tudi uvodno predavanje, bila avtorica več predavanj in posterjev in moderatorka več sekcij.

Naslovi izbranih predavanj in posterjev omenjenih raziskovalk in raziskovalcev so navedeni na koncu tega prispevka in potrjujejo veliko raznolikost raziskav in izjemno povezanost domačih in mednarodnih raziskovalk in raziskovalcev.

Colleagues and alumni from the Department of Wood Science and Technology at the Biotechnical Faculty of the University of Ljubljana (DWST BF UL) also took part in the 67th International SWST Conference in Portorož from 30 June to 5 July 2024.

Prof. Dr. Manja Kitek Kuzman and Prof. Dr. Milan Šernek, long-standing members of the Society of Wood Science & Technology (SWST) were also involved in the organisation of the event. Prof. Dr Manja Kitek Kuzman was the recipient of the "Women Ambassador" Award, which is presented by SWST to promote the work of women in wood science and technology. It is awarded to exceptional individuals for their contribution and mentorship of women in the wood science field. SWST is an internationally-recognized professional organization of wood scientists, engineers, marketing specialists and other professionals concerned with lignocellulosic materials.

Prof. Dr. Katarina Čufar attended the conference as a representative of the International Acad-

Slika 1. Profesor, profesorici in mladi raziskovalki Oddelka za lesarstvo BF UL na konferenci SWST.
Figure 1. Professors and young researchers from the Department of Wood Science and Technology BF UL at the SWST conference.

Slika 2. Pred plakati na konferenci SWST.
Figure 2. Poster session at the SWST conference.

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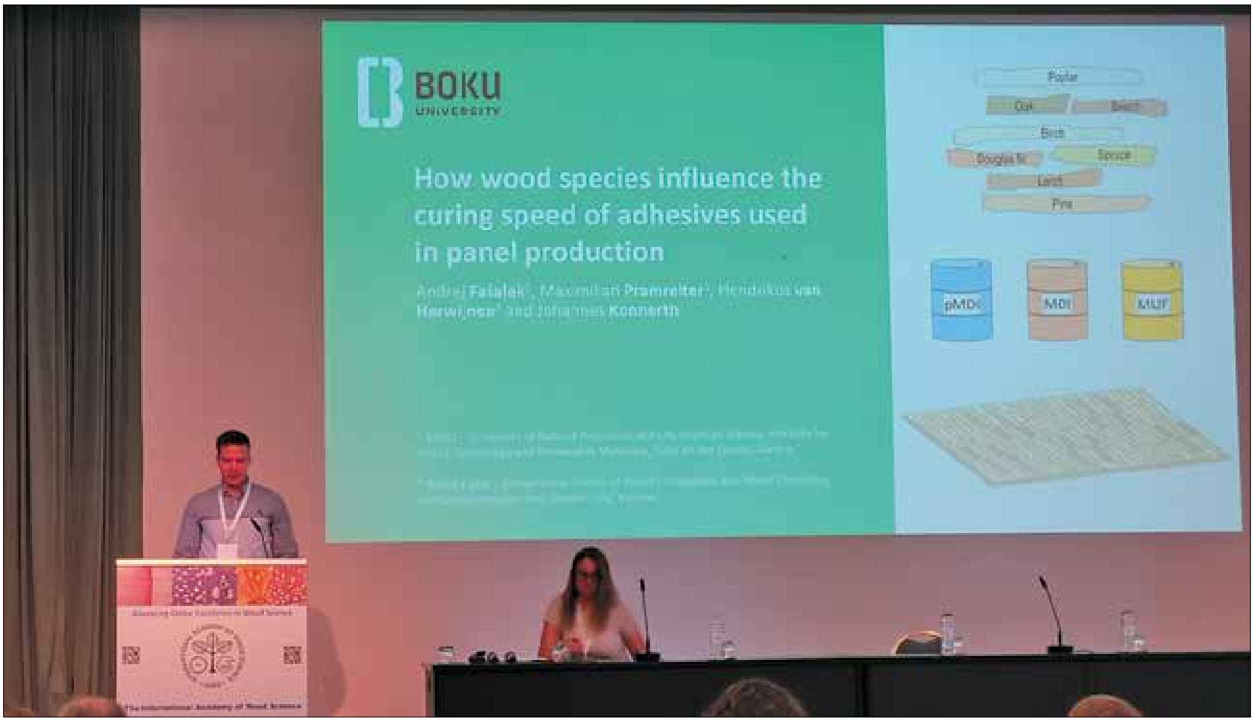

Slika 3. Predavanji sta predstavila tudi Andrej Fašalek (zgoraj) in Ana Pršlja (spodaj), oba na doktorskem študiju na BOKU Dunaj in alumna Oddelka za lesarstvo. Za Ano je bilo to prvo predavanje na konferenci.
Figure 3. The lectures were also presented by Andrej Fašalek (above) and Ana Pršlja (below), both PhD students at BOKU Vienna and alumni of the Department of Wood Science and Technology. For Ana, this was her first lecture at the conference.

emy of Wood Science (IAWS), which organized a special session with presentations by IAWS fellows. Katarina Čufar gave an invited talk in this session.

The poster presentations and talks by PhD students were particularly interesting. DWST BF UL was represented by three young researchers, Meta Pivk, Neja Bizjak Štrus and Katarina Remic. In addition, Ana Pršlja and Andrej Fašalek, alumni who recently completed their Master's degree at DWST BF UL and are now PhD students at BOKU (University of Natural Resources and Life Sciences) in Vienna, Austria, also presented their work at the SWST conference.

Last but not least, several researchers from the InnoRenew CoE Research Institute and the University of Primorska, who presented their work at the SWST conference, are also alumni of DWST BF UL. The most prominent among them is Prof. Dr. Andreja Kutnar, Director of InnoRenew CoE and main organiser of the SWST convention. Andreja Kutnar, who graduated and received her doctorate from DWST BF UL, also gave a keynote speech and several oral presentations, co-authored posters and moderated several sessions.

Izbrana predavanja in posterji zaposlenih in alumnov Oddelka za lesarstvo BF UL
Selected oral presentations and posters of the staff and alumni of the Department of Wood Science and Technology BF UL

Manja Kitek Kuzman, Mirko Kariž, Jože Kropivšek (University of Ljubljana, Slovenia)
"Advancing the woodworking industry through integration of Artificial Intelligence"

Eva Haviarova, Jue Mo (Purdue University, USA), Manja Kitek Kuzman (University of Ljubljana)
"Mapping the value chain of wood products"

Milan Šernek (University of Ljubljana, Slovenia), Andrej Fašalek (BOKU, Austria)
"Hybrid GLULAM made of beech and spruce wood bonded with MUF and PUR adhesives"

Marek Nociar, Tomas Pipiska, Pavel Král (Mendel University in Brno, Czech Republic), Samo Grbec, Milan Šernek (University of Ljubljana, Slovenia)
"Effect of the percentage coverage of MUF adhesive on the shear strength for bonding different wood species"

Katarina Čufar, Angela Balzano, Nina Škrk Dolar, Luka Krže, Aleš Straže, Jure Žigon, Maks Merela (University of Ljubljana, Slovenia)
"Wood anatomy and dendrochronology - a long tradition and current challenges"

Katarina Remic, Teja Bizjak Govedič, Manja Kitek Kuzman (University of Ljubljana, Slovenia)
"The potential of integrating life cycle assessment into the design phase of wood products"

Neja Bizjak (University of Ljubljana, Slovenia), Dávid Brodňanský, Jakub Kelar (Masaryk University, Czech Republic), Sebastian Dahle (University of Ljubljana, Slovenia)
"DCSBD Plasma treatment as an alternative to commercial surface degreasing agents before applying clear water-based wood coatings"

Meta Pivk, Jaka Levanič, Miha Humar (University of Ljubljana, Slovenia)
"Possibilities of hyperspectral imaging for sorting of recovered wood"

Ana Pršlja, Rupert Wimmer (BOKU, Austria), Falk Liebner, Alaudini Nurali (Institute of Chemistry of Renewable Resources, Austria), Benjamin Kromoser (Institute of Green Civil Engineering, Austria)
"Revolutionizing sustainable construction: The 3DP biowalls project approach to resource efficiency and circular economy"

Andrej Fašalek, Maximilian Pramreiter (BOKU, Austria), Hendrikus Van Herwijnen (Wood K plus, Austria), Johannes Konnerth (BOKU, Austria)
"How wood species influence the curing speed of adhesives used in panel production"

Andreja Kutnar (InnoRenew CoE & University of Primorska [UP], Slovenia)
"Where is wood science going" - Keynote Speach -

Andreja Kutnar (InnoRenew CoE & UP, Slovenia), Victoria Herian (USA)
"Historical overview of themes at the SWST's Conventions"

Andreja Kutnar (InnoRenew CoE & UP, Slovenia)
"Buildings and education in wood ecosystem for the New European Bauhaus – BE-WoodEN"

Andreja Kutnar (InnoRenew CoE & UP, Slovenia), Michael Burnard (InnoRenew CoE & UP, Slovenia, University of Helsinki, Finland)
"The New European Bauhaus (NEB) Academy Pioneer Hub for sustainable built environments with

renewable materials building up NEB Academy Alliance”

Črtomir Tavzes, Balázs Dávid, Jaka Gašper Pečnik (InnoRenew CoE & UP, Slovenia), Marica Mikuljan, Daša Majcen, Erwin M. Schau (InnoRenew CoE, Slovenia), Andreja Kutnar (InnoRenew CoE & UP, Slovenia)
“Use of green tax policies for enhanced use of wood and other natural materials from renewable sources for faster climate neutrality transition”

Marica Mikuljan, Tania Langella (InnoRenew CoE, Slovenia), Lei Han, Mariem Zouari (InnoRenew CoE & UP, Slovenia), David DeVallance (Commonwealth University of Pennsylvania, USA)
“Effect of biochar impregnation on wood properties”

Jaka Gašper Pečnik (InnoRenew CoE & UP, Slovenia), Marica Mikuljan (InnoRenew CoE, Slovenia), Ievgen Pylypchuk (Stockholm University, Sweden), Grzegorz Kowaluk (Warsaw University of Life Sciences, Poland), Matthew Schwarzkopf (InnoRenew CoE & UP, Slovenia)
“Use of lignin-based adhesive for fibreboard and plywood”

Prof. dr. Lidija Zadnik Strin je prejela nagrado »EURO Distinguished Service Award«

Prof. Dr Lidija Zadnik Strin received the EURO Distinguished Service Award

Katarina Čufar, Leon Oblak

Naša kolegica prof. dr. Lidija Zadnik Strin je prejela nagrado EURO Distinguished Service Award (EDSA) 2024 za življenjsko delo in prispevek na področju operacijskih raziskav, vključno z izobraževanjem, raziskavami in storitvami, tako v Sloveniji kot na mednarodni ravni.

Slika 1. Prof. dr. Lidija Zadnik Strin, prejemnica nagrade EURO Distinguished Service Award, in prof. dr. Michel Bierlaire, predsednik komisije za podelitev nagrade EDSA (Foto: dovoljenje EURO, 2024).
Figure 1. Prof. Dr Lidija Zadnik Strin, the recipient of the EURO Distinguished Service Award, and Prof. Dr Michel Bierlaire, chair of the EDSA jury (photo: courtesy EURO, 2024).

Nagrado je prejela na konferenci EURO 2024 v København, na kateri je bilo 3029 registriranih udeležencev iz 70 držav, ki so prisluhnili 2458 kakovostnim predstavitvam.

Konferenco je 30. junija 2024 odprl Rasmus Larsen, rektor Tehnične univerze Danske. Podelitev nagrade EURO Distinguished Service Award je v obliki kviza z naslednjimi vprašanji izvedel prof. dr. Michel Bierlaire iz Belgije.

Kdo je oseba

- ki je sodelovala z Univerzo v Washingtonu in Univerzo v Münchnu ter razvila optimizacijske modele za upravljanje naravnih virov, zlasti v gozdarstvu,
- v modele okoljskega odločanja vključila stohastiko, mehko logiko, dinamiko in večkriterijsko odločanje,
- znana po interdisciplinarnih raziskavah na področju operacijskih raziskav, računalništva in okoljskega upravljanja ter avtorica več kot 600 publikacij in urednica več vrhunskih revij,
- vplivna v evropskih raziskovalnih projektih in je vodila pobude, kot sta MEDMONT iz 5. okvirnega programa EU in projekt COOL v ERA-NET WoodWisdom-Net 2,

- soustanovila Sekcijo za operacijske raziskave (SOR) v Sloveniji in je od leta 1997 njena predsednica; s svojimi aktivnostmi pa je bistveno povečala mednarodno prepoznavnost SOR in interdisciplinarnih raziskav na področju operacijskih raziskav v Sloveniji?

Pravilni odgovor na vsa vprašanja je bil Lidija Zadnik Stirn.

Protokol o izboru nagrajencev določa, da predloge za nagrajence podajo le tuje fakultete ali ustanove, ne pa tudi matična ustanova ali kolegi, s katerimi nagrajenka ali nagrajenec sodeluje. Informacije za nominacijo in izbor za nagrado izhajajo iz javno dostopnih virov.

Lidija Zadnik Stirn se je zahvalila za priznanje na področju, na katerem že dolgo z velikim navdušenjem deluje. Zahvalila se je vsem, ki so z njo sodelovali na Biotehniški fakulteti ter v drugih ustanovah in združenjih v Sloveniji in v mednarodnem prostoru. Zahvalila se je Biotehniški fakulteti Univerze v Ljubljani, ki ji kot zaslužni profesorici nudi prijazno in spoštljivo delovno okolje. Povedala je tudi, da priznanje vidi kot obvezo, da bo še naprej delala v korist Biotehniške fakultete in Univerze v Ljubljani.

Na Oddelku za lesarstvo Biotehniške fakultete Univerze smo na kolegico prof. dr. Lidijo Zadnik Stirn zelo ponosni. Čestitamo ji za velike dosežke in ji želimo, da bi ostala zdrava in aktivna, ter da bi še naprej prispevala k mednarodni in slovenski znanosti!

Slika 2. Prof. dr. Lidija Zadnik Strin na konferenci EURO 2024 v Københavnu (Foto: osebni arhiv LZS).
Figure 2. Prof. Dr Lidija Zadnik Strin, at the EURO 2024 conference in Copenhagen (photo: personal archive LZS).

Our colleague Prof. Dr Lidija Zadnik Strin has received the EURO Distinguished Service Award (EDSA) 2024 for her lifetime achievements and extensive contributions to operations research, including education, research and service activities, both in Slovenia and internationally.

She received the award at the EURO 2024 conference in Copenhagen. This was the conference which welcomed 3,029 registered participants from 70 countries who listened to a total of 2,458 high quality presentations.

On 30 June 2024, Rasmus Larsen, Rector of the Technical University of Denmark, opened the conference and warmly welcomed the participants. The presentation of the EURO Distinguished Service Award was introduced by Prof. Dr Michel Bierlaire from Belgium in the form of a quiz, with the following questions:

Who co-operated with the University of Washington and the University of Munich and developed optimization models for natural resource management, especially in forestry?

Who has integrated stochastics, fuzzy logic, dynamics and multi-criteria decision making into environmental decision models?

Who is known for her interdisciplinary research in operations research, computer science and environmental management and has authored more than 600 publications and is an editor for several top journals?

Who has been an influential figure in European research projects, leading initiatives such as MEDMONT from the 5th EU Framework Programme and the COOL project in the ERA-NET WoodWisdom-Net 2?

Who co-founded the Section for Operations Research (SOR) in Slovenia and has been its president since 1997, significantly increasing its international visibility?

The correct answer to all the questions was Lidija Zadnik Stirn.

The protocol for the selection of the winner stipulates that nominations for the award are made only by foreign faculties or institutions, not by the home institution or colleagues with whom the award winner collaborates. The information for the nomination and selection of the winning candidate comes from publicly available sources.

Lidija Zadnik Stirn expressed her gratitude for being honoured in a field in which she has been working with great enthusiasm for many years. She thanked all those who have worked with her at the Biotechnical Faculty and in other institutions and associations in Slovenia and internationally. She thanked the Biotechnical Faculty of the University of Ljubljana, where she finds a friendly working environment and respect as a professor emerita. She sees the recognition that comes with this award as an obligation to continue working for the benefit of the Biotechnical Faculty and the University of Ljubljana.

At the Department of Wood Science and Technology BF UL, we are proud of our colleague. We congratulate her on her great achievements and hope that she will stay healthy and active, and continue to contribute to international and Slovenian science!

VIR
REFERENCE

EURO the *'Association of European Operational Research Societies'.* URL: https://www.euro-online.org/web/pages/255/distinguished-service-award-edsa (17. November 2024)

Ekološka inovacija Mycosurf med najboljšimi na Rektorjevi nagradi UL

Mycosurf – among the best innovations at the UL Rector's Awards

Davor Kržišnik*

22. oktobra 2024 je v okviru festivala UNI.MINDS potekal izbor za Rektorjeve nagrade za najboljše inovacije Univerze v Ljubljani. Rektorjeva nagrada za najboljšo inovacijo Univerze v Ljubljani, ki jo podeljujejo že 13 let, je eden najpomembnejših dogodkov z namenom spodbujanja razvoja in komercializacije inovacij med študenti in zaposlenimi na Univerzi v Ljubljani. Nagrada se podeljuje v sodelovanju z Ljubljanskim univerzitetnim inkubatorjem (LUI).

V kategoriji študentov in alumnov Univerze v Ljubljani sta 3. mesto osvojila Nej Bizjak z Biotehniške fakultete in Hana Klincov z Akademije za likovno umetnost in oblikovanje. Njuna inovacija Mycosurf naslavlja resen ekološki problem kopičenja odpadne plastike v morjih in oceanih. Mycosurf je deska za surfanje, ki namesto sintetičnega polnila uporablja glivni biokompozit z ustreznimi lastnostmi, kar predstavlja trajnostno alternativo sintetičnim materialom in kaže na potencial tehnologije glivnih biokompozitov za širšo uporabo v proizvodnji večjih izdelkov.

Nej Bizjak, študent magistrskega študijskega programa Biotehnologija, je ob prejemu nagrade povedal: "Biti tretji na Rektorjevi nagradi je izjemen občutek in velika čast. Posebej me veseli, da je bil projekt – deska za surfanje iz glivnih biokompozitov, torej fizičen produkt–v finalu z dvema študentskima projektoma na področju umetne inteligence. Zares inovirati je v fizičnem svetu, še posebej v svetu biotehnologije, težje in dražje, zato je nagrada potrditev, da smo na pravi poti."

Prvo in drugo mesto v kategoriji študentov in alumnov UL sta osvojili ideji Modern Legal in FoodIQ.

Deska Mycosurf je bila razvita pod mentorstvom doc. dr. Davorja Kržišnika in somentorstvom izr. prof. dr. Aleša Stražeta na Oddelku za lesarstvo kot del diplomske naloge. Avtorji so postopek izdelave opisali tudi v znanstveni reviji Les/Wood v članku z naslovom »Izdelava velikih glivnih biokompozitov z nizko gostoto«, ki je objavljen v tej številki (Bizjak et al., 2024).

On 22 October 2024, the Rector's Award for the Best Innovations at the University of Ljubljana was presented as part of the UNI.MINDS festival. The Rector's Award for the Best Innovations at the University of Ljubljana, which has been awarded

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for 13 years, is one of the most important events promoting the development and commercialization of innovations among the students and staff of the University of Ljubljana. The prize is awarded in cooperation with the Ljubljana University Incubator (LUI).

In the category Students and Alumni of the University of Ljubljana, 3rd place went to Nej Bizjak from the Biotechnical Faculty and Hana Klincov from the Academy of Fine Arts and Design. Their innovation, called Mycosurf, addresses the serious ecological problem of the accumulation of plastic

Slika 1. Prejemniki rektorjevih nagrad za najboljše inovacije Univerze v Ljubljani v letu 2024 (Foto: Nebojša Tejić/STA).

Figure 1. Recipients of the Rector's Awards for the Best Innovations at the University of Ljubljana in 2024 (photo: Nebojša Tejić / STA).

Slika 2. Mycosurf – projekt deska za surfanje, izdelana iz glivnih biokompozitov, je zasedel 3. mesto med Rektorjevimi nagradami za najboljše inovacije Univerze v Ljubljani v kategoriji študentov in alumnov UL (Foto: Nej Bizjak).

Figure 2. Mycosurf – a surfboard made of fungal biocomposite won third place in the Rector's Award for the Best Innovations at the University of Ljubljana, in the students and alumni UL category (Photo: Nej Bizjak).

waste in the seas and oceans. Mycosurf is a surfboard that uses a fungal biocomposite with suitable properties instead of synthetic fillers. It represents a sustainable alternative to synthetic materials and demonstrates the potential of fungal biocomposite technology for wider application in the manufacture of larger products.

Nej Bizjak, a MSc Biotechnology student, commented on the award: "It is a great pleasure and honour to receive 3rd place in the Rector's Award. I am particularly pleased that the project – a surfboard made of fungal biocomposites, i.e. a physical product – reached the final with two other student projects in the field of artificial intelligence. It is more difficult and more expensive to be truly innovative in the physical world, especially in the world of biotechnology, so this award is a confirmation that we are on the right track."

First and second places in the UL Student and Alumni category went to Modern Legal and FoodIQ.

The Mycosurf board was developed under the mentorship of Assoc. Prof. Dr Davor Kržišnik and the co-mentorship of Assoc. Prof. Dr Aleš Straže at the Department of Wood Science and Technology BF UL as part of Nej Bizjak's master's thesis. The authors have also described the production process in an article published in this issue of *Les/Wood* (Bizjak et al., 2024).

VIRI
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Četrto mednarodno srečanje ekologov in terenskih mikologov z naslovom "Ekološki in naravovarstveni pomen gliv"

Fourth International Meeting of Ecologists and Field Mycologists on "The Ecological and Nature Conservation Importance of Fungi"

Davor Kržišnik*

Med 7. in 10. novembrom 2024 je v prostorih kmečkega turizma Babuder v Velikih Ločah in na izbranih lokacijah v okolici vasi Hotična, v občini Hrpelje-Kozina, potekalo četrto mednarodno mikološko srečanje "Ekološki in naravovarstveni pomen gliv". Srečanja se je udeležilo 27 udeleženk in udeležencev iz Slovenije, Brazilije, Finske, Hrvaške in Nemčije.

Namen srečanja je bilo mreženje in dolgoročno sodelovanje slovenskih in tujih mikologov ter pridobivanje podatkov o razširjenosti gliv v občini Hrpelje-Kozina, terensko delo in določevanje vrst ter popularizacija ekološkega in naravovarstvenega pomena gliv. Posebna zanimivost letošnje lokacije je dejstvo, da na območju vasi Hotična in Brkinov do zdaj še ni bil izveden sistematičen popis gliv.

Srečanje je vključevalo vabljeno strokovno predavanje vodje krajevne enote Kozina pri ZGS OE Sežana, Daneta Miloševića Štukla z naslovom »Posebnosti izvajanja gozdnogospodarskih ukrepov na primeru toploljubnih listavcev« ter debatni večer z razpravo na temo »Gomoljike v Braziliji in predstavitev namena raziskave tripartitnega odnosa: pekan oreh-ektomikoriza (gomoljike)-nematodi«, ki ga je vodil Juliano Borela Magalhãesm, doktorski študent na Zvezni Univerzi Santa Maria v Braziliji.

V štirih terenskih dneh so udeleženci zbrali 336 bioloških podatkov, od tega 10 za prave sluzavke (kraljestvo Protista) in 326 za glive (kraljestvo Fungi). Skupno je bilo evidentirano 10 vrst pravih sluzavk in 218 vrst gliv. Za primerjavo, na lanskem srečanju, ki je potekalo na območju Ljubljane, so udeleženci zbrali 414 bioloških podatkov, pripadali so 233 vrstam gliv in štirim vrstam pravih sluzavk.

Med vrstami so letos prevladovale glive iz rodov vlažnic (*Hygrocybe* s.l.) (9 vrst), mlečnic (*Lacta-*

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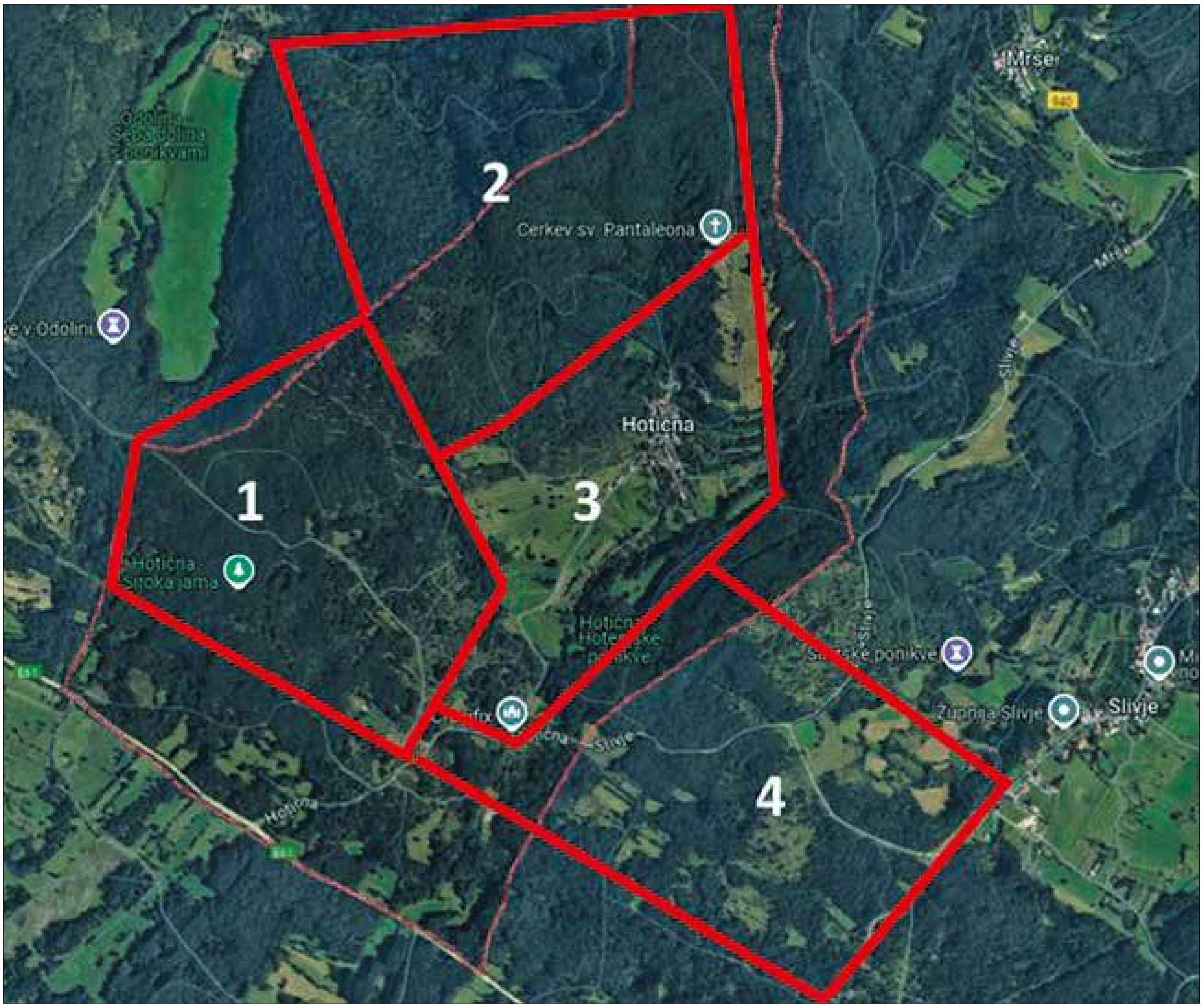

Slika 1. Območja terenskega dela.
Figure 1. Fieldwork areas.

rius s.l.) (7 vrst), golobic (*Russula*) (7 vrst), mušnic (*Amanita*) (6 vrst) in ploskocevk (*Trametes*) (6 vrst). Posebno pozornost smo namenili 11 ogroženim vrstam gliv, med katerimi je pet vrst na slovenskem rdečem seznamu gliv in devet vrst na globalnem rdečem seznamu.

Poudariti je treba odkritje štirih vrst gliv, za katere smo podali prvi zapis za posamezno vrsto na območju Slovenije: *Anthostoma dryophylum*, *Genea fragrans*, *Parmastomyces mollisimus* in *Stereophlebia tuberculata*.

Organizacijski odbor, v sestavi Luka Šparl (Gobarsko-mikološko društvo Ljubljana), dr. Matej Skočaj (Oddelek za biologijo, Biotehniška fakulteta Univerze v Ljubljani) in dr. Davor Kržišnik (Oddelek za lesarstvo, Biotehniška fakulteta Univerze v Ljubljani), se zahvaljuje vsem udeležencem in sodelujočim za njihov prispevek k uspehu srečanja ter bogatenju znanja o ekološkem in naravovarstvenem pomenu gliv.

From 7 to 10 November 2024, the 4th international mycological meeting titled “The Ecological and Nature Conservation Importance of Fungi” was held at the premises of the Babuder Rural Tourism Centre in Velike Loče, and at selected locations around the village of Hotična in the municipality of Hrpelje-Kozina, Slovenia. The meeting was attended by 27 participants from Slovenia, Brazil, Finland, Croatia and Germany.

The aim of the meeting was to encourage networking and long-term cooperation between Slovenian and international mycologists, obtaining

Slika 2. Udeleženci srečanja pri cerkvi sv. Pantaleona.
Figure 2. Participants of the meeting at St Pantaleon's Church.

data on the distribution of fungi in the municipality of Hrpelje-Kozina, field work and species identification, as well as promoting the ecological and conservation importance of fungi. The special interest of this year's location lies in the fact that to date no systematic fungal inventory has been carried out around the village of Hotična and the Brkini Hills.

The meeting included an invited expert lecture by the head of the local unit Kozina of the Slovenian Forest Service regional unit Sežana, Dane Milošević Štukl, entitled "Special features in the management of termophyllus deciduous trees", and an evening discussion on the topic "Truffles in Brazil and stories about ecological research on the relationship between pecans-ectomycorrhiza (Tuberaceae) and nematodes", moderated by Juliano Borela Magalhãesm, PhD student at the Federal University of Santa Maria, Brazil.

During the four field days, 336 biological data were collected, of which 10 were for true slime moulds (kingdom Protista) and 326 for fungi (kingdom Fungi). A total of 10 species of true slime moulds and 218 species of fungi were recorded. For comparison, at last year's meeting, which took place in the Ljubljana area, participants collected 414 biological data belonging to 233 species of fungi and four species of true slime moulds.

This year, fungi from the genus *Hygrocybe* s.l. (9 species), *Lactarius* s.l. (7 species), *Russula* (7 species), *Amanita* (6 species) and *Trametes* (6 species) dominated among the species found. Special attention was paid to 11 endangered species of fungi, five of which are on the Slovenian Red List of Threatened Species of Fungi and nine on the Global Red List.

Of particular note is the discovery of four species of fungi, which represent the first record of each species in Slovenia: *Anthostoma dryophylum*, *Genea fragrans*, *Parmastomyces mollisimus* and *Stereophlebia tuberculata*.

The organizing committee, consisting of Luka Šparl (Mushroom and Mycological Society of Ljubljana), Dr Matej Skočaj (Department of Biology, Biotechnical Faculty, University of Ljubljana) and Dr Davor Kržišnik (Department of Wood Science and Technology, Biotechnical Faculty, University of Ljubljana), would like to thank all the participants for their contribution to the success of the meeting and for enriching the knowledge about the ecological and conservation importance of fungi.

16. srečanje kluba alumnov Oddelka za lesarstvo BF UL v letu 2024

16th Meeting of the Alumni Club of the Department of Wood Science and Technology BF UL in 2024

Katarina Čufar, Boštjan Lesar*, Tomaž Kušar, Jure Žigon

Alumni Oddelka za lesarstvo Biotehniške fakultete Univerze v Ljubljani (OL BF UL) so se 21. 11. 2024 srečali na tradicionalnem letnem srečanju. Udeležilo se ga je okoli 110 diplomantk in diplomantov različnih programov in generacij študija lesarstva (sliki 1 in 2). Glavna sponzorja srečanja sta bili podjetji Leitz GmbH & Co.KG in Leitz, orodja, d.o.o. Srečanje so po tradiciji podprli tudi OL BF UL, Društvo lesarjev Slovenije (DLS) in seveda Klub alumnov UL, Biotehniške fakultete, kamor spada naša Sekcija alumnov lesarstva.

Kot običajno je srečanje potekalo v tednu med 1. in 2. blokom študijskega leta, ko na Oddelku ni predavanj, zato so bili številni zaposleni odsotni zaradi neodložljivih službenih poti, so pa sodelovali pri pripravi dogodka. Ogledi Oddelka so bili letos v duhu pravkar zaključene prenove trakta B. Udeleženci so si ogledali lepo prenovljene kabinete in laboratorije, ki so pripravljeni za vgradnjo opreme.

Program je v polni veliki predavalnici predstavil Boštjan Lesar (vodja Sekcije alumnov lesarstva), ki je skupaj s Katarino Čufar tudi vodja kluba alumnov pri DLS, Aleš Straže pa je predstavil novosti na Oddelku. Naš alumen Boštjan Pogačnik, direktor Leitz, orodja, d.o.o. in kolega Alen Kašnik sta predstavila letošnjega glavnega sponzorja. Predstavila se nam je tudi generacija, ki je univerzitetni študij lesarstva vpisala v študijskem letu 1996 / 1997.

Slika 1. Uradni del srečanja se je tudi tokrat začel v veliki predavalnici.
Figure 1. The official part of the alumni reunion started in the lecture hall.

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Raziskovalne dosežke je predstavil Matic Jančar v imenu ekipe Evapotricity, ki jo sestavljata še Vid Rozman in Maks Brus. Vsi trije so magistrski študentje lesarstva na OL BF. Skupina je na zaključnem tekmovanju mednarodnega natečaja BISC-E v konkurenci 65 študentskih ekip iz 17 držav dosegla izvrstno tretje mesto. Mentor in koordinator raziskav je prof. dr. Primož Oven ob podpori izr. prof. dr. Ide Poljanšek.

Srečanje je pripravila in brezhibno organizirala širša ekipa zaposlenih na OL BF, ki si zasluži vse pohvale in iskreno zahvalo.

On 21 November 2024, the alumni of the Department of Wood Science and Technology of the Biotechnical Faculty of University of Ljubljana (DWST BF UL) met for their traditional annual reunion. Around 110 alumni from various generations took part in the event. The main sponsors of the meeting were the companies Leitz GmbH & Co KG and Leitz, orodja, d.o.o. As usual, the meeting was also supported by DWST BF UL, the Association for Wood Science and Technology of Slovenia (DLS) and the Alumni Club of UL BF.

This year, the renovated offices and laboratories in Building B were shown during the department tours.

The programme was presented to a full auditorium. After the welcoming speech, the most important recent achievements of DWLS were presented. Alumnus Boštjan Pogačnik, general manager of Leitz, orodja, d.o.o., and his colleague Alen Kašnik introduced us to the main sponsor, Leitz.

The research results were presented by Matic Jančar on behalf of the Evapotricity team, which also includes Vid Rozman and Maks Brus, all MSc students of Wood Science and Technology at OL BF. The team achieved a third place in the final round of the international BISC-E competition with 65 student teams from 17 countries. The mentor and coordinator of the research was Prof. Dr Primož Oven, supported by Assoc. Prof. Dr Ida Poljanšek. Finally, the generation that began their studies in the 1996/1997 academic year presented themselves.

The meeting was prepared and organised by a large team of DWST staff, who deserve great praise and sincere thanks for their dedicated work.

Slika 2. Srečanje se je nadaljevalo s pogostitvijo in druženjem.
Figure 2. The meeting continued with a banquet and socializing.

Leitz GmbH & Co. KG in Leitz, orodja, d.o.o. glavna sponzorja srečanja alumnov lesarstva 2024

Leitz GmbH & Co.KG and Leitz, orodja, d.o.o. Principal Sponsors of the Alumni Meeting 2024

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Podjetje je leta 1876 v Nemčiji v mestu Oberkochen ustanovil Albert Leitz. Družinsko podjetje, ki ga vodi že peta generacija, je prisotno na vseh kontinentih in zaposluje preko 3000 sodelavcev. Proizvodnja poteka v 7 obratih v Evropi, Aziji in Ameriki. Matično podjetje ima 38 lastnih prodajno-servisnih podjetij, ki delujejo v 120 brusilnicah po svetu.

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Orodja imajo vgrajene rezilne materiale v DIA, HW, HS kvaliteti, odvisno od vrste obdelovanega materiala. Leitz orodje ima vgrajene čipe, ki so vezni členi med orodjem, strojem in uporabnikom.

Servisna mreža brusilnic nam omogoča, da lahko orodje naših strank naostrimo in pripravimo za delo.

Naši prodajni inženirji so stalno prisotni na trgu, pri čemer strankam optimirajo obdelovalne pogoje na najboljši možni način.

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We manufacture tools and tool systems for processing wood, wood products, plastic materials, composites and light metals. The company was founded by Albert Leitz in 1876 in Oberkochen, Germany.

This family business, now run by the fifth generation, is present on all continents and has over 3,000 employees. Production takes place in seven plants in Europe, Asia and North America. The parent company has 38 of its own sales and service companies that work with 120 grinding mills worldwide.

Leitz doesn't just sell tools, it sells solutions, simplifying and optimizing your production, speeding up processing. We offer cheap processing per unit of production, reducing energy consumption, the amount of noise produced and the consumption of materials.

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The service network of grinders allows us to sharpen and prepare our customers' tools for work. Our sales engineers are always working closely with customers, with whom they work to optimize the processing conditions.

Skupaj smo močni / Together we are powerful

12. Razvojni dan gozdno-lesnega sektorja 2024
Veliki val okoljskih politik EU in vpliv na gozdno – lesni sektor

12th Forest and Wood Sector Develompment Day 2024
The big wave of EU environmental policies and theis impact on the forest and wood sector

Bernard Likar*

14. novembra 2024 je na Gospodarskem razstavišču v Ljubljani, v okviru sejma Ambient in Dom plus, potekal 12. Razvojni dan gozdno-lesnega sektorja, ki ga je organiziral SPIRIT Slovenija v sodelovanju z Ministrstvom za gospodarstvo, turizem in šport. Letošnji Razvojni dan gozdno-lesnega sektorja je bil posvečen zelo aktualni tematiki okoljskih politik EU in vpliva na poslovanje in razvoj lesnih in pohištvenih podjetij.

Dogodka se je udeležilo več kot 160 udeležencev iz različnih področij, med njimi vodstveni in razvojni kader iz podjetij, raziskovalci, arhitekti, projektanti, študentje, predstavniki ministrstev in mediji, povezoval pa ga je Gregor Murn. Udeleženci so imeli priložnost prisluhniti zanimivim predavanjem in razpravam strokovnjakov iz akademskega, gospodarskega in javnega sektorja. Ti so predstavili svoje poglede, izkušnje in primere dobrih praks glede implementacije zelenega prehoda, ki ga EU pospešuje z uredbami iz Zelenega dogovora. Z naslednjim letom se bo to področje zagotovo pojavilo visoko na agendi podjetij in tudi politike, raziskovalcev, arhitektov ter oblikovalcev, saj bodo v polno veljavo prišle številne direktive, ki bodo zelo zahtevne za implementacijo, tako časovno, vsebinsko in finančno ter bodo imele velik vpliv na konkurenčnost.

Dogodek je otvoril državni sekretar na Ministrstvu za gospodarstvo, turizem in šport Dejan Židan, ki je poudaril pomen gozdno-lesnega sektorja za Slovenijo ter izrazil podporo njegovemu zelenemu prehodu. Sledil mu je pozdravni nagovor generalnega direktorja Direktorata za gozdarstvo in lovstvo na Ministrstvu za kmetijstvo, gozdarstvo in prehrano Gregorja Meterca.

Prvi del dogodka je bil posvečen predstavitvam uredb EU iz Zelenega dogovora, ki so za gozdno-lesni sektor izredno pomembne. Simona Vrevc z Ministrstva za kmetijstvo, gozdarstvo in prehrano je predstavila uredbo EU o proizvodih, ki ne povzročajo krčenja gozdov ali krajše EUDR uredbo. Sledila je Gabriella Kemendi, generalna sekretarka European Furniture Industries Confederation, ki je predstavila Uredbo EU o okoljsko primerni zasnovi za trajnostne izdelke (ESPR), zelo pomembni za pohištvena podjetja. Prvi del dogodka je zaključila Darja Virjent iz svetovalne družbe Ernst & Young Slovenija, ki je predstavila uredbo EU o poročanju podjetij o trajnostnosti (CSRD).

Drugi del dogodka je bil namenjen predstavitvi dobrih praks in projektov glede lesene gradnje in zelenega prehoda. Dr. Boštjan Lesar z Oddelka za lesarstvo Biotehniške fakultete Univerze v Ljubljani je predstavil smernice za kakovostno leseno gradnjo, Mojca Pintar iz M Sora d.d. je govorila o izkušnji s trajnostnim poročanjem in ogljičnim odtisom, Matic Navotnik iz TAB d.d. pa o uvajanju digitalnega potnega lista produkta. Zlatka Poličar iz A1 Slovenija se je osredotočila na njihov primer dobre prakse krožnosti, Janja Ribič z Direktorata za lesarstvo pri MGTŠ pa na učinkovitost zelenega javnega naročanja lesenih produktov.

Tretji del dogodka je bil namenjen razpravi na temo velikega vala okoljskih politik EU in vpliv na gozdno-lesni sektor (slika 1). Razpravo je vodil dr. Aleš Ugovšek, M Sora d.d., sodelovali pa so mag. Mitja Piškur iz SiDG d.o.o., Janez Rihter iz Rihter d.o.o., dr. Luka Juvančič, z Biotehniške fakultete UL in Ana Struna Bregar iz CER–Partnerstva za trajnostno gospodarstvo. Razpravljavci so izmenjali mnenja, izkušnje in predloge, kako lahko država podpre zeleni prehod in kaj morajo storiti podjetja in akademska sfera.

Za zaključek so podali priporočila za ukrepe in aktivnosti za podporo gozdno-lesnemu sektorju pri zelenem prehodu:

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Slika 1. Okrogla miza–razprava o velikem valu okoljskih politik EU in njihov vpliv na gozdno-lesni sektor.
Figure 1. Roundtable discussion on the big wave of EU environmental policies and their influence on the forest and wood sector.

Trenutno so podjetja v valu okoljskih in trajnostnih ukrepov, na katere pa niso ustrezno pripravljena. Spremljanje vsega je skoraj nemogoče, trajnostni in krožni poslovni modeli pa so redki in ekonomsko (še) neustrezni.

Okrepiti je treba sodelovanje med podjetji, raziskovalnimi organizacijami in državo pri zelenem prehodu z novimi raziskavami in razvojem, usposabljanjem, izmenjavo dobrih praks (tudi tujimi) ter ozaveščanjem.

Podjetja morajo razmisliti o novih poslovnih modelih, vključujoč vitke, energetsko in okoljsko trajnostne procese, krožno oblikovanje za zanesljivejše izdelke, ki jih je mogoče ponovno uporabiti, nadgraditi in popraviti, ter ravnanje z ostanki in odpadki. Govorimo tudi o uvajanju koncepta dvojne (zelene in digitalne) tranzicije oz. Industrije 5.0.

S strani države je treba implementirati Uredbo EU o zelenih trditvah, ki prepoveduje uporabo zavajajočih okoljskih trditev. Tako bodo kupci lažje prepoznali prave zelene produkte, kar je v interesu podjetij, ki resno vlagajo v zeleno tranzicijo.

Država mora poskrbeti za boljše komuniciranje in hitrejšo implementacijo evropskih »zelenih« direktiv v slovenski prostor ter finančno podpreti razvoj in investicije v podjetjih, ki se nanašajo na zeleni prehod.

On 14 November 2024, the 12th Forest and Wood Sector Development Day was organized by SPIRIT Slovenia in cooperation with the Ministry of Economy, Tourism and Sport. It took place at the Gospodarsko razstavišče exhibition centre in Ljubljana as part of the Ambient and Dom plus trade fairs. This year's Forest and Wood Sector Development Day focussed on the highly topical issue of EU environmental policies and their impact on the business activities and development of companies dealing with wood and furniture.

The event was attended by more than 160 participants from various sectors, including management and development staff from companies, researchers, architects, designers, students, representatives from ministries and the media, and was moderated by Gregor Murn. The participants had the opportunity to listen to interesting presentations and discussions by experts from academia, business and the public sector, who presented their views, experiences and examples of best practise in implementing the green transition that the EU is accelerating through its Green Deal regulations. From next year, this area will certainly be high on the agenda of businesses, politicians, researchers, architects and designers, as a number of directives will come into force that will be very challenging to implement in terms of time, content and cost, and will have a major impact on competitiveness.