UNIVERSITY OF FORESTRY

FACULTY OF FOREST INDUSTRY

PROCEEDINGS

THIRTEENTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE

INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN – INNO'2026

8–10 October 2026 | Park Hotel Vitosha | Sofia, Bulgaria

Conference Co-Organisers

ISSN: 3033-1005

Published

Faculty of Forest Industry, University of Forestry, Sofia, Bulgaria

Printed

Intel entrance Ltd.

The Conference INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN – INNO'2026 is supported by the Bulgarian National Science Fund under Contract No. КП-06-МНФ/22 of 18.08.2026

InnovaWood

INNO'2026 is included in the InnovaWood calendar.

THIRTEENTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE

INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN – INNO'2026

8–10 October 2026 | Park Hotel Vitosha | Sofia, Bulgaria

PROGRAMME COMMITTEE

Honorary Chairman: Assoc. Prof. Hristo Danchev Mihaylov, PhD – Rector of University of Forestry, Sofia, Bulgaria
Chairman: Prof. Dimitar Hristov Angelski, PhD – Dean of the Faculty of Forest Industry, University of Forestry, Sofia, Bulgaria
Vice Chairman: Prof. Viktor Petrov Savov, PhD – Vice Dean of the Faculty of Forest Industry, University of Forestry, Sofia, Bulgaria

Members:

Prof. i.R. Dr h.c. Alfred Teischinger (BOKU University, Austria)
Prof. DrSc. Pavlo Bekhta (Technical University in Zvolen, Slovakia)
Prof. DrSc. Ružica Beljo Lučić (University of Zagreb, Croatia)
Prof. DrSc. Kazimierz Orlowski (Gdańsk University of Technology, Poland)
Prof. DrSc. Nencho Deliiski (University of Forestry, Sofia, Bulgaria)
Prof. DrSc. Diana Ivanova (University of Forestry, Sofia, Bulgaria)
Prof. Josip Margaletič, PhD (University of Zagreb, Croatia)
Prof. Alan Antonovič, PhD (University of Zagreb, Croatia)
Prof. Ján Sedliačik, PhD (Technical University in Zvolen, Slovakia)
Prof. Jerzy Smardzewski, PhD (Poznań University of Life Sciences, Poland)
Prof. Ladislav Dzurenda, PhD (Technical University in Zvolen, Slovakia)
Prof. Robert Németh, PhD (University of Sopron, Hungary)
Prof. Lidia Gurău, PhD (Transilvania University of Brașov, Romania)
Prof. Mihaela Câmpean, PhD (Transilvania University of Brașov, Romania)
Prof. Mihai Ispas, PhD (Transilvania University of Brașov, Romania)
Prof. Maria Kristina Timar, PhD (Transilvania University of Brașov, Romania)
Prof. Vassil Jivkov, PhD (University of Forestry, Sofia, Bulgaria)
Prof. Arch. Orlin Davchev, PhD (UACEG, Sofia, Bulgaria)
Prof. Regina Raicheva, PhD (University of Forestry, Sofia, Bulgaria)
Prof. Zhivko Gochev, PhD (University of Forestry, Sofia, Bulgaria)
Prof. Iliya Zhelezarov, PhD (Technical University of Gabrovo, Bulgaria)
Prof. Petar Antov, PhD (University of Forestry, Sofia, Bulgaria)
Prof. Silvana Prekrat, PhD (University of Zagreb, Croatia)
Prof. Yusuf Erdil, PhD (Muğla Sıtkı Koçman University, Turkey)
Assoc. Prof. Alin Olărescu, PhD (Transilvania University of Brașov, Romania)
Assoc. Prof. Maria Luminița Brenci, PhD (Transilvania University of Brașov, Romania)
Assoc. Prof. Arch. Aleksandrina Nenkova, PhD (UACEG, Sofia, Bulgaria)
Assoc. Prof. Vjekoslav Živković, PhD (University of Zagreb, Croatia)
Assoc. Prof. Danijela Domljan, PhD (University of Zagreb, Croatia)
Assoc. Prof. Pavlin Vitchev, PhD (University of Forestry, Sofia, Bulgaria)
Assoc. Prof. Ivaylo Ivanov, PhD (University of Forestry, Sofia, Bulgaria)
Assoc. Prof. Krasimir Drumev, PhD (Technical University of Gabrovo, Bulgaria)
Assoc. Prof. Plamen Tsankov, PhD (Technical University of Gabrovo, Bulgaria)
Nadir Yildirim, PhD (Hamad Bin Khalifa University, Education City, Doha, Qatar)
Assist. Prof. Miljenko Klarić, PhD (University of Zagreb, Croatia)

ORGANISING COMMITTEE

Honorary Chairman: Assoc. Prof. Hristo Danchev Mihaylov, PhD – Rector of University of Forestry, Sofia, Bulgaria
Chairman: Prof. Dimitar Hristov Angelski, PhD – Dean of the Faculty of Forest Industry, University of Forestry, Sofia, Bulgaria
Vice Chairman: Prof. Viktor Petrov Savov, PhD – Vice Dean of the Faculty of Forest Industry, University of Forestry, Sofia, Bulgaria

Members:

Assoc. Prof. Valentin Atanasov Atanasov, PhD – Dept. of Woodworking Machines, FFI
Assist. Engindzhan Ali Halim – Dept. of Woodworking Machines, FFI
Assist. Viktoriya Plamenova Dudeva – Dept. of Mechanical Wood Technology, FFI
Assist. Georgi Ivaylov Ivanov – Dept. of Mechanical Wood Technology, FFI
Chief Assist. Krasimira Aleksieva Atanasova-Aleksandrova, PhD – Dept. of Furniture Manufacturing, FFI
Assist. Dobriyan Mishev Dobriyanov – Dept. of Furniture Production, FFI
Assist. Anna Dimitrova Kraeva – Dept. of Furniture Production, FFI
Assist. Galina Vasileva Kutova – Dept. of Furniture Production, FFI
Chief Assist. Maria Marinova Konstantinova, PhD – Dept. of Interior and Furniture Design, FFI
Assist. Karmella Luigi Lombardi – Dept. of Interior and Furniture Design, FFI
Assist. Adriana Vasileva Yankova-Hristova – Dept. of Interior and Furniture Design, FFI
Chief Assist. Georgi Kostantinov Kovachev, PhD – Dept. of Woodworking Machines, FFI
Chief Assist. Adelina Gencheva Ivanova, PhD – Dept. of Mathematics, Physics and Informatics, FFI

THIRTEENTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE

INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN – INNO'2026

8–10 October 2026 | Park Hotel Vitosha | Sofia, Bulgaria

ORGANISED BY THE FACULTY OF FOREST INDUSTRY, UNIVERSITY OF FORESTRY, SOFIA, BULGARIA

WITH THE KIND SUPPORT OF

ACADEMIC PUBLISHING WORKSHOP AND MEDIA PARTNER

INNO'2026 is supported by the Bulgarian National Science Fund under Contract No. КП-06-МНФ/22 of 18.08.2026

https://inno.ltu.bg | inno_conference@ltu.bg

CONTENTS

INTEGRATED DESIGN AND DEVELOPMENT OF GIANT REED COMPOSITE PARTICLEBOARDS FOR ECO-CONSCIOUS PUBLIC TRANSPORTATION SEATING 11

George Mermelas, Dimitra Dimopoulou, Andriana Katsadouri, Konstantinos Ninikas, Georgios Ntalos, Andromachi Mitani, Yannis Kazoglou

WOOD PRODUCTION FROM THE FORESTS OF BULGARIA 19

Svetoslav Petrov

APPLICATION OF SIGNAL DEVICES FOR REGULATING THE SPEED OF AUXILIARY MOVEMENT IN PRIMARY WOOD PROCESSING 29

Damjan Stanojevic, Zoran Trposki, Vladimir Koljozov, Anastasija Temelkova, Monika Koljozova

ENERGY RECOVERY FROM WOOD RESIDUES: THE ROLE OF LASER TECHNOLOGY IN OPTIMIZING CUTTING PROCESSES 36

Konstantinos Ninikas, Andromachi Mitani, Dimitrios Koutsianitis, Pavlos Ntalos, Georgios Ntalos

GOLDEN SECTION EFFECT ON MECHANICAL PROPERTIES OF LIGHTWEIGHT STREET FURNITURE ELEMENTS 44

Tolga Kuskun, Jerzy Smardzewski

HUMAN-AI COLLABORATION IN INTERIOR DESIGN: ENHANCING DECISION-MAKING IN THE DESIGN PROCESS 53

Desislava Grigorova, Pavlina Vodenova

DESIGN INNOVATIONS IN ECCLESIASTICAL FURNITURE: ERGONOMIC AND AESTHETIC PREFERENCES IN GREEK ORTHODOX CHURCH STALLS FOR THE ELDERLY 61

Ioannis Bothos, Michalis Skarvelis, Konstantinos Ninikas

ANALYSING THE PEDAGOGICAL POTENTIAL OF INTELLIGENT DIGITAL TOOLS IN CONCEPTUAL INTERIOR DESIGN 73

Adriana Vasileva Yankova-Hristova

CONCEPT FORMATION IN INTERIOR AND FURNITURE DESIGN EDUCATION: PEDAGOGICAL APPROACHES TO DEVELOPING CONCEPTUAL THINKING 81

Desislava Angelova, Adriana Vasileva Yankova-Hristova

INFLUENCE OF RELATIVE HUMIDITY ON THE TYPE OF FITTING IN MORTISE AND TENON JOINTS 91

Nikola Mihajlovski, Elena Jevtoska, Gjorgi Gruevski

INFLUENCE OF THE BEVEL ANGLE OF THE BANDSAW ON CUTTING RESISTANCE 95

Zoran Trposki, Vladimir Koljozov, Anastasija Temelkova, Ana Marija Stamenkoska, Damjan Stanojević, Monika Koljozova

ALIGNING FACULTY AND STUDENT PERSPECTIVES ON DIGITAL LEARNING FORMATS: A CASE STUDY FROM THE UNIVERSITY OF FORESTRY, BULGARIA 101

Desislava Angelova, Tsvetan Stoykov, Vanina Tabakova, Adriana Yankova-Hristova, Denislav Lyubenov, Eli-Naya Konetsovska and Anna-Maria Sofianska

THE IMPACT OF ASH DIEBACK ON THE CHEMICAL AND MECHANICAL PROPERTIES OF WOOD: METHODOLOGICAL EXPERIENCES AND UNCERTAINTIES 111

Anett Sütő, Róbert Németh

INFLUENCE OF SITE CONDITIONS AND STAND COMPOSITION ON THE WOOD PROPERTIES OF ROBINIA PSEUDOACACIA AND QUERCUS CERRIS IN HUNGARY 117

Róbert Németh, James Kudjo Govina, Fath Alrhman Awad Ahmed Younis, Mátyás Báder, Miklós Bak, Anett Sütő, Tamás Hofmann, Szabolcs Komán

EVALUATE FLAMMABILITY OF WOOD BY MULTIPLE SCALE TESTS 124

Prof. Dr Qiang Xu

MECHANICAL AND HYGROSCOPIC PROPERTIES OF CASTANEA SATIVA WOOD ORIGINATED FROM HOLY MOUNTAIN OF GREECE 125

Georgios Ntalos, Andromachi Mitani, Dimitrios Koutsianitis, Konstantinos Ninikas, Paulos Ntalos, Kassiani Theodorakou

AUXETICS, FROM WOOD AND FOR FURNITURE 126

Prof. Jerzy Smardzewski

QUO VADIS WOOD TECHNOLOGY? 127

Prof. Tomasz Krystofiak 127

ECODESIGN AND FURNITURE: CHALLENGES AND OPPORTUNITIES FOR THE EUROPEAN FURNITURE INDUSTRY 128

Vassil Jivkov

POTENTIAL OF WOOD IN THE ENERGY BALANCE OF BULGARIA 129

Tsvetelina Simeonova-Zarkin, Kalin Simeonov

SURFACE LEVEL EFFECTS OF FOREST FIRE ON NORWAY SPRUCE AND SCOTS PINE WOOD: INSIGHTS FROM MICROINDENTATION 130

Sauradipta Ganguly, Luka Albreht, Miha Humar, Jaka Levanič, Veikko Möttönen, Erkki Verkasalo, Marko Petrič

EFFECT OF CORN OIL IMPREGNATION ON THE SURFACE AND HYGROSCOPIC PROPERTIES OF ABIES WOOD AFTER ARTIFICIAL AGING 131

Maria Papakonstantinou, Andromachi Mitani, Dimitrios Koutsianitis. Konstantinos Ninikas, Georgios Ntalos

FUNCTIONALIZED NANOCELLULOSE AS A MODIFIER OF UREA-FORMALDEHYDE RESIN FOR PARTICLEBOARD PRODUCTION 132

Jakub Kawalerczyk

LINKING TREE PHYSIOLOGY, GROWTH, AND BIODIVERSITY: LONG-TERM ECOLOGICAL RESEARCH FROM THE PETROHAN FOREST SITE (BULGARIA) 133

Svetoslav Anev, Sonya Damyanova, Tsvetan Tonchev, Veselina Dimitrova, Plamen Pavlov, Stanislava Ruseva, Tihomir Nedelin, Georgi Kadinov

THE POTENTIAL OF BULGARIAN BEECH FORESTS AS A SUSTAINABLE SOURCE OF TIMBER FOR THE FURNITURE INDUSTRY 134

Metodi Atanasov

MICROBIAL AND ENZYMATIC ACTIVITY DURING THE PRODUCTION AND APPLICATION OF MULTI-COMPONENT ORGANO-MINERAL AMENDMENTS DERIVED FROM PLANT RESIDUES: EFFECTS ON THE GROWTH OF TOMATO SEEDLINGS 135

Boyka Malcheva, Gergana Mladenova, Milena Yordanova, Bilyana Grigorova-Pesheva, Alexandrina Kostadinova-Slaveva

SOIL RESOURCE MANAGEMENT THROUGH GIS, OPEN SPATIAL DATA AND ARTIFICIAL INTELLIGENCE 136

Galin Milchev, Elena Tsvetkova, Radoslav Miltchev

QUANTIFYING YIELD EFFICIENCY IN SAWMILLING USING REAL AND SIMULATED DATA 137
Ana Marija Stamenkoska, Goran Zlateski, Anastasija Temelkova, Branko Rabadziski
INFLUENCE OF TEMPERATURE ON THE BEARINGS LOAD ON A CIRCULAR SAW MILL 138
Georgi Kovatchev, Valentin Atanasov
EXPERIMENTAL DETERMINATION OF CUTTING FORCE FOR THE DESIGN OF HEAVY-DUTY CIRCULAR SAW SHAFTS 139
Valentin Atanasov, Georgi Kovatchev
EXPERIMENTAL STUDY ON THE INFLUENCE OF WORKPIECE MATERIAL AND CUTTING PARAMETERS ON NOISE EMISSION DURING CNC WOOD MACHINING 140
Pavlin Vitchev, Rosen Lozanov
MECHANISMS OF SURFACE IRREGULARITY FORMATION IN CNC MILLING OF SOLID WOOD 141
Lukáš Adamčík, Richard Kminiak, Adrián Banski
STUDY OF SURFACE QUALITY DURING CO2 LASER CUTTING OF BEECH PLYWOOD 142
Engindzhan Halim, Lukáš Adamčík, Zhivko Gochev
INTERACTION OF A PULSED CUBR VAPOR LASER WITH DIFFERENT WOOD SPECIES 143
Nikolai Minkovski, Nikolai Bardarov
INFLUENCE OF TEMPERATURE ON THE MECHANICAL PROPERTIES OF SPRUCE WOOD 144
Nikolai Bardarov, Olena Pinchevskaya, Daniel Madzharov
BEARING LOADING DURING LONGITUDINAL MILLING OF SPECIMENS FROM KOTO 145
Georgi Kovatchev
ENERGY RECOVERY AND RETURN TO THE GROUND OF WOOD BIOMASS 146
Anelie Petrissans, Jerome Remy, Ria Aniza, Che-An Lin, Bernhard Zeller, Corentin Didier, Mathieu Petrissans
BIOMASS DISTRICT HEATING NETWORKS AND ENERGY OPTIMIZATION OF PUBLIC BUILDINGS: FEEDBACK FROM A LOCAL AUTHORITY 147
Hugo Mark, Sami Kriouche, Mathieu Pétrissans, Anélie Pétrissans
GEOGRAPHIC INFORMATION SYSTEM FOR BIOENERGY PRODUCTION IN BULGARIA 148
Adelina Ivanova, Boriana Delijska
GREEN EFFICIENCY OF WOOD WASTE VALORISATION ALTERNATIVES: EVIDENCE FROM THE MALMQUIST–LUENBERGER PRODUCTIVITY INDEX 149
Nikolay Neykov, Mariana Sedliačiková, Petar Antov, Maria Osvaldová, Vesela Dimchova, Viktoria Dudeva
CIRCULAR ECONOMY IN MATERIAL ECODESIGN: BRICK PRODUCTION FROM MINE WASTE 150
Aleksandrina Kostadinova-Slaveva, Ekaterina Todorova, Nikolay Neykov
CLIMATE ROADMAPS AS A MEANS OF INTRODUCING A CIRCULAR ECONOMY IN BULGARIAN MUNICIPALITIES: EXPERIENCE FROM THE MUNICIPALITY OF SANDANSKI ... 151
Emil Kitchoukov, Nikolay Neykov, Georgi Kadinov, Alexandrina Kostadinova-Slaveva
REVISITING CLIMATE NORMALS: EVIDENCE OF A REGIME SHIFT AND ITS LINK TO FOREST FIRE ACTIVITY IN SOUTHWESTERN BULGARIA 152
Antonia Goleva

ECONOMICS, ORGANIZATION AND MANAGEMENT OF THE FOREST INDUSTRY UNDER INCREASING RISK OF FOREST FIRES 153

Todor Stoyanov, Nikolay Neykov

SPATIAL DISTRIBUTION OF PHYSICAL CHARACTERISTICS IN DOUGLAS FIR (PSEUDOTSUGA MENZIESII MIRB.) STEMS CONTAINING COMPRESSION WOOD 154

Martina Todorova, Tatiana Vilkovská

INVESTIGATION OF PRESSURE LOSSES IN ELBOWS USED IN PNEUMATIC CONVEYING SYSTEMS FOR WOOD PARTICLES 155

Petar Nikolov, Pavlin Vitchev

UPHOLSTERED FURNITURE FRAME CONSTRUCTION IN THE CONTEXT OF DESIGN FOR DISASSEMBLY (DFD): STRENGTH AND DEFORMATION BEHAVIOR OF CORNER JOINTS USING LAMELLO INVIS MX2 CONNECTORS 156

Desislava Hristodorova

IMPORT TRENDS IN THE EU MARKET FOR WOODEN TRANSPORT PACKAGING PRIOR TO THE IMPLEMENTATION OF REGULATION (EU) 2025/40 157

Slavica Petrović

IMPACT OF OPERATING TEMPERATURE ON THE HEAT BALANCE AND EFFICIENCY OF PITS WHEN STEAMING UNFROZEN LOGS 158

Nencho Deliiski, Dimitar Angelski, Pavlin Vitchev, Krasimira Atanasova

A METHOD FOR EVALUATING THE HOMOGENIZATION OF WET SAWN TIMBER COLORATION DURING AUTOCLAVE STEAMING 159

Nencho Deliiski, Ladislav Dzurenda, Dimitar Angelski, Pavlin Vitchev, Krasimira Atanasova

ENGINEERED WOOD PRODUCTS FOR MODERN AND SUSTAINABLE CONSTRUCTION IN THE UK AND WESTERN EUROPE 160

Mila Duncheva, Marius-Catalin Barbu, Eugenia Mariana Tudor

DEMONSTRATING VERSATILE FIBRE-BASED VALUE CHAINS FROM BIOMASS GROWN ON MARGINAL LANDS 161

Stergios Adamopoulos, Percy Alao

EXPERIMENTAL VALIDATION OF COMPUTATIONAL METHODS USED IN TIMBER STRUCTURAL DESIGN THROUGH DESTRUCTIVE TESTING OF FULL-SCALE TIMBER FRAMES 162

Miltiadis Pappas, Georgios Ntalos, Andromachi Mitani, Dimitrios Koutsianitis, Konstantinos Ninikas, Paulos Ntalos

EFFECT OF DENSITY ON THE PROPERTIES OF BIOCOMPOSITE BOARDS FROM WOOD FIBRES AND WHEAT BRAN 163

Viktor Savov, Maria Angelova, Georgi Ivanov

LOW-TEMPERATURE PLASMA TREATMENT AS A SUSTAINABLE APPROACH FOR ELIMINATION OF HEAVY METALS CONTAMINATION EFFECTS 164

Plamena Marinova, Milena Yordanova, Vera Petrova, Alexsandrina Kostadinova, Iliana Apostolova, Evgenia Benova, Yovanna Todorova, Ludmila Čechová, Sanja Živković

INVESTIGATION OF STRENGTH PROPERTIES OF WOOD PLASTIC COMPOSITE FOR EXTERIOR FLOORING TYPE DECKING 165

Vladimir Mihailov

VARIATION OF THE PHYSICAL PROPERTIES IN THE VOLUME OF THE STEM IN DOUGLAS FIR (PSEUDOTSUGA MENZIESII MIRB.) 166
Martina Todorova, Tatiana Vilkovská
AGING OF WATERBORNE WOOD COATINGS EXPOSED TO NATURAL CLIMATE CONDITIONS 167
Krasimira Atanasova, Tomasz Krystofiak, Dimitar Angelski, Barbara Lis, Dobriyan Dobriyanov
PROPERTIES OF HARD WAX OIL COATINGS ON VENEERED SURFACES 168
Dobriyan Dobriyanov, Dimitar Angelski, Tomasz Krystofiak, Barbara Lis, Krasimira Atanasova, Stefan Petrov
PRODUCTION AND PROPERTIES OF BIOCOMPOSITE MATERIALS FROM HEMP SHIVES AND LIGNOSULFONATE 169
Georgi Ivanov, Konstantin Vasilev, Viktor Savov
CASCADE USE OF WOOD WASTE IN MEDIUM-DENSITY FIBERBOARD PRODUCTION: RECYCLING, ADHESIVE SYSTEMS AND CIRCULAR ECONOMY PERSPECTIVES 170
Viktoria Dudeva, Georgi Ivanov
MECHANICAL PROPERTIES OF THREE-LAYER FURNITURE PANELS WITH PARTICLEBOARD CUTTING WASTE CORE 171
Krasimira Atanasova, Dimitar Angelski, Vanesa Angelova
DEVELOPMENT OF A CRITERIA SYSTEM FOR ASSESSING MODULARITY IN CABINET FURNITURE 172
Vassil Jivkov, Polina Yunchova-Kolova, Boryana Petrova
COMPARATIVE ANALYSIS OF TRADITIONAL 3D METHODS AND NERF IN FURNITURE VISUALIZATION 173
Radoslav Miltchev, Galin Milchev, Mihail Zagorski
SUSTAINABLE TIMBER CONSTRUCTION AND PREFABRICATION FOR A LOW-CARBON BUILDING 174
Gauthier Colloch, Flavien Bouquet, Mathieu Pétrissans, Anélie Pétrissans
THE FORMAL LOGIC OF THE TRADITIONAL MACEDONIAN HOUSE: STRUCTURE, GEOMETRY, AND EXPRESSION 175
Branko Temelkovski, Vladimir Karanakov, Elena Jevtoska
IMAGE RECOGNITION IN INTERIOR DESIGN PRACTICE 176
Stela Borisova Tasheva 176
THE ROLE OF NEW TECHNOLOGIES IN SUPPORTING INDEPENDENT LIVING AMONG OLDER ADULTS: CHALLENGES AND OPPORTUNITIES IN BULGARIA 177
Maria Kitchoukova
PERFORMANCE REQUIREMENTS FOR SURFACES OF SPECIALIZED VETERINARY EQUIPMENT: RESISTANCE TO MECHANICAL DAMAGE AND CHEMICAL CLEANING 178
Yoanna Fikincheva, Vassil Jivkov
DESIGN AND ARCHITECTURE FESTIVALS AS LABORATORIES FOR TEMPORARY ARCHITECTURE: MATERIAL INNOVATION AND SPATIAL EXPERIMENTATION 179
Ralitsa Dikanska
INFLUENCE OF MOISTURE CONTENT ON THE BENDING STRENGTH AND MODULUS OF ELASTICITY OF BEECH AND SPRUCE WOOD 180
Galina Kutova

EFFECT OF HOMOGENIZATION PRESSURE ON THE VISCOSITY OF MICROFIBRILLAR CELLULOSE 181

Stoyko Petrin, Ivaylo Gavrilov, Petya Mileva-Petrova, Ivo Valchev

PROFILE AS A FACTOR THAT INFLUENCES ON AIR PERMEABILITY RESISTANCE 182

Elena Jevtoska, Gjorgi Gruevski, Nikola Mihajlovski, Branko Temelkovski

INTEGRATION OF LEAN AND CIRCULAR ECONOMY IN THE FURNITURE INDUSTRY 183

Ivana Antovska, Mira Stankevikj Shumanska

INFLUENCE OF THE OUTER INTERMEDIATE LAYER OF TURKEY OAK (QUERCUS CERRIS L.) ON THE PHYSICO-MECHANICAL PROPERTIES OF FIVE-LAYER PARTICLEBOARDS 184

Rosen Grigorov

FROM THEORY TO DIGITAL PRACTICE: DESIGN, IMPLEMENTATION AND EVALUATION OF ELECTRONIC LEARNING GUIDES IN DESIGN EDUCATION 185

Desislava Angelova, Tsvetan Stoykov, Vanina Tabakova, Adriana Yankova-Hristova, Denislav Lyubenov, Eli-Naya Konetsovska and Anna-Maria Sofianska

BRIDGING THE GAP BETWEEN TRADITIONAL TEACHING MODELS AND CONTEMPORARY LEARNING HABITS IN DESIGN STUDENTS: A CONCEPTUAL AND EMPIRICAL PERSPECTIVE 186

Desislava Angelova, Tsvetan Stoykov, Vanina Tabakova, Adriana Yankova-Hristova, Denislav Lyubenov, Eli-Naya Konetsovska and Anna-Maria Sofianska

TRANSFORMATION OF THE ACADEMIC ENVIRONMENT THROUGH ARTIFICIAL INTELLIGENCE: AN EMPIRICAL STUDY AMONG STUDENTS AND FACULTY 187

Melina Neykova, Galin Milchev, Viktor Savov

THE IMPORTANCE OF A MULTIDISCIPLINARY APPROACH IN THE DESIGN OF RETAIL SPACES 188

Carmella Lombardi

INNOVATION ACTIVITY OF THE FOREST INDUSTRY IN BULGARIA FOR THE PERIOD 2018–2022 189

Vesela Dimchova, Nikolay Neykov, Radostina Popova-Terziyska

INDUSTRY 4.0 IN THE WOODWORKING AND FURNITURE INDUSTRY: TECHNOLOGICAL SOLUTIONS, APPLICATIONS AND FUTURE TRENDS 190

Aleksandar Doichinov

Session 2 | Contribution 6

INTEGRATED DESIGN AND DEVELOPMENT OF GIANT REED COMPOSITE PARTICLEBOARDS FOR ECO-CONSCIOUS PUBLIC TRANSPORTATION SEATING

George Mermelas, Dimitra Dimopoulou, Andriana Katsadouri, Konstantinos Ninikas, Georgios Ntalos, Andromachi Mitani, Yannis Kazoglou

Department of Forestry, Wood Sciences & Design, University of Thessaly, Greece

e-mails: mermelasgeorge@yahoo.gr, kninikas@uth.gr, gntalos@uth.gr, amitani@uth.gr, ykazoglou@uth.gr, dimopoulou.dimi@gmail.com, andri.katsadouri@gmail.com

ABSTRACT

The pursuit of sustainable materials for use in transportation has increased interest in renewable alternatives to traditional wood-based and petroleum-derived products. This study explores the use of giant reed (*Arundo donax*) as a primary component in composite particleboards for public transportation seating structures. Natural fibres composites are valued for their renewability, low density, biodegradability, and reduced carbon footprint, and giant reed stands out due to its rapid growth, high yield, and mechanical strength, especially widespread in Mediterranean regions. By utilising locally sourced giant reed, the study aligns with circular economy principles, aiming to reduce reliance on conventional wood materials. To assess the feasibility of giant reed-based particleboards, an experimental schedule was designed involving the collection, drying, and mechanical processing of giant reed, which was then blended with industrial wood particles. Composite boards were manufactured in three formulations: 100% giant reed, 100% wood, and a 50:50 hybrid. Two adhesive systems—phenol-formaldehyde (PF) and urea-melamine-formaldehyde (UMF)—were employed to determine their influence on board performance. The resulting panels underwent standardised testing to evaluate bending strength, tensile properties, and hygroscopic behaviour. The findings of this research aim to identify optimal material compositions and adhesives for producing durable, lightweight, and environmentally friendly composite boards suitable for the stringent demands of public transportation. This work highlights the potential of giant reed as a sustainable raw material, supporting both environmental objectives and the advancement of innovative materials in the transportation sector.

Keywords: Giant reed biomass, design strategy, particleboards, natural fibres composites, bio-based materials, sustainable transportation, circular economy.

1. INTRODUCTION

The transition to a circular bioeconomy model in the transport sector requires a radical reassessment of the materials used. The ongoing depletion of traditional timber stocks (McNutt et al., 1992; Youngquist et al., 1993), has created a gap in the supply chain, making the search for alternative lignocellulosic raw materials an urgent economic and environmental need (Maloney, 1993; Roffael, 1997). In this context, giant reed (*Arundo donax*), as a fast-growing biomass with a high spread in the Mediterranean basin, offers a viable alternative for the production of composite wood products. Its integration into public transport seats aims not only to reduce the carbon footprint, but also to meet strict ergonomic specifications. The design of seats for public use must cover the anthropometric range from the 5th to the 95th percentile of the population, ensuring accessibility and comfort (Bothos et al., 2021). Therefore, the development of biogenic particleboards must combine mechanical integrity with the requirements of universal design.

The present research focuses on the development of a new composite material based on giant reed as a natural fibrous raw material, aiming at its application in the manufacturing of public transport seating. The growing need for sustainable technological solutions in the transport industry makes the evaluation of alternative low environmental footprint materials imperative. Seats in buses, trams, and trains are subjected to significant mechanical and environmental stresses. Tensile strength, fatigue behaviour, moisture resistance, and fire safety constitute critical design parameters.

2. LITERATURE REVIEW

Natural Fiber Reinforced Composites (NFRCs) have been extensively studied over the last decades (Molari et al., 2021). Fibers such as flax, hemp, jute, and bamboo have been utilised in automotive applications and

structural elements (Fiore et al., 2014). The advantages of natural fibres encompass low density, biodegradability, and reduced CO_2 emissions during production (Molari et al., 2021; Suárez, L. et al., 2024). However, they present moisture sensitivity and property variability due to their natural origin (Míguez, C, 2022).

The selection of giant reed as the primary raw material for developing a new industrial application material is founded on a combination of environmental, mechanical, and economic parameters that make it particularly attractive in the context of sustainable production (Suárez, L. et al., 2024). Giant reed, specifically the species *Arundo donax*, is a fast-growing perennial plant with high biomass and broad geographical distribution, particularly in Mediterranean regions (Suárez, L. et al., 2024). Primarily, giant reed is characterised by a high growth rate and significant annual biomass production, making it a renewable and readily available raw material source (Suárez, L. et al., 2024). Unlike forest species that require a multi-year growth cycle, giant reed can be harvested in a short period without needing replanting, as it naturally regenerates from its massive rhizomes. This property reduces cultivation costs and limits soil interventions, enhancing the sustainability of the production process (Suárez, L. et al., 2024).

Regarding composition, giant reed exhibits high cellulose and hemicellulose content, along with a significant lignin percentage, making it suitable for producing composite materials, bio-polymers, and bio-composite products (Manniello et al., 2022). Its fibrous structure grants satisfactory mechanical properties, such as tensile strength and good specific strength-to-weight ratio, which are crucial characteristics for applications requiring lightweight yet durable materials (Ramos D. et al., 2017). Furthermore, giant reed can be cultivated in degraded or semi-arid soils without high irrigation or fertilizer demands, thus limiting competition with food crops. Concurrently, it has the ability to sequester carbon dioxide, contributing to a reduction in the raw material's carbon footprint (Suárez, L. et al., 2024).

Its utilisation integrates into the circular economy framework, allowing the production of biodegradable or recyclable materials with reduced dependence on fossil resources (Ramos D. et al., 2017). Finally, from an economic perspective, the broad availability and low harvesting cost of giant reed make it a competitive alternative to conventional raw materials, particularly in applications aiming to replace synthetic or petrochemical materials (Molari et al., 2021). The potential for local production also boosts regional development and reduces transportation costs (Suárez, L. et al., 2024). Overall, giant reed combines features that make it a suitable and strategically sound choice for developing innovative industrial materials, balancing mechanical adequacy, environmental sustainability, and economic efficiency (Mannielo, C. et al., 2022).

2.1. GIANT REED AS A MATERIAL AND ITS MORPHOLOGY

Giant reeds grow randomly in various environments, making them widely distributed in temperate and warm regions globally (Molari, L. et al., 2021; Fiore, V. et al., 2014). *A. donax* is a hydrophyte capable of growing in water-rich soils, especially near canals, rivers, lakes, ponds, and marshes, where it exhibits maximum biomass yields (Manniello, C. et al., 2021; Fiore et al., 2014). The phylogenetic origin is not very clear because the number of chromosomes is still uncertain due to their large number and small size, leading various authors to report different chromosome counts (Scalici, T. et al., 2016; Fiore et al., 2014). However, genetic diversity is very low, as expected for a plant reproducing agamically (Suárez, L. et al., 2024; Fiore et al., 2014).

Giant reeds hold particular economic interest because they can be used in numerous applications such as manufacturing musical instruments and furniture, natural shading, windbreaks for arable lands, and biofuel preparation (Fiore et al., 2014). Morphologically, *Arundo donax* L. is distinguished by its large, tall rhizomatous perennial stem that can reach 3 to 8.2 meters in height, its shoot leaves, its open, large, feathery panicle-shaped inflorescences, the semi-equal flowers, long white spikes, and bisexual flowers. The rhizomes have various shapes with a thickness of 3.5 to 5 cm, growing horizontally; they are fleshy when young and woody when mature. They are creeping, thick, scaly, solid in cross-section, often forming a dense network, and are firm and knotted at the stem bases. The root system also features roots reaching depths up to 5 meters. The rhizomes and shoot segments with nodes easily develop roots and new shoots under suitable conditions such as moist soil, mud, sand, or gravel (Manniello, C. et al., 2021; Fiore et al., 2014).

The shoot and leaves are smooth and waxy. The vegetative culms (hollow stems with nodes) are erect, cylindrical, semi-woody (Molari, L. et al., 2021; Fiore, V. et al., 2014), rigid, about 1 to 4 cm thick, and up to 6 meters tall in wild European populations. The culms gradually narrow towards the top, bearing numerous nodes and internodes that are green, turning greenish yellow upon maturity (Molari, L. et al., 2021; Fiore, V. et al., 2014), straw-coloured when dry, herbaceous when young, and becoming woody, smooth, and glossy

when mature. The leaves are simple, cauline, and distichous. They are blade-shaped, flat, and green; their base is light yellow, and the apical part curves towards the ground. The leaves gradually narrow towards the apex, which is long and acuminate, with rough edges, while both surfaces are smooth and glaucous. The midrib is grooved above and raised below, with numerous distinct parallel veins on both surfaces. The auricles are pale yellow and externally hairy; they have membranous ligules 1 to 2.3 mm long with a fine fringed margin. The collars are pale yellow and hairy, while the leaf sheaths are pale green, overlapping, and tightly enclosing the culm. Branch leaves are usually smaller than shoot leaves, measuring 12 to 55 by 1 to 7 cm respectively. The inflorescence consists of an open, large, feathery panicle, terminal, purple-coloured, turning light brown with age, and measuring 70 to 165 cm in length including the pedicel (Suárez, L. et al., 2024; Fiore et al., 2014).

3. EXPERIMENTAL METHODS

For the purposes of this research, an experiment was designed and conducted, requiring the creation of particleboards. The creation of these particleboards aims to evaluate their properties through laboratory measurements, intending to use these specific materials. Initially, the material was collected, cleaned, and naturally dried by placing the stems in the open air for approximately 18 months. This was followed by mechanical shredding and sieving for homogeneous distribution. The giant reeds were shredded and subsequently crushed in a 5 mm hole sieve. The resulting crushed material was collected and stored in a protected area until the particleboards were created.

Subsequently, two different types of standard resins have been suggested: one Phenol-Formaldehyde (PF) and one Urea-Melamine-Formaldehyde (MUF). Before creating the boards, a moisture content check revealed that despite natural drying, the giant reed retained a moisture level of approximately 10% to 12%. The desired moisture level to be deemed suitable for board creation and to limit moisture impact on the final specimens' mechanical properties is less than 5%, so the material was placed in an oven. The experimental design aims to comparatively evaluate the properties of giant reed as a structural material, both on its own and in combination with industrial wood.

Specimens were constructed in the form of boards, with varying raw material compositions. Three different composition percentages were selected, and to prevent failure, a total of six boards were created initially, two for each different composition. Specifically, the first composition consisted of 100% giant reed material as the raw material to evaluate the mechanical and physical properties without the influence of other components. The second composition was made of 100% industrial wood, serving as a reference or control material to enable comparative analysis. The third composition was a hybrid of 50% giant reed and 50% industrial wood, aiming to investigate potential synergistic effects between the two materials. During board construction, production parameters such as dimensions, compression process, and drying conditions were kept constant to make sure that the only variable was the material composition. This ensured experimental validity and reliable comparison of the results. A total of twelve boards were created, six for each glue used.

The dimensions of the boards were 500 x 500 mm with an 18 mm thickness, prepared via thermal compression at controlled temperature and pressure. After preparation, the materials were weighed based on predetermined proportions, and the adhesive was added by spraying at a specific percentage of the dry mass, followed by mixing until a homogeneous blend was achieved. The mixture was placed in a wooden mold of specific dimensions and subjected to a compression process under controlled pressure and temperature for a defined period. This process aimed to achieve the desired density and proper bonding of the individual fibers. The bonding process was conducted using a vacuum press, a necessary choice due to the nature of the thermo-setting adhesives used. These adhesives activate and develop their mechanical properties through the application of heat and simultaneous pressure, conditions effectively ensured in a vacuum environment. The vacuum press allows uniform pressure distribution across the entire specimen surface, reducing the likelihood of air entrapment and discontinuities at the adhesive interface. Concurrently, the combined action of temperature and negative pressure optimizes adhesive penetration into the material fibers, ensuring higher cohesion and improved mechanical properties.

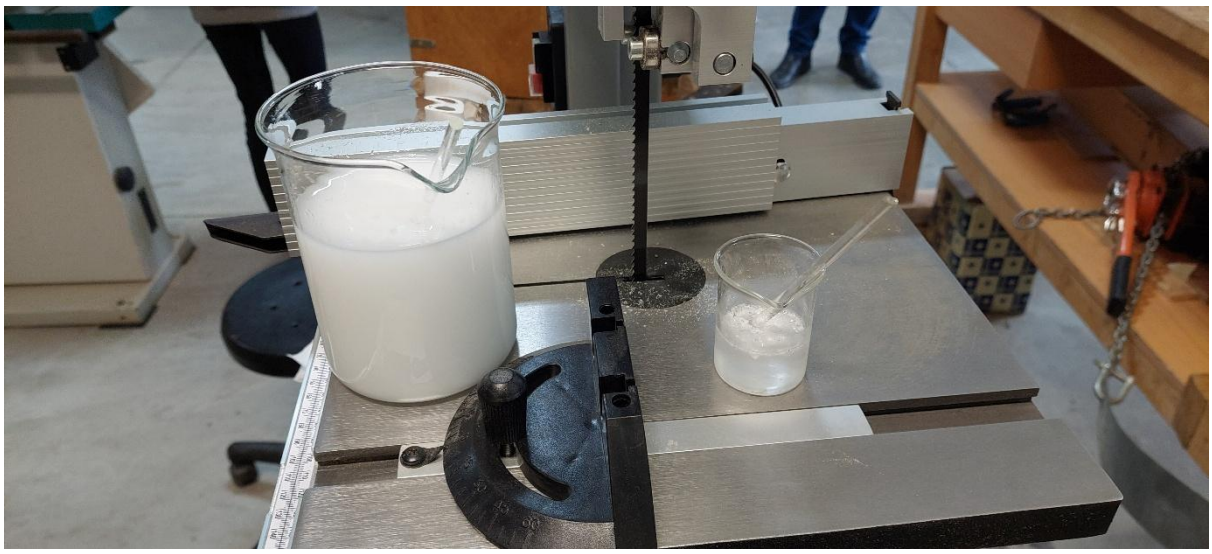


Figure 1: Mixture of the adhesive in the appropriate proportion

After compression, the boards were left to cool and stabilise under controlled environmental conditions. Following stabilisation, the produced boards underwent perimeter cutting to remove edges, which might present nonuniformities in density, compression, or adhesive distribution. The squaring of the boards ensured uniform geometry and reduced the probability of errors during measurements. The squared boards were then cut into smaller specimens according to testing requirements. Notably, only six of the twelve created boards were cut for testing. During quality control, it was found that not all produced boards were suitable for further processing. Some specimens exhibited manufacturing defects such as uneven compression, localised delamination, air entrapment, or thickness variations resulting from the pressing process. Boards presenting obvious deviations were rejected from the cutting and testing phase to ensure the validity of the results.

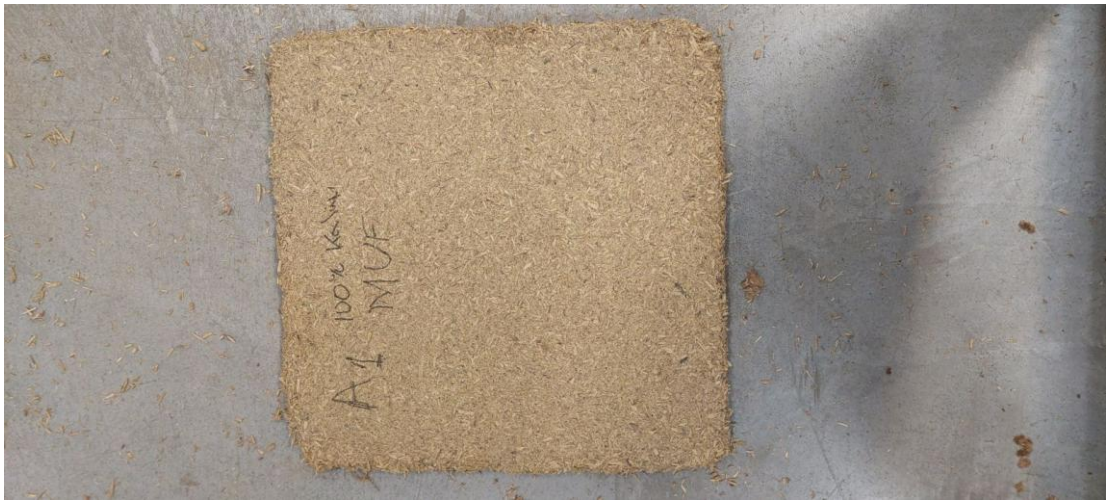


Figure 2: Sample of the particleboard

4. RESULTS

4.1. MODULUS OF THE RUPTURE

Modulus of Rupture (MOR) and Internal Bond (IB) are essential metrics for evaluating the mechanical integrity of composite particleboards intended for demanding applications like public transportation seating. The Modulus of Rupture indicates the maximum stress the material can endure before structural failure occurs during bending. Internal Bond, on the other hand, measures the cohesion of the board's core, describing how effectively the individual particles are bonded together.

The testing initially focused on the bending strength of the specimens. The testing machine was set to a speed of 12mm/min, and thickness was measured at the center of each specimen. The tables below (Tables 1-6) outline the measurements obtained for each board.

Table 1: Modulus of Rupture results for Sample A1 (100% Giant Reed with Urea-Melamine-Formaldehyde (MUF))

a/a	Width (cm)	Thickness (cm)	Length (mm)	Fmax (N)	Modulus of Rupture (N/mm^2)
A1.1	50.00	16.93	370.00	57.13	0.749
A1.2	50.00	16.13	355.00	33.78	0.446
A1.3	50.00	17.31	355.00	14.47	0.178
A1.4	50.00	17.46	355.00	9.43	0.115
A1.5	50.00	18.00	355.00	34.69	0.410

Table 2: Modulus of Rupture results for Sample B1 (50% Giant Reed – 50% Wood with MUF)

a/a	Width (cm)	Thickness (cm)	Length (mm)	Fmax (N)	Modulus of Rupture (N/mm^2)
B1.1	50.00	14.72	365.00	40.02	0.595
B1.2	50.00	14.81	350.00	48.09	0.682
B1.3	50.00	16.11	350.00	72.34	0.943
B1.4	50.00	17.55	350.00	77.96	0.933
B1.5	50.00	15.66	350.00	70.06	0.940

Table 3: Modulus of Rupture results for Sample C1 (100% Wood with MUF)

a/a	Width (cm)	Thickness (cm)	Length (mm)	Fmax (N)	Modulus of Rupture (N/mm^2)
C1.1	50.00	14.90	378.00	80.69	1.228
C1.2	50.00	12.58	365.00	61.24	1.066
C1.3	50.00	13.83	365.00	86.75	1.374
C1.4	50.00	14.44	365.00	99.43	1.508
C1.5	50.00	13.67	365.00	90.02	1.442

Table 4: Modulus of Rupture results for Sample D1 (100% Giant Reed with PF)

a/a	Width (cm)	Thickness (cm)	Length (mm)	Fmax (N)	Modulus of Rupture (N/mm^2)
D1.1	50.00	14.57	363.00	5.12	0.077
D1.2	50.00	16.49	373.00	3.56	0.048
D1.3	50.00	16.08	373.00	27.28	0.380
D1.4	50.00	16.52	373.00	10.28	0.139
D1.5	50.00	14.82	373.00	32.73	0.494

Table 5: Modulus of Rupture results for Sample E2 (50% Giant Reed – 50% Wood with PF)

a/a	Width (cm)	Thickness (cm)	Length (mm)	Fmax (N)	Modulus of Rupture (N/mm^2)
E2.1	50.00	16.03	367.00	24.02	0.330
E2.2	50.00	12.86	373.00	39.49	0.687
E2.3	50.00	13.71	373.00	24.31	0.397
E2.4	50.00	14.78	373.00	16.34	0.247
E2.5	50.00	14.06	373.00	13.27	0.211

Table 6: Modulus of Rupture results for Sample F1 (100% Wood with PF)

a/a	Width (cm)	Thickness (cm)	Length (mm)	Fmax (N)	Modulus of Rupture (N/mm^2)
F1.1	50.00	14.93	368.00	53.68	0.794
F1.2	50.00	14.05	360.00	66.50	1.022
F1.3	50.00	14.83	360.00	57.89	0.843
F1.4	50.00	15.06	360.00	62.55	0.897
F1.5	50.00	15.30	360.00	36.48	0.515

Fig. 3 presents the results of test on Modulus of Rapture for produced particleboard. These tests are critical in evaluating the material's performance. The Modulus of Rapture indicates the maximum stress the material can endure before breaking.

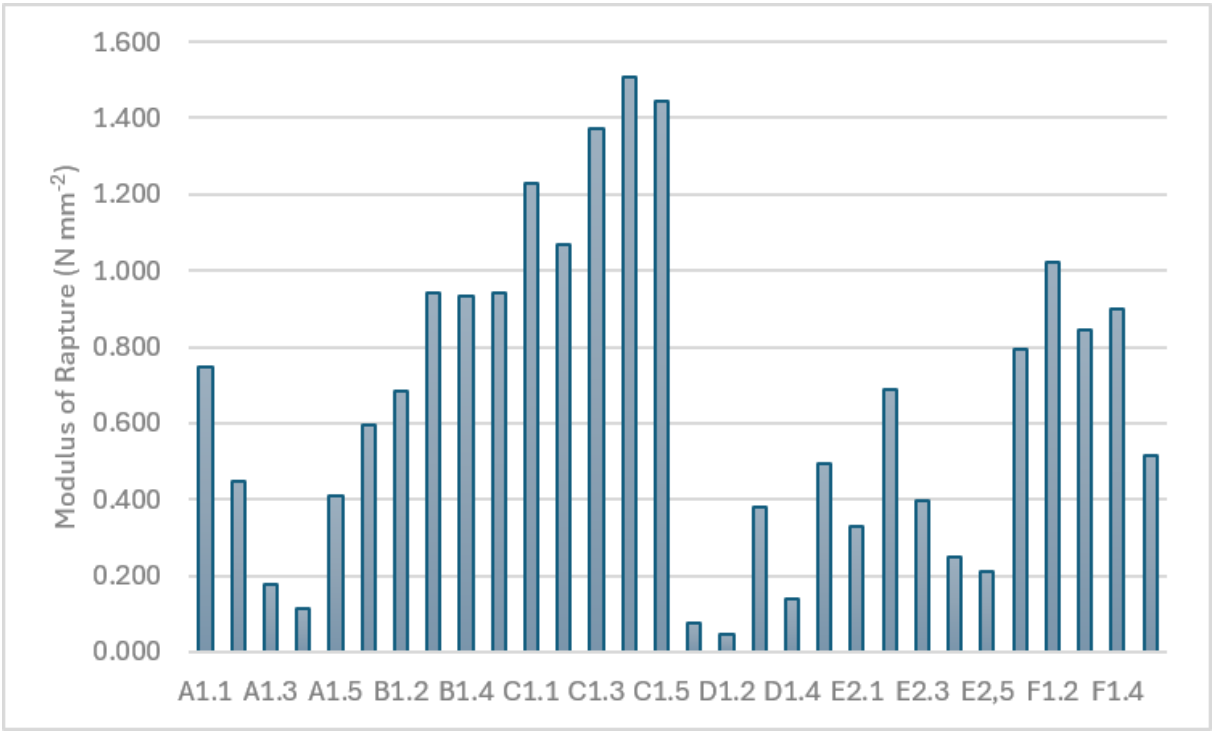


Figure 3: Test results of Modulus of Rapture

4.2. INTERNAL BOND

The internal bond (IB) test describes the degree to which the particles in the core layer of the particleboard are bonded together. This parameter is critical for the material's structural integrity, as high internal cohesion

ensures the improvement of the overall mechanical properties of the composite product. Fig. 4 presents the internal bond results of the particleboards.

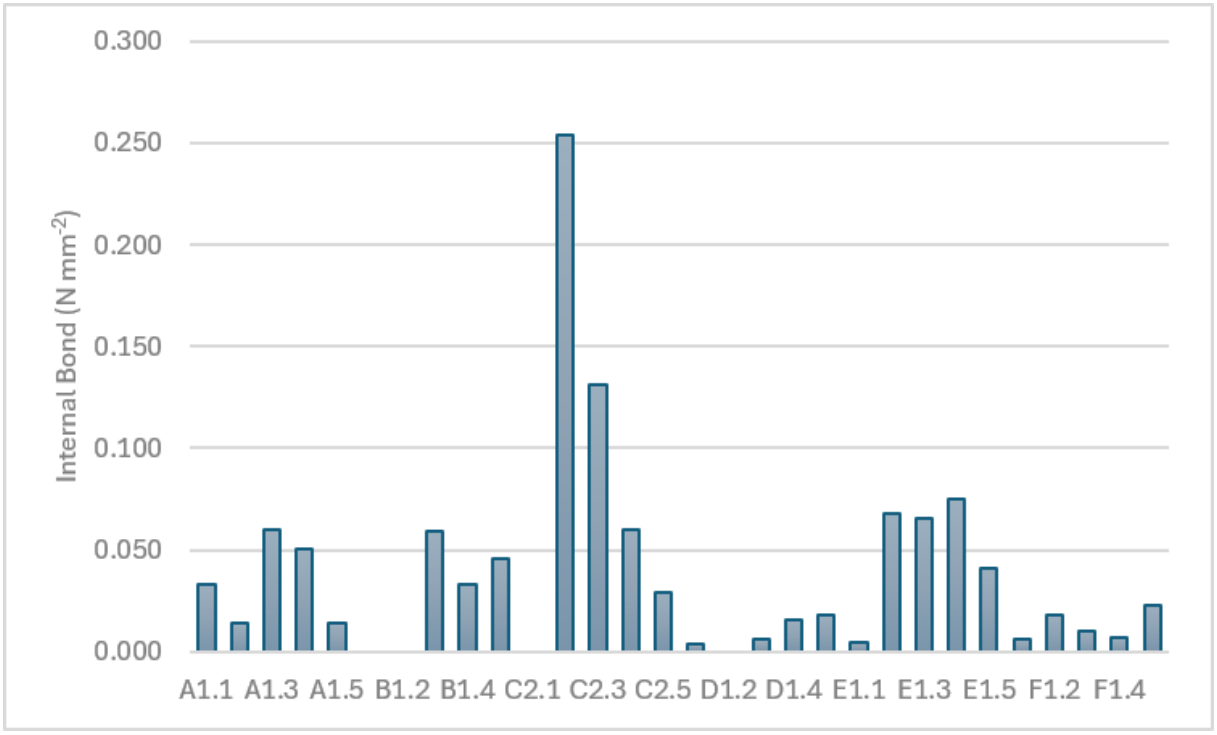


Figure 4: Test results of Internal Bond

5. CONCLUSIONS

The developed composite material presents significant prospects for application in public transport seating. The use of giant reed significantly reduces the carbon footprint compared to conventional materials like fiberglass. Furthermore, the recycling potential and the local availability of the raw material strongly enhance the sustainability of the proposed solution.

Beyond its environmental advantages, the research demonstrates that giant reed-based particleboards, especially in hybrid formulations with industrial wood, can achieve mechanical properties suitable for demanding applications. While pure giant reed panels exhibited lower modulus of rupture compared to wood-based counterparts, while the 50:50 giant reed-wood hybrid offered a promising balance between strength, weight, and ecological benefit. This suggests that with further optimisation of processing techniques and adhesive systems, giant reed composites can be tailored to meet specific performance criteria for public transportation seating.

However, the transition from laboratory findings to industrial-scale adoption presents certain challenges. Issues such as consistency in raw material quality, variability in mechanical properties due to environmental growth conditions, and long-term durability under cyclic loading and exposure must be systematically addressed. Additionally, the integration of fire-retardant additives and the development of adhesives with lower environmental impact are pivotal areas for future research. Collaboration with manufacturers and transport authorities will also be essential to ensure that the new materials comply with safety, ergonomic, and regulatory standards.

In a broader context, the successful application of giant reed composite particleboards could serve as a model for circular economy practices in the transport sector and beyond. By valorising locally abundant, renewable biomass, this approach not only reduces dependence on imported or non-renewable resources but also stimulates rural economies and supports biodiversity. The findings of this study underscore the potential for innovative, bio-based materials to drive the next generation of eco-conscious design and manufacturing, paving the way for more resilient and sustainable urban infrastructure.

Moreover, this work opens up opportunities for interdisciplinary collaboration between material scientists, industrial designers, and environmental managers and policy makers. Such a holistic approach can accelerate the development of comprehensive solutions that address technical, aesthetic, and policy-related challenges in

sustainable transportation. The lessons learned from giant reed composite development can be transferred to other natural fiber resources, broadening the impact and scalability of bio-based innovations.

Finally, the societal and educational value of this research should not be underestimated. Integrating sustainability principles into engineering and design curricula, as well as promoting public awareness about the benefits of renewable materials, can foster a culture of environmental responsibility. By championing such materials in high-visibility public applications like transportation seating, the project has the power to inspire further innovation and support global efforts to mitigate environmental degradation.

REFERENCES

Barboutis I., Vasileiou V. (2013). Stasidia (Church stalls) of the greek-orthodox church – a standing seat for elderly. XXVIth International Conference Research for Furniture Industry: 1–6. https://www.researchgate.net/publication/340594841_Stasidia_CHURCH_STALLS_of_the_greek_orthodox_church_-a_standing_seat_for_elderly

Bothos I., Skarvelis M. (2021). Examining Furniture Preferences of the Elderly in Greece. In: Pires I. M., Spinante S., Zdravevski E., Lameski P. (eds), Smart Objects and Technologies for Social Good: 7th EAI International Conference, Goodtechs 2021, Virtual Event, September 15–17, 2021, Proceedings: 300–310. Springer, Cham. https://doi.org/10.1007/978-3-030-91421-9_23

Fiore, V., Scalici, T., & Valenza, A. (2014). Characterization of a new natural fiber from Arundo donax L. as potential reinforcement of polymer composites. Carbohydrate Polymers, 106(1), 77-83.

Kelly M. W. (1977). Critical review of relationships between processing parameters and physical properties of particleboard. General Technical Report FPL-10.

Maloney T. M. (1993). Modern Particleboard and Dry-Process Fiberboard Manufacturing. Miller Freeman Publications.

Míguez, C., Cancela, Á., Sánchez, Á., & Álvarez, X. (2022). Possibilities for Exploitation of Invasive Species, *Arundo donax* L., as a Source of Phenol Compounds. Waste and Biomass Valorization, 13, 3105–3118.

Molari, L., Coppolino, F. S., & Garcia, J. J. (2021). *Arundo donax*: A widespread plant with great potential as sustainable structural material. Construction and Building Materials, 268, 121143.

Manniello, C., Cillis, G., Statuto, D., Di Pasquale, A., & Picuno, P. (2022). Concrete Blocks Reinforced with *Arundo donax* Natural Fibers with Different Aspect Ratios for Application in Bioarchitecture. Applied Sciences, 12(4), 2167.

McNutt B. et al. (1992). The use of wood-based panels in the United States and Canada. Forest Products Journal.

Nemli G., et al. (2003). Suitability of kiwi (*Actinidia sinensis* Planch.) prunings for particleboard manufacturing. Industrial Crops and Products.

Ninikas K. (2018). Assessment of the thermal permeability of wooden walls and new insulating materials made from forest and plant residues. Diploma Thesis, Technological Educational Institute of Thessaly, Greece.

Scalici, T., Fiore, V., & Valenza, A. (2016). Effect of plasma treatment on the properties of *Arundo donax* L. leaf fibres and its bio-based epoxy composites: A preliminary study. Composites Part B: Engineering, 94, 167-175.

Suárez, L., Barczewski, M., Kosmela, P., Millar, B., Cunningham, E., & Ortega, Z. (2024). Influence of Giant Reed (*Arundo donax* L.) Culms Processing Procedure on Physicochemical, Rheological, and Thermomechanical Properties of Polyethylene Composites. Journal of Natural Fibers, 21(1), 2296909.

Rammou A. (2017). Utilisation of fast-growing plants native to the Greek region for the production of particleboards. Master's Degree thesis, Department of Wood and Furniture Design and Technology, Technological Educational Institute of Thessaly.

Ramos, D., Salvadó, J., & Ferrando, F. (2017). High Mechanical Performance Boards Made from Fibers of *Arundo donax* without Added Adhesives. BioResources.

Roffael E. 1997. Formaldehyde release from particleboards. Wood Science and Technology.

Youngquist J. A. et al. (1993). Wood-based composites: The past and the future. Forest Products Journal.

Zabowski B., Wronka A., Kowaluk G. (2024). Selected Physical and Mechanical Properties of Particleboards Manufactured from Plantation Willow and Poplar Wood Materials.

Session 3 | Contribution 2

WOOD PRODUCTION FROM THE FORESTS OF BULGARIA

Svetoslav Petrov

Forest Research Institute, BAS
e-mail: sg.svetoslav@gmail.com

ABSTRACT

Wood production is the main economic function of forests. Even at the current stage of technological development, in many cases wood cannot be replaced by another material. It is a renewable but exhaustible resource which requires it to be used as rationally as possible. An analysis of production of round wood from the forests of Bulgaria has been made. The influence of production factors has been examined. Based on a comparison with data for European countries, the quality and efficiency of the wood production process in Bulgaria have been assessed. Conclusions and recommendations have been made.

Keywords: wood production, quality, efficiency.

1. INTRODUCTION

The roundwood production process encompasses the activities and operations from the emergence/creation of the forest to the harvesting of wood from some of the trees and its storage in a temporary warehouse. The production of a high-quality product is the goal of every economic activity in a market economy. This means that high quality must be achieved at each of the stages of wood production. This paper analyzes how each of the stages is carried out in Bulgaria, the influence of production factors, what the problems are and how they can be solved. A comparison with other European countries was used to assess the situation.

Roundwood is a raw material for the wood processing industry. It needs quality wood to produce competitive products. Quality is a category that describes the characteristics of an object. Quality is a set of properties and characteristics of an object that determine its ability to satisfy certain needs. In this sense, the perception of quality is subjective. From the point of view of industrial production, roundwood is of better quality when it is healthy and free of defects. Its quality increases with increasing diameter and length. Due to the diverse properties of wood, different products can be produced from a single stem. Economic logic dictates that those that have the highest price should be produced. Value is an indicator of quality.

On the other hand, wood is a limited resource, so it is especially important to use it rationally, especially considering that production (especially of the highest quality) takes decades.

As an indicator of the quality of roundwood production, the percentage share of the highest quality assortments – logs and the lowest quality – firewood, relative to the total quantity of harvested wood can be used.

2. MATERIALS AND METHODS

Empirical and theoretical methods were used. An analysis of statistical data, publications and documents on timber harvesting and harvested assortments in some countries in Europe was made. Comparisons were made between Bulgaria and these countries. The influence of production factors on the quality of the produced wood was analyzed.

Based on data from EUROSTAT and publications of the United Nations Economic Commission for Europe on the quantities of wood harvested differentiated into logs, firewood, total harvest and others (EUROSTAT,2023;UNECE, 2023-2024), the percentage share of firewood and the percentage share of logs in relation to the total quantity of wood harvested for 2023 have been calculated for Bulgaria, Bosnia-Herzegovina, Croatia, Czechia, Greece, Hungary, Montenegro, North, Macedonia, Romania, Serbia, Slovakia, Slovenia, Türkiye and Europe in general. The reasons for choosing these countries are twofold.

The first is that in the State of Europe's Forests document, which is prepared every 5 years under the auspices of the FOREST EUROPE political platform, Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Greece, Montenegro, North Macedonia, Serbia, Slovenia and Turkey are considered in one group – countries from South-East Europe. Albania and Cyprus are not included in the study. Albania has not provided data for 2023, and logging in Cyprus is extremely small. The second reason is that large areas of Romania fall on the territory of the Balkan Peninsula. In addition, Romania is neighboring Bulgaria and is very suitable for

comparisons. At the same time, it is included in the group of Central-East Europe countries. This group also includes Czechia, Hungary and Slovakia, whose recent historical past is very similar to that of Bulgaria. For these reasons, these 4 /four/ countries were also analyzed (UNECE, 2020).

The data are examined separately for coniferous and deciduous trees, since the morphological features of coniferous wood allow for the extraction of a larger percentage of construction wood and, in particular, logs compared to deciduous trees, and in different countries the ratio between the volumes of coniferous and deciduous wood harvested is different.

In order to establish the influence of the "emergence/establishment of the fortest" stage on the quality of the production process, data on the origin of forests in various European countries were analyzed.

In the following years of the development of the stands, silvicultural activities are carried out, which aim to maintain the healthy state of the forests, thereby ensuring the fulfillment of their ecological functions and producing quality wood. These silvicultural activities are based on following natural processes and, above all, self-thinning. Even at the modern stage of development of science and technology, the main silvicultural intervention remains felling. Silvicultural science has created a system of fellings, which are carried out at different ages of the stands depending on the tree species, the origin of the forest and the richness of the habitat. This means that even at the initial stage of forest development, foresters are aware of what fellings will be applied in the coming years. In Bulgaria, this is done by classifying the stands into different economic classes according to the above-mentioned characteristics. The grouping into economic classes is carried out during the forest inventory. Each economic class is assigned a specific production goal, which must be achieved at maturity (or age of rotation). The production objective is the production of wood of a certain diameter, which will be harvested during regeneration felling. The economic classes are described in Annex 5 of Regulation 18 on inventory and planning in forest areas (National Assembly, 2015, Regulation 18). This means that when preparing the forest management plans and programs, the future development of the stand is planned, i.e. the wood that will be produced at maturity as well as the wood that will be harvested from the regeneration fellings. This process must be market-driven. Production must be targeted at potential existing customers. This means that planners must identify customers by identifying available facilities that are within the distance from the plantation that makes economic sense to transport roundwood. They must then identify the specific sizes of wood that these facilities process and, based on this data, set the production target. The quality requirements are determined by the customer.

The majority of the thinnings (cultivation fellings) carried out in Bulgaria are carried out using methods that are aimed at modeling the development of the stand as a whole. They are not aimed at providing favorable conditions for the development of specific selected quality trees. For this reason, they achieve proper development of the forest as a whole, but this does not guarantee the achievement of the maximum possible production of quality assortments. Regulation No. 8 on felling in forests regulates what fellings can be carried out in Bulgaria and describes the rules under which they are carried out. Since 2015, the regulation has created the possibility of carrying out a system of fellings for individual production of high-quality wood in stands of good vegetation (Minister of Agriculture and Food, 2011, Regulation No. 8).

According to data from the Executive Forestry Agency (EFA), by the end of 2024, state forest areas managed by state forest enterprises (SFE) and state hunting enterprises (SHE) under Article 163 of the Forestry Act amounted to 73.15% of the total area of forest areas in Bulgaria (EFA, 2025). Currently, there are 163 territorial units in Bulgaria in which an inventory of forest areas is carried out, i.e. the same number of forest management plans for state forest areas are prepared in them (EFA registers, 2026). In 28 of them, the following was checked:

- Have potential customers been identified, the quantities and qualities of wood they need?
- In how many cases has the designer proposed a different production goal than that specified in Annex №5 of Regulation №18 on inventory and planning in forest areas, in order to meet the demand established in the previous point?
- In how many cases and on what areas has felling been explicitly designed for individual production of high-quality wood?

The planning of the use of wood in a particular year, in addition to forestry and economic-organizational principles, must also be in line with market demand. When awarding the logging contract, the assortments that are currently in demand and their prices must be identified. The order must be made in such a way as to guarantee maximum income. For this reason, it was made how these activities are carried out in Bulgaria.

Tender documents for awarding the logging contract and selling the harvested wood from a warehouse in 2026 were checked. of the SFE Borino (South-Central State Enterprise).

All decisions taken during the harvesting phase have irreversible consequences on the final volume and value recovery and cannot be counterbalanced in subsequent steps (Pnevmaticos S., Mann, S.,1972;Kivinen V., 2004; Bennemann C., Lussier J-M; Labelle E., 2025). For this reason, an analysis was carried out of how the logging process affects the quality of the round wood produced.

When performing the analyses, the influence of the main production factors was also considered.

3. RESULTS AND DISCUSSION

3.1. ASSESSMENT OF THE ACHIEVED LEVEL OF QUALITY AND EFFICIENCY OF WOOD PRODUCTION FROM THE FORESTS OF BULGARIA

In order to assess the quality of wood produced in Bulgaria, the percentage of firewood and the percentage of logs were compared to the total amount of wood harvested for 2023 for Bulgaria, Bosnia-Herzegovina, Czechia, Croatia, Greece, Hungary, Montenegro, North Macedonia, Romania, Serbia, Slovakia, Slovenia, Türkiye and Europe in general. The results are presented in the figures below:

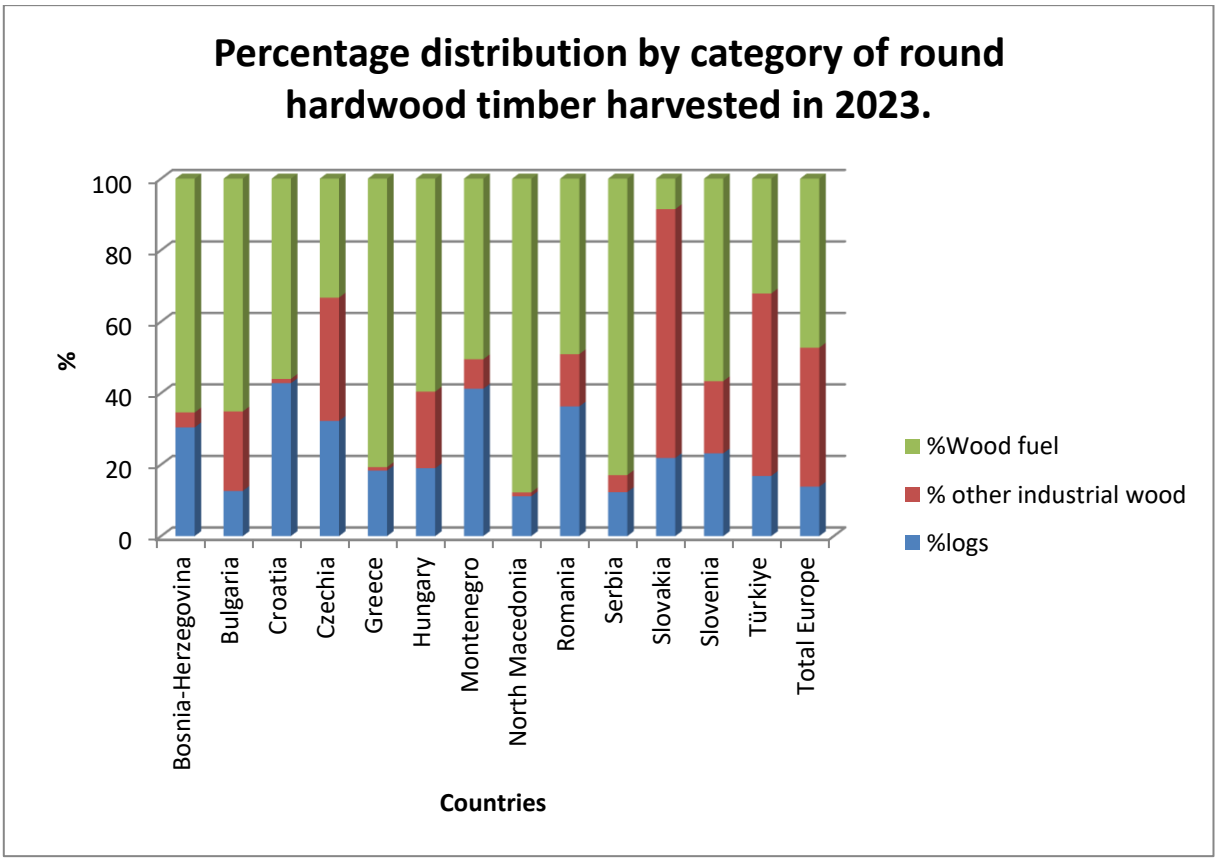


Figure 1: Percentage distribution by category of round hardwood timber harvested in 2023.

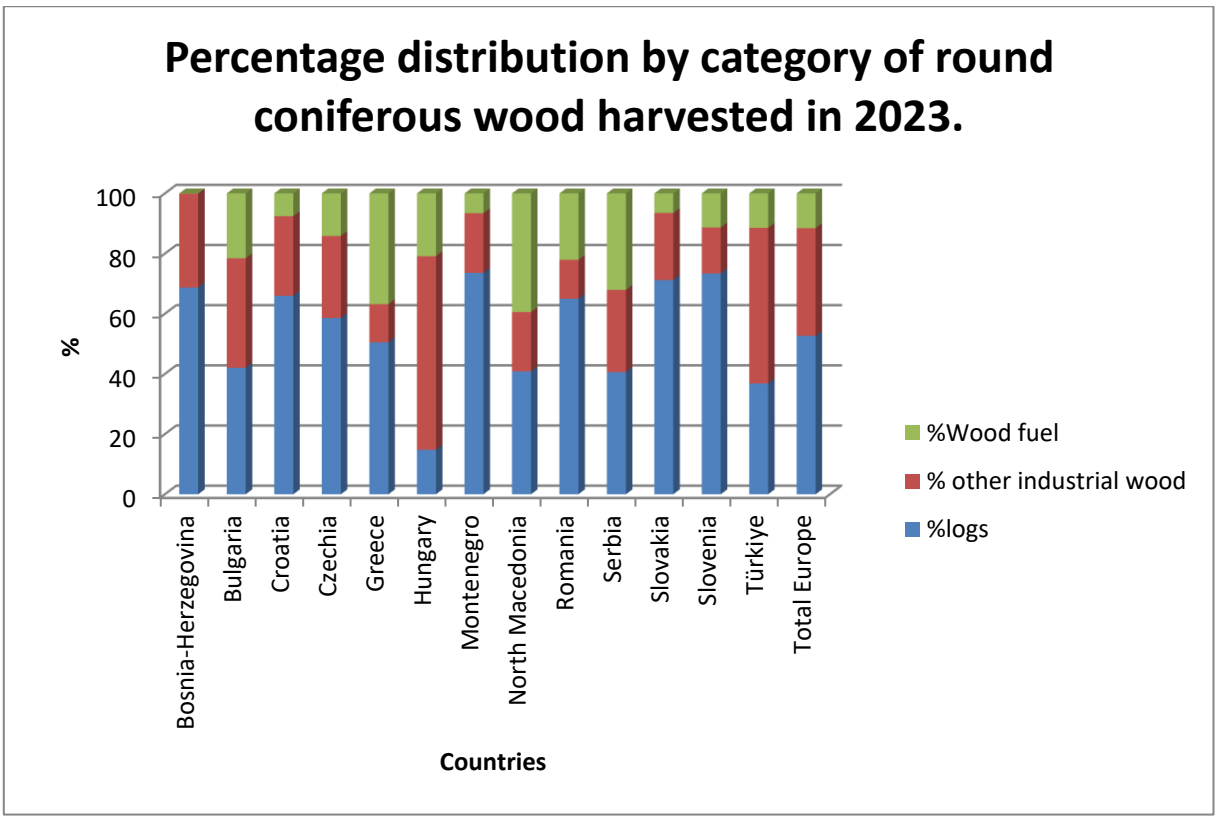


Figure 2: Percentage distribution by category of round coniferous wood harvested in 2023.

The results show that in the case of broadleaf trees, out of the 12 countries considered, only 2 /two/ countries produce a lower percentage of logs than Bulgaria, and these are Serbia and North Macedonia. Moreover, the difference between these three countries is within 1.49%. This means that in Bulgaria, Serbia and North Macedonia approximately the same percentage of logs is produced. At the same time, in Croatia this percentage is 42.8%, in Montenegro 41.24%, and in Romania – 36.29%. This shows that there is potential for a higher percentage in our country. In Bulgaria, the percentage of harvested logs from broadleaf species is almost equal to the average for Europe. Most likely, this is due to the northern countries.

In 4/four/ countries the percentage of harvested hardwood firewood is higher than that of Bulgaria and these are Serbia, North Macedonia, Greece and Bosnia-Herzegovina. And if the difference with Bosnia-Herzegovina is negligible (0.27%), then the difference with the other 3 is more than 15.5%. All other countries (8 pcs.) have a smaller percentage of wood. Moreover, Bulgaria harvests almost 18% more fuelwood than the European average. The situation is similar if we consider the percentage share of the entire volume of hardwood industrial wood.

In 2023. only 3/three/ countries produce a lower percentage of coniferous logs than Bulgaria and these are Serbia, North Macedonia, Turkey and Hungary. The difference between the first two and Bulgaria is minimal – within 1.46%, and the difference with Turkey is 5.24%. At the same time, these percentages for Montenegro, Slovenia and Slovakia are respectively – 73.59%, 73.41% and 71.21%. In Romania, this percentage is 64.99%. On average, over 10.5% more coniferous logs are produced in Europe compared to Bulgaria.

In 4/four/ countries the percentage of harvested coniferous firewood is higher than that of Bulgaria and these are Serbia, North Macedonia, Greece and Romania. In the remaining 8 of the countries considered this percentage is lower. In Bulgaria over 10.0% more coniferous fuelwood is harvested compared to the average yield in Europe. The situation is similar if we consider the percentage share of the entire volume of coniferous industrial wood.

Wood production in terms of harvested volumes will be effective when it reaches the planned felling quantities. For a period of 13 years from 2012-2024, Bulgaria has accumulated a failure to meet the planned felling volumes of 6.531 million m^3, which is more than the average annual use for the period, which amounts to 6.352 million m^3. During this period, our wood processing industry has missed the potential benefits of processing these volumes. Since the forestry sector is linked to other branches of the national economy, this

implies that wood-using industries were also inefficient during the period under review. (Petrov S., Boyadzhiev, D,2025).

Wood production is an organic outdoor production. As such, it is strongly influenced by natural conditions – climate, relief, humidity, soil conditions, etc. Only in 4 countries – Turkey, Greece and parts of Hungary and Romania, there are natural conditions that hinder the development of quality wood. At the same time, the data mentioned above show that this has not prevented a larger percentage of the higher quality wood categories from being produced in these countries. In the remaining 8 countries, the natural conditions are similar to those in Bulgaria. This shows that the production factor "Natural Resources" should not be the reason for the lower quality of the wood produced in Bulgaria.

The comparisons and analyses of the data show that the production of roundwood in Bulgaria is not efficient enough and is inferior in quality to most neighboring countries. In order to identify weaknesses in the production process, all its stages were examined.

3.2. ANALYSIS OF THE STAGES OF ROUND WOOD PRODUCTION IN BULGARIA

3.2.1. EMERGENCE/CREATION OF THE FOREST

The roundwood production process begins with the emergence/creation of the forest. As of 31.12.2024, according to the Report on the Distribution of the Total Forest Area in ha by Forest Type (RDTFA1, 2024), 48.8% of the forested area is occupied by coppice forests. The countries with a higher percentage of coppice forests than Bulgaria are Bosnia and Herzegovina, North Macedonia, Serbia and Greece. The countries with over 25% of coppice forests are Montenegro, Turkey, Croatia and Hungary. The average percentage for Europe is 4.8%. (UNECE;Unrau, A et al.). Coppice forests produce lower quality wood compared to seed forests. At the same time, however, as we have seen, the data on the harvested broadleaf wood categories in 2023 from the listed countries show that we can claim that only in Serbia and North Macedonia, the harvested broadleaf wood was of lower quality than that harvested in Bulgaria. This means that the coppice origin of forerests significantly affects the quality of the harvested hardwood, but this is not the main reason for the lower quality realized in Bulgaria. This once again shows that the production factor "Natural Resources" should not be the reason for the lower quality of the harvested wood in Bulgaria.

3.2.2. DEFINING PRODUCTION GOALS AND PLANNING ACTIVITIES

Activities in forests are carried out on the basis of forest management plans and programs. They define the economic goal for each stand and design the activities that must be carried out at the different stages of its development. In order to study how forest management planning affects the quality of the logging process, 28 forest management plans were studied, prepared in 2020 and 2023 by 8 different planning organizations. These are the plans of the state forest enterprises Aytos, Asenovgrad, Borino, Dospat, Garmen, Gurkovo, Katuntsi, Maglizh, Parvomay, Petrich, Pirdop, Rakitovo, Strumyani, Trigrad, Tvarditsa, Zemen, Byala, Bolyarka, Cherni Osam, Ivaylovgrad, Omurtag, Razlog and Seslav, and the plans of the state hunting enterprises Aramliet, Chepino, Izvora, Zhenda and Vitinya. The studies established the following:

- In none of them are the potential customers, the quantities and qualities of the wood they need identified. In Chapter Two – Economic Conditions, in some projects the names of some local customers are mentioned without specifying the quantities and qualities of the wood processed. In most of them it is written that wood is important for heating the local people and industry.
- In none of the plans has the designer proposed a different production goal than that specified in Annex №5 of Regulation №18 on inventory and planning in forest areas, in order to meet the demand of traditional and potential customers. In 13 plans there is a change in the production goals, which were made on the basis of instructions from the EFA regarding the management of coniferous plantations and coppice forests, and a deteriorated health condition. In the event of a shortage of areas, the different stands with different quality are referred to generalized classes, but the rotations and production goals are differentiated according to quality and tree species in accordance with Annex 5.
- Only one plan explicitly projects logging for individual production of high-quality wood, and that on an area of only 24.0 ha.

In 2024, the results of the Overview of Global Long-Distance Road Transportation of Industrial Roundwood were published. The results show that worldwide, road transport accounts for an average of 89% of the total volume of long-distance industrial roundwood transport. In Bulgaria, it is 95%. The average distance for road

transport of industrial roundwood is 128 km., and in Bulgaria it exceeds 200 km. (K. Kärhä et al.). These data can be used to identify potential customers.

The data analysis shows that in Bulgaria, the setting of production goals for forest stands and the planning of activities to achieve them are not sufficiently market-oriented.

3.2.3. ADMINISTRATION AND IMPLEMENTATION OF FOREST MANAGEMENT PLANS

Achieving maximum effect from activities provided for in the forest management plan can be achieved when they are carried out in the most appropriate manner and at the most appropriate time.

The structure of the timber designated for harvesting in a given year must be guided not only by purely silvicultural and operational-organizational principles but also by market demand—specifically, domestic consumption and exports. This requires the development of national and regional marketing programs and timber balance sheets—tasks that lie beyond the capabilities and remit of any single business entity, research institution, government agency, or public administration body (Trichkov L., Petrov S.). This should be done through in-depth market research and discussions with stakeholders.

In theory, selling timber from a temporary warehouse allows for the sale of individual lots of different assortments and achieving the highest selling prices. This is good for the industry, because the client buys exactly the assortment he needs. In Bulgaria, the situation is different. In procedures for logging to a temporary warehouse, the SFE and the SHE assign operators to harvest assortments that are defined in the entire range of the respective assortment. When assigning, they do not give specific sizes of the assortments that are related to current market demand in the area of the enterprise.The SFE employees do not control how the operator's workers buck the stems. This allows the operators to choose the sizes of the assortments that will be harvested. The criterion is the convenience and efficiency of their work, and not achieving maximum economic effect for the client. This leads to the extraction of a small group of historically established assortments with certain sizes, some of which do not correspond to modern market requirements. In addition, in a number of cases, a group of assortments are offered in a package at auctions. Consequently, some wood processors find themselves compelled to purchase timber they do not actually need. Furthermore, the modern market is highly dynamic, potentially requiring multiple adjustments to timber assortments within a single year. In contrast, a company that purchases standing timber with the aim of maximizing profit harvests only those assortments that are in market demand. This implies that, under the conditions described, the second option is more market-oriented within the Bulgarian context.

The above is very well illustrated by the following example: An open competition has been announced for 15.07.2026 with the subject "Felling, bucking of assortments, transportation to temporary storage and ramping of felled wood from Site No. 2615 – section 91, subsections "a", "b" and "d", included in the 2026 logging plan in the territorial scope of activity of territorial division "State forest enterprise – Borino"". The timber from this site was offered for sale through an electronic auction with bidding for the sale of harvested timber in estimated quantities. The table below provides starting prices for some assortments.

Table 1: Starting prices for logging and sale of some and the harvested assortments in site No. 2615 – section 91, subsections "a", "b" and "d" of the Borino State Forest Enterprise

Indicator	**Starting price[€/m³]**				
Type of procedure	Contracting out logging activities			Sale of wood from warehouse	
Site	91 „a“	91 „b“	91 „d“	91 „a“, 91 „b“ и 91 „d“	
Tree type	Scots pine and Norway spruce			Scots pine	Norway spruce
Sawlogs with a diameter of the thin end – 50 [cm]	16,91	18,73	19,46	97,10	106,80
Sawlogs with a diameter of the thin end – 30÷49 [cm]				94,50	104,30
Sawlogs with a diameter of the thin end – 18÷29 [cm]				89,40	99,10
Round materials for craft processing				61,30	61,30

The announced starting price for extraction to temporary storage for each subdivision is the same for all listed assortments. At the same time, the assortments from each of the listed categories have a different price, with Sawlogs with a diameter of the thin end – 50 cm. having the highest price, and Round materials for craft processing – the lowest.

In the specification for dimensions and quality of wood assortments that are harvested and sold by the South Central State Enterprise, the city of Smolyan and its territorial divisions, attached to the tender documentation, the following requirements for the assortments of each group are specified.

Table 2: Requirements for the assortments of each group

Requirements	**Assortment**			
	Sawlogs with a diameter of the thin end – 50 [cm]	Sawlogs with a diameter of the thin end – 30÷49 [cm]	Sawlogs with a diameter of the thin end – 18÷29 [cm]	Round materials for craft processing
Length [m]	>2	>2	>2	1 – 4
Knags	not fused – up to 5 pcs. on average per linear meter, with a diameter of up to 60 mm. or up to 3 pcs. per linear meter, without restrictions on diameter.			without restrictions
Internal rot and cavity	Pith – 25% of the log diameter	Pith – 15% of the log diameter	Pith – 5% of the log diameter	It is permissible in the central part of the trunk, provided there is a sound peripheral zone of at least 10 cm.
Curves	one-sided up to 3%, two-sided up to 1.5% of the length			one-sided up to 6%, two-sided – up to 3% of the length
Cracks	а) in one plane – with a length of up to ½ of the length of the log; б) in more than one plane – are not allowed, except in cases where the cracks are superficial – up to 5 cm long			without restrictions

The table shows that specific lengths of the assortments in the different categories are not specified. This means that the production of round wood from them is not related to meeting the needs of specific industries. This creates a risk of producing assortments with sizes for which there is no demand. In addition, during the extraction of Round materials for craft processing, most defects are not removed, therefore they are extracted with less effort from the logs and in a larger volume than one stem, at the same price for the work performed. Hypothetically, it is possible to extract logs of shorter length from a given stem, but from different assortments, or one with a total length equal to the sum of the two, but from the lower-quality assortment. This requires that the tender documents provide financial incentives for the production of higher quality assortments.

At the current stage of market development, it is necessary to purposefully design and produce assortments for certain industries. At the moment, this cannot be achieved in Bulgaria, because the State Forestry Enterprises and the State Hunting Enterprises do not have the necessary administrative and personnel capacity. The above shows the main problems in the production factor "Entrepreneurship, organization and management", which lead to the achievement of a lower quality of the harvested wood compared to what is potentially possible.

3.2.4. LOGGING PROCESS

The quality of the production of wood processing enterprises depends mainly on the quality of the raw material. The quality of the raw material depends to a very large extent on the quality of the logging process, which is influenced by the following factors:

3.2.4.1. Logging technology

The technology for felling is determined by Regulation No. 8 on felling in forests, which regulates the methods for their implementation. These methods are not consistent with modern mechanization and technologies for

logging. In a number of cases, the strict application of leads to restrictions on the sizes of the assortments that can be transported to a temporary warehouse.

3.2.4.2. Equipment

The Strategic Plan for the Development of the Forestry Sector in Bulgaria for the period 2014-2023 states that the logging process is characterized by a low level of technical and technological provision. A significant part of the work is done manually. A very large percentage of the transportation of wood is carried out by animal traction (Ministry of Agriculture and Food, 2014). Despite the identified measures, the situation by 2026 has hardly changed. For these reasons, the logging process has a high cost, low quality and low productivity. The extraction of wood by animal traction leads to limitations in the size of the assortments that are harvested, and hence their quality.

A major problem in logging in Bulgaria is the overwhelming predominance of equipment in operation over 10 years old (89%), and hence their lower production levels and higher maintenance and repair costs. Bulgarian forestry needs new, modern logging equipment, which is a prerequisite for increasing productivity and improving working conditions (Stoilov S., 2021).

In 2021, Mikael Lundbäck, Carola Häggström and Tomas Nordfjell published results from 2 /two/ models to predict the rate of CLT adoption in many countries, including Bulgaria. The main parameters are: diesel price, share of steep terrain in forest areas, GDP per capita and the interaction between diesel price and share of forest areas that are publicly owned. The results of both models for Bulgaria show that the observed rate of CLT adoption is lower than the amount predicted by the model (Lundbäck M., Häggström C., Nordfjell T., 2021). This means that even in the current situation in the country, it is possible to increase mechanized timber harvesting.

Technical equipment and technologies for logging is part of the production factor "Capital". This production factor should be given special attention. It is necessary to find funds for investments. Given the economic situation of Bulgaria, it is most realistic to realize this through financing under European programs.

3.2.4.3. Contractors and workers. Work organization

It has already been stated that the level of mechanization and technology in the logging process in Bulgaria is low. A significant part of the work is done manually. Most logging workers in Bulgaria do not have specialized education. The education system does not have the capacity to train workers who have the skills to operate modern logging machines (Ministry of Agriculture and Food, 2014). Employers train workers at their own expense and risk.

Training courses are held in Bulgaria to certify operators for the use of chainsaws and specialized, self-propelled forestry machinery. The aim of these courses is to instruct workers on the operational procedures for chainsaws, skidders, forwarders, and harvesters—covering proper setup, maintenance, handling techniques, the replacement of consumables, and occupational safety rules. These courses do not aim to teach workers the rules for timber bucking, as that operation falls outside their scope of work. Unfortunately, no specialized training on proper timber bucking is currently conducted in the country.

At the same time, bucking stage is critical to increase economic gain in timber production.

In traditional bucking method, the trees are cut by depending on the loggers' experiences which may not guarantee the optimum bucking solution; however, optimum bucking method employing computer-assisted techniques can search for the optimum solution among a large number of alternatives (Akay A., 2017). In optimum bucking method, large number of bucking alternatives should be evaluated to determine the optimum bucking combination that maximizes the total economic value of a tree. Such a problem with many solutions can be solved by using computer assisted methods such as network analysis, dynamic programming, and heuristic techniques (Laroze and Greber, 1997; Laroze, 1999; Wang et al. 2004; Pak M., Gulci N., 2017). Studies conducted in China have shown that an optimal bucking method can lead to a 13.8% increase in the potential gross value of logs. (Wang et al., 2004). The use of an optimal bucking method increased the average economic value of oriental beech trees (Fagus orientalis) by 14.37% in northeastern Turkey. (Mehmet Pak, Neşe Gulci, 2017)

Logging with harvesters has a number of advantages. One of the most important is the ability to use computer algorithms to most efficiently cut the stem to specific sizes for the assortments ordered by the customer. On-board computers (OBC) of harvesting machines can now provide optimized bucking (task of cutting stems

into different log lengths) by relying on value and demand matrices. The operator can use the program or switch to manual bucking. Studies show that the operators used manual bucking (the operator does not use a program) more frequently in thinning stands with small-sized and defected log stems Labelle e., Bergen M., Windisch J., 2017; Kärhä K., et al., 2017).

Maximizing saw log percentage and including special assortments meets the interests of forest owners and those of wood processing industries when there is a shortage of wood in the market. However, when the users of wood have no raw material shortage, the value recovery from the sawable timber can be increased by increasing minimum allowable log diameter and length, thus, increasing the average size of the logs (Malinen J., Kilpeläinen H., Wall T., Verkasalo E., 2006).

"Labor and human resources" is an important factor of production. Given the demographic crisis in Bulgaria, it is necessary to intensify the logging process. This can be achieved through the widespread introduction of fully mechanized logging. For the correct and effective use of modern machines and optimal bucking of the stems, it is necessary to introduce specialized training.

Improving the organization of labor leads to a more complete use of machines and workers' labor, and hence to an increase in labor productivity. It reduces losses of raw materials and energy. It also reduces occupational accidents. In the logging process in Bulgaria, machines that have been in operation for over 10 years are used, many of them are adapted – they were not originally manufactured for logging. The operators of these machines are low-skilled. This creates a high risk of accidents. Under these conditions, labor standards cannot be applied to synchronize the productivity of different machines (the different phases of logging). Last but not least, there is no possibility of standardizing operations, which leads to a decrease in the quality of production. To overcome these weaknesses, the creation of good labor organization plays a key role. To this end, it is necessary to increase the capacity of the managers of the logging process. Investments are needed that will lead to the improvement of the production factors "Entrepreneurship, Organization and Management", "Labor and Human Resources" and "Capital".

4. CONCLUSIONS

Analyses show that neighboring countries with similar natural conditions and a similar level of mechanization produce better quality varieties than Bulgaria. The most indicative results are those achieved by Romania, Turkey, Bosnia and Herzegovina and Montenegro.

The logging process in Bulgaria is not efficient enough. As a result, the planned quantities of wood have not been harvested in the last decade. Our wood processing industry has missed the potential benefits of processing these volumes. The large volume of unexecuted fellings means that in many stands the planned activities, the implementation of which guarantees the achievement of the set production target, are not carried out. Since forestry is linked to other sectors of the national economy, this means that wood-using industries were also inefficient during the period under review.

The planning of wood production in Bulgaria is not sufficiently market-oriented. In the current stage of market development, it is necessary to purposefully design and produce assortments for certain enterprises.

The Bulgarian forestry sector needs new and modern logging equipment. It is necessary to find funds for investments. Given the economic situation of Bulgaria, it is most realistic to realize this through financing under European programs.

Specialized training should be introduced for forestry workers, focusing on the optimal bucking of timber.

REFERENCES

Akay A. (2017). Potential Contribution of Optimum Bucking Method to Forest Products Industry, European journal of Forest Engineering, 3(2): 61.

Bennemann C., Lussier J-M; Labelle E. (2025). An Open-Source Tree Bucking Optimizer Based on Dynamic Programming, Forests 2025, 16(5), 780; https://doi.org/10.3390/f16050780: 1

EFA. (2025). EFA Annual Report for 2024, ISSN 3033-0572: 5, 6

EFA registers. (2026). https://procurement.iag.bg/cgi-bin/lup.cgi

EUROSTAT. (2026). EC, https://ec.europa.eu/eurostat/databrowser/explore/all/all_themes, on the state by 2026.

Kärhä K., et al. (2017). Analyzing the Antecedents and Consequences of Manual Log Bucking in Mechanized Wood Harvesting, Mechanics, Materials Science & Engineering journal, ISSN 2412-5954, https://doi.org/10.2412/mmse.45.20.957

Kärhä K., et al. (2024). Overview of Global Long-Distance Road Transportation of Industrial Roundwood, Croatian journal of forest engineering, volume: 45, https://doi.org/10.5552/crojfe.2024.2286: 217, 223

Kivinen, V.-P. (2004). A Genetic Algorithm Approach to Tree Bucking Optimization. For. Sci. 2004, 50, 696–710. [Google Scholar] [CrossRef]

Labelle e., Bergen M., Windisch J. (2017). The effect of quality bucking and automatic bucking on harvesting productivity and product recovery in a pine-dominated stand, European Journal of Forest Research, 136(2/3): 639–652

Laroze, A. J., Greber, B. J. (1997). Using tabu search to generate stand-level, rule-based bucking patterns. Forest Science, 43(2): 367-379.

Laroze, A.J. (1999). A linear programming, tabu search method for solving forest-level bucking optimization. Forest Science 45(1): 108-116.

Lundbäck M., Häggström C., Nordfjell T. (2021). Worldwide trends in methods for harvesting and extracting industrial roundwood, International Journal of Forest Engineering, ISSN: 1494-2119 (Print) 1913-2220 (Online) Journal homepage: www.tandfonline.com/journals/tife20: 210, 211

Malinen J., Kilpeläinen H., Wall T., Verkasalo E. (2006). Variation in the value recovery when bucking to alternative timber assortments and log dimensions, Forestry Studies, 45: 89–100

Minister of Agriculture and Food. (2011). Regulation No. 8 on felling in forests: 10

Ministry of Agriculture and Food. (2014). Strategic Plan for the Development of the Forestry Sector 2014–2023: 46, 47.

National Assembly. (2015). Regulation 18 on inventory and planning in forest areas, Annex 5: 93-95

Pak M., Gulci N. (2017). A comparative economic evaluation of bucking deciduous trees: A Case study of Oriental beech (Fagus orientalis) stands in Northeastern Turkey, Journal of the Faculty of Forestry Istanbul University 2017, 67(1): 72-79

Petrov S., Boyadzhiev, D. (2025). Efficiency of wood production from Bulgarian forest territories, 34 International scientific conference "management and quality" Ecology and management of forest ecosystems, reports, ISSN 2603-4395: 140

Pnevmaticos, S.M.; Mann, S.H. (1972). Dynamic Programming in Tree Bucking. For. Prod. J. 1972, 22, 26–30. [Google Scholar]

RDTFA1. (2024). Statistics of EFA – RDTFA, Form 1 GF for 2024

South Central State Enterprise, the city of Smolyan, https://ucdp -smolian.com/bg/protseduri?t=nurvigt, on the state by 2026.

Stoilov S. (2021). Logging equipment in Bulgaria – current state and future prospective, Forestry ideas, 2021, vol. 27, no 1 (61): 24, 25

Trichkov L., Petrov S. (2003). Analysis of the production of round wood from the state forest fund of the Republic of Bulgaria and the export of round and shaped wood materials and charcoal for the period 2000 – 2002, University of Forestry, Sofia, Management and Sustainable Development, 1-2/2003, ISSN 1311-4506: 54, 63

UNECE. (2020). State of Europe's Forests 2020, Ministerial Conference on the Protection of Forests in Europe – FOREST EUROPE Liaison Unit Bratislava: 115, 249, 299

UNECE. (2026). UN ECE and FAO Statistics, www.unece.org/forests/, on the state by 2026.

Unrau, A et al. (2018). Coppice Forests in Europe, Albert Ludwig University Freiburg Printing Press Germany, ISBN: 978-3-9817340-2-7: 366

Wang, J., LeDoux, C. B., McNeel, J. (2004). Optimal tree-stem bucking of northeastern species of China. Forest Products Journal 54(2): 45–52.

Session 4 | Contribution 2

APPLICATION OF SIGNAL DEVICES FOR REGULATING THE SPEED OF AUXILIARY MOVEMENT IN PRIMARY WOOD PROCESSING

Damjan Stanojevic[1], Zoran Trposki[2], Vladimir Koljozov[2], Anastasija Temelkova[2], Monika Koljozova[2]

[1]Academy of Technical and Educational Vocational Studies Nis – Vranje Department, Republic of Serbia

[2]Ss. Cyril and Methodius University in Skopje, Faculty of Design and Technologies of Furniture and Interior – Skopje, Republic of North Macedonia

e-mails: damjan.stanojevic@akademijanis.edu.rs, trposki@fdtme.ukim.edu.mk, koljozov@fdtme.ukim.edu.mk, temelkova@fdtme.ukim.edu.mk, koljozova@fdtme.ukim.edu.mk

ABSTRACT

The subject of this paper is the application of signal devices for the correction of the speed of auxiliary movement during the technological process of cutting logs on a band saw in primary wood processing. The correction of the feed rate is done with the help of the control of the path of the cut, during the cutting process. Due to various reasons (insufficiently tensioned saw blade, excessive pressure on the back side of the blade due to excessive movement speed or dulling of the saw), the saw can move laterally during the work process and as a result, assortments of unequal thickness along their length can be obtained. By using an electromagnetic sensor, which is placed on the upper guide and a light signal, the machine operator can react in time and reduce the speed of movement. In this way, the lateral movement of the saw blade will be reduced, and thus less variability of the thickness of the assortments along their entire length will be achieved.

Keywords: Band saw, electromagnetic sensor, feed rate, thickness.

1. INTRODUCTION

In the sawmill processing of logs, in the Republic of Serbia, band saws-log cutters occupy the most important place. The reason for this is the presence of beech, which is the most economically important wood species in our country. The processing of beech requires individual cuts, due to the presence of false heartwood, in order to increase the qualitative and thus quantitative utilization of the raw material.

When splitting logs with band saws-log cutters, due to pronounced movement speeds, lateral displacement of the saw occurs. The reason for this is the increased pressure on the back side of the teeth. The resultant force on the back side is much greater than the resultant force on the front side (Figure 1). This results in instability of the teeth and an imperceptible creep of the entire saw in the cutting zone (the force on the front side of the teeth N is significantly lower than the force on the back side of the teeth Po). The saw is no longer parallel to the cutting path and therefore a gradual curvature of the cut occurs. If the pressure is not reduced, i.e. the speed of the movement remains the same, or even worse, it increases, this curvature of the cut will increase.

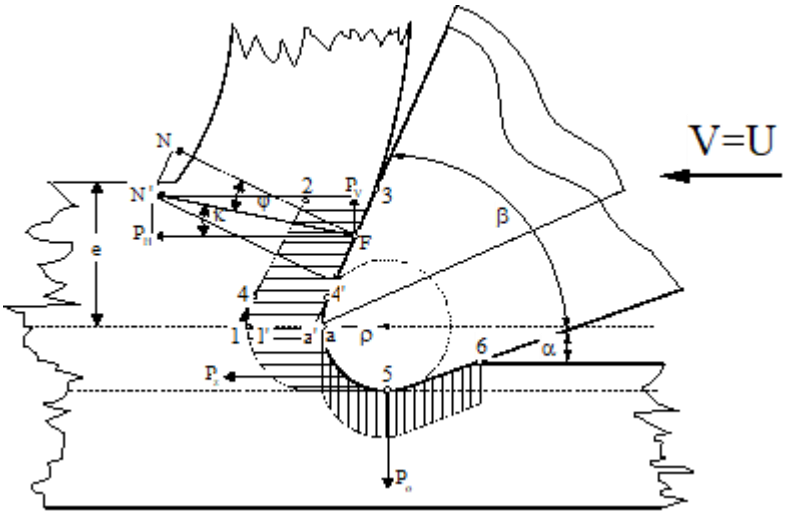


Figure 1: Diagram of the forces caused by the interaction of the blade and the wood

This phenomenon results in variability of the thickness of the assortments at a certain length of the assortments, so that in one there is an increase in thickness and in the next a decrease or vice versa. This error is most often of a subjective nature. Usually, the worker-subject, in order to avoid it, strives to choose lower movement speeds, which on the other hand significantly reduces the capacity of the machine. However, the choice of lower movements of the trolley can cause a decrease in the thickness of the shavings to a zone close to micro-shavings (0.1mm). In this case, increased resistance to cutting occurs, i.e. the teeth do not cut but rather scrape and crush the wood (Figure 2). These resistances increase the temperature of the saw, during which the metal expands, the teeth cut in difficult conditions, the resistances increase even more, the teeth quickly become dull, the electric motor increases the consumption of electricity, etc., and the effect of the work is reduced.

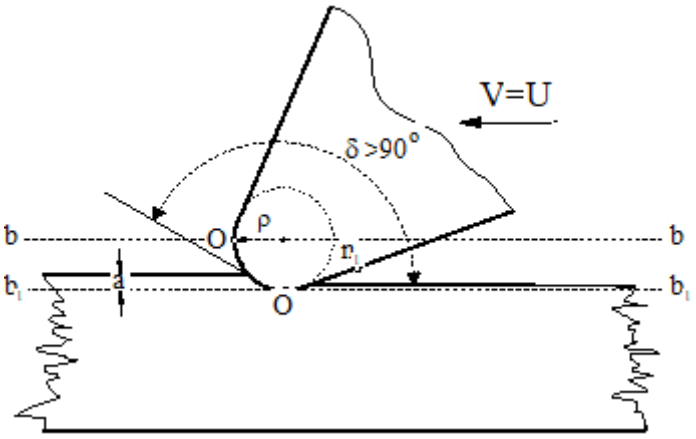


Figure 2: Crushing and scratching of the tree (a condition under which cutting is impossible)

Therefore, it is very important to choose carriage displacements that will be close to the limiting speeds while keeping the lateral displacement of the saw within the permissible limits. In objective conditions, on the one hand, this is almost impossible due to the late visual determination of the saw deflection by the worker, and on the other hand, with a quick reaction (correction of the displacement by reducing the displacement speed) the saw inertially returns to the normal cutting trajectory.

2. EXPERIMENTAL METHODS

Signal devices for timely detection of lateral displacement of the saw enable movement speeds close to optimal. In this way, the effect is two-sided. Assortments with equal thickness along the length will be obtained and the capacity of the machine will be increased. The use of signaling also reduces the long-term concentration of the worker, to visually monitor the saw. In this way, he can devote more attention to other activities, again related to the quantity and quality of processing.

Accordingly, the goal of this research is to increase the quantity and quality of beech logs felling with a band saw-log feller, by using an electromagnetic sensor and a light signaling device in conjunction, for timely correction of the speed of movement, while keeping the lateral displacement of the saw within permissible limits, which will result in greater accuracy of the dimensions of the timber in thickness, i.e. in shortened form, increasing the quality of felling in band saw-log fellers by using signaling devices for displacement correction.

2.1. SELECTION OF THE MATERIAL

The logs are with the same growing location, second quality class, with a length of 4.0m with an oversize of 10.0cm, and a diameter of 33.0 to 35.0cm.

The permissible errors that these logs should have are shown in Figure 3.

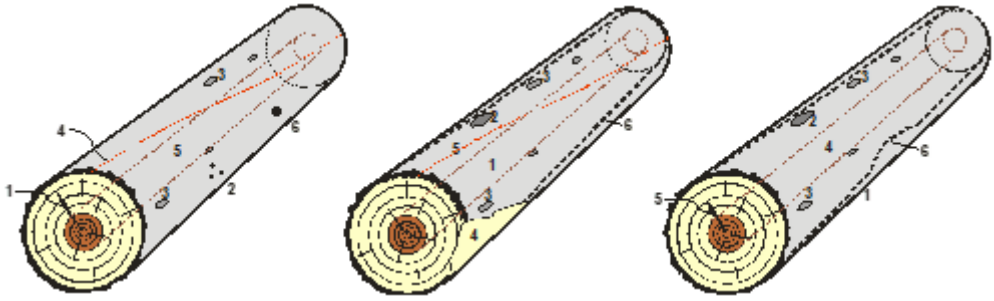


Figure 3: Permissible errors in beech logs of second quality class

In order to obtain more precise measurement results that can be compared with high accuracy, 10 logs with almost identical characteristics and diameters were selected. They were grouped into two groups of 5 logs each. The first group of five logs was sawn without using the electromagnetic sensor and the signal light, and the second group of five logs was also sawn using the electromagnetic sensor and the signal light, under production conditions. First, the first log from the first group was processed, then the first log from the second group, then the second log from the second group, and so on (Figure 4). In this way, the influence of tooth dulling is largely avoided.

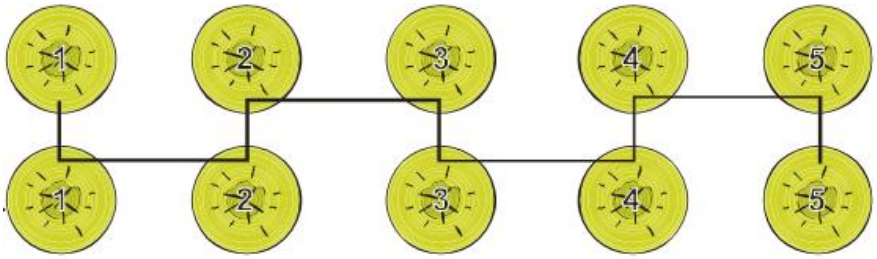


Figure 4: Order of cutting the logs

2.2. MEASUREMENT AND MEASURING INSTRUMENTS

In order to avoid the preparation time, i.e. manipulation of the logs and other preparation times, as a variable quantity, we measured only the active working time, i.e. only the whipping time, for each board, i.e. board separately. The speed of movement of the cart (the speed of movement) is controlled by the worker operating the band saw-log saw. Its value is variable and will be discussed as a function of the active working time. The whipping time was measured with a stopwatch and recorded in a table appropriate for each log and cut separately.

The method of measuring the thickness deviation (variability) is shown in Figure 5.

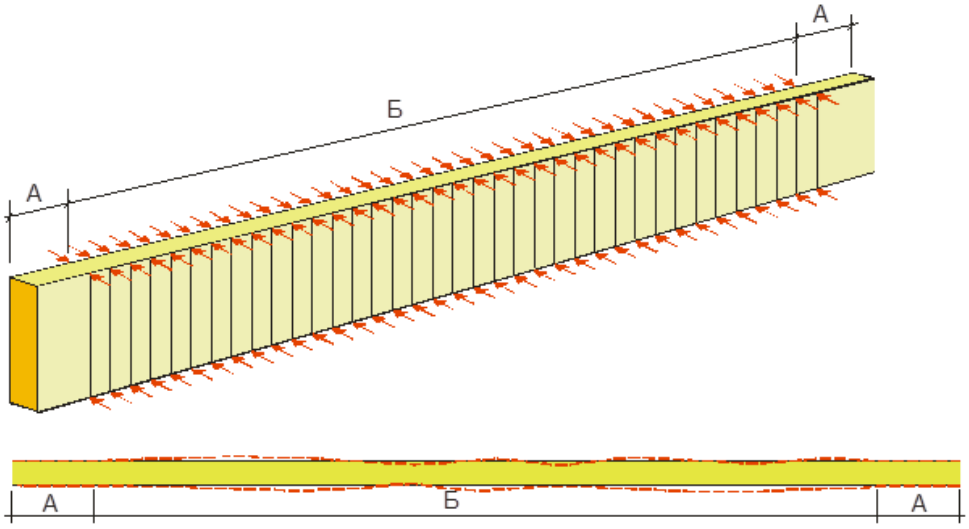


Figure 5: Thickness deviation measurements: A-zone of reference thickness, B-zone of deviation measurements

This image shows the reference thickness zone (A) and the deviation measurement zone (B). The reference thickness zone was obtained by gradually, i.e. at a low speed, penetrating 25cm from the front of the log at the start of the sawing process. Also, 25cm before the end of the cut, the speed of movement was reduced to a minimum. In this way, the reference (true) thickness of the board or plank is obtained. Between these two reference zones, the thickness deviation measurements were made at exactly 37 locations. The distance between the measurement locations is 10cm, which means that the length of the measurement zone is 3.60m. The deviation was measured in the following way: with a digital caliper, the thickness was measured at both ends of the board (plank). The average value of these two measurements represents the reference thickness. We adjust the caliper to the obtained average value and then reset it to "0". From now on, each thickness measurement in the deviation measurement zone measures only the deviations, with a positive or negative sign. The positive sign means that we have a thickening of the board and conversely a thinning of the board. This procedure is performed on both the upper and lower parts of the board, as it is placed in the log. For each cut, 37 measurements are obtained above and 37 measurements below, separately for each board (plank). In this way, 6660 measurements are obtained.

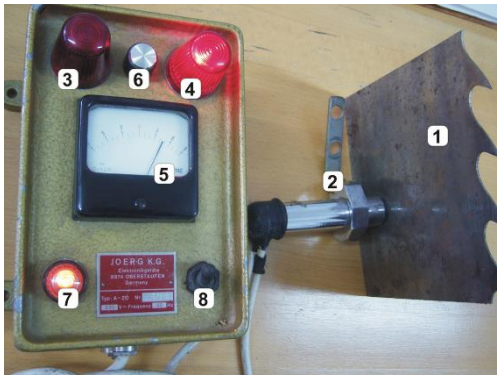


Figure 6: Electromagnetic sensor with light signaling device
Legend: 1-band saw, 2-electromagnetic sensor, 3, 4-signaling lights (the saw moves left or right), 5-instrument for measuring the size of the displacement (in 0.1mm), 6-potentiometer for adjusting the measuring scale, 7-device on indicator, 8-power button

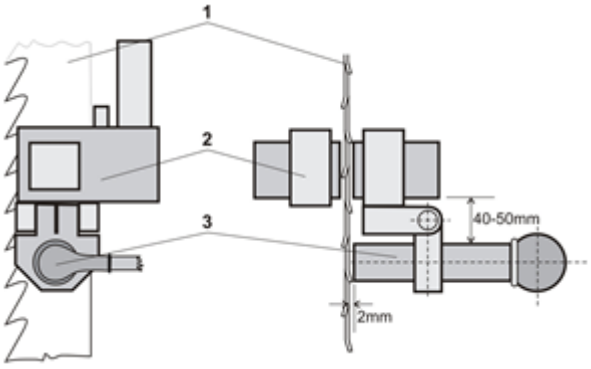


Figure 7: Positioning of electromagnetic sensor in relation to the saw
Legend: 1-band saw, 2-upper guide, 3-electromagnetic sensor

Figure 6 shows the setup of an electromagnetic sensor with a light signal that warns the operator if the board thickness deviates from the reference thickness. A legend with numerical designations and an explanation is also provided. Figure 7 shows a diagram of mounting an electromagnetic sensor on a band saw.

3. RESULTS

The obtained measurements are presented in tables and graphs. The columns clearly show the measurements for each board (slab) respectively for each cut, without and with a signaling device (e.g.: B1/1 means that the measurements were made without a signaling device, first log, first board-slab and S 1/1 that the measurements were made with a signaling device for the first board-slab, etc.). For a clearer view of the statistical indicators, the corresponding columns for the corresponding cuts, without and with the use of signaling, are placed next to each other. "g" and "e" indicate the place where the measurements were taken, i.e. above or below the board. The positive or negative sign shows the deviation of the thickness in the positive or negative direction. At the

end of each table is shown the statistical processing of the data, which contains: mean value, standard error of the mean value, maximum value of the corresponding measurement, standard deviation and coefficient of variation. After the grouping and graphic display of the measurements, the mathematical analysis is performed, that is, the statistical parameters are determined. The tabular and graphically presented data provide only general information about the nature of the collection of measurements.

Table 1: Results of mesurement

	B1/1		**S1/1**		**B1/2**		**S1/2**		**B1/3**		**S1/3**	
	g[mm]	e[mm]	g[mm]	e[mm]	g[mm]	e[mm]	g[mm]	e[mm]	g[mm]	e[mm]	g[mm]	e[mm]
1	+0,00	+0,00	+0,00	+0,20	+0,00	+0,40	+0,15	+0,00	-0.15	+0,05	+0,05	+0,20
2	+0,00	+0,15	-0,15	+0,40	+0,00	+0,35	+0,15	+0,15	-0.15	+0,10	+0,20	+0,00
3	+0,45	+0,60	+0,20	+0,50	-0,15	+1,30	+0,40	+0,35	+0,25	+0,80	+0,55	+0,50
4	+0,20	+0,30	-0,15	-0,15	-0,35	+1,35	-0,50	+0,10	+0,30	+0,70	+0,10	+0,45
5	+0,85	+0,90	+0,30	+0,30	+0,90	+1,85	+0,60	+0,65	+1,90	+0,90	+0,70	+0,65
6	+1,10	+0,90	+0,40	-0,05	+0,55	+1,75	+0,35	+0,65	+2,10	+1,50	+0,05	+0,45
7	+1,45	+1,30	+0,45	+0,50	+2,10	+1,50	+0,45	+0,60	+1,75	+1,20	+0,10	+0,05
8	+1,00	+0,95	+0,15	-0,10	+1,80	+2,05	+0,40	+0,45	+0,95	+1,05	+0,20	+0,10
9	+1,05	+0,90	+0,20	+0,60	+0,70	-0,05	-0,05	+0,30	+0,20	+0,45	+0,30	-0,25
10	+0,30	+0,30	-0,15	-0,45	+0,50	-0,20	+0,05	-0,05	+0,35	+0,05	+0,10	+0,20
RESULTS OF TEST												
Xsr	0,60	0,88	0,24	0,27	0,66	0,82	0,32	0,34	0,86	0,85	0,27	0,26
Sx	0,08	0,09	0,03	0,03	0,10	0,12	0,04	0,03	0,10	0,09	0,03	0,03
max	2,15	2,20	0,70	0,65	2,20	2,80	0,85	0,75	2,10	1,85	0,85	0,75
SD	0,49	0,56	0,17	0,19	0,61	0,72	0,22	0,20	0,63	0,57	0,21	0,21
KV	81,89	63,24	69,95	70,58	92,84	88,28	69,43	59,56	73,48	66,61	76,56	78,82

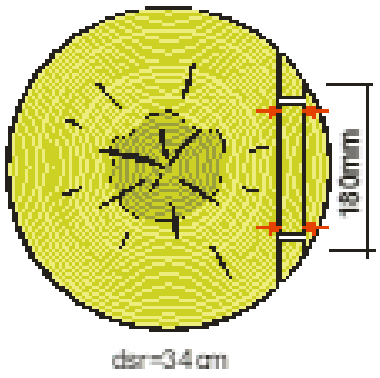


Figure 8: Lay a plank on a cross-section of a log

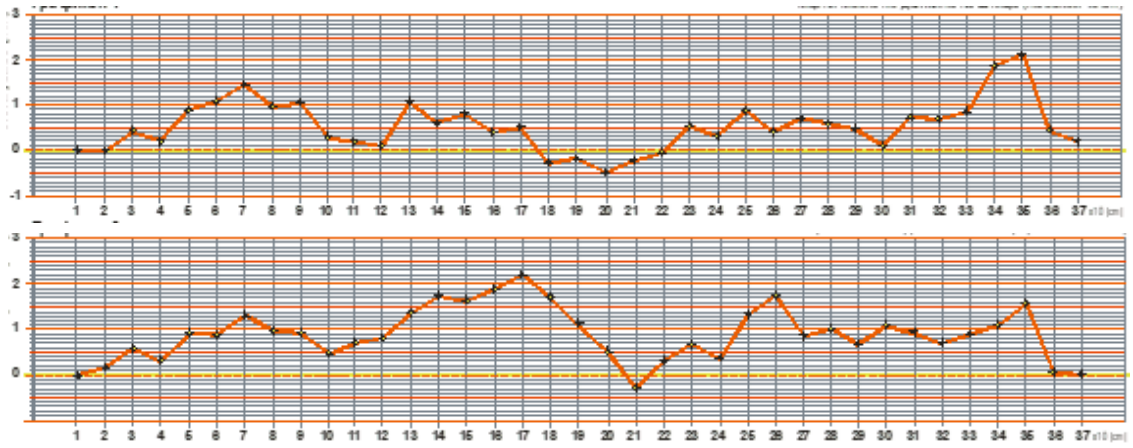


Figure 9: Measurement of deviations of the upper and lower part of the board without using a signaling device

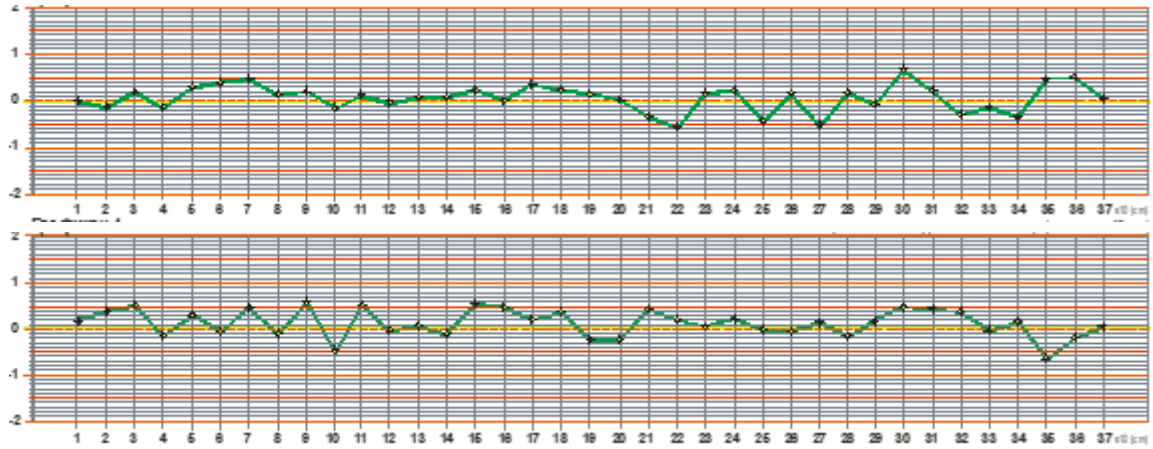


Figure 10: Measurement of deviations of the upper and lower part of the board with using a signaling device

It is noted that the measurements for the first logs in all statistical indicators of the measurements without using signaling have more than two to three times higher values, i.e. the mean value of the measurements without signaling (first group) ranges from 0.31mm to 0.88mm, while the mean value of the measurements with signaling (second group) is from 0.18mm to 0.39mm. The standard error of the measurements from the first group ranges from 0.03 to 0.12mm while in the measurements from the second group from 0.02 to 0.05mm. The maximum in the first group is 2.80mm and in the second 1.15mm. The standard deviation in the first group ranges from 0.19 to 0.72mm and in the second from 0.13 to 0.31mm. The coefficient of variation of the measurements in both groups, for the first three slices, shows a more pronounced inhomogeneity, i.e. in the first group it ranges from 60.22 to 92.84%, while in the second from 57.80 to 80.86%. The t-test values also show high (+++) and pronounced (++) significance (difference) between the corresponding comparison pairs.

4. CONCLUSIONS

The mean value of the measurements in the first group is from 0.29mm to 1.00mm, while the mean value of the measurements in the second group is from 0.16mm to 0.34mm; the second group, i.e. measurements with signaling, have more than two times smaller values. The standard error of the measurements in the first group ranges from 0.04 to 0.12mm while in the measurements in the second group from 0.02 to 0.05mm; the second group has two times smaller values. The maximum in the first group (measurements without a signaling device) is 2.80mm and in the second (with a signaling device) is 1.15mm; more than two times smaller values in the second group. The standard deviation in the first group of measurements ranges from 0.19 to 0.72mm and in the second group of measurements from 0.11 to 0.31mm; two times smaller values for the second group. The coefficient of variation of the measurements in both groups shows a more pronounced inhomogeneity, i.e. in the first group it ranges from 60.37 to 95.90%, while in the second group of measurements from 55.86 to 89.57%; due to the greater inhomogeneity of the data, the coefficient of variation is incomparable, but still the second group shows better homogeneity. The values of the t-test show a very high and pronounced significance (difference) between the corresponding comparison pairs; the t-test shows that when using signaling devices a

significant positive difference appears. The total active time of whipping the logs from the first group (without signaling) and the second group (with signaling) differs by 128 s, in favor of the first group; the time difference is insignificant in relation to the obtained precision of the cut.

Overall, the results prove that the use of light signaling devices during bandsaw logging, in order to correct the movement of the cart, is justified and significant from the point of view of the quantity and quality of raw material utilization.

REFERENCES

Breznjak M., Moen K. (1972). On the lateral movement of the bandsaw blade under various sawing conditions, Blindern: Norsk Tretehnisk institutt 46.

Brown, P.H. (1952). Texbook of wood technology vol. II, MCGRAW-Hill, New York: 61–65.

Kollmann F., et al. (1975). Principles of wood science and Technology, PART 2, Springer-Verlag, Berlin-New York: 312–313.

V. Koljozov, Z. Trposki, R. Klinčarov. (2006). Vlijanie na brojot na vrteži vrz silata na reženje i moknosta na reženje pri obrabotka so lentovidna pila. Šumarski pregled, vol.41, Šumarski fakultet, Skopje: 29-33.

Stambuk M. (1988). Snizenje ekstremnih naprezanja u listu tracnih pila regulacijom kuta ukrstenosti kotaca, Zagreb: Drvna industrija 39 5-6: 109–112.

Tjokina, P. et al. (1974). Obshaya Tehnologia Lesopileno – derevo obrabotivajshego proizvodstva, Moskva, “Vishaya Shkola”: 11–27.

Session 5 | Invited lecture

ENERGY RECOVERY FROM WOOD RESIDUES: THE ROLE OF LASER TECHNOLOGY IN OPTIMIZING CUTTING PROCESSES

Konstantinos Ninikas[1], Andromachi Mitani[1], Dimitrios Koutsianitis[2], Pavlos Ntalos[1], Georgios Ntalos[1]

[1]Department of Forestry, Wood Sciences & Design, University of Thessaly, Greece
e-mails: kninikas@uth.gr, amitani@uth.gr, pntalos@uth.gr, gntalos@uth.gr.

[2]Department of Forestry and Natural Environment Management, Agricultural University of Athens
e-mail: dkoutsianitis@aua.gr

ABSTRACT

The efficient valorisation of wood residues is now recognised as a cornerstone in the wood industry's ongoing transition toward sustainability and the adoption of circular economy models. As the demand for wood products continues to rise and environmental pressures mount, innovative approaches for waste minimisation and the recovery of energy from byproducts have become increasingly critical. A considerable portion of wood processed at every stage—from initial logging to the final shaping of products—ends up as residue, which has often been underutilised or simply disposed of. Harnessing these residues for thermal and electrical energy purposes can dramatically reduce the sector's carbon footprint, enhance energy self-sufficiency, and support regional economic growth. Recent developments in laser technology have steered in a new era for wood and composite material processing, offering unparalleled levels of precision, speed, and automation. Unlike conventional cutting methods, laser processing minimises residue generation and enhances the uniformity and quality of byproducts, making them particularly suitable for immediate energy recovery or conversion into value-added products such as pellets or biofuels. This study explores current best practices and recent innovations in the energy recovery of wood residues, with an emphasis on the transformative role of laser technology. It examines the types and characteristics of residues, methodologies for energy utilisation, and the multifaceted benefits for the environment, the economy, and society. In addition, the technical aspects, industrial applications, and future prospects for laser integration are discussed, alongside ongoing challenges related to investment, personnel, and regulatory requirements.

Keywords: Wood residues, laser manufacturing, cutting process optimisation.

1. INTRODUCTION

The wood industry stands at a crossroads of opportunity and responsibility. On one hand, global demand for wood-based products – from construction materials to furniture – continues to grow. On the other hand, the environmental footprint of wood processing is under increasing scrutiny. Wood residues, generated at every stage of the supply chain – from forestry operations to final product shaping – can constitute a substantial proportion of material output. Historically, these byproducts have been underexploited, often ending up in landfills or being burned without energy capture, resulting in resource inefficiency and environmental harm. In response, the efficient recovery of energy from wood residues is now central to achieving both economic and ecological sustainability (Fig. 1).

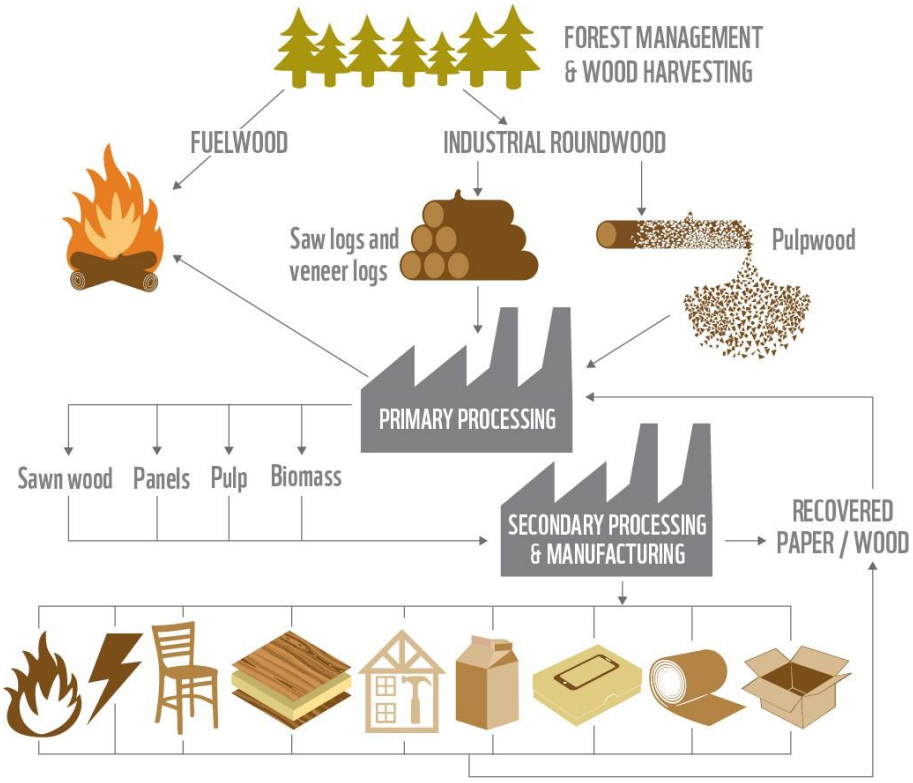


Figure 1: Schematic diagram showing the flow of wood from forest harvest through processing, residue collection, and energy recovery pathways.
Source: https://wwf.panda.org/wwf_news/?207367/Industry-key-to-conserving-forests-as-demand- for-wood-projected-to-triple-by-2050

In addition to the growing global market for wood-based products, the wood industry is increasingly shaped by the evolution of policy frameworks targeting climate change mitigation and resource efficiency. Initiatives such as the European Green Deal, the United Nations Sustainable Development Goals (SDGs), and national bioeconomy strategies have set ambitious targets for reducing waste, decarbonizing energy systems, and fostering sustainable growth (Koppejan & van Loo, 2021). Within this context, wood residues—comprising up to 50% of the original biomass after harvesting and primary processing—are recognized as a substantial, yet underutilized, resource (García et al., 2023). When managed effectively, these residues can provide not only local energy solutions but also significant reductions in net greenhouse gas emissions, supporting both rural development and industrial competitiveness (Kulig et al., 2022).

Recent advances in digitisation, automation, and process monitoring have further enabled the industry to optimize every stage of the wood value chain, from residue collection to conversion into energy or value-added materials. The integration of laser technologies exemplifies the convergence of precision engineering and sustainable resource management, enabling manufacturers to tailor wood processing operations to maximize both economic and environmental outcomes. As the industry continues to evolve, the challenge will be to ensure that technological innovations are matched by supportive regulatory, financial, and educational frameworks that facilitate adoption across diverse scales of operation (Lin et al., 2023).

Laser technology is increasingly recognised as a pivotal tool in this context. Laser cutting and engraving systems offer precision, repeatability, and automation that significantly reduce

material waste and generate uniformly fine residues. These byproducts are ideal for energy recovery, particularly in combustion or pelletisation processes. Furthermore, laser systems facilitate seamless integration with digital design tools, enabling rapid transitions between customized production runs and supporting Industry 4.0 frameworks. By bridging manufacturing efficiency and waste valorisation, laser technology positions itself as an essential driver of circular economy practices in the wood sector. This paper aims to analyse the synergy between laser processing and energy recovery from wood residues, exploring the technical, environmental, and social dimensions of this integration.

2. LITERATURE REVIEW

Recent scholarships underscore the urgency and potential of sustainable wood residue valorisation, particularly through advanced technologies. Lilonfe et al. (2026) provides a thorough review of thermochemical valorisation pathways such as gasification and pyrolysis, highlighting dual fluidized-bed gasification and sorption-enhanced gasification as mature techniques with high efficiency and the potential for net-negative greenhouse gas emissions. Encon Man et al. (2026) demonstrate the viability of solar-driven hydrothermal liquefaction, a process that converts moist wood waste into bio-oil with significantly reduced environmental impact. Aniszewska et al. (2024) explore how variations in CO_2 laser parameters affect residue surface chemistry, revealing opportunities to enhance residue quality for downstream energy applications.

The mechanisms underpinning laser–wood interactions have been synthesised by Ding et al. (2026), covering photothermal, photochemical, and photomechanical effects and their implications for residue control and functionalisation. The potential of laser-induced graphitisation is illustrated in Materials Research Bulletin (2025) and extended by research in Nano-Micro Letters (2026), which highlight how lignin-based laser-induced graphene (LIG) enables the conversion of wood residues into conductive carbon structures for energy storage and environmental applications. Additionally, the study of laser-scribed wood photo- absorbers demonstrates innovative dual-function systems for solar steam generation and electricity production, using laser-engraving to create photothermal graphite–Co_3O_4 layers. Kulig et al. (2022) examined the role of decentralized energy systems in rural areas, finding that the valorisation of forestry residues could support energy security and rural livelihoods while reducing transportation-related carbon emissions. García et al. (2023) highlighted the importance of optimizing forest residue supply chains, emphasising that logistics and preprocessing are pivotal for the economic viability of bioenergy projects.

The application of artificial intelligence and digital twins in sustainable bioenergy production has received considerable attention in recent years, with Lin et al. (2023) demonstrating that AI-driven process control can significantly improve efficiency and adaptability in dynamic supply chains. In terms of laser-based technologies, recent work by Spirin et al. (2025) provides a detailed analysis of laser cutting parameters for different wood species, showing that laser processing can influence not only residue particle size but also combustion reactivity and pellet quality. Silva and Sales-Contini (2025) present an overview of advances in laser materials and processing technologies, noting the potential for digital manufacturing to facilitate residue valorisation and product diversification.

Environmental assessment remains a central theme. Life cycle analyses (LCAs) and techno- economic evaluations suggest that coupling advanced residue processing (including laser

optimisation) with carbon capture or biochar production can drastically lower the carbon footprint of wood-based industries (Khatri et al., 2025; Lilonfe et al., 2026).

Li et al. (2026) review the use of laser-induced graphene (LIG) from lignocellulosic waste, illustrating a new frontier for converting wood residues into high-value functional materials for applications in energy storage and environmental sensing. Together, these studies underscore the multifaceted impact of integrating advanced process technologies—such as lasers—within the broader pursuit of a circular, low-carbon bioeconomy.

Further value is found in system-level reviews of biomass valorisation. The RSC Advances review (2025) outlines thermochemical pathways and the emerging role of AI in optimising bioenergy production, while a comprehensive systematic review published in Bioresource Technology (2025) explores a range of biomass waste-to-energy techniques, including pyrolysis, gasification, and hybrid systems, offering techno-economic and sustainability insights. These advancements collectively reinforce the strategic importance of integrating laser technologies within sustainable, circular wood-based energy systems. All these approaches are summarised in the following table 1.

Table 1: Summary of recent research on wood residue valorization and laser technologies

Study	Technology/Process	Key Findings	Reference Year
Lilonfe et al.	Dual fluidised-bed gasification, sorption-enhanced gasification	Net-negative GHG emissions, hydrogen yield 95%, methanol efficiency 78%	2026
EnconMan et al.	Solar hydrothermal liquefaction	83% bio-oil yield, GHG reduction of 89% compared to incineration	2026
Aniszewska et al.	CO_2 Laser Processing	Laser-tuned residues show 20% higher calorific value, better pelletization	2024
Ding et al.	Laser–Wood Interactions	LIG formation, tunable particle size for energy storage	2026
Materials Research Bulletin	Laser-Induced Graphitisation	Conductive carbon from wood residues; resistivity 1.5 Ω·cm	2025
Nano-Micro Letters	LIG from Lignin	Supercapacitor performance up to 112 F/g	2026

3. BASIC METHODS OF ENERGY UTILISATION FROM WOOD RESIDUES

Wood residues can be converted into energy through a spectrum of methods, each with specific technological, economic, and environmental implications. Direct combustion of wood waste in biomass boilers is the most established and globally widespread method, utilized in both industrial and district heating contexts. This process produces reliable heat and, through combined heat and power (CHP) systems, allows for electricity generation. The pelletisation and briquetting of sawdust and fine residues result in high-density fuels, which are easier to store, transport, and use in both small-scale and industrial heating systems. Thermochemical conversion techniques, particularly pyrolysis and gasification, have gained traction for their ability to yield not only syngas and bio-oil but also biochar, which can sequester carbon and improve soil health (Figure 2).

Emerging processes such as solar-driven hydrothermal liquefaction show promise for efficiently converting high-moisture residues into liquid biofuels. Life cycle assessments consistently show that energy recovery from wood residues, especially when paired with carbon capture or biochar production, can result in net-negative emissions and significant environmental benefits. The method chosen for energy conversion depends on the type, purity, and moisture content of the residue. Laser-generated residues—characterised by their fine particle size and low contamination—are particularly well-suited for direct combustion and pelletisation, requiring minimal pre-treatment.

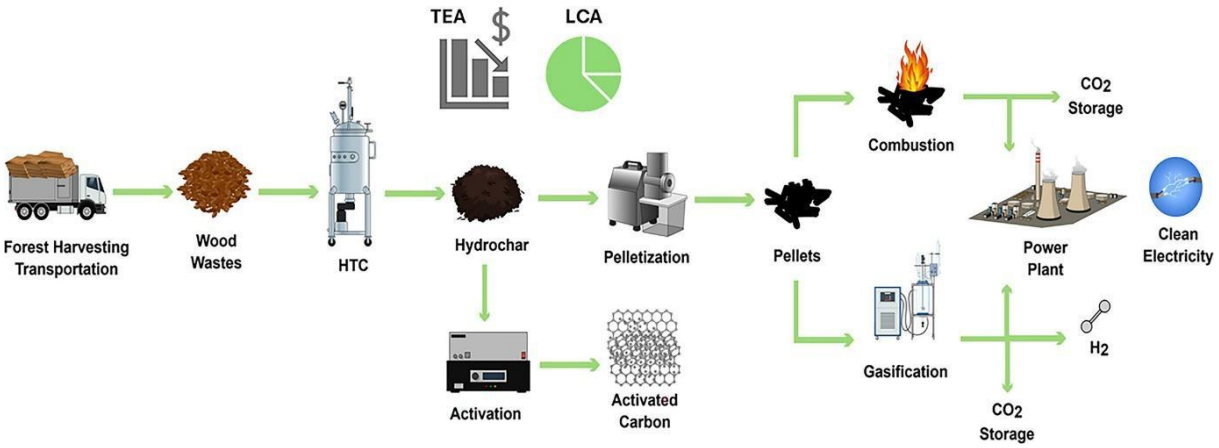


Figure 2: Flowchart comparing energy recovery methods from wood residues: direct combustion, pelletisation, pyrolysis, gasification, and hydrothermal liquefaction.
Source: https://ars.els- cdn.com/content/image/1-s2.0-S1385894725131306-ga1_lrg.jpg

Method	Typical Energy Yield (kWh/ton)	Suitable Residue Type	Moisture Content (%)	Emissions Reduction vs. Landfill (%)
Direct Combustion	4300	Fine, dry, low-ash	<15	85
Pelletisation	4900	Fine, uniform, low resin	<10	80
Pyrolysis	3,700 (bio-oil), 1,100 (biochar)	Homogeneous, low impurities	<12	90
Gasification	4,400 (syngas)	Uniform, well-dried	<10	92
Hydrothermal Liquefaction	5,300 (bio-oil)	High-moisture, shredded	30 – 60	89

Data for Table 2 adapted from: Bazargan, A., McKay, G., & Arami-Niya, A. (2021), Koppejan, J., & van Loo, S. (2021), Inayat, I., et al. (2025), Khatri, P., et al. (2025).

While each energy recovery method offers distinct advantages depending on residue quality and processing requirements, the ability to generate clean, fine, and uniform wood residues is a critical factor influencing both energy yield and conversion efficiency. Traditional

mechanical processing often produces heterogeneous byproducts with variable particle size and contamination, which can complicate downstream utilisation and require extra preprocessing. In contrast, advanced technologies such as laser-based cutting and engraving are increasingly recognised for their capacity to deliver highly consistent residue streams ideally suited for energy recovery pathways like combustion and pelletisation.

As the wood industry seeks to maximise both material efficiency and environmental benefits, the integration of laser technologies into processing workflows presents a promising route to optimize residue characteristics and support a circular, low-carbon economy. The following chapter explores the principles, types, and industrial applications of laser systems in wood and composite material processing, emphasizing their transformative impact on both manufacturing precision and residue valorization.

4. USE OF LASER TECHNOLOGIES IN WOOD & COMPOSITES MATERIALS PROCESSING

Laser technology has shifted paradigms in wood and composite processing by providing not just non-contact precision but also real-time digital control. The ability of lasers to create intricate cuts and engravings, combined with the absence of mechanical tool wear, leads to significant reductions in maintenance costs and downtime.

Among the various laser systems employed in wood and composite material processing, the most commonly used types are CO_2 lasers, fiber lasers, and, to a lesser extent, Nd:YAG (neodymium-doped yttrium aluminum garnet) lasers. CO_2 laser machines are by far the most prevalent in wood processing due to their high efficiency in cutting, engraving, and surface modification of organic materials. Operating at a wavelength of 10.6 μm, CO_2 lasers are highly absorbed by wood cellulose and lignin, enabling clean and precise cuts even at moderate power levels (typically ranging from 40 W for desktop engravers to over 1,000 W for industrial machines). These machines can process a wide range of wood thicknesses, generally up to 20–25 mm for cutting applications, and are favored for their smooth edge quality, minimal charring, and ability to engrave complex patterns. Many CO_2 laser systems used in industry are equipped with advanced cooling systems, high-speed galvanometric scanning heads, and automated worktables, enabling rapid transitions between different production tasks and seamless integration with CAD/CAM software (Silva & Sales-Contini, 2025; Spirin et al., 2025).

Fiber lasers, while more commonly associated with the processing of metals and synthetic materials, are increasingly gaining attention in the woodworking sector for their high beam quality, energy efficiency, and long operational lifetimes. Fiber lasers typically operate at shorter wavelengths (~1.06 μm), which results in different interactions with wood substrates compared to CO_2 lasers. While less efficient for deep cutting of organic materials, fiber lasers excel in high-precision surface marking, microstructuring, and processing of composite panels with polymeric additives. Their compact size, low maintenance requirements, and robust

design make them suitable for integration into automated production lines where multi- material processing is required. Nd:YAG lasers are less commonly used in mainstream wood manufacturing, but they are sometimes applied in specialized settings for fine marking, engraving, or where pulsed laser operation is desirable (Table 3).

Table 3: Common Laser Machine Types for Wood Processing and Their Characteristics

Laser Type	Typical Wavelength	Power Range (W)	Key Characteristics	Common Applications
CO_2 Laser	10.6 μm	40 – 1,000+	High absorption by wood, smooth edges, low charring, suitable for thick materials, widespread industrial use	Cutting, engraving, surface modification
Fiber Laser	~1.06 μm	20 – 500+	High beam quality, energy efficient, compact, low maintenance, precise marking, best for composites or thin materials	Surface marking, microstructuring, processing wood-plastic composites
Nd:YAG Laser	1.06 μm (pulsed)	10 – 200+	Pulsed operation, high peak power, precise engraving, less common for wood, specialized setups	Fine marking, detailed engraving, special effects

Data for Table 3 adapted from: Silva, F. J. G., & Sales-Contini, R. C. M. (2025), Spirin, O., Talykh, A., Chugin, V., & Syunev, V. (2025), Ding, Y., et al. (2026).

Each laser type offers a distinct combination of wavelength, power, spot size, and operational flexibility, and the selection is determined by the desired processing outcomes, material type, and production scale (Silva & Sales-Contini, 2025; Spirin et al., 2025; Ding et al., 2026).

Laser-generated residues are typically consistent in size, clean, and free from contaminants attributes that are highly advantageous for subsequent energy recovery or for conversion into advanced products (Table 4). Integration with CAD/CAM systems enables manufacturers to move seamlessly from digital design to production, supporting mass customisation and rapid prototyping.

Table 4: Comparison of residue characteristics: laser vs. mechanical processing

Parameter	Laser Processing	Mechanical Processing
Mean particle size (μm)	24	140
Ash content (%)	0.4	1.1
Calorific value (kWh/kg)	4.7	4.2
Pelletization suitability (score, 1–10)	9	6
Metal/contaminant content (ppm)	<5	35

Data for Table 4 adapted from: Aniszewska, M., et al. (2024), Materials Research Bulletin. (2025), Spirin, O., Talykh, A., Chugin, V., & Syunev, V. (2025), Štefančin, L., et al. (2025), Bazargan, A., McKay, G., & Arami- Niya, A. (2021).

Laser-induced graphitisation is particularly notable, as shown in Materials Research Bulletin (2025), enabling the conversion of wood residues into conductive carbon materials for energy storage and sensor applications. Laser-scribed wood photoabsorbers, as reported recently, enable dual-use energy systems for solar steam and electricity generation. Moreover, process optimization studies (e.g., Štefančin et al., 2025) have demonstrated that energy input, feed rate, and material density must be carefully balanced to maximise efficiency and maintain quality across different wood types and composite substrates.

4.1. PROS & CONS OF LASER COMPARED TO TYPICAL WOOD PROCESSING METHODS

Laser wood processing systems offer distinct advantages over mechanical cutting, including unmatched precision, reduced wear, lower maintenance costs, and rapid adaptation to changing product designs. The

digital control and automation inherent in laser systems enable higher productivity and mass customisation. The residues produced by laser systems are not only cleaner but also better suited for direct energy applications, such as combustion or pelletisation, without extensive preprocessing. This results in operational efficiencies and enhances the sustainability of the manufacturing process.

Nevertheless, the adoption of laser systems is not without challenges. The high initial capital investment for machinery, ventilation, and safety infrastructure remains a barrier for many companies, particularly SMEs (Table 5). Additionally, processing thicker or denser woods may require higher energy inputs or multiple passes, potentially reducing process efficiency. Skilled operators and technicians are essential for optimal system maintenance and process tuning. Safety risks—especially related to fine particulate emissions and fire hazards— necessitate advanced filtration, monitoring, and compliance with stringent regulations.

Table 5: Comparison of laser and mechanical methods in operational and environmental parameters

Parameter	Laser Processing	Mechanical Processing
Cutting Precision (mm)	0.1	1–2
Setup/Changeover Time (min)	5	20
Maintenance Frequency (per year)	2	15
Energy Use (kWh/m³ wood)	58	48
Operator Skill Level	High	Medium
Safety Risk (1=Low, 5=High)	3	2
Initial Equipment Cost CNC (€)	65000	55000

4.2. CHALLENGES & LIMITATIONS

While laser integration in wood processing brings environmental and operational advantages, several challenges persist. High capital and operational costs can restrict access to advanced laser systems, particularly for small and medium enterprises. Technical complexity and rapid innovation cycles necessitate ongoing training and upskilling of staff. Safety and regulatory compliance require significant investment in dust extraction, air filtration, and fire suppression

systems. In some markets, policy incentives or carbon credits may be necessary to offset the initial costs and encourage the transition to laser-enabled production.

Despite these barriers, the environmental and socioeconomic benefits are considerable. Laser- optimised residue recovery reduces landfill use and uncontrolled burning, directly lowering CO_2 and particulate emissions. By supporting regional energy self-sufficiency and enabling new circular value chains, laser processing can catalyse job creation in both high-tech manufacturing and the bioenergy sector. Socially, cleaner production processes and enhanced energy independence improve community health and resilience. LCA and techno-economic analyses (Khatri et al., 2025; Lilonfe et al., 2026) reinforce that the overall system can achieve net-negative emissions and substantial long-term cost savings when scaled appropriately.

5. CONCLUSIONS

Laser technology marks a transformative step for the wood industry by uniting high-precision manufacturing with sustainable residue management. Through the production of uniform, high-quality residues, laser systems enhance energy recovery options and support a transition toward circular, low-carbon economies. While challenges related to cost, complexity, and safety require targeted solutions and policy support, the long-term benefits—including reduced environmental impact, operational efficiency, and socioeconomic value—firmly establish laser-enabled systems at the forefront of future wood processing innovation. Advancing this integration will require further research into process optimization, AI- enhanced control, and expanded material compatibility, as well as collaboration across academia, industry, and policy.

The scientific and practical relevance of laser technology in the wood sector extends beyond the boundaries of cutting precision and automation. By generating residues with consistent characteristics, laser processing enhances the effectiveness of subsequent energy recovery processes such as combustion, gasification, and pelletization. The adaptability of laser systems to a wide range of wood and composite materials ensures that manufacturers can respond to shifting market demands and regulatory requirements with minimal downtime

and waste. Despite these promising developments, challenges remain. Economic barriers—particularly the high capital cost of laser systems and the need for skilled operators—must be addressed through targeted incentives, workforce development, and supportive policy frameworks. Furthermore, the continued advancement of digital manufacturing, AI-enhanced monitoring, and life cycle assessment will be crucial to quantifying and maximizing the sustainability benefits of these technologies at scale (Lin et al., 2023; Saleh et al., 2025).

The integration of laser processing into wood residue management represents a key opportunity for the wood sector to achieve both economic resilience and climate objectives. Through ongoing research, cross-sector collaboration, and policy alignment, the full potential of laser-enabled, circular wood industries can be realized, paving the way for a more sustainable and innovative bioeconomy.

Moreover, as demonstrated by the emerging field of laser-induced graphene and photothermal applications, laser-optimized residues may serve as feedstocks for entirely new classes of advanced materials (Li et al., 2026; Materials Research Bulletin, 2025).

REFERENCES

Lilonfe, M., et al. (2026). Circular thermochemical valorization of forest industrial residues: A 4E process safety and sustainability review. Process Safety and Environmental Protection.

EnconMan, J., et al. (2026). Solar-driven hydrothermal liquefaction of wood waste for bio-oil production. Energy.

Aniszewska, M., et al. (2024). Influence of CO_2 laser beam power and feed rate on the water contact angle of cut wood surfaces. European Journal of Wood and Wood Products.

Ding, Y., et al. (2026). Laser–wood interactions: From functionalization to sustainable wood processing. MRS Bulletin.

Štefančin, L., et al. (2025). Energy dose and specific cutting energy in CO_2 laser cutting of solid and engineered wood materials. Acta Facultatis Xylologiae Zvolen.

Saleh, Y., Ali, L., & Altarawneh, M. (2025). Recent advances in biomass valorization through thermochemical processes, bio-oil production and AI strategies: a concise review. RSC Advances.

Khatri, P., et al. (2025). Evaluating life cycle greenhouse gas emissions from alternative forest residue utilization: Energy and product pathways. Biomass and Bioenergy, 201, 108059.

Bazargan, A., McKay, G., & Arami-Niya, A. (2021). Energy recovery from biomass: A review of thermal conversion technologies and economic analysis. Renewable and Sustainable Energy Reviews, 135, 110152.

García, B. B., Suárez, C. A., et al. (2023). Optimization of forest residue supply chains for bioenergy. Forests, 14(2), 240.

Inayat, I., et al. (2025). Valorization techniques for biomass waste in energy generation: A systematic review. Bioresource Technology.

Koppejan, J., & van Loo, S. (2021). The Handbook of Biomass Combustion and Co-firing. Earthscan.

Kulig, R., et al. (2022). Decentralized energy from forestry residues: Techno-economic implications for rural development. Energy Policy, 168, 113121.

Li, Y., et al. (2026). Advances in laser-induced graphene from lignocellulosic biomass: Mechanisms and emerging applications. Nano-Micro Letters, 18, 32.

Lin, H., et al. (2023). Digital twins and AI for process optimization in sustainable bioenergy.

Bioresource Technology, 375, 128841.

Materials Research Bulletin. (2025). Laser-induced graphitization of softwood for conductive carbon layer formation. Materials Research Bulletin.

Silva, F. J. G., & Sales-Contini, R. C. M. (2025). Advances in laser materials and processing technologies: An overview. AIMS Materials Science, 12(1), 23–27.

Spirin, O., Talykh, A., Chugin, V., & Syunev, V. (2025). Study of parameters of laser cutting of soft and hard wood species using a CO_2 laser setup. Forestry Engineering Journal, 14(4), 208–221.

Session 7A | Contribution 1

GOLDEN SECTION EFFECT ON MECHANICAL PROPERTIES OF LIGHTWEIGHT STREET FURNITURE ELEMENTS

Tolga Kuskun[1], Jerzy Smardzewski[2]

[1]Muğla Sıtkı Koçman University, Faculty of Technology, Department of Woodworking Industrial Engineering, Muğla, Türkiye
e-mail: tolgakuskun@mu.edu.tr

[2]Poznań University of Life Sciences, Faculty of Forestry and Wood Technology, Department of Furniture Design, Poznan, Poland
e-mail: jsmardzewski@up.poznan.pl

ABSTRACT

In urban infrastructure, concrete and steel are widely used in production. However, manufacturing and utilization of street furniture result in a high carbon footprint. Construction sector uses approximately 45% of basic raw materials and produces more than 30% of all waste generated. To overcome this problem, low energy manufacturing processes will be developed for sandwich panels with low weight, sandwich cylindrical cell tubes. This research focuses on the design of lightweight energy-absorbing street furniture through the integration of auxetic geometries to enhance performance under static loading. Within the scope of the study, the energy absorption mechanisms of auxetic structure were investigated using small-scale specimens. In this context, re-entrant hexagonal honeycomb auxetic patterns were integrated both horizontally and vertically using two distinct approaches within cylindrical columns. In the first approach, the cross-section was divided into three equal layers to accommodate the pattern. In the second, the pattern was arranged by partitioning the cross-section into three layers based on the golden ratio. Four type of auxetic structure configurations with constant relative density were generated, incorporating radial and perpendicular to radial orientation. Circular samples were subjected to compression tests to determine the mechanical properties and auxetic responses of the cylindrical columns. In addition, numerical analyses were performed for each group using FEM algorithm to analyse the energy absorption and compared with experimental results. The data obtained within the scope of this study will serve as a guideline for the modelling of full-scale, lightweight street furniture with auxetic cross-sections and high energy absorption capacity.

Keywords: street furniture, auxetic cross-section, energy absorption, FEM, architectured, golden section.

1. INTRODUCTION

Street furniture comprises permanently installed urban infrastructure intended to improve the functionality, safety, comfort, and aesthetics of public spaces. Typical street furniture elements include benches, bus shelters, lighting columns, signposts, protective bollards, railings, and various supporting structures integrated into transport and recreational environments (Fig. 1). These components are continuously exposed to complex service conditions involving static and dynamic mechanical loads, wind actions, vandalism, accidental impacts, cyclic loading. Consequently, contemporary street furniture must combine high structural stiffness, impact resistance, durability, lightweight construction, ease of transportation and installation, and increasingly stringent sustainability.



Figure 1: Street furniture in Poznan

In these conditions of use, conventional street furniture elements such as concrete or steel poles should be replaced by lightweight, more durable and energy-absorbing cellular structures.

Cylindrical structures, in particular, are frequently employed in structural applications due to their advantageous geometric and mechanical properties, such as high strength, uniform load distribution, and high material efficiency. Incorporating auxetic patterns and characteristics into these structures significantly enhances their shear resistance and energy absorption capabilities (Gomes et al., 2023; Yuan et al., 2026). Nevertheless, the limited number of existing studies in the literature have reported that auxetic patterns enhance the mechanical properties, energy absorption, and vibration damping of cylindrical tubular structures (Dell et al., 2024; Qin et al., 2024; Zhang et al., 2021).

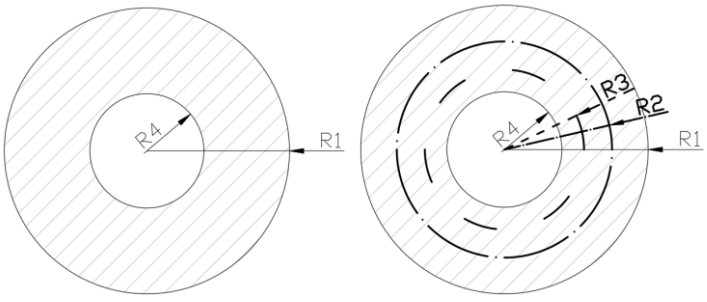
Using the golden ratio is an emerging trend in material design. While it is famous for creating visually pleasing geometry in art and architecture, very few studies have actually explored how this ratio affects the physical strength and mechanical properties of structures (Deng et al., 2026; Salelkar & Kandolkar, 2020).

This research focuses on the design of lightweight energy-absorbing street furniture through the integration of auxetic geometries to enhance performance under static loading. Within the scope of the study, the energy absorption mechanisms of auxetic structure were investigated using small-scale specimens. In this context, re-entrant hexagonal honeycomb auxetic patterns were integrated both horizontally and vertically using two distinct approaches within cylindrical columns.

2. EXPERIMENTAL METHODS

2.1. ARCHITECTURED TUBE CROSS-SECTION

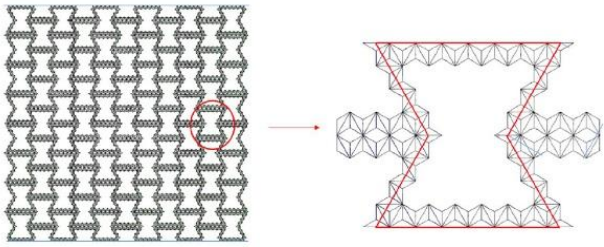
In the design phase of cylindrical tubes produced within the scope of the study incorporate two distinct parameters: inner and outer diameters. The cylindrical tubes were formed by integrating the patterns into the region between these two diameters (Fig. 2).



a. **b.**

Figure 2: a) Applied area of tubes patterns, b) 3 annular layers for periodic application

Figure 2 shows the tube's cross-section, which is divided into three layers to integrate auxetic patterns. The total design space lies between a fixed outer radius of 25 mm and an inner radius of 10 mm. Two design methods were used to divide this space: a Golden Ratio approach (where layer thicknesses shrink proportionally from outer wall to inner wall 9.27 mm, 3.54 mm, and 2.19 mm) and an Equidistant approach (where the space is split into three equal 5 mm layers). Ultimately, a re-entrant hexagonal honeycomb pattern was chosen because it flawlessly adapts to these circular boundaries under both design methods. (Fig. 3a).

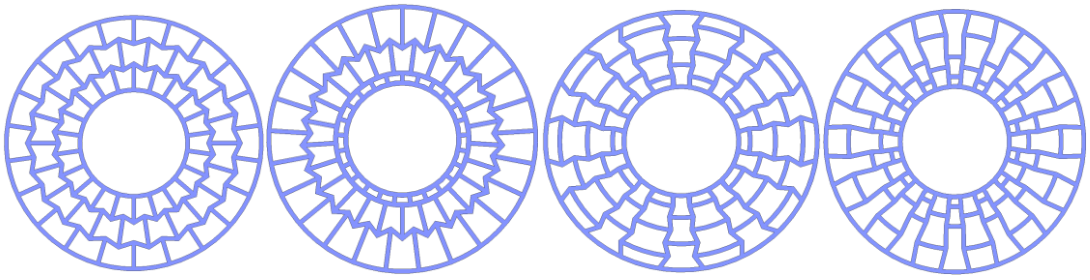


a. **b.**

Figure 3: a. Re-entrant hexagonal honeycomb auxetic pattern, b. Re-entrant hexagonal cell (Lian et al., 2023)

As shown in Figure 3b, the re-entrant hexagonal cells were implemented in both horizontal and vertical directions within the sections partitioned by the golden ratio and equidistant partitioning approaches. Accordingly, four different cylindrical tube configurations were developed, based on a combination of the two partitioning methods and two directions of the auxetic patterns.

Since a minimum of three layers is required to establish periodicity, a three-layer configuration was designed for this study and applied to the cross-section to have auxetic behavior. All cylindrical tubes produced possess an equal relative density. The cross-sectional views of the auxetic tubes are presented in Fig. 4.



a. H_C_08_22 **b. H_G_08_25** **c. V_C_08_10** **d. V_G_08_14**

Figure 4: Cross-section of auxetic tubes

In the codes shown in Figure 4, 'H' states that the re-entrant hexagonal shape is horizontal, and 'V' is vertical; 'C' indicates that the layer division approach is equal, and 'G' is with the golden ratio. The '08' found in the codes means that the wall thickness is 0.8 mm, and the numbers at the end of the code indicate the number of pattern repetitions. In this context, the cylindrical tubes were modeled based on five distinct parameters: the cross-sectional partitioning approach (equidistant, golden ratio), the orientation of the re-entrant hexagonal honeycomb pattern (horizontal, vertical), the number of pattern repetitions (n), the auxetic pattern wall thickness, and pattern inclination angle. Parameters used in models are presented in Table 1.

Table 1: Parameters of models

Parameter	Symbol	Unit	H_C_08_22	H_G_08_25	V_C_08_10	V_G_08_14
Partitioning approach	-	-	Equidistant	Golden ratio	Equidistant	Golden ratio
Orientation	-	-	Horizontal	Horizontal	Vertical	Vertical
Pattern repetitions	n	-	22	25	10	14
Wall thickness	t	mm	0.8	0.8	0.8	0.8
Inclination angle	f	rad	0.09π	0.08π	0.2π	0.14π

2.2. PRINTING TECHNOLOGY

Auxetics columns were prepared in the Fused Deposition Modeling (FDM) technology with 3D Zortrax inventure printer (Zortrax, Zajęcza, Warsaw, Poland). FDM method has recently been extensively utilized across various sectors engaged in additive manufacturing. Compared to conventional manufacturing methods, this technique generates less material waste and facilitates the faster and easier production of complex geometries. Polylactide (Z-PLA Pro; Zortrax, Warsaw, Poland) was utilized for production, selected for its compatibility with the 3D printer used in this study. The manufacturing parameters were set to a nozzle temperature of 210°C, a layer thickness of 0.15 mm, and an infill density of 100%.

2.3. MATERIAL PROPERTIES

The development and use of bio-based raw materials in production are becoming increasingly prevalent due to rising efforts to reduce carbon footprints and consumer preferences for eco-friendly products (Chen, 2014; Murariu et al., 2014; Murariu & Dubois, 2016). As a renewable and biodegradable material, PLA has found widespread application across numerous areas, including the furniture industry (Murariu & Dubois, 2016). PLA-based Z-PLA Pro was used in the manufacturing process to be compatible with the 3D printer used within the scope of the study. PLA Pro contains special additives that increase its mechanical properties compared to standard PLA. This situation makes PLA Pro more suitable for structures that require higher strength and durability (Boztepe, 2026; Kadhum et al., 2023).

Bending tests were performed to determine the PLA properties which used for the cylindrical tubes produced via 3D printing technology. In accordance with the ASTM-D0790 standard, the test specimens were produced using the identical 3D printer utilized for the tubes before undergoing the bending tests (Fig. 5).

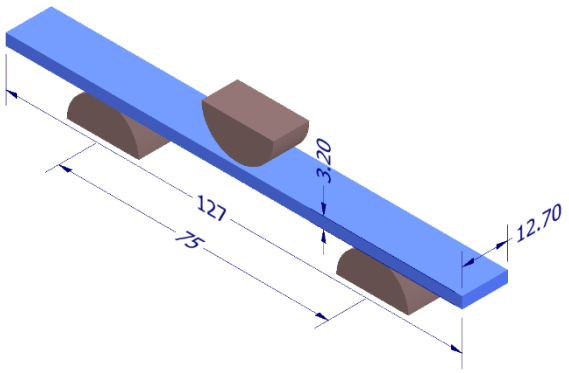


Figure 5: Bending test setup and dimensions (mm)

All parameters which obtained from bending test and used for FEM analyses are shown in Table 2. All data in Table 2 were obtained as a result of bending tests; only the Poisson's Ratio of PLA based materials is 0.35 was taken from previous studies in the literature (Aldosari et al., 2023; Boztepe, 2026; Ferreira et al., 2017).

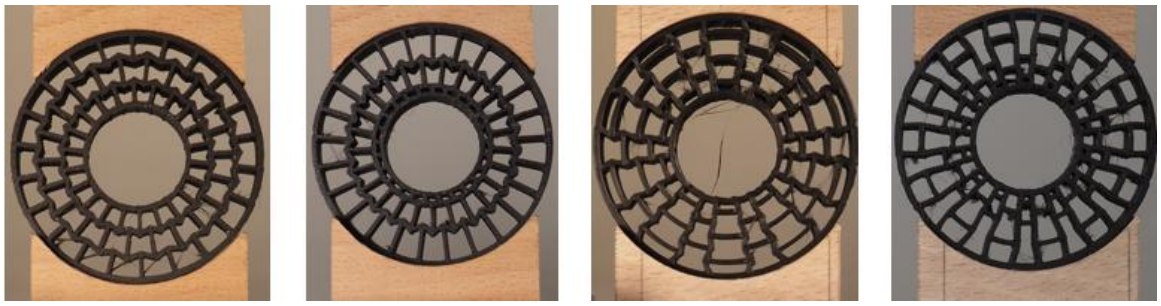
Table 2: Data obtained from bending tests used for the calibration of the FEM model.

Property	Unit	Mean	SD	V (%)
F max	(N)	90	6	6.2
h	(mm)	3.36	0.01	0.3
D	(kg/m3)	1290	9	0.7
MOE	(MPa)	3129	264	8.4
MOR	(MPa)	69.11	4.19	6.1
EA	(J)	1.14	0.15	13.0
SEA	(J/kg)	160.20	20.75	13.0
Poisson's Ratio	-	0.30	-	-

2.4. COMPRESSION TEST OF THE TUBES

In this research, four different groups of auxetic cylindrical tubes were produced with five replications each, and a total of 20 tubes were subjected to static compression tests. The compression tests were conducted by

placing wooden supports at both the top and bottom ends of the cylindrical tubes. These semi-circular wooden supports ensured the uniform compression of each specimen (Fig. 6).



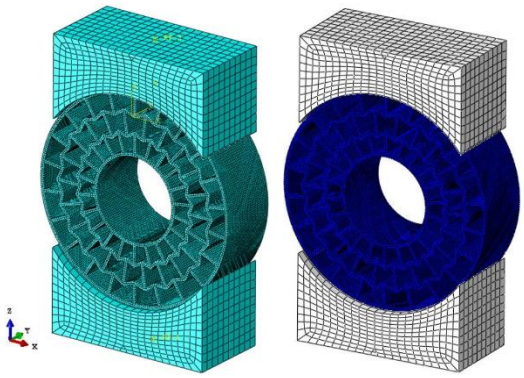
a. H_C_08_22 **b. H_G_08_25** **c. V_C_08_10** **d. V_G_08_14**

Figure 6: Auxetic cylindrical tubes and supports used in compression tests

According to the test results, load-displacement graphs were plotted and the deformation characteristics were compared with the FEM analysis results.

3. FEM METHODS

3D models were prepared using Autodesk Inventor Professional (2027), and corresponding FEM analyses were performed at the Poznań Supercomputing and Networking Center using the Eagle computing cluster and Abaqus (2025). In the FEM analyses, consistent with the experimental setup, rigid supports were placed at the top and bottom sides of the tubes. Simulations were performed by fix support at the bottom as boundary condition and applying a 5 mm displacement in the -z direction to the top support (Fig. 7a).



a. **b.**

Figure 7: Numerical model: a. Boundary condition b. Mesh used in analyses

In this study, following the evaluation of various mesh sizes for the calibration of the FEM analysis, the simulations were performed using a mesh size of 0.5 mm (Fig. 8b). The supports were modeled as rigid bodies using R3D4 4-node, 3-bilinear rigid quadrilateral elements, but elements were modeled by using C3D8R, an 8-node linear brick element with reduced integration and hourglass control. For the FEM calibration, individual analyses were conducted using mesh sizes of 0.30, 0.45, 0.50, 0.55, and 0.60 mm. The results demonstrated that mesh sizes between 0.30 – 0.6 mm did not significantly affect the analyses. In this context, a mesh size of 0.50 mm was selected to both reduce the solution time and achieve accurate calibration. Following the completion of the calibration phase, the finite element analyses were performed. During these simulations, force, deformation, von Mises stress, strain energy, and damage energy were calculated.

4. RESULTS AND DISCUSSION

Figure 8a shows that the HG model was the highest, handling a maximum force of 2200 N at a 2.5 mm deflection. The VG model came in second at around 1870-1880 N, making it 15% lower than HG. The HC and VC models were the lowest and showed almost identical results, both handling about 1550–1570 N. Overall, the HG model was roughly 40-42% higher than the HC/VC models, while the VG model was about 19-21% stiffer than them.

Therefore, the most favorable mechanical effect was achieved for the HG structure, i.e., auxetic cells with a horizontal orientation and a distribution consistent with the golden ratio. This means that the golden ratio geometric distribution significantly increased the radial stiffness of the tube. Horizontal orientation was more favorable than vertical orientation for the same distribution type, as HG > VG. In the case of the proportional distribution, the effect of cell orientation was small, as the HC and VC models achieved very similar force-deflection characteristics.

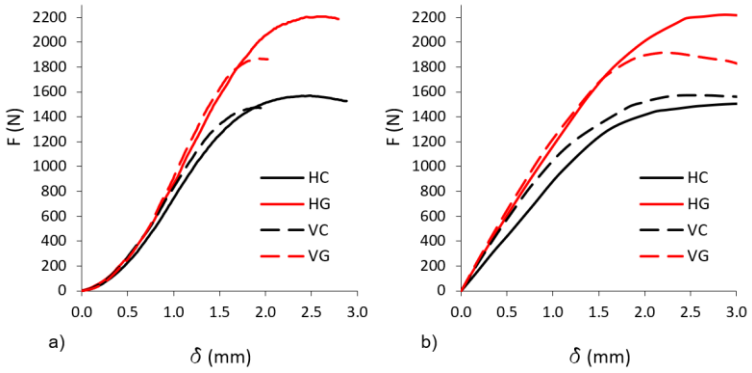


Figure 8: Force-displacement graphs a. Experimental results, b. FEM results

The numerical simulations (Figure 9b) successfully confirmed the experimental strength hierarchy: HG > VG > VC ≈ HC. The predictions were highly accurate when comparing simulated max forces to physical tests. The HG and VC models showed exceptional accuracy with a difference of 1% or less. The VG model had a minor deviation of 2–3%, while the HC model differed by only 3–5%. The only noticeable differences appeared early in the compression phase, where experimental curves were more non-linear. According to the literature, these minor percentage deviations between FEM and experiments are typical and caused by 3D printing flaws (Gong et al., 2026).

Figures 9a and 9b compare the simulated and experimental stress deformations. While all models reached similar maximum stress levels (roughly 83–91 MPa), the key difference was how this stress was distributed. In the golden ratio models (HG and VG), the high-stress zones (60–90 MPa) were spread evenly across the structure. This uniform load sharing explains why these models are stiffer and stronger. In contrast, the proportional models (HC and VC) suffered from highly concentrated stress spots, particularly near bending areas, making them less efficient at handling loads.

Cell orientation primarily influences the direction of stress band development. Horizontal variants exhibit greater activity in oblique and circumferential zones, while vertical variants involve radial elements more strongly. The HC and HG models deform more symmetrically about the loading axis, with a pronounced flattening of the ring in the compression direction and lateral deformation of the cellular structure. The HC model exhibits local rib bending and greater variation in individual cell deformation. The HG model maintains a more orderly form of deformation, with deformation distributed across a larger number of cells. In the VC and VG models, deformation is more radial. Vertical cells undergo greater bending and rotation along the direction of force. The VG model exhibits the most continuous, distributed deformation of the entire ring wall, while the VC model is characterized by a more localized deformation mechanism.

Qualitatively, it can be concluded that structures with a golden ratio distribution, particularly HG and VG, provide a more favorable deformation mechanism: more uniform, stable, and involving a larger portion of the cellular structure.

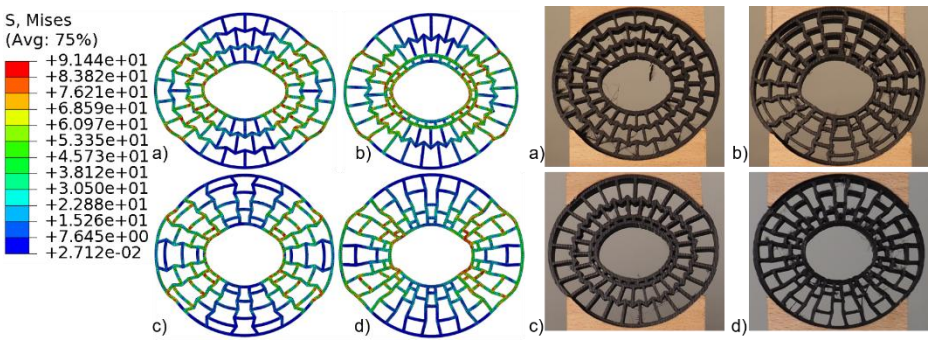


Figure 9: Comparison of deformation characteristics of experimental and FEM results. a. H_C_08_22, b.H_G_08_25, c.V_C_08_10, d. V_G_08_14

When comparing stress-strain values obtained from the FEM analyses for the tubes, results exhibit a similar trend to the force-displacement outcomes. Similarly, the HG group yielded the highest stress values, whereas the lowest stress values were obtained for HC group. This phenomenon is explained by the fact that among cylindrical tubes with equal relative cross-sectional areas, the tube bearing a higher load experiences greater stress (Fig 10).

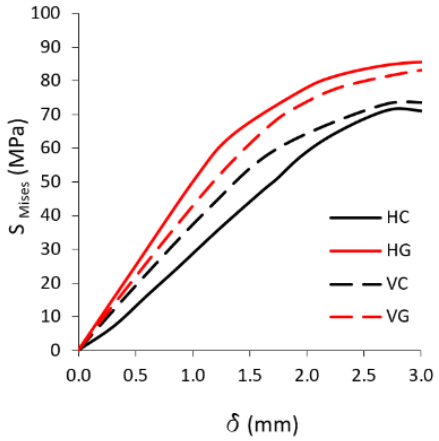


Figure 10: Stress-Deflection curve

When the findings of the study are examined, it is determined that the auxetic cylindrical tubes designed with the golden ratio provide higher stress values. This is in agreement with the limited number of papers in the literature regarding the effect of the golden ratio on structural properties. Specifically, studies conducted by Deng et al., (2026) and Salelkar & Kandolkar, (2020) have reported that designs incorporating the golden ratio yield higher stress values and enhanced load-carrying capacities in both metamaterials and structural elements.

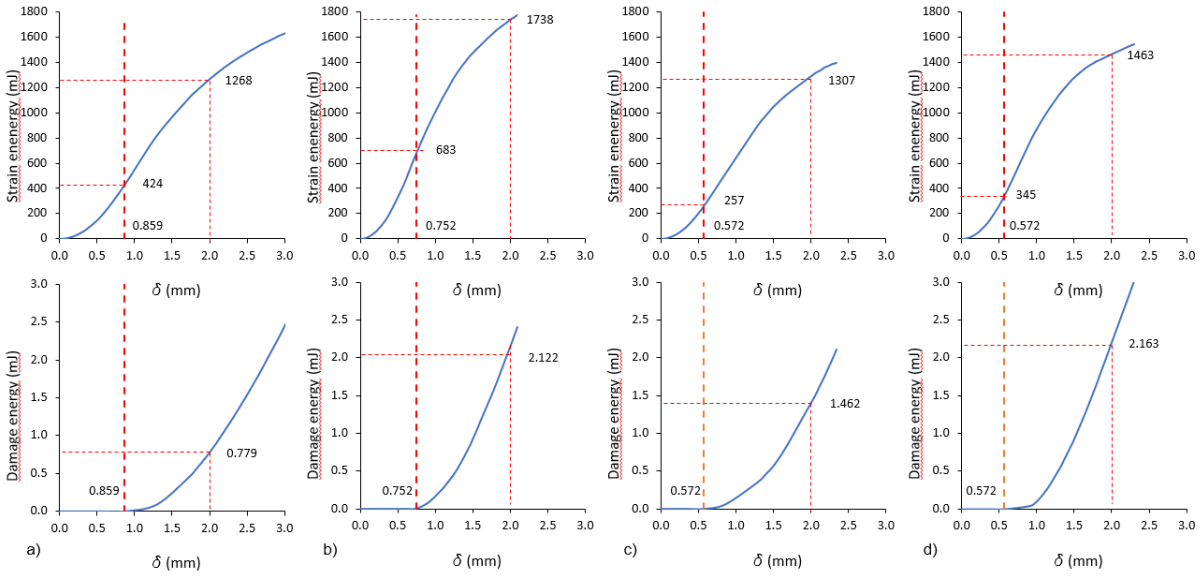


Figure 11: Energy curves. a. H_C_08_22, b. H_G_08_25, c. V_C_08_10, d. V_G_08_14

As seen in Fig. 11, the strain and damage energy trends for each model during compression. The HG model absorbs strain energy the fastest, reaching 1738 mJ at a 2.0 mm deflection. The VG model also shows high strain energy (1468 mJ at 2.0 mm), while the proportional models (HC and VC) absorb energy more gradually. Regarding damage energy, all models maintain low levels initially before a rapid increase. Notably, the VG model accumulates damage energy the most intensely, reaching the highest final value of all models at 3000 mJ, whereas the others peak between 2300 and 2500 mJ.

This indicates that the HG model has the greatest capacity for strain energy storage, confirming the beneficial effect of horizontal cell orientation and a distribution consistent with the golden ratio. The VG model also exhibits high strain energy, but is distinguished primarily by the highest damage energy. Structures with a distribution consistent with the golden ratio, i.e., HG and VG, achieve higher energy values than the corresponding proportional structures, HC and VC. This indicates that modifying the cell arrangement improves the tubes' ability to absorb energy during radial compression. HC exhibits the lowest intensity of damage energy accumulation, while VG exhibits the highest intensity. This means that the vertical arrangement with the golden ratio favors the development of degradation mechanisms while also providing the greatest ability to dissipate energy during the damage process.

5. CONCLUSIONS

The results of experimental research and numerical calculations allow us to formulate the most important conclusions and observations:

- The results clearly indicate that in circular structures, a cell distribution consistent with the golden ratio (G) increases the efficiency of radial load transfer and favors the mechanism of energy accumulation during compression.
- The horizontal orientation of cells (H) in the ring walls provided them with greater stiffness than the vertical orientation (V) of cells, which favors more intensive development of damage processes in the later stages of deformation of radially compressed rings.
- The deformation modes confirmed the influence of cell geometry on the ring deformation mechanism. The HG and VG structures deformed more uniformly, involving a larger number of cells in load transfer, while in the HC and VC models, deformation was more localized.
- The numerical analysis correctly reproduced the experimental results both qualitatively and quantitatively. The stiffness sequence of the analysed structures was identical (HG > VG > HC ≈ VC), and the differences between the experimentally obtained and numerically computed maximum force values did not exceed 5%, demonstrating the high reliability of the developed computational model.
- The presented results clearly indicate that the HG structure achieved the most favorable mechanical properties among the analyzed solutions, while the VG model distinguished itself by the greatest ability to dissipate energy through damage development. Both variants using the golden ratio cell arrangement

demonstrated better functional properties than the corresponding proportionally distributed structures, which was confirmed by both experimental tests and numerical analysis.

- It can be suggested that ring shapes such as HG and VG can be used to produce rigid, durable, and energy-absorbing cellular telecommunication poles, lighting poles, road signs, advertisements, and other fillings of urban space.

REFERENCES

ADDIN Mendeley Bibliography CSL_BIBLIOGRAPHY Aldosari, F., Khan, M. A. A., Asad, M., & Djavanroodi, F. (2023). Finite Element Analysis of PolyLactic Acid (PLA) under Tensile and Compressive Loading Finite Element Analysis of PolyLactic Acid (PLA) under Tensile and Compressive Loading. Journal of Physics, Conference. https://doi.org/10.1088/1742-6596/2468/1/012094

ASTM-D0790. (2008). Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. *ASTM*. https://doi.org/10.1520/D0790-07E01.2

Boztepe, M. H. (2026). Mechanical Characterization of PLA + Specimens with Different Geometries Using Experimental and Numerical Methods. Polymers, 1–21.

Chen, J. (2014). Global markets and technologies for bioplastics. BCC Research Report PLS050C.

Dell, A., Krynkin, A., Horoshenkov, K. V, & Sailor, G. (2024). Low frequency attenuation of acoustic waves in a perforated pipe. 1801(April 2015), 1791–1801. https://doi.org/10.1121/10.0017644

Deng, J., Wang, X., Zhao, R., Li, Z., Liu, K., Yuan, K., An, J., Li, X., Chua, C. K., & Wang, Z. (2026). Golden-Ratio – Guided Aperiodic Architected Metamaterials with Simultaneously Enhanced Strength and Toughness. Advanced Functional Materials, 16315, 1–11. https://doi.org/10.1002/adfm.202516315

Ferreira, R. T. L., Amatte, I. C., Dutra, T. A., & Daniel, B. (2017). Experimental characterization and micrography of 3D printed PLA and PLA reinforced with short carbon fibers. Composites Part B: Engineering, 124, 88–100.

Gomes, R. A., de Oliveira, L. A., Francisco, M. B., & Gomes, G. F. (2023). Tubular auxetic structures: A review. Thin-Walled Structures, 188, 110850. https://doi.org/https://doi.org/10.1016/j.tws.2023.110850

Gong, Q., Wang, D., Dong, Q., & Wang, H. (2026). Bending resistance and transverse energy absorption behaviors of auxetic tubes with orthogonal pattern of peanut-shaped perforations. Mechanics of Advanced Materials and Structures, 33(1). https://doi.org/10.1080/15376494.2025.2450079

Kadhum, A. H., Al-zubaidi, S., & Abdulkareem, S. S. (2023). Effect of the Infill Patterns on the Mechanical and Surface Characteristics of 3D Printing of PLA , PLA + and PETG Materials. Chemengineering, 7(46).

Lian, J., Xu, L., Wu, D., & Wang, Z. (2023). Study on re-entrant hierarchical honeycombs in-plane impact. Scientific Reports, 13(1), 21423. https://doi.org/10.1038/s41598-023-48356-2

Murariu, M., & Dubois, P. (2016). PLA composites : From production to properties. Advanced Drug Delivery Reviews, 107, 17–46. https://doi.org/10.1016/j.addr.2016.04.003

Murariu, M., Laoutid, F., Dubois, P., Fontaine, G., Bourbigot, S., Devaux, E., Campagne, C., Ferreira, M., & Solarski, S. (2014). Chapter 21 – Pathways to Biodegradable Flame Retardant Polymer (Nano)Composites (C. D. Papaspyrides & P. B. T.-P. G. F. R. Kiliaris (eds.); pp. 709–773). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-444-53808-6.00021-4

Qin, R., Liu, X., Wang, X., Niu, H., & Li, Q. (2024). Mechanical behavior and energy absorption of expansion circular tube with negative Poisson ’ s ratio. Alexandria Engineering Journal, 109(September), 638–654. https://doi.org/10.1016/j.aej.2024.09.080

Salelkar, V. A. S., & Kandolkar, S. (2020). A Study on ‘ Golden Ratio ’ (ϕ) and its ’ Implications in Structural Engineering. International Journal of Innovative Research in Science, Engineering and Technology, 9(8), 7698–7705.

Yuan, Y., Chang, Y., & Wang, H. (2026). Demand-driven inverse structural design of perforated auxetic tubes featuring dual tunability in stiffness and natural frequency. Mechanics of Advanced Materials and Structures, 33(1). https://doi.org/10.1080/15376494.2026.2674850

Zhang, C., Xiao, S.-H., Qin, Q.-H., & Wang, H. (2021). Tunable compressive properties of a novel auxetic tubular material with low stress level. Thin-Walled Structures, 164, 107882. https://doi.org/https://doi.org/10.1016/j.tws.2021.107882

Session 7A | Contribution 3

HUMAN-AI COLLABORATION IN INTERIOR DESIGN: ENHANCING DECISION-MAKING IN THE DESIGN PROCESS

Desislava Grigorova, Pavlina Vodenova

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
Department of Furniture Production, Faculty of Forest Industry
e-mails: desislava.grigorova@ltu.bg, p.vodenova@ltu.bg

ABSTRACT

The increasing integration of artificial intelligence (AI) in design practices is reshaping the interior design process, introducing new opportunities for collaboration between human designers and intelligent systems. Traditional design approaches rely heavily on subjective decision-making and iterative workflows, which can result in inefficiencies and inconsistent outcomes. This study examines the role of human-AI collaboration as a tool for enhancing decision-making in interior design. The research focuses on the interaction between designers and AI-based systems in key stages of the design process, including concept generation, spatial organisation and design evaluation. A comparative approach is applied to analyse differences between traditional and AI-assisted workflows. The findings suggest that AI technologies can support designers by providing data-driven recommendations, accelerating visualisation processes, and expanding the range of design alternatives. At the same time, human expertise remains essential for contextual interpretation, creative direction and final decision-making. The study highlights the potential of human-AI collaboration to improve the efficiency and quality of interior design processes while also addressing current limitations related to control, authorship and reliability of AI-generated outputs.

Keywords: interior design, artificial intelligence, human-AI collaboration, decision-making, design process.

1. INTRODUCTION

Interior design is a multidisciplinary process that requires the integration of aesthetic, functional, ergonomic, technical, economic and environmental considerations to create spaces that satisfy user needs and expectations while meeting project constraints. Throughout the design process, professionals continuously make decisions related to spatial organisation, material selection, lighting, furniture arrangement, colour schemes and user experience. These decisions are rarely independent, as each choice may influence the overall functionality, visual coherence, sustainability and feasibility of the final design solution. Consequently, decision-making represents one of the most critical and complex aspects of interior design practice.

Traditionally, design decisions have relied on the knowledge, experience and creativity of designers, supported by iterative design development and continuous communication with clients. While this human-centred approach enables contextual interpretation and creative problem-solving, it is often characterized by lengthy design iterations, subjective evaluation, and the exploration of a limited number of alternatives. As design projects become increasingly complex and client expectations continue to evolve, there is growing interest in technologies that can support designers in making faster, more informed, and evidence-based decisions (Karadag & Ozar, 2025; Ogawa et al., 2025)

Recent advances in artificial intelligence (AI), particularly in generative AI and machine learning, have introduced new opportunities for supporting initial stages of the interior design process (Tian, 2026). AI-powered systems can generate design concepts, recommend spatial layouts, produce realistic visualisations, analyse user preferences and assist in evaluating alternative solutions (Abdulaziz et al., 2025). Rather than functioning solely as automation tools, these systems increasingly act as intelligent decision-support technologies that complement human expertise by expanding design exploration and accelerating iterative workflows. Previous research has shown that AI can reduce repetitive tasks, improve design efficiency, and enable designers to evaluate a broader range of alternatives while maintaining creative control over the final outcome (Ronderos-Lopéz, 2026; Tian, 2026).

The growing adoption of AI has shifted the focus from automation towards human-AI collaboration, in which designers and intelligent systems contribute complementary capabilities throughout the design process. In collaborative workflows, AI primarily supports computationally intensive tasks such as concept generation, visualisation, optimisation, and information analysis, whereas designers remain responsible for interpreting

project requirements, evaluating AI-generated solutions, incorporating contextual knowledge, and making final design decisions (Baker et al., 2025; Çelik, 2026; Jiang, 2025; Tian, 2026; Zhang et al., 2025). Recent studies indicate that such collaboration can improve design efficiency and increase user satisfaction, particularly when AI is used by experienced professionals as a decision-support tool rather than an autonomous designer (Ogawa et al., 2025; Pathak et al., 2026; Tian, 2026). At the same time, research also demonstrates that AI-generated solutions require critical human evaluation and may be less effective when originality, contextual understanding, or highly novel design solutions are required. Furthermore, the effectiveness of collaboration is strongly influenced by designer expertise and the ability to critically interpret AI-generated outputs (Baker et al., 2025; Fares, 2025; Ogawa et al., 2025; Ronderos-Lopéz, 2026; Tian, 2026).

Despite the rapid development of AI applications used in design, much of the existing literature focuses on the technical capabilities of AI systems, individual design tools, or creative outcomes. Comparatively fewer studies examine how human-AI collaboration influences decision-making across the entire interior design process or provide a structured comparison between traditional human-centred workflows and AI-assisted approaches (Baker et al., 2025; He et al., 2023; Li & Yang, 2025; Tian, 2026; Wang et al., 2024). This indicates a need for a broader understanding of how AI contributes to different stages of design decision-making while preserving the essential role of human creativity and professional judgement.

Therefore, this study aims to investigate the role of human-AI collaboration in supporting decision-making throughout the interior design process by comparing traditional and AI-assisted design workflows. The analysis focuses on three key stages of the design process: concept generation, spatial organisation and design evaluation. Through a comparative analysis of current research, the study identifies the respective contributions of human designers and AI systems, discusses the advantages and limitations of collaborative decision-making and proposes a conceptual framework that illustrates how human expertise and artificial intelligence can complement one another within contemporary interior design practices.

2. METHODOLOGY

This study adopts a qualitative research approach based on a structured review of recent literature and conceptual comparative analysis. The objective is to examine how human-AI collaboration influences decision-making throughout the interior design process by comparing traditional design workflows with AI-assisted approaches.

The analysis is based on peer-reviewed publications addressing artificial intelligence in design, human-AI collaboration, decision support and interior design. In addition to the existing body of literature, empirical studies specifically investigating human-AI collaboration in interior design were examined to identify current trends, reported benefits, limitations, and patterns of collaborative decision-making (Baker et al., 2025; Li & Yang, 2025; Tian, 2026; Wang et al., 2024). The reviewed studies included experimental research, case studies, mixed-methods investigations and comparative evaluations involving professional designers, students and end users.

To facilitate comparison, the interior design process was divided into three decision-making stages that consistently appear in the reviewed literature: concept generation, spatial organisation and design evaluation. These stages were selected because they represent key phases in which designers make decisions that directly influence the quality, functionality and usability of interior spaces (He et al., 2023; Jiang, 2025; Tian, 2026). The comparative analysis was conducted using five evaluation criteria derived from the reviewed literature: efficiency of the design process, generation of design alternatives, support for decision-making, level of human control and limitations and implementation challenges.

The findings from the selected studies were synthesised and interpreted to identify common patterns regarding the complementary roles of human designers and AI systems. Rather than evaluating the performance of individual AI tools, the analysis focuses on understanding how collaboration between human expertise and artificial intelligence contributes to more effective decision-making throughout the interior design process. The general structure of the traditional and AI-assisted workflows analysed in this study is presented in Figure 1.

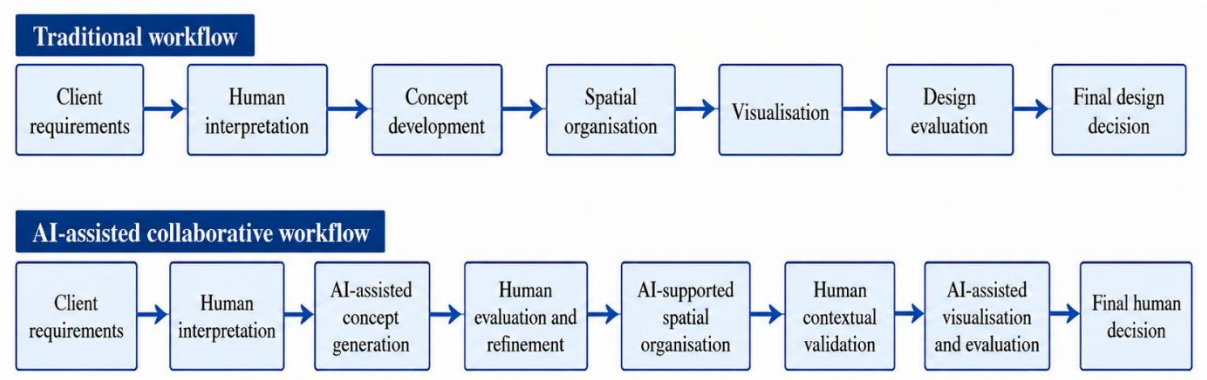


Figure 1: Traditional and AI-assisted interior design workflows

3. RESULTS AND DISCUSSION

3.1. AI-ASSISTED CONCEPT GENERATION

Concept generation represents the initial stage of the interior design process, during which designers transform client requirements into preliminary design ideas and explore alternative solutions. Traditionally, this phase relies on professional experience, creative thinking and iterative sketching to develop concepts that satisfy both functional and aesthetic objectives. Although this human-centred approach encourages originality and contextual interpretation, it is often time-intensive and constrained by the designer's individual experience and the number of alternatives that can be realistically explored within project deadlines (Jiang, 2025; Li et al., 2024; Swift & Chattopadhyay, 2024; Walton et al., 2025; Wang et al., 2024).

The introduction of generative AI has significantly changed this stage of the design process. Contemporary AI systems are capable of producing multiple design concepts from textual prompts, reference images, sketches, or user preferences within a relatively short period (He et al., 2023; Luo, 2025; Tian, 2026; Walton et al., 2024). Rather than replacing creative thinking, AI enables designers to rapidly explore a broader design space and evaluate a greater number of potential solutions before selecting concepts for further development (Jiang, 2025; Li et al., 2024; Swift & Chattopadhyay, 2024; Walton et al., 2025; Wang et al., 2024). This expansion of design alternatives has been consistently identified as one of the primary advantages of AI-assisted workflows (Tian, 2026; Walton et al., 2024; Walton et al., 2025).

The reviewed studies indicate that the role of AI in concept generation is predominantly supportive rather than autonomous (Alharthi, 2025; Pathak et al., 2026; Tian, 2026). AI contributes by generating visual concepts, suggesting stylistic directions, and assisting with early-stage ideation, while designers remain responsible for defining project objectives, formulating prompts, evaluating generated alternatives, and selecting concepts that satisfy functional, aesthetic, and contextual requirements (Alharthi, 2025; Pathak et al., 2026; Tian, 2026). This complementary distribution of responsibilities reflects a collaborative decision-making process in which computational capabilities enhance, rather than replace, professional judgement. At the same time, the literature emphasises that the quality of generated concepts depends heavily on human guidance, including the ability to formulate effective prompts, interpret AI-generated outputs, and critically evaluate proposed solutions (Naqvi et al., 2025; Tholander & Jonsson, 2023; Tian, 2026). Experienced designers generally achieve better outcomes because they are more capable of identifying relevant alternatives and integrating them into coherent design proposals (Li et al., 2024; Tian, 2026).

Despite the advantages, AI-assisted concept generation also presents several limitations. Current systems frequently generate visually convincing but contextually inappropriate solutions, may reproduce existing design patterns rather than highly original concepts, and often require multiple iterations before satisfactory results are achieved (Baker et al., 2025; Li & Yang, 2025; Naqvi et al., 2025; Park et al., 2024; Tian, 2026; Verheijden & Funk, 2023).

3.2. AI-ASSISTED SPATIAL ORGANISATION

Following concept generation, designers translate initial ideas into functional spatial solutions by determining room layouts, circulation paths, furniture arrangement and the harmony between different interior elements. Decisions made during this stage directly influence the usability, comfort, accessibility and overall functionality of the designed space. Traditionally, spatial organisation relies on professional experience,

knowledge of ergonomic principles, building regulations and continuous evaluation of alternative layouts. This iterative process often requires multiple revisions to balance client requirements, spatial constraints, and aesthetic considerations (He et al., 2022; Ji & Yu, 2025; Wan et al., 2024; Wang et al., 2024).

Recent advances in artificial intelligence have introduced new possibilities for supporting spatial organisation through data-driven analysis and optimisation. AI-assisted systems are capable of generating alternative layouts, analysing spatial relationships, identifying potential conflicts and recommending design solutions based on predefined constraints or user preferences (He et al., 2022; Pathak et al., 2026; Wang et al., 2024). Rather than replacing designers, these systems function as decision-support tools that enable faster exploration of layout alternatives while reducing the time required for repetitive planning tasks (He et al., 2022; Pathak et al., 2026; Wang et al., 2024).

The reviewed literature indicates that AI contributes most effectively when handling computationally intensive analyses, such as evaluating multiple layout configurations or optimising space utilisation according to functional requirements (Pathak et al., 2026; Wang et al., 2024). Designers, however, remain responsible for interpreting project-specific constraints, assessing the practicality of AI-generated layouts, and ensuring that proposed solutions satisfy ergonomic standards, client expectations, and contextual requirements (He et al., 2022; Pathak et al., 2026; Wang et al., 2024). This collaborative workflow combines the analytical capabilities of AI with the contextual knowledge and professional judgement of human designers, leading to more informed spatial decisions.

Despite the benefits, current AI systems continue to exhibit certain limitations. The reviewed studies report challenges related to spatial rationality, ergonomics, cultural preferences, and contextual understanding (He et al., 2022; Wang et al., 2024). AI-generated layouts may optimise measurable criteria while overlooking qualitative aspects such as user behaviour, emotional experience, or project-specific requirements (He et al., 2022; Wang et al., 2024). Consequently, human validation remains an essential component of the decision-making process. These findings reinforce that the greatest value of AI lies in supporting evidence-informed spatial decision-making rather than replacing professional expertise.

3.3. AI-ASSISTED DESIGN EVALUATION

Design evaluation represents the final stage of the interior design process, during which alternative solutions are assessed before a final design proposal is selected. At this stage, designers evaluate whether proposed concepts satisfy functional, aesthetic, ergonomic, technical, economic, and client-specific requirements. Unlike concept generation or spatial organisation, design evaluation relies heavily on critical thinking, professional judgement and contextual understanding, making it the stage where human expertise remains most essential.

AI supports design evaluation by providing rapid visualisations, generating alternative design scenarios, analysing user preferences and identifying potential design inconsistencies (Pathak et al., 2026; Tian, 2026; Wang et al., 2024). These capabilities enable designers to compare multiple solutions more efficiently and facilitate communication with clients by presenting realistic visual representations during the decision-making process (Lin et al., 2026; Wang et al., 2024). Rather than replacing professional judgement, AI expands the information available to designers, allowing decisions to be based on a broader range of alternatives and objective analyses.

The reviewed literature consistently demonstrates that human designers remain responsible for validating AI-generated outputs and selecting the final design solution (Baker et al., 2025; Li & Yang, 2025; Tian, 2026). AI-generated recommendations often require careful interpretation to ensure that they satisfy project-specific constraints, client expectations, cultural preferences, and contextual requirements.

Several studies further report that AI-assisted evaluation improves collaboration between designers and clients (Ronderos-Lopéz, 2026; Tian, 2026). Interactive visualisations allow clients to better understand proposed solutions, provide feedback earlier in the design process, and participate more actively in decision-making (Ronderos-Lopéz, 2026; Tian, 2026). This iterative exchange may reduce misunderstandings, shorten revision cycles and contribute to higher satisfaction with the final design outcome.

Despite these advantages, current AI systems are unable to fully assess qualitative aspects such as emotional responses, cultural meaning, personal preferences, or project-specific design intentions (Li et al., 2024; Luo, 2025; Naqvi, 2025; Park et al., 2024; Walton et al., 2025). Moreover, AI-generated recommendations may reflect biases within training data or favour commonly occurring design solutions rather than contextually

appropriate alternatives (Luo, 2025; Rathore & Thakkar 2025). Consequently, final responsibility for evaluating alternatives and approving design solutions continues to rest with human designers, who integrate technical knowledge, creativity, ethical considerations, and client communication into the decision-making process (Naqvi et al., 2025; Tholander & Jonsson, 2023; Tian, 2026). The reviewed literature therefore suggests that AI functions most effectively as an intelligent decision-support system, while the authority and accountability for final design decisions remain fundamentally human.

3.4. COMPARATIVE ANALYSIS OF HUMAN-ONLY AND HUMAN-AI COLLABORATIVE DECISION-MAKING

The comparative analysis demonstrates that the primary contribution of artificial intelligence in interior design is not the replacement of human designers but the enhancement of decision-making through complementary collaboration. Across all stages of the interior design process, AI contributes computational capabilities such as rapid concept generation, spatial optimisation, information processing and visualisation, while human designers provide contextual interpretation, creative direction, professional expertise and final judgement (Baker et al., 2025; Çelik, 2026; Jiang, 2025; Tian, 2026; Zhang et al., 2025).

During concept generation, AI enables designers to explore a substantially larger number of design alternatives within a shorter period compared to traditional workflows. This broader exploration supports creative thinking by exposing designers to multiple stylistic and functional possibilities that may not emerge through conventional brainstorming alone. Nevertheless, the reviewed studies indicate that originality and conceptual coherence continue to depend on human creativity and the ability to critically evaluate AI-generated proposals (Baker et al., 2025; Vo, 2025; Zhou et al., 2025). Consequently, AI functions primarily as a catalyst for ideation rather than as an independent creative agent.

A similar distribution of responsibilities is evident during spatial organisation. AI systems efficiently analyse layout alternatives, optimise spatial configurations and identify potential design constraints, thereby reducing the time required for repetitive planning activities (He et al., 2023; Luo, 2025; Tian, 2026; Walton et al., 2024). However, the interpretation of spatial relationships, ergonomic requirements, user behaviour and project-specific constraints remains dependent on professional judgement. Human designers therefore act as decision-makers who validate AI-generated recommendations before incorporating them into the final design solution.

The strongest evidence for complementary collaboration emerges during design evaluation. AI facilitates rapid comparison of alternatives, supports client communication through realistic visualisations, and provides additional analytical information that assists the evaluation process (Pathak et al., 2026; Tian, 2026; Wang et al., 2024). However, final approval of design solutions consistently remains a human responsibility because many evaluation criteria, including aesthetics, cultural appropriateness, emotional response, ethical considerations and client expectations, cannot be assessed solely through computational analysis.

The reviewed literature further indicates that the effectiveness of human-AI collaboration is influenced by several moderating factors. Designer expertise plays a particularly important role, as experienced professionals generally demonstrate greater ability to formulate effective prompts, interpret AI-generated outputs and integrate computational recommendations into coherent design solutions (Li et al., 2024; Tian, 2026). Conversely, novice designers may experience increased cognitive load when evaluating numerous AI-generated alternatives or may rely excessively on AI suggestions without sufficient critical assessment (Luo, 2025; Naqvi et al., 2025). These findings suggest that AI should be understood as a professional decision-support technology whose effectiveness depends on the knowledge and judgement of its users rather than on autonomous system performance.

Overall, the comparison between traditional and AI-assisted workflows suggests that the greatest value of AI lies in augmenting human capabilities rather than automating professional decision-making. Effective collaboration combines the computational efficiency of AI with the contextual understanding, creativity and ethical responsibility of human designers. Consequently, interior design is evolving towards a model of collaborative intelligence in which humans and AI contribute complementary strengths to achieve higher-quality design outcomes.

The main differences between the two approaches are summarised in Table 1, which compares human-only and human-AI collaborative workflows across key decision-making dimensions.

Table 1: Comparative analysis of human-only and human-AI collaborative decision-making in interior design

Decision-making dimension	Human-only workflow	Human-AI collaborative workflow
Concept generation	Designer relies on personal creativity, experience, precedent studies and manual ideation.	AI rapidly generates multiple alternatives, while the designer evaluates, selects and refines concepts.
Spatial organisation	Layout planning is based on manual analysis, professional experience and iterative revisions.	AI suggests layout alternatives and optimisation options, while the designer validates ergonomics, context and functionality.
Design evaluation	Designer assesses aesthetics, functionality, client needs and feasibility.	AI provides visualisations and analytical support, while the designer makes the final decision.
Exploration of alternatives	Limited by time, experience, and project resources.	Broader exploration through rapid generation of multiple options.
Decision-making speed	Moderate, often dependent on several rounds of revision.	Higher due to AI-supported analysis, visualisation, and iteration.
Creativity	Potentially higher originality and stronger contextual interpretation.	Greater diversity of ideas, although originality depends on human refinement.
Human involvement	Full responsibility throughout all stages of the design process.	Shared workflow with AI support, but final responsibility remains human.
Overall role of AI	Not applicable.	Decision-support technology that augments human expertise.

4. CONCLUSION

The integration of artificial intelligence in interior design is reshaping the way design decisions are generated, evaluated and refined. Rather than functioning as an autonomous replacement for designers, AI increasingly serves as an intelligent decision-support technology that complements human expertise throughout the design process. The findings of this study demonstrate that collaborative workflows combining human judgement with AI capabilities offer significant advantages over traditional human-only approaches in terms of efficiency, exploration of design alternatives and support for evidence-informed decision-making.

The comparative analysis reveals that AI contributes most effectively during concept generation, spatial organisation, and design evaluation by rapidly generating alternatives, analysing design options, and supporting visual communication with clients. However, the literature consistently indicates that human designers remain responsible for interpreting project requirements, evaluating AI-generated outputs, integrating contextual knowledge and making final design decisions (Baker et al., 2025; Çelik, 2026; Jiang, 2025; Tian, 2026; Zhang et al., 2025). Creativity, professional judgement, ethical responsibility and contextual understanding continue to represent uniquely human capabilities that cannot currently be replicated by artificial intelligence.

The study also highlights that the effectiveness of human-AI collaboration depends on several factors, including designer expertise, project complexity and the ability to critically evaluate AI-generated recommendations. While experienced designers can successfully integrate AI into their workflows to improve productivity and design quality, less experienced users may encounter challenges related to prompt formulation, interpretation of AI outputs and increased cognitive load (Baker et al., 2025; Pathak et al., 2026; Tian, 2026). These findings suggest that the successful adoption of AI in interior design requires not only technological development but also the acquisition of new professional competencies that enable effective collaboration between designers and intelligent systems.

Overall, the results support the view that the future of interior design lies in collaborative intelligence rather than design automation. AI should be understood as a technology that augments human capabilities while designers continue to guide the creative process and retain responsibility for final decisions. Consequently, the greatest value of AI emerges not from replacing human creativity but from strengthening the quality and

efficiency of decision-making through meaningful collaboration between human expertise and artificial intelligence.

This study is limited by its reliance on published literature and conceptual comparative analysis rather than empirical validation in professional design practice. Future research could evaluate the proposed collaborative decision-making framework through experimental studies involving professional interior designers, compare the performance of different AI-assisted design tools across specific project types and investigate how designer experience influences the effectiveness of human-AI collaboration in real-world design environments.

REFERENCES

Alharthi, S. A. (2025). Generative AI in Game Design: Enhancing Creativity or Constraining Innovation? Journal of Intelligence, 13(6), 60. DOI: https://doi.org/10.3390/jintelligence13060060

Baker, M., Kirk, D.,and Blythe, M.(2025) Human-AI Collaboration in Interior Design Education: GPT-Assisted Creativity and Innovation, in Chang, C.-Y., Chen, C.-H., & Hsu, Y. (eds.), IASDR 2025: Design Next, 02-05 December, Taipei, Taiwan. https://doi.org/10.21606/iasdr.2025.706

Çelik, T. (2026). A Generative AI–Based Decision-Support Framework for Early-Stage Architectural Design: Evidence from Sustainable Tiny Houses. Argumentation Based Systems Journal, 2, pp.175–192. doi:https://doi.org/10.59543/nnc2a471.

Fares, G. (2025). Integrating AI in the Creative Process: A Case Study in Interior Design Education. Art and Design Review, 13(02), pp.140–158. doi:https://doi.org/10.4236/adr.2025.132010.

He, F., Huang, Y. and Wang, H. (2022). iPLAN: Interactive and Procedural Layout Planning. 2022 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR). doi:https://doi.org/10.1109/cvpr52688.2022.00764.

He, Z., Li, X., Fan, L., Wang, H.J. (2023). Revamping Interior Design Workflow Through Generative Artificial Intelligence. In: Stephanidis, C., Antona, M., Ntoa, S., Salvendy, G. (eds) HCI International 2023 Posters. HCII 2023. Communications in Computer and Information Science, vol 1835. Springer, Cham. https://doi.org/10.1007/978-3-031-36001-5_78

Ji, Z. and Yu, Y. (2025). Intelligent Interior Design Systems: Optimizing Layouts and Aesthetics Using AI and User Data. IEEE Access, 13, pp.135127–135137. doi:https://doi.org/10.1109/access.2025.3591135.

Jiang, J. (2025). Enhancing interior design and space planning via human–machine intelligent interaction for artistic cognition. Sci Rep 15, 32344. https://doi.org/10.1038/s41598-025-15520-9

Karadağ, D. and Ozar, B. (2025). A new frontier in design studio: AI and human collaboration in conceptual design, Frontiers of Architectural Research, Volume 14, Issue 6, 2025, Pages 1536-1550, ISSN 2095-2635, https://doi.org/10.1016/j.foar.2025.01.010.

Li, J., Cao, H., Lin, L., Hou, Y., Zhu, R. & Abdallah, A. (2024). User Experience Design Professionals' Perceptions of Generative Artificial Intelligence. DOI: https://doi.org/10.1145/3613904.3642114

Li, Y. and Yang, Z.(2025). An AIGC-Integrated Platform and Interior Design Workflow, in Chang, C.-Y., Chen, C.-H., & Hsu, Y. (eds.), IASDR 2025: Design Next, 02-05 December, Taipei, Taiwan. https://doi.org/10.21606/iasdr.2025.103

Lin, Y.C., Chen, C.-Y., Hou, K.-H., Chen, H.-Y. and Kuo, P.-C. (2026). AIDED: Augmenting Interior Design with Human Experience Data for Designer-AI Co-Design. arXiv.org. [online] doi:https://doi.org/10.1145/3772318.3791378.

Luo, Y. (2025). Designing With AI: A Systematic Literature Review on the Use, Development, and Perception of AI-Enabled UX Design Tools. Advances in Human-Computer Interaction, 2025(1). DOI: https://doi.org/10.1155/ahci/3869207

Naqvi, S.M., He, R. & Kaur, H. (2025). Catalyst for Creativity or a Hollow Trend?: A Cross-Level Perspective on The Role of Generative AI in Design. Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems, pp.1–16. DOI: https://doi.org/10.1145/3706598.3713233

Ogawa, N., Okafuji, Y., Hatada, Y. and Baba, J. (2025). Understanding Collaboration between Professional Designers and Decision-making AI: A Case Study in the Workplace. Proc. ACM Hum.-Comput. Interact. 9, 7,Article CSCW505 (November 2025), 26 pages, https://doi.org/10.1145/3757686

Park, H., Eirich, J., Luckow, A. & Sedlmair, M. (2024). 'We Are Visual Thinkers, Not Verbal Thinkers!': A Thematic Analysis of How Professional Designers Use Generative AI Image Generation Tools. Nordic Conference on Human-Computer Interaction, 1–14. DOI: https://doi.org/10.1145/3679318.3685370

Pathak, Mr.K., Yadav, M.S. and Sircar, M.S. (2026). THE ROLE OF ARTIFICIAL INTELLIGENCE IN TRANSFORMING INTERIOR DESIGN: A COMPREHENSIVE ANALYSIS. EPRA International Journal of Multidisciplinary Research (IJMR), p.985. doi:https://doi.org/10.36713/epra27947.

Rathore, N.S.,and Thakkar, S.(2025) From Jugaad to Generative AI: A Framework for Culturally Responsive Human-Centered AI, in Chang, C.-Y., Chen, C.-H., & Hsu, Y. (eds.), IASDR 2025: Design Next, 02-05 December, Taipei, Taiwan. https://doi.org/10.21606/iasdr.2025.537

Ronderos-Lopéz, D. (2026). Augmented Designer. The International Journal of Design Education. doi:https://doi.org/10.18848/2325-128x/cgp/a328.

Swift, I.P. & Chattopadhyay, D. (2024). A Value-Oriented Investigation of Photoshop’s Generative Fill. arXiv (Cornell University). DOI: https://doi.org/10.48550/arxiv.2404.17781

Tholander, J. & Jonsson, M. (2023) Design Ideation with AI – Sketching, Thinking and Talking with Generative Machine Learning Models. Conference on Designing Interactive Systems. DOI: https://doi.org/10.1145/3563657.3596014

Tian, J. (2026). From Rendering to Decision: A Process-Based Framework of Interior Design Judgement in Human–AI Co-creation. International Journal of Culture and History, 13(1), p.120. doi:https://doi.org/10.5296/ijch.v13i1.23804.

Verheijden, M.P. & Funk, M. (2023) Collaborative Diffusion: Boosting Designerly Co-Creation with Generative AI. Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems. DOI: https://doi.org/10.1145/3544549.3585680

Vo, K.H.T. (2025) ‘“Who” designs better? A competition among human, artificial intelligence and human–AI collaboration’, Design Science, 11, p. e37. doi:10.1017/dsj.2025.10029.

Walton, S.P., Evans, B.J. & Rahat, A.A.M. (2024) Does mapping elites illuminate search spaces? A large-scale user study of MAP-Elites applied to human-AI collaborative design. arXivorg (Cornell University). DOI: https://doi.org/10.48550/arXiv.2402.07911

Walton, S.P., Evans, B.J., Rahat, A.A.M., Stovold, J. & Vincalek, J. (2025). From Metrics to Meaning: Time to Rethink Evaluation in Human–AI Collaborative Design. ACM Transactions on Interactive Intelligent Systems. DOI: https://doi.org/10.1145/3773292

Wan, Z., Tang, J., Cai, L., Tong, X. and Liu, C. (2024). Breaking the Midas Spell: Understanding Progressive Novice-AI Collaboration in Spatial Design. [online] arXiv.org. Available at: https://arxiv.org/abs/2410.20124.

Wang, S.-Y., Su, W.-C., Chen, S., Tsai, C.-Y., Misztal, M., Cheng, K.M., Lin, A., Chen, Y. and Chen, M.Y. (2024). RoomDreaming: Generative-AI Approach to Facilitating Iterative, Preliminary Interior Design Exploration. doi:https://doi.org/10.1145/3613904.3642901.

Zhang, Z., Shen, D. and Li, Y. (2025). Interactive Genetic Algorithm with Convolutional Neural Network-based Filtering for Personalized Interior Space Design. 2025 4th International Conference on Distributed Computing and Electrical Circuits and Electronics (ICDCECE), pp.1–8. doi:https://doi.org/10.1109/icdcece65353.2025.11035135.

Zhou, X., Kim, S. and Ma, S. (2025). Exploring Indoor Design Process Strategies Using AI Agents Based on the CMS Model. Proceedings of the 2025 International Conference on Artificial Intelligence, Virtual Reality and Interaction Design, pp.65–72. doi:https://doi.org/10.1145/3777730.3777742.

Session 7A | Contribution 5

DESIGN INNOVATIONS IN ECCLESIASTICAL FURNITURE: ERGONOMIC AND AESTHETIC PREFERENCES IN GREEK ORTHODOX CHURCH STALLS FOR THE ELDERLY

Ioannis Bothos[1], Michalis Skarvelis[1], Konstantinos Ninikas[1]

[1] Department of Forestry, Wood Sciences & Design, University of Thessaly, Greece
e-mails: ibothos@uth.gr, skarvelis@uth.gr, kninikas@uth.gr

ABSTRACT

Designing furniture for elderly citizens represents a field of significant interest, particularly regarding the use of ecclesiastical stalls during Orthodox Church services. Despite their frequent use by elderly congregants, there is a lack of studies focusing on the design and usability of this specific furniture type. Present research examines how design features can be incorporated to enhance the ergonomic and aesthetic experience of elderly users. The study adopts a mixed-methods approach, including a literature review, participatory field observation, and digital data collection using a 3D scanner (Creality Scan 1) to analyse users' interaction with the stalls. Qualitative data were also gathered through semi-structured interviews, and the resulting variables were analyzed statistically with SPSS. Furthermore, three-dimensional STL files generated from CAD design programmes, which were utilised to create descriptive visualisations of stall design variations. As part of the research, 12 church stalls with distinct constructional and aesthetic design differences were designed, diverging from pre-existing models. In present case study 33 elderly users (23 men and 10 women), were participating each with approximately two years of experience using these stalls, offering informed perspectives on design, aesthetics, ergonomics, and functionality. The findings highlight key design elements that can enhance the comfort and satisfaction of older users in the context of traditional church seating.

Keywords: Ergonomics, Furniture Design for the Elderly, Church Stall Design, 3D Scanner.

1. INTRODUCTION

Elderly people represent a highly diverse group, exhibiting significant heterogeneity in terms of economic status, health conditions, and personal beliefs. In Greece, previous research (Skarvelis & Bothos, 2025) has shown that the use of furniture among older adults is shaped by a variety of factors, including established usage habits and the broader socio-cultural environment. When designing furniture for public spaces frequented by a large population of older adults, it is crucial to consider the unique and varied needs that stem from this diversity. The furniture must be adaptable and sensitive to the differences within this age group to ensure comfort, accessibility, and safety. Despite these requirements, studies indicate that elderly individuals in Greece often find themselves using furniture that is not specifically designed for their age group (Kamberidou & Barboutis, 2017; Kamperidou, 2017; Bothos & Skarvelis, 2021). As a result, they are frequently compelled to adjust themselves to furniture that fails to accommodate their specific needs and preferences. This mismatch can lead to discomfort and even pose health risks, highlighting the importance of developing age-appropriate furniture solutions in public spaces

2. INFUENCES AND DESIGN ON FURNITURE FOR THE ELDERLY

Personalised approaches to furniture manufacturing are increasingly recognised as essential for addressing the diverse needs of users. While the principles of inclusive and participatory design (Bjerknes & Bratteteig, 1995) and universal design establish important guidelines for accommodating a wide range of users, there is a growing necessity to provide even greater individual satisfaction by tailoring furniture to each user's unique requirements.

Demographic shifts, particularly in Europe and more acutely in Greece, underscore this need, as there is a significant and ongoing increase in the elderly population (individuals over 65 years old) (Eurostat, 2024). Numerous studies investigating factors that enhance the quality of life for older adults have focused on aspects of daily living, including the use and accessibility of furniture (Hrovatin et al., 2012; Klos et al., 2014; Jonsson & Sperling, 2010; Nikopoulos, 2010). When designing furniture for individuals with atypical or extreme body types, practitioners typically rely on statistical data. Standard practice involves targeting the design to accommodate from the 5th percentile (representing the smallest segment, often women) to the 95th percentile

(the largest segment, often men) of the population, thereby serving at least 90% of potential users. Kaewdok et al. (2022) recommend that these 5th and 95th percentile values, determined through anthropometric measurements, be systematically integrated into the functional design characteristics of spaces and furnishings intended for elderly users. Similar conclusions have been drawn by Beer et al. (2017), who advocate for an ergonomic design range encompassing the 5th to 95th percentiles when creating products for a general or "anonymous" user base. Comparable methodologies have also been outlined in the earlier work of Openshaw et al. (2006).

3. CHURCH STALLS AND OTHER PRAYER FURNITURE IN LITERATURE

Among the furniture most commonly used by elderly individuals in Greece are church stalls, a type of ecclesiastical furniture integral to Orthodox religious services (Barboutis & Vasileiou, 2013). The existing literature on church stalls is relatively limited. According to Makris (1982), these stalls are typically situated along the longitudinal walls of the church and between the columns that delineate the aisles. Featuring high backs and dual-purpose armrests—serving both as elbow supports and for general comfort—church stalls are specifically designed to assist older congregants in participating more comfortably in sacred services. Contemporary observations reveal that the use of church stalls has diversified, reflecting a range of applications beyond their traditional roles. Historically, church stalls originated in monasteries before becoming common in parish churches. The high backrest is intended to support worshippers who are standing, often terminating in semicircular forms. The armrests are designed with two levels: one for use while standing and another used in seating position. Additionally, church stalls often vary in size and decorative carving according to the hierarchical status of their users. Dimensional analysis indicates that the overall height of church stalls ranges from 130 cm to 170 cm, with seat heights between 45 cm and 48 cm. The seat depth varies from 18 cm to 26 cm, while the internal width ranges from 44 cm to 52 cm. Middle armrests are generally positioned at a height of 76 cm (with a range of 75–80 cm) (Barboutis & Vasileiou, 2013). Comparable research has been conducted internationally, broadening the understanding of religious seating. For example, Pollák and Török (2022) conducted a structural analysis of an existing chair design, integrating advanced design technologies such as the Creo Parametric 7.0 Generative Design system. In their study, an existing chair was digitally modeled and subsequently modified to meet specific structural requirements and design constraints. These processes included the application of calculated loads, the introduction of measurable structural constraints, and the assessment of mechanical strength for individual components. Notably, the armrests were produced using 3D printing technologies with precise specifications. Similar approaches to the modernization and adaptation of religious seating have been documented in other studies focused on prayer seats (Nigrum et al., 2020; Zawawi et al., 2021).

4. EXPERIMENTAL METHODS

Many similar studies in the literature (Ito et al., 2020; Jonsson, 2013; Nigrum et al., 2020; Wang et al., 2024) use case studies to investigate in depth mainly the beliefs and opinions of elderly furniture users. These studies mainly use existing users in order to examine in depth their relationship with the furniture they use in their daily lives. Also, in other studies (Fabisiak et al., 2014; Fabisiak & Klos, 2012) qualitative methodology and thematic analyses are used to approach this specific age group. With an emphasis on the users' experience, other studies collected data using questionnaires that focused on questions about the people's experience with their home furniture (Hrovatin et al., 2012). In studies such as those of Ito et al. (2020) and Nikopoulos (2010), the importance of participatory observation is emphasised in the design approach process regarding elderly people.

For the present study's research approach, 12 new church stalls (Type A) were constructed with constructional and aesthetic differences compared to the pre-existing furniture in space (Fig. 1).



Figure 1: Part of Church stalls which were designed and manufactured for this research.

The description and characteristics of type A construction are presented in Table 1. Tables 2 and 3 below list the other two types of seats (B, C) that previously existed in the hall, but they were completely reconstructed (by means of finish and structural stability) due to their age and in order to be able to compare them with the new ones that were installed. The new type A is available in colors X1 (light brown), X2 (medium brown) and X3 (dark brown) and differs, among other things, mainly in the seat depth (upper and lower sitting position), in the different armrest heights (upper, lower and standing position), and a different design with simple turned and carved elements. Also, in type A there is the possibility of two intermediate sitting positions, which do not exist in types B and C.

Table 1: Type A church stalls (new constructions).

Specimen (Type: A)	Seat depth [cm]	Seat width [cm]	Seat height [cm]	Seat depth [cm] (upper position)	Seat width [cm] (upper position)	Seat height [cm] (feet on the auxiliary mat)	Armrest height [cm] (sitting position)	Armrest height [cm] (standing position)
X1 (Light brown colour)	50.00	50.50	51.00	26.00	38.00	54.00	74.50	106.00
X2 (Medium brown colour)	50.00	50.50	51.00	26.00	38.00	54.00	74.50	106.00
X3 (Dark brown colour)	50.00	50.50	51.00	26.00	38.00	54.00	74.50	106.00



Figure 2: Type A church stalls: (from left to right: X1, X2, X3)

Table 2: Type B church stalls (existing construction).

Specimen (Type: B)	Seat depth [cm]	Seat width [cm]	Seat height [cm]	Seat depth [cm] (upper position)	Seat width [cm] (upper position)	Seat height [cm] (feet on the auxiliary mat)	Armrest height [cm] (sitting position)	Armrest height [cm] (standing position)
X2 (Medium brown colour)	25.5	49.00	50.50	N/A	N/A	N/A	81.50	111.50

N/A (Non-Applicable)



Figure 3: Type B church stall: X2 (existing construction).

Table 3: Type C church stalls (existing construction).

Specimen (Type: B)	Seat depth [cm]	Seat width [cm]	Seat height [cm]	Seat depth [cm] (upper position)	Seat width [cm] (upper position)	Seat height [cm] (feet on the auxiliary mat)	Armrest height [cm] (sitting position)	Armrest height [cm] (standing position)
X3 (Dark brown colour)	21	42.50	52.50	N/A	N/A	N/A	82.00	112.00



Figure 4: Type C church stall: X3 (existing construction).

Elderly people who use the furniture were invited to respond to a semi-structured interview regarding their experience of using the seats (stalls). The case study sample consisted of 23 men and 10 women who had tested (at least the majority of them) the seats (3 different types) for long periods of time (the new seats -Type A- had been placed in full use in the space for approximately 2 years until the completion of the research) and have formed an opinion in the areas of aesthetics, ergonomics and functionality. The research is based on a literature

review and participatory field observation by the researchers. The study tools are the construction characteristics of the three types (A, B, C) and a 3D scanner (creality scan 1) which were the basis of data collection for the 33 users (digital data collection for analysis). The results of the qualitative process of the semi-structured interview were evaluated by analysing the variables obtained with the statistical programme SPSS. Also, the three-dimensional STL files that resulted from the CAD design programs were used for descriptive visualisations.

The new structures were placed in the area in April 2023, after on-site observation and repair of the existing structures (2022-2023). By the time the research was completed, in March 2025, the new seats had completed approximately two years of use in the field. Due to the lack of familiarity of participating people with the technology used (difficulty in accepting scanning with a 3D scanner), this research presented particular difficulty in approaching the target group, which completed a special consent form to accept the scan. This is also evident from the results, in which from the sample (N=33 people) only 20 people consented to the scanning process (see research results). Also, the selection of the target group was carried out after on-site observation of the area that was fulfilled in a long period of time. Finally, among the limitations of the research, the exceptional lack of literature on this specific issue should be highlighted. In order to address scanning issues and special configuration of the space, a pilot process was carried out between September-October 2024 to resolve problems in the approach. Figure 5 shows one of the pilot's efforts of 3D scanning.

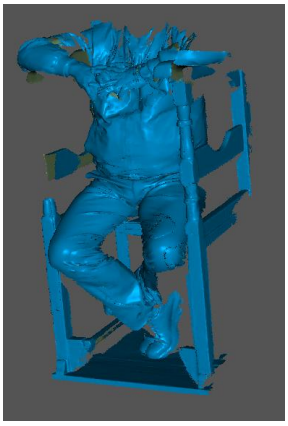


Figure 5: STL file created (using CR Studio programme) for further processing.

5. RESULTS AND DISCUSSION

5.1. STATISTICAL METHODOLOGY

The continuous variables used in the study are described through the measures of central position (mean and median) as well as the measures of dispersion (standard deviation, minimum and maximum value), while the qualitative variables are described as number and percentage. Then, the normality hypothesis for the quantitative variables was tested, as the choice of appropriate statistical tests is determined based on the strength or not of the specific hypothesis. The normality hypothesis of the variables was tested using Kolmogorov-Smirnov, for samples of more than 30. The hypotheses tested are of the following form: H0: The distribution of the data does not differ from the normal distribution H1: The distribution of the data differs from the normal distribution. If the p-value is less than 0.05 ($p<0.05$), the null hypothesis is rejected and the question category does not follow the normal distribution, while if the p-value is greater than 0.05 ($p>0.05$), then the question category follows the normal distribution. To test the equality of the mean values of two samples, the non-parametric Mann-Whitney procedure was used, which does not assume the normality of the data. Finally, the Pearson X^2 test was performed to evaluate possible differences between two qualitative variables. The condition required by the X^2 independence test is that the expected cell frequencies are at least equal to 5. When this assumption is not satisfied, then the p-values calculated based on the Fisher's exact test are tested. The statistical analysis in the context of this paper was performed in the IBM SPSS Statistics 25.0 statistical program. In addition, $p< 0.05$ was used as the level of statistical significance.

5.2. DESCRIPTIVE FEATURES

Table 4 presents the basic demographic characteristics of the participants. The majority of respondents were male (69.7%, N=23), with a mean age of 67.06 (10.45) years, a mean height of 171.15 (7.79) cm and a mean

weight of 82.24 (14.24) kg. Regarding physical illnesses/motor problems, only 21.2% (N=7) stated that they had any. Regarding the educational level of the sample, 72.7% (N=24) have completed secondary education, 21.2% (N=7) primary education and 6.1% (N=2) higher education. Regarding income, 80% (N=8) of respondents stated that they receive <10,000€, while only 20% (N=2) receive <20,000€. Finally, most participants were married (78.8%, N=26), followed by widowers with a percentage of 12.1% (N=4) and singles (9.1%, N=3).

Table 1: Demographic characteristics of respondents (N=33).

		Number	**%**
Gender	*Male*	23	69.7
	Female	10	30.3
Age	*Mean (Std.Deviation)*	67.06(10.45)	
Hight	*Mean (Std.Deviation)*	171.15(7.79)	
Weight	*Mean (Std.Deviation)*	82.24(14.24)	
Educational level	*Primary*	7	21.2
	Secondary	24	72.7
	Higher	2	6.1
Income	*<10000*	8	80.0
	<20000	2	20.0
Physical ailments /mobility problems	*Yes*	7	21.2
	No	26	78.8

According to the given answers (Table 5), the participants stated that they tried all three types of seats available in the Church (84.8%, N=28) and considered Type A to be the most comfortable (100%, N=33) with satisfactory construction quality (100%, N=33). The majority of respondents claimed that they did not feel pain in any parts of the body after prolonged use (87.9%, N=29), the dimensions of the seat were satisfactory (87.9%, N=29), the heights of the armrests were in the appropriate position (84.8%, N=28), the two different positions of the seat (Type A) were equally ergonomic (81.8%, N=27), the armrests of the seat had satisfactory dimensions (length, width, geometry) (97%, N=32).

Table 5: Descriptive characteristics regarding the church stalls chosen by the individuals.

		Number	**%**
Have you tried all three types of seats available in the field?	*Yes*	28	84.8
	No	5	15.2
Which type do you find more comfortable?	*Type A*	33	100
Is the construction quality satisfactory? Does the furniture provide you with a sense of security?	*Yes*	33	100
Do you feel pain in some parts of your body after prolonged use?	*Yes, in back*	3	9.1
	Yes, in legs	1	3
	No	29	87.9
Are the seat dimensions satisfactory (seat height, width, depth)?	*Yes*	29	87.9
	No, the seats are deep	3	9.1
	No, the seats are high	1	3
Are the armrest heights in the appropriate position?	*Yes*	28	84.8
	Wrong dimension on the upper arm of the seat	1	3

		Number	%
	No	2	6.1
	The lower ones are not	2	6.1

The shade they would choose was mostly medium brown (X2) (45.5%, N=15), the finish (gloss) of the furniture meets their aesthetic preferences (97%, N=32) and they would choose a similar style of furniture for their home (84.4%, N=27). Following, the respondents claimed that they generally prefer wood as the construction material for seats (97%, N=32), medium (X2) and light brown (X1) colors (42.4%, N=14), respectively (Table 6).

Table 6: Descriptive characteristics regarding the church stalls chosen by the individuals.

		Number	%
If you were choosing a piece of furniture for your home, would you choose this specific shade?	*No*	1	3
	Light brown(X1)	13	39.4
	Medium brown (X2)	15	45.5
	Dark brown (X3)	4	12.1
The finish (gloss) of the furniture meets your aesthetic preferences?	*yes*	32	97
	No	1	3
Would you choose such a furniture style for your home?	*Yes*	27	84.4
	No	3	9.4
	More modern	1	3.1
	In combination with decoration	1	3.1
What material do you prefer for furniture construction?	*Wood*	32	97
	Metall/Plastic	1	3
Of the different colors present in the furniture in this particular space, which shade do you prefer?	*Light brown*	14	42.4
	Medium brown	14	42.4
	Dark brown	5	15.2

Table 7 presents the Pearson x^2 test to evaluate possible differences in the choice of furniture shade in relation to the age of the participants. According to the results, no statistically significant relationship was observed (x^2= 5.740, p-value= 0.102) between the age of the respondents and the choice of shade.

Table 7: Pearson X2 test results to assess potential differences in furniture color choice in relation to age.

		AGE			
		50 – 65 y.o.	**> 65 y.o.**	**X^2 value**	**p-value**
If you were choosing a piece of furniture for your home, would you choose this specific shade?	*No*	1(5.9%)	0(0%)	5.740	0.102
	X1	7(41.2%)	6(40%)		
	X2	5(29.4%)	9(60%)		
	X3	4(23.5%)	0(0%)		

Table 8 presents the non-parametric Mann-Whitney U test to investigate possible differences in the height of the participants in relation to their degree of satisfaction with the seat dimensions (height, width, depth). Based

on the results, no statistically significant differences were observed in the answers given by the respondents (Mann-Whitney U = 48.500, p – value= 0.599).

Table 8: Results of the Mann-Whitney U test for evaluating differences in participants' height in relation to their degree of satisfaction with the seat dimensions (height, width, depth).

	Are the seat dimensions satisfactory (seat height, width, depth)?	N	Median	Mean Rank	Mann-Whitney U	p-value
Height	*Yes*	29	170.0	16.67	48.500	0.599
	No	4	172.5	19.38		

Table 9 presents the non-parametric Mann-Whitney U test to investigate possible differences in participants' weight in relation to their degree of satisfaction with the seat dimensions. Based on the results, no statistically significant differences were observed in the answers given by the respondents (Mann-Whitney U = 43.500, p-value = 0.423).

Table 9: Results of the Mann-Whitney test for evaluating differences between participants in relation to their degree of satisfaction with the dimensions of the seat.

	Are the seat dimensions satisfactory (seat height, width, depth)?	N	Median	Mean Rank	Mann-Whitney U	p-value
Weight	*Yes*	29	82.0	17.50	43.500	0.423
	No	4	78.0	13.38		

Table 10 presents the non-parametric Mann-Whitney U test to investigate possible differences in the participants' height in relation to their desire to make changes to the specific furniture. Based on the results, no statistically significant differences were observed in the answers given by the respondents (Mann-Whitney U = 85.00, p-value =0.370).

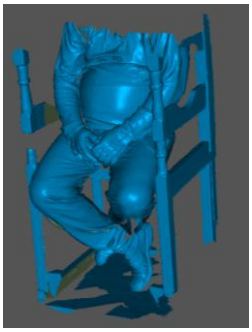
Table 10: Results of the Mann-Whitney U test for the desire for changes in furniture in relation to height.

	If you wanted to make any changes to this particular piece of furniture, what would it be?	N	Mean Rank	Mann-Whitney U	p-value
Height	*With no changes*	24	170.00	85.00	0.370
	With changes	9	175.00		

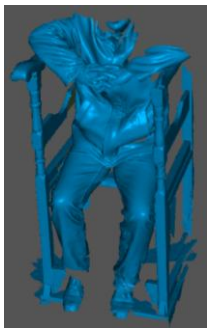
5.3. DIGITAL DISPLAY OF THE RESULTS

Table 11 presents the visual results of the individuals who agree to be scanned while using the furniture. The files presented in image format in the table below have been exported in 3D STL or OBJ model format with corresponding evaluation capabilities provided by these models at a 1:1 scale. During the scanning process, individuals were asked to remain in the posture they considered most comfortable (they were placed in immobility for approximately 20 min). The scan was performed in a sitting position and most of them appear not to touch their lower extremities on the pedestal but nevertheless consider the use of the furniture comfortable.

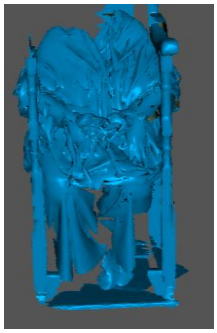
Table 11: Digital representation of the individuals who took part in the research (random order of users).



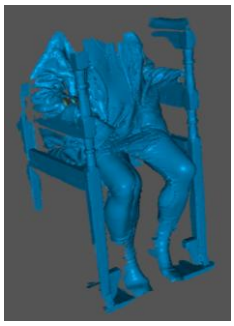
3



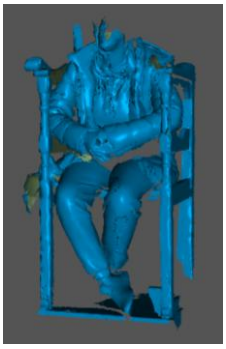
5



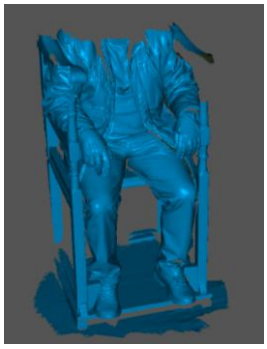
16



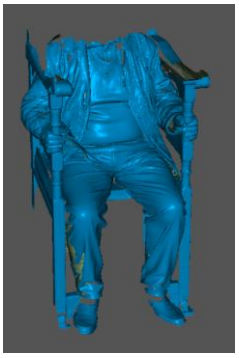
7



13



11



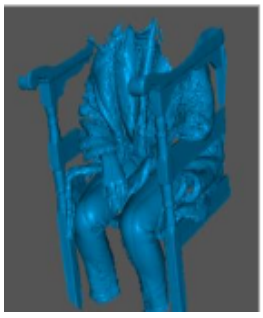
12



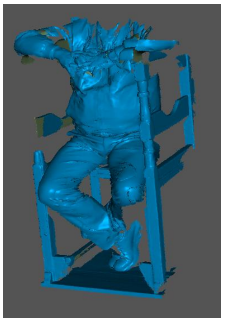
4



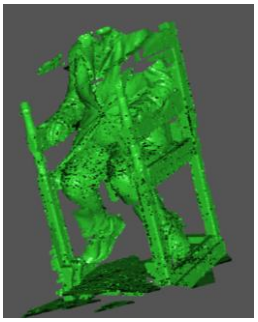
8



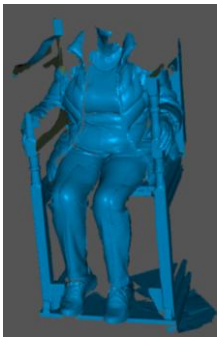
20



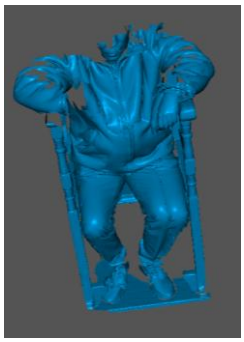
6



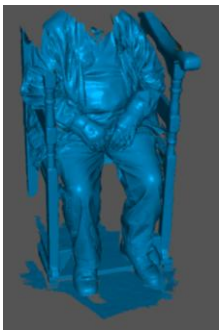
15



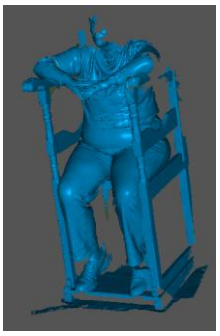
14



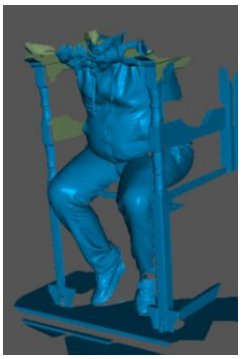
17

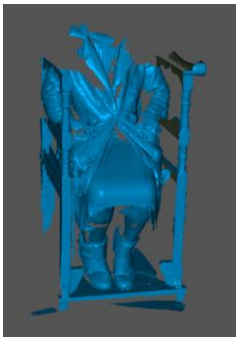


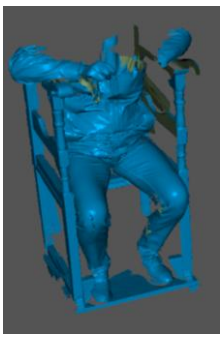
18

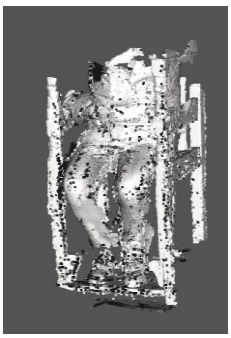


10


9


19


2


1

6. CONCLUSIONS

This case study, conducted over a period of approximately two years, demonstrates that the majority of elderly participants consistently preferred the newly introduced seat (Stall-Type A) inside a Church. The main distinguishing features of Stall-Type A were the greater seat depth and the lower armrest height in all positions it supports (sitting, intermediate and standing positions). Notably, the inclusion of an intermediate seating position—achieved through a folding mechanism absent in the pre-existing stalls but common in other types of church stalls proved to be a significant advancement in user comfort and adaptability.

The use of 3D scanning technology to capture the anthropometric data of participants represented a novel and intensive process for this demographic. Despite the unfamiliarity and time commitment required, 20 out of 33 individuals willingly participated and cooperated, contributing valuable insights to the interactive design process. During the 3D scan, individuals were asked to assume the most comfortable position for them. User feedback collected during the study revealed that, while some subjects were not ergonomically covered by the seat elements when viewed in the 3D models (as shown in Table 11), the vast majority did not report any dissatisfaction with the seat height in the corresponding questionnaire questions (Table 8). From an aesthetic perspective, most participants preferred the lighter colour shades X1 and X2 over the darker brown shade X3 (Table 6). Also, a similar trend was observed when participants were asked about color preferences for furniture in their own homes (Table 7). Additionally, wood emerged as the predominant material of choice for furniture construction among elderly Greeks, further emphasising the importance of material preferences in user-centered design (Table 6).

These findings highlight the significance of integrating ergonomic, aesthetic, and participatory approaches in the design of furniture for the elderly, ensuring both functional and psychological satisfaction.

Beyond the immediate results, this research underscores the importance of adopting evidence-based, user-centered methodologies in ecclesiastical and community furniture design. By actively involving elderly users in the evaluation process through interviews, participatory observation, and digital modeling, the study provides a replicable model for future interventions not only in religious contexts but also in other public environments where aging populations are present. The overwhelmingly positive response to Stall-Type A suggests that even small modifications—such as dimensions of seat and armrests—can yield substantial improvements in comfort and perceived safety for older users. Importantly, the study draws attention to the challenges and opportunities associated with introducing new technologies (such as 3D scanning) to older adults. While initial hesitancy was observed, the eventual participation rate demonstrates a willingness among elderly users to engage with innovative processes, provided that clear communication and support are offered. This insight points toward the potential for further digital integration in ergonomic research, such as virtual prototyping or remote feedback mechanisms, which may facilitate even broader user involvement in the future.

Several limitations should be acknowledged. The sample was limited to a specific geographic and cultural context, with participants all being active members of Greek Orthodox congregations. Thus, while the results are highly relevant within this setting, caution should be exercised in generalising them to other religious or cultural backgrounds. Furthermore, the study relied heavily on self-reported measures of comfort and satisfaction, which, although valuable, may be complemented in future research by objective assessments of posture, musculoskeletal health, or long-term use outcomes.

Looking ahead, the findings advocate for a more systematic integration of anthropometric data and participatory design in future ecclesiastical furniture projects. There is scope for further exploration of how

digital fabrication technologies, sustainable material choices, and modular design principles can be leveraged to better serve not only elderly populations but also individuals with mobility limitations or other special needs. Additionally, longitudinal studies tracking user adaptation and satisfaction over extended periods would further enrich our understanding of how furniture innovations affect quality of life within community settings.

Overall, this study demonstrates that meaningful improvements in the design of ecclesiastical furniture are both possible and welcomed by elderly users when ergonomics, aesthetics, and user participation are prioritized. By bridging traditional craftsmanship with contemporary research and digital tools, it is possible to create environments that are not only respectful of heritage but also responsive to the evolving needs of aging congregations.

REFERENCES

Barboutis I., Vasileiou V. (2013). Stasidia (Church stalls) of the greek-orthodox church – a standing seat for elderly. XXVIth International Conference Research for Furniture Industry: 1–6. https://www.researchgate.net/publication/340594841_Stasidia_CHURCH_STALLS_of_the_greek_orthodox_church_-a_standing_seat_for_elderly

Bjerknes G., Bratteteig T. (1995). User participation and democracy: A discussion of Scandinavian research on system development. Scandinavian Journal of Information Systems, 7, 1: 73–98.

Bothos I., Skarvelis M. (2021). Examining Furniture Preferences of the Elderly in Greece. In: Pires I. M., Spinante S., Zdravevski E., Lameski P. (eds), Smart Objects and Technologies for Social Good: 7th EAI International Conference, Goodtechs 2021, Virtual Event, September 15–17, 2021, Proceedings: 300–310. Springer, Cham. https://doi.org/10.1007/978-3-030-91421-9_23

Eurostat. (2024). Statistics Explained. http://ec.europa.eu/eurostat/statistics-explained

Fabisiak B., Klos R., Wiaderek K., Sydor M. (2014). Attitudes of elderly users towards design and functionality of furniture produced in Poland in the second half of the XXth century and nowadays. Annals of Warsaw University of Life Sciences-SGGW. Forestry and Wood Technology, 86.

Fabisiak B., Kłos R. (2012). Comparative analysis of difficulty of activities performed in kitchen by people aged 40–60 and over 60 years with visual impairment in the context of furniture design. Annals of Warsaw University of Life Sciences-SGGW, Forestry and Wood Technology, 77: 216–221.

Hrovatin J., Širok K., Jevšnik S., Oblak L., Berginc J. (2012). Adaptability of Kitchen Furniture for Elderly People in Terms of Safety. Drvna Industrija, 63, 2: 113–120. https://doi.org/10.5552/drind.2012.1128

Ito S., Ito S., Suteu I. (2020). AI Mobility Solutions for an Active Ageing Society. Introducing Aesthetic Affordances in the Design of Smart Wheelchairs. In: Degen H., Reinerman-Jones L. (eds), Artificial Intelligence in HCI. HCII 2020. Lecture Notes in Computer Science: 339–352. Springer. https://link.springer.com/chapter/10.1007/978-3-030-50334-5_23

Jonsson O., Sperling L. (2010). Wishes for furniture design among persons in the third age. Proceedings of the 7th International Conference on Design & Emotion, Chicago.

Kaewdok T., Norkaew S., Sirisawasd S., Choochouy N., Taptagaporn S. (2022). Anthropometric Measurement of Thai Older Farmers for Agricultural Tools and Workplace Design. Designs, 6, 5: 81. https://doi.org/10.3390/designs6050081

Kamperidou V. (2017). Critical points in the construction of aged people furniture. Pro Ligno, 13, 4: 592–599. https://www.researchgate.net/publication/340771813_CRITICAL_POINTS_IN_THE_CONSTRUCTION_OF_AGED_PEOPLE_FURNITURE

Kamperidou V., Barboutis I. (2017). Features of furniture design and manufacturing that constitute risk factors for causing accidents to users. XXVIIITH International Conference Research for Furniture Industry. https://www.researchgate.net/publication/340793626_FEATURES_OF_FURNITURE_DESIGN_AND_MANUFACTURING_THAT_CONSTITUTE_RISK_FACTORS_FOR_CAUSING_ACCIDENTS_TO_USERS

Klos R., Fabisiak B., Kaczmarek M. (2014). Analysis of human needs in kitchen design for people with visual impairment. Drvna Industrija, 65, 1: 43–50. https://doi.org/10.5552/drind.2014.1329

Makris K. (1982). Ecclesiastical wood carvings. Athens.

Nigrum N. C., Alimin N. N., Kusuma P. A., Purwaningrum L. L. (2020). The effect of adding armrest and seat assist on chair for elderly prayer performance (sitting to standing). AIP Conference Proceedings, 2217, 1.

Nikopoulos F. (2010). Shediasmos epiplwn gia ilikiwmenous: Anagkes xrhstwn kai xarakthristika epiplwn. [Furniture design for the elderly: User needs and furniture characteristics]. Master's Thesis. Aristotle University. http://ikee.lib.auth.gr/record/124268/files/nikop.pdf_

Openshaw S., Taylor E., Minder G., Witherow W., Long T., Ford M. (2006). Ergonomics and design: A reference guide. Allsteel Inc. https://ehs.oregonstate.edu/sites/ehs.oregonstate.edu/files/pdf/ergo/ergonomic-sanddesignreferenceguidewhitepaper.pdf

Pollák M., Török J. (2022). Use of Generative Design Tools in the Production of Design Products using 3D Printing Technology. TEM Journal, 11: 249–255. https://doi.org/10.18421/TEM111-31

Skarvelis M., Bothos I. (2025). Sociocultural Characteristics Influencing Furniture Preferences by Older Citizens. In: Klimczuk A. (ed), Social Determinants of Active Ageing – Building Resilience and Empowerment. IntechOpen. https://doi.org/10.5772/intechopen.1009314

Zawawi B. S., Hazim Z., Haron S. S., Ayob S. (2021). Sustainable prayer chair design characteristic for people with disabilities. Virtual Go Green “Rethinking Built Environment: Towards a Sustainable Future.” https://ir.uitm.edu.my/id/eprint/65619/1/65619.pdf

Wang J., Sayuti N., Ayn A., Li Z. (2024). Artificial Intelligence Innovation Method for Bamboo Furniture Based on User Perception. Pakistan Journal of Life and Social Sciences (PJLSS), 22, 1. https://doi.org/10.57239/pjlss-2024-22.1.00297

Session 7B | Contribution 3

ANALYSING THE PEDAGOGICAL POTENTIAL OF INTELLIGENT DIGITAL TOOLS IN CONCEPTUAL INTERIOR DESIGN

Adriana Vasileva Yankova-Hristova

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Faculty of Forest Industry, Department of Interior and Furniture Design
e-mail: adriana.yankova@ltu.bg

ABSTRACT

The rapid development of intelligent digital technologies is transforming the early conceptual stages of design practice and design education. In interior and furniture design education, these tools provide new opportunities for supporting idea generation, visual exploration, and conceptual development. At the same time, their integration into the pedagogical process raises important questions regarding their educational value, methodological application, and potential limitations.

The present study analyses the pedagogical potential of intelligent digital tools in the conceptual phase of interior design. The research focuses on three main aspects: analysis of currently available digital tools, systematization of these tools according to their functional characteristics, and identification of their pedagogical opportunities and limitations within design education.

Based on a review of contemporary digital platforms used for visual ideation, generative image creation, and concept development, the study proposes a functional classification of intelligent digital tools according to their role in the conceptual design process. The analysis distinguishes several categories of tools that support visual inspiration, concept generation, iterative exploration of design alternatives, and presentation of conceptual ideas.

The paper also discusses how such tools can stimulate creative thinking, accelerate the exploration of multiple design scenarios, and support students in working with visual associations and analogical reasoning. At the same time, potential risks are identified, including over-reliance on automatically generated visual outputs and the possible reduction of independent conceptual thinking.

The results highlight the importance of a structured pedagogical framework that integrates intelligent digital tools as supportive instruments within the conceptual design process while preserving the central role of human creativity, critical reflection, and design thinking in design education.

Keywords: interior design education, intelligent digital tools, conceptual design, design pedagogy, visual ideation, digital creativity.

1. INTRODUCTION

The multifaceted nature of interior design and the need for multidisciplinary knowledge often induce a sense of uncertainty among students and novice professionals. Especially in the earliest phase of design – the creation of a concept – the "fear of the blank page" and doubts about one's own artistic and engineering skills can lead to a creative block. It is precisely here that intelligent digital technologies emerge as a key factor in overcoming these barriers. Their development and proper application could fundamentally transform the early conceptual stages of design practice and design education. In the context of interior and furniture design education, these tools can reveal entirely new horizons in supporting idea generation, visual exploration, and conceptual development. Traditional learning models in design disciplines, which have long been based on linear processes, must now adapt to a dynamic environment where artificial intelligence (AI) acts as a catalyst for ideas and innovations. As Kahraman (Kahraman et al., 2024) points out, the integration of AI tools serves as a "cognitive collaborator" that does not merely automate tasks but stimulates creative thinking through the rapid visualization of ideas. The proper application of intelligent digital tools can transform the early conceptual stages, turning the previously linear educational processes into a dynamic environment where artificial intelligence acts as a catalyst for innovations and visual experiments that redefine the student's role from an executor to a "director of ideas."

Despite these advantages, the integration of intelligent tools into the pedagogical process raises critical questions regarding their educational value and potential limitations. A primary concern in contemporary

design pedagogy is the risk of over-reliance on automatically generated results, which can lead to the erosion of independent conceptual thinking and critical reflection. There is a danger that students will focus on "surface aesthetics," neglecting the fundamental principles of ergonomics and spatial logic. As Georges Fares (Fares, 2025) notes, their successful integration requires a balanced approach that combines the use of intelligent tools with the development of critical assessment, creative autonomy, and an awareness of ethical aspects in learners, in order to preserve the authorial independence of future designers.

The aim of this research is to analyze the pedagogical potential of intelligent digital tools in the conceptual stage of interior design and to propose a functional grouping of these tools according to their role in the design process.

2. CONCEPTUAL DESIGN IN INTERIOR DESIGN EDUCATION

2.1. THE CONCEPT IN THE DESIGN PROCESS

One of the earliest phases of interior design is the creation of a concept. Often, this phase is perceived as the most fun, easy, and pleasant part of designing, as it is not yet directly tied to the need for deep technical and engineering knowledge in the field, requiring only the discovery of an interesting idea. This initially light and pleasant feeling disappears extremely quickly in the educational process as young designers delve deeper into the essence of the subject matter. They quickly realize that creating a conceptualization is the intellectual core of the interior project. As Nigel Cross (Cross, 2023) notes, conceptual design represents the central cognitive activity in the design process, during which the main idea of the future solution is formed. It represents a transition from the analysis of the specific assignment, the architectural framework of the available architectural space, and the creator's vision to the formation of a specific, real spatial idea and a concrete solution. As researcher Bryan Lawson (Lawson 2021) notes, the conceptual stage represents a process of continuous interaction between the analysis of the design problem and the generation of possible solutions, in which the designer gradually builds and refines the main spatial idea. In the early conceptual stages, the focus is not on detail, but on the synthesis of function, aesthetics, and meaning, as Nigel Cross (Cross, 2023) states. The process of visual and spatial exploration allows the designer to test multiple hypotheses before fixating on a specific solution. This exploration requires a heavy cognitive load, as it brings together multiple components that must quickly take their visual expression. As contemporary theorists and researchers in the field of design pedagogy, such as Nigel Cross (Cross, 2023), emphasize, this stage is the most vulnerable to creative blocks and premature "design fixation" on a single idea, but at the same time, it is the most decisive for the innovativeness of the final design product. To help overcome creative blocks more quickly and reduce intensive cognitive load, design pedagogy traditionally relies on specific reference points that support the process and structure complex spatial thinking. Classical educational processes apply an established linear methodological framework of tools that help students materialize their abstract ideas step by step, transforming the feeling of insecurity into a controlled creative process.

2.2. METHODS SUPPORTING THE FORMATION OF THE CONCEPTUAL DESIGN PHASE

Traditional conceptual development relies on a set of established methods that serve as external cognitive support for the designer and facilitate the transition from abstract thought to material form. As Nigel Cross and Bryan Lawson (Cross, 2023; Lawson, 2005) summarize in their works on the topic – sketches, visual analogies, and conceptual diagrams are considered the main means for the external representation and development of the design idea, while mood boards are a widely used tool for visually defining the atmosphere, materiality, and aesthetic direction of the project.

Sketches are one of the earliest, fastest, and most unpretentious ways to communicate a given concept. A piece of paper, a pencil, and an idea are sufficient for a hand sketch. They allow for rapid iteration and the capturing of spatial volumes without the need for special tools or the limitations of technical drafting precision. According to researcher Bryan Lawson (Lawson, 2021), the sketch functions as a thinking tool that allows the designer to explore and evaluate different design possibilities even in the early conceptual stages.

The use of visual analogies is perhaps the most primal conceptual method, as it uses metaphors from nature, art, or other spheres of life to transfer visual structure and mood into the interior. As Nigel Cross (Cross, 2023) notes, designers often develop their new ideas through analogical thinking, in which existing models, familiar images, and previous experience are transformed into new design solutions. This is a process of analogical reasoning that lies at the heart of creativity from early human development.

Conceptual diagrams are a schematic representation of functional connections, movement flows, and functional zones that turn the abstract idea of a given space into a logically clear structure. As Rivka Oxman (Oxman, 2017) notes, visual models and diagrams are not solely a means of representing the project, but fulfill the role of a cognitive tool that supports the analysis, structuring, and development of the design solution.

The mood board is a highly effective design tool that can very easily convey an overall visual idea and define the desired atmosphere in a given space. It can be a digital or physical collage in which images of materials, colors and textures, object samples, and often brief textual descriptions are visually organized. As Steve Garner and Deana McDonagh-Philp (Garner & McDonagh-Philp, 2002) emphasize in their research, the mood board fulfills not only a representational but also a cognitive function, as it aids in interpreting the design problem and developing the conceptual idea through visual associations.

In the contemporary educational reality, this classic toolset can no longer function in isolation. Traditional methods are not rejected or replaced, but are expanded with the help of intelligent digital tools. As Rivka Oxman (Oxman, 2017) notes, the development of digital technologies does not abolish established design approaches, but expands their potential through new forms of visual thinking, modeling, and generation of design solutions.

The dynamic penetration of generative artificial intelligence and algorithmic systems is changing the way students create sketches, look for analogies, or structure their mood boards. Digitalization allows their rapid transformation from classic, static, two-dimensional images into dynamic databases through an almost unlimited set of tools and possibilities for conceptual interpretation. The key question is how young designers navigate the sea of digital tools in an ocean of digital applications without these new tools altering the quality of human creative and conceptual thinking, but rather providing it with new, "intelligent" partners for cognitive collaboration. As Georges Fares (Fares, 2025) points out, the effective integration of generative artificial intelligence in design education depends not so much on the technological capabilities of the tools as on the students' ability to use them critically, consciously, and in accordance with the goals of the creative process. For this technological leap to be pedagogically effective and not lead to creative fixation, it is necessary to review, analyze, and structure the existing software diversity in the context of its practical application. Based on this, the following section provides an overview and functional grouping of existing intelligent digital tools according to their specific role and application in the conceptual phase of interior design.

3. ANALYSIS AND FUNCTIONAL GROUPING OF INTELLIGENT DIGITAL TOOLS

The overall digital transformation we are currently witnessing necessitates a qualitative rethinking of the contemporary software ecosystem, especially in the scientific and educational sphere. The available digital toolset is highly dynamic, fragmented, and rapidly evolving; therefore, the present research proposes a broad functional grouping and a brief analysis of the available tools. The platforms are structured according to their core functionality, applicability, and the way they support the development of the design concept. The proposed functional grouping also seeks another pattern: how, with the advancement of conceptual design and the growth of the learners' design skills, the mode of use and the role of intelligent digital tools gradually change – from a means for free idea generation to an intelligent visualization tool, where control over the design solution increasingly returns to the hands of the developing designer.

3.1. "TEXT-TO-IMAGE"

The primary selection of tools by novice designers is significantly influenced by their immediate peer networks. Often, young people's first choice consists of some of the most widespread, accessible, and popular digital tools among their peers – recommended by upper-course colleagues, acquaintances studying in other scientific fields, or tools initially used by themselves to solve everyday life situations. Practical observations on interior design education show that students usually start working with the most popular and easily accessible platforms before gradually expanding the set of specialized tools used. This trend is also confirmed in the research of Laura Alonso-Muñoz and Andreu Casero-Ripollés (Alonso-Muñoz & Casero-Ripollés, 2026), who find that generative AI tools are perceived by students as easily accessible means for increasing the efficiency of the learning process, generating ideas, and supporting creative tasks. The best examples of such large language and generative models are ChatGPT, Gemini, and Microsoft Copilot. They are distinguished by a low barrier to entry, an intuitive interface, and a wide range of functionalities, making them a natural starting point in the conceptual design process.

In a professional context, for a large portion of young designers, the first step in the conceptual search naturally shifts towards "text-to-image" tools; such assistants for visual inspiration include Midjourney, DALL-E 3, and Ideogram. These platforms significantly lower the barrier to entry into conceptual design, as they do not require prior detailed classical artistic skills or specialized software knowledge. However, their successful application brings to the forefront the skill of precisely formulating textual commands (prompts), which gradually becomes the main tool for managing the generation process and a determining factor for the quality of interaction between the human and generative artificial intelligence. In this sense, as Jeba Rezwana and Mary Lou Maher (Rezwana & Maher, 2023) note, generative artificial intelligence holds the greatest value not as a means for automatic image creation, but as an intelligent partner in the process of co-generating, evaluating, and iteratively refining design ideas.

For example, when tasked with creating a color scheme, a mood board in a specific style, designing an entire interior, or a single piece of furniture, students can use universal generative AI platforms like ChatGPT, Gemini, and Microsoft Copilot or specialized Text-to-Image systems like Midjourney, Ideogram, or DALL-E 3. These tools allow them to easily generate dozens of visual variations in minutes by changing just a few keywords related to the applied materials, colors, lighting, or stylistics. Thus, in this early stage, learners have the opportunity to experiment, explore, reject, and accept multiple variant results without losing days and weeks in detailed development or precise 3D modeling, and the process of conceptual search turns into a series of rapid iterations rather than a mandatory linear sequence of decisions.

Figures 1 and 2 present the results of generating images using the generative AI model Gemini (Google) when creating an initial conceptual idea for a chair in the interior of a 'luxury Alpine tea house.' The author utilizes a textual description (prompt), which generates a visual image of the desired object during the initial conceptual phase.

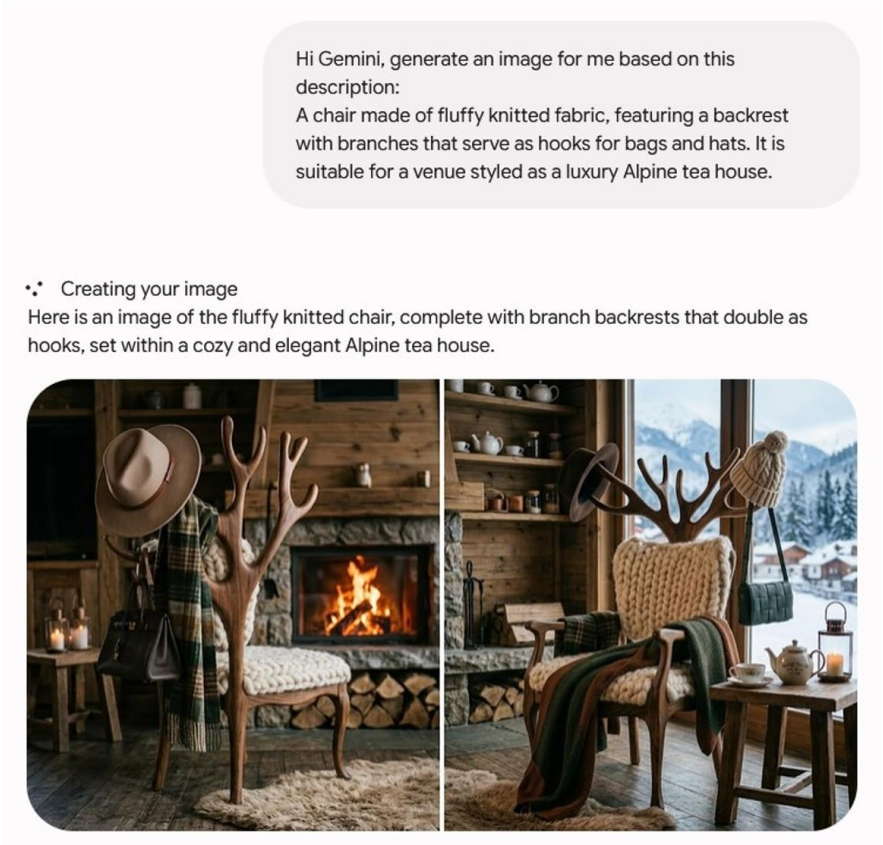


Figure 1: Conceptual model of a chair. The image is generated through Google Gemini (Model: Gemini 3.5 Flash, 2026)

Figure 2 shows the change that occurred in the generated image after changing just one word in the initial assignment. The word 'chair' has been replaced with 'armchair'.

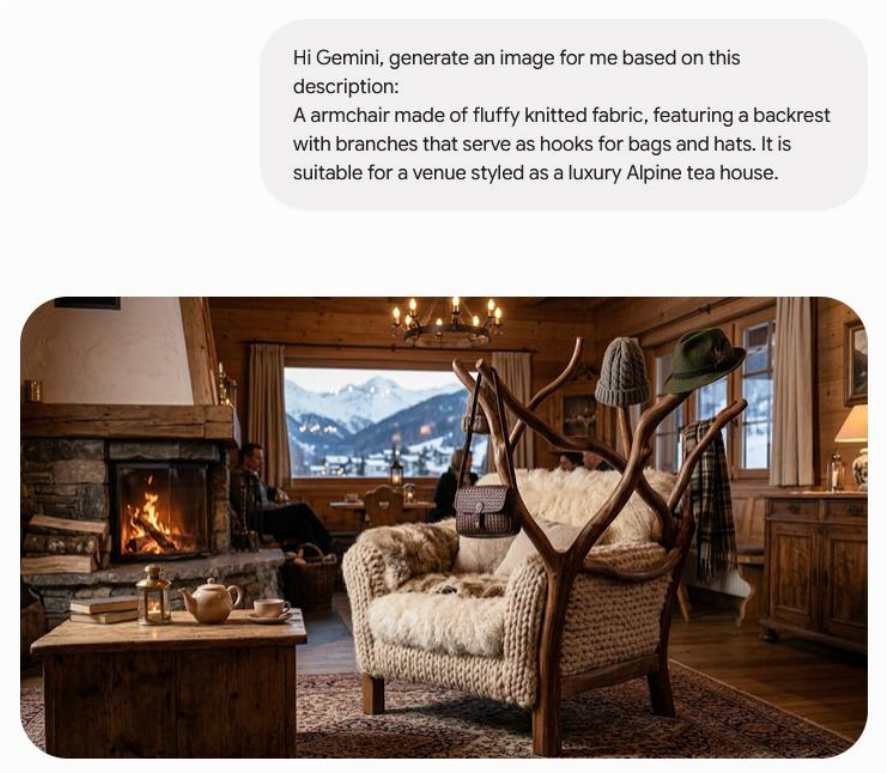


Figure 2: Conceptual model of an armchair. The image is generated through Google Gemini (Model: Gemini 3.5 Flash, 2026)

3.2. "IMAGE-TO-IMAGE"

With the development of a given concept or proceeding to the subsequent early stages of the design process in design education, a moment arrives when pure textual inspiration proves insufficient. This naturally compels learners to transition to the next step in working with modern generative tools, namely "Image-to-Image." This direction has its variations depending on the applied input data. Some of the widely used applications, which are often utilized by private consumers to aid in the rapid visual transformation of existing spaces – the so-called "digital home staging" – function through an 'Art-to-Concept' methodology. Tools like HomeDesigns AI, Krea AI, or Leonardo AI allow users to input a photo of a real, already depreciated, or empty space as a source image. The algorithm captures the architectural features of the room and completely transforms them according to a specified new color concept or historical style. This method is suitable for end-users and laypeople but quickly proves unsuitable for young designers whose creative work strives to create innovative concepts. Although such systems are particularly effective for rapidly visualizing different stylistic solutions and color concepts, their application in interior design education has certain limitations. Since the algorithm operates on a pre-existing image, the student often remains within the confines of the predefined spatial structure, limiting the possibilities for creating entirely new conceptual solutions. Automated Art-to-Concept transformations often generate standardized, clichéd solutions that limit the students' authorial autonomy and originality. According to Socrates Yiannoudes (Yiannoudes, 2025), the educational value of generative AI tools is determined not solely by the quality of the generated images, but by the way they support the learners' analytical, critical, and creative participation in the design process.

It is precisely for this reason that testing this type of tool and the practical experience gained with them lead young designers to the "Sketch-to-Render" approach. Unlike systems that transform a finished photograph, Sketch-to-Render platforms preserve the author's leading role in the process of compositional and spatial thinking. The source image is no longer a real photo, but the student's own design sketch, which preserves the author's intent and turns generative AI into a means of visualization rather than a replacement for the creative process. The Sketch-to-Render direction transforms the way young designers present their primary volumetric and spatial ideas. Specialized platforms such as Vizcom, PromeAI, ReRoom AI, Perspectia, ArchSynth, and REYA allow the student to upload their own original sketch, drawn by hand or generated as a basic 2D or 3D drawing. The algorithms recognize the contours of the perspective and automatically 'clothe' it in photorealistic materials, lighting, and details, strictly preserving the author's geometry of the furniture or room. In this way,

the generative AI does not construct the spatial idea instead of the student, but visualizes the already created original concept, shortens the technical execution time, and develops the student's ability to quickly assess whether their idea looks aesthetically sound in reality. As research by Bartlett, Mills, and Hagins (Bartlett, R., Mills, M., & Hagins, M., 2024) shows, combining an original sketch with AI-based photorealistic visualization improves the understanding and communication of design concepts while preserving the author's leading role in shaping the design solution.

It is this feature that gives the Sketch-to-Render approach high pedagogical value. Instead of generating the spatial idea solely based on a textual description, the algorithm works on an already created original concept, turning the hand sketch into a photorealistic visualization. Thus, the student retains control over the composition, proportions, and spatial organization, while artificial intelligence primarily supports the visualization process. The main challenge with Image-to-Image systems in education is that they require at least basic artistic skills from the user and a longer technological time to master their working principles. Their free versions often limit the resolution or fine control over details, and the algorithms' tendency to 'make up' architectural and decorative elements requires students to have a developed visual culture, critical thinking, and skills for subsequent software post-processing. Figure 3 presents an example of the Sketch-to-Render approach, showing the transformation of a hand-drawn original conceptual sketch into an AI-based photorealistic visualization. The visualization demonstrates the preservation of the compositional structure and the author's geometry while automatically generating materials, textures, and lighting. The example visualizes the essential difference of the Sketch-to-Render approach from Text-to-Image systems, where visual interpretation is built solely on the basis of a textual instruction.



Figure 3: Example of transforming an original hand-drawn conceptual sketch into a photorealistic visualization via the ReRoom AI platform

4. PEDAGOGICAL OPPORTUNITIES AND LIMITS

The pedagogical value of intelligent digital tools is most evident in their capacity to expedite the technical execution of numerous design variants, thereby freeing up cognitive resources for conceptual, critical, and strategic thinking. In this sense, modern intelligent generative tools can be viewed as a means of cognitive augmentation, where the automation of routine operations supports the creative process without displacing the author's leading role. This understanding is close to Ben Shneiderman's (Shneiderman, 2007) concept of creativity support tools, according to which digital technologies assist humans in exploring, combining, and evaluating multiple possible solutions. Similarly, Margaret Boden (Boden, 2004) in her book "The Creative Mind," emphasizes that technological systems can expand the space of possible creative solutions by supporting the processes of idea generation and development. But alongside this enormous potential exists the equally enormous risk of excessive cognitive offloading, in which some of the activities that build design competence and responsibility are gradually transferred to the algorithms. In an educational context, this creates a danger that the student might achieve a visually convincing result without having gone through the

necessary analytical stages of spatial thinking and analysis, structuring the form, evaluating scale, and understanding the causal relationships between the idea, its design solution, and its subsequent material realization. Precisely in this regard, Raja Parasuraman and Victor Riley's (Parasuraman & Riley, 1997) fundamental model warns that excessive automation can lead to improper task delegation and unjustifiably high trust in technological systems. Therefore, the main pedagogical challenge is not whether modern intelligent generative systems should be used, but how their application can preserve the leading role of the human, their judgment, critical thinking, and authorial responsibility.

To objectively assess the pedagogical value of modern intelligent generative tools and their advantages, they must be considered in comparison with traditional professional CAD, BIM, and 3D platforms that have defined interior design education for decades. Although these systems remain indispensable in professional practice, mastering them is associated with significant technical, economic, and time requirements. The need for powerful hardware, licensed software, and prolonged training often poses a serious barrier for students. It is against this backdrop that generative AI tools are perceived as a significantly more accessible environment for early conceptual experimentation. It is important to emphasize that the comparison between traditional CAD/3D platforms and modern intelligent generative tools does not aim to juxtapose the two approaches. On the contrary, they perform different functions in the learning process and complement each other. It is indicative that this trend is already very seriously reflected in the strategies of leading professional software developers, who are gradually integrating generative AI functionalities into their established platforms. This again shows that the future of design education is tied not to the replacement of traditional methods, but to their effective integration with intelligent technologies.

Despite their express efficiency, generative platforms possess a number of technical and methodological limitations that educators should clearly acknowledge. Due to the probabilistic nature of generative models, they often create geometric and structural inaccuracies, which limits their application in stages requiring spatial reliability and precise accuracy. The limitations imposed on users regarding access to free versions, dynamic changes, and lack of overall control, as well as lower resolution in work details and obtained visual results, further solidify the role of these tools as means for conceptual exploration, rather than as substitutes for professional design.

Special attention is also warranted for the pedagogical risks associated with excessive reliance on generative systems. If education allows the delegation of the early stages of conceptual development entirely to algorithms, there is a danger of weakening fundamental design skills, reducing or failing to develop spatial intuition, and impairing the ability for independent compositional thinking in young professionals. In the event of a sudden lack of access to current generative technologies, the strong dependence built upon them can lead to difficulties in applying the abilities for traditional methods of sketching and conceptualization, and at a later stage, to their complete loss. This strongly underscores the need for generative intelligence to be viewed as a tool to assist, not replace, human thinking.

From a pedagogical point of view, this necessitates building hybrid resilience in interior design education. Such an understanding resonates with both Ben Shneiderman's (Shneiderman, 2022) concept of human-centered AI and the view of Rezwana and Maher (Rezwana & Maher, 2023) that generative artificial intelligence should function as an intelligent partner in the co-design process, rather than as a substitute for human creative activity. Intelligent digital tools should be integrated as an extension of human capacity in symbiosis with classical methods for conceptualization, visual thinking, and spatial analysis. Only such a balanced approach can guarantee that authorial identity, critical thinking, spatial reasoning, and decision-making capabilities will remain independent of technological platforms and their future development.

5. CONCLUSIONS

This research analyzes the pedagogical potential of intelligent digital tools in the early conceptual stages of interior design and proposes their functional grouping according to their role in the process of generating, visualizing, developing, and communicating the design idea. The conducted analysis shows that these technologies should not be viewed as a substitute for design thinking, but as a means of expanding the learners' creative capabilities and supporting the processes of concept building, visual exploration, and experimentation.

The proposed functional differentiation of tools into the Text-to-Image and Image-to-Image categories shows that different generative technologies possess specific pedagogical potential. It is directly dependent on the design stage in which they are applied, as well as on the learners' existing artistic skills. Incorporating them

into interior design education can shorten the time for visualizing ideas, encourage the exploration of multiple design alternatives, and free up cognitive resources for deeper conceptual thinking in the early design phase and subsequent project development. At the same time, the analysis confirms that the effective use of these technologies requires a careful pedagogical approach. Over-reliance on automatically generated results carries the risk of limiting the learners' independent design thinking, critical assessment, and spatial intuition. The boundary between technological assistance in the design process and the complete displacement of the author's function by artificial intelligence is directly proportional to the student's theoretical and practical preparation. Therefore, the higher the level of expertise built within the learner, the more resilient their control over the creative process and the more minimized the risk of intellectual usurpation of design decisions. For this reason, modern intelligent generative tools should be integrated as a tool that supports, but does not replace, the creative process, professional training, and authorial responsibility of future interior designers.

In conclusion, the pedagogical utility of intelligent digital tools is contingent not so much upon their technological capabilities, but by the way they are integrated into the learning process. With purposeful and methodologically sound application, they can become an effective means of developing creative thinking, visual culture, and decision-making skills in contemporary interior design education.

Consequently, the main pedagogical question is no longer whether generative artificial intelligence should be included in design education, but how its use can be structured to support the development of design expertise without replacing the cognitive processes through which this expertise is built. A sustainable educational model should view artificial intelligence as a means of expanding human capabilities while simultaneously preserving the fundamental practices of analysis, conceptualization, spatial thinking, and authorial decision-making.

REFERENCES

Alonso-Muñoz, L., & Casero-Ripollés, A. (2026). Adoption of Generative AI in Higher Education: Perceptions of Journalism Students. Information, 17(2), 189. https://www.mdpi.com/2078-2489/17/2/189?utm_source=chatgpt.com

Bartlett, R., Mills, M., & Hagins, M. (2024). Comparing Understandability of Hand Sketches Versus AI-Generated Renders for Product Design. Proceedings of the 26th International Conference on Engineering and Product Design Education (E&PDE 2024). https://dje.designsociety.org/publication/47234/COMPARING+UNDERSTANDABILI+OF+HAND+SKETCHES+VERSUS+AI-GENERATED+RENDERS+FOR+PRODUCT+DESIGN

Boden, M. A. (2004). The Creative Mind: Myths and Mechanisms (2nd ed.). London: Routledge. https://doi.org/10.4324/9780203508527

Cross, N. (2023). Design Thinking: Understanding How Designers Think and Work (2nd ed.). Bloomsbury Publishing. https://www.bloomsbury.com/uk/design-thinking-9781350305069/

Fares, G. (2025). Integrating AI in the Creative Process: A Case Study in Interior Design Education. "Art and Design Review". https://www.scirp.net/journal/paperinformation?paperid=142502

Garner, S., & McDonagh-Philp, D. (2002). Problem Interpretation and Resolution via Visual Stimuli: The Use of Mood Boards in Design Education. Journal of Art & Design Education. https://onlinelibrary.wiley.com/doi/abs/10.1111/1468-5949.00250?utm_source=chatgpt.com

Kahraman, M. U., Şekerci, Y., Develier, M., & Koyuncu, F. (2024). Integrating Artificial Intelligence in Interior Design Education: Concept Development. Journal of Computational Design, 5(1), 31–60. https://doi.org/10.53710/jcode.1418783

Lawson, B. (2021). How Designers Think: The Design Process Demystified (5th ed.). Routledge. https://www.researchgate.net/publication/30872105_How_Designers_Think_-_The_Design_Process_Demystified

Oxman, R. (2017). Thinking styles and digital design pedagogy. Design Studies, 52, 26–51. https://doi.org/10.1016/j.destud.2017.05.001

Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. Human Factors, 39(2), 230–253. https://doi.org/10.1518/001872097778543886

Rezwana, J., & Maher, M. L. (2023). User Perspectives on Ethical Challenges in Human-AI Co-Creativity: A Design Fiction Study. In Proceedings of the 15th Conference on Creativity and Cognition (pp. 1–19). ACM. https://doi.org/10.1145/3591196.3593364

Shneiderman, B. (2007). Creativity support tools: Accelerating discovery and innovation. Communications of the ACM, 50(12), 20–32. https://doi.org/10.1145/1323688.1323689

Shneiderman, B. (2022). Human-Centered AI. Oxford University Press. https://doi.org/10.1093/oso/9780192845290.001.0001

Yiannoudes, S. (2025). Shaping Architecture with Generative Artificial Intelligence: Deep Learning Models in Architectural Design Workflow. Architecture, 5(4), 94. https://doi.org/10.3390/architecture5040094

Session 7B | Contribution 4

CONCEPT FORMATION IN INTERIOR AND FURNITURE DESIGN EDUCATION: PEDAGOGICAL APPROACHES TO DEVELOPING CONCEPTUAL THINKING

Desislava Angelova, Adriana Vasileva Yankova-Hristova

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Faculty of Forest Industry, Department of Interior and Furniture Design
e-mails: d.angelova@ltu.bg, adriana.yankova@ltu.bg

ABSTRACT

Concept formation represents a fundamental stage in the design process, where abstract ideas, associations, and interpretations of the design problem are transformed into coherent conceptual directions that guide further development. In interior and furniture design education, this stage is particularly significant because it supports creative thinking, spatial imagination, and the ability to translate intangible ideas into structured design strategies.

The present paper examines concept formation as a key transitional phase between problem definition and the development of design solutions. Particular attention is given to the cognitive and creative mechanisms involved in conceptual thinking, including associative reasoning, analogical transfer, and exploratory ideation. The paper also discusses pedagogical approaches that facilitate the development of conceptual thinking among design students, such as visual exploration, associative mapping, analogical thinking, iterative idea generation, reflective learning, and project-based education.

By integrating theoretical perspectives, empirical evidence, and long-term pedagogical experience, the study proposes an integrated cognitive-pedagogical model of concept formation in design education. The model highlights the interaction between designer cognition, problem framing, analogical reasoning, conceptual expansion, iterative reflection, collaborative project interaction, and the development of a coherent design concept.

Keywords: conceptual design, design education, interior and furniture design, creative thinking.

1. INTRODUCTION

The conceptual stage occupies a central position in the design process, as it represents the phase in which initial ideas are structured into coherent conceptual directions that guide the subsequent development of the project. In disciplines such as interior and furniture design, where spatial, functional, and aesthetic considerations must be integrated into a unified solution, the formulation of a clear concept plays a particularly important role. The concept acts as an organizing principle that connects the interpretation of the design problem with the development of spatial form, material expression, and functional organization.

Within the broader context of design methodology, the concept is often understood as a framework that structures the relationships between different components of a design project. Rather than representing a single idea, it defines the underlying logic that informs the entire design process. In this sense, concept formation can be seen as a cognitive and creative activity through which designers interpret design problems, explore possible directions, and establish meaningful connections between abstract ideas and concrete design solutions. This process involves the transformation of intuitive insights, associations, and visual impressions into structured design strategies that can be further developed during later stages of the project.

In design education, the conceptual phase has an additional pedagogical significance. For students, the ability to formulate a coherent concept represents an important step in the development of design competence. It requires not only creative thinking, but also the capacity to interpret complex design problems, to synthesize information from different sources, and to articulate design intentions in a structured manner. Developing these abilities is particularly important in the early stages of architectural, interior, and furniture design education, where students are learning to move beyond purely intuitive approaches toward more reflective and systematic design thinking.

However, despite its recognized importance, the conceptual stage is often one of the most challenging phases for students. Many beginning designers tend to focus primarily on the formal appearance of objects or spaces,

moving quickly toward the development of visual solutions without establishing a clear conceptual foundation. As a result, design proposals may remain fragmented or lack internal coherence. This highlights the need for pedagogical approaches that support students in developing conceptual thinking and encourage them to explore multiple interpretations of a design problem before committing to a specific solution.

From a cognitive perspective, concept formation in design involves a number of mental processes that support creative exploration. These include associative thinking, visual reasoning, and analogical transfer between different domains of knowledge and experience. Designers frequently draw inspiration from natural forms, cultural references, technological systems, or everyday objects, translating these sources into spatial and formal strategies. Such processes enable designers to reinterpret familiar ideas in new contexts and to generate innovative design directions. Within educational settings, encouraging these mechanisms can significantly enhance the ability of students to generate original and meaningful design concepts.

Pedagogical strategies that support concept formation often involve methods that stimulate visual and associative thinking. Techniques such as visual exploration, mood boards, conceptual diagrams, and analogical references are commonly used in design studios to help students articulate and develop their ideas. Through iterative processes of sketching, reflection, and reinterpretation, students gradually refine their conceptual intentions and learn to establish stronger relationships between concept, form, function, and spatial experience. In this sense, the conceptual stage becomes not only a generator of ideas but also a structuring mechanism that organizes the design process as a whole.

Understanding the role of concept formation in design education is therefore essential for developing effective teaching approaches in interior and furniture design. By examining how concepts emerge and evolve within the design process, it becomes possible to identify methods that support the development of conceptual thinking and enhance the overall quality of student design projects.

The aim of this paper is to analyse the role of concept formation in the interior and furniture design process and to outline pedagogical approaches that support the development of conceptual thinking in design education. The study focuses on the conceptual stage as a key transitional phase between problem definition and the development of design solutions, emphasizing its cognitive, methodological, and educational dimensions.

Beyond reviewing existing theoretical perspectives, the paper synthesizes cognitive theories, empirical evidence, and long-term pedagogical experience into an integrated cognitive-pedagogical model for developing conceptual competence in interior and furniture design education.

2. CONCEPT FORMATION IN THE DESIGN PROCESS

Within design methodology, the concept is widely regarded as a central organizing element that structures the development of a design project. Rather than representing a single isolated idea, the concept functions as a guiding framework that establishes coherence between the different components of the design solution, including form, function, spatial organization, and symbolic meaning. Consequently, concept formation should not be understood as a discrete phase but as a continuous process that progressively organizes design knowledge throughout the entire project. In this sense, concept formation represents a transitional phase between the interpretation of a design problem and the materialization of design proposals.

In many models of the design process, the conceptual stage appears as a key intermediate step linking problem definition with the generation and evaluation of design alternatives. Nigel Cross describes design activity as a process of exploring solution spaces in which designers gradually develop structured proposals through iterative cycles of thinking and making. Within this framework, conceptual thinking plays a crucial role in defining the direction of the design exploration and in organizing the relationships between different design parameters.

Similarly, Bryan Lawson emphasizes that design problems are often ill-defined and require designers to construct their own interpretations of the problem situation before developing solutions. According to Lawson, designers frequently move back and forth between problem analysis and solution generation, gradually refining their ideas through iterative processes of sketching, testing, and reflection. The formulation of a concept in this context serves as a stabilizing structure that helps designers manage the complexity of the design task.

The importance of reflective thinking in the design process has also been highlighted by Donald Schön, who describes design activity as a form of "reflection-in-action." In this view, designers engage in a continuous

dialogue with the emerging design situation, where ideas are tested, reconsidered, and transformed through interaction with sketches, models, and spatial representations. The concept evolves within this reflective process, gradually becoming more explicit and structured as the design develops.

More recent research in design theory further expands this perspective by emphasizing the role of framing and reframing in conceptual design. Kees Dorst argues that innovation in design often emerges through the reinterpretation of design problems and the construction of new conceptual frames that connect previously unrelated elements. According to Dorst, designers create innovative solutions by identifying underlying relationships that allow different domains of knowledge, experience, and meaning to be combined in novel ways.

Taken together, these theoretical perspectives suggest that concept formation should not be understood as a single moment in the design process, but rather as a dynamic and iterative activity that develops through continuous interaction between thinking, drawing, and reflection. The concept evolves as designers explore alternative interpretations of the design problem and gradually establish a coherent direction for the project.

An important mechanism that supports concept formation in design is analogical thinking. Designers frequently generate ideas by drawing connections between different domains of knowledge and experience, transferring principles, structures, or relationships from one context to another. Through such analogical processes, familiar concepts can be reinterpreted in new design situations, enabling the generation of innovative spatial and formal solutions.

Analogical reasoning allows designers to move beyond direct functional problem solving and to explore more abstract relationships between forms, systems, and meanings. For example, natural structures, technological systems, cultural symbols, or everyday objects may serve as sources of inspiration for conceptual development. By identifying structural similarities between different domains, designers are able to translate ideas from one context into another, thereby enriching the conceptual foundation of the project.

In the context of interior and furniture design, analogical thinking often plays a particularly important role in the early stages of concept development. Spatial compositions, structural principles, and formal expressions may emerge from analogies with natural forms, biological systems, mechanical structures, or cultural narratives. Such analogical transfers enable designers to construct conceptual frameworks that guide the transformation of abstract ideas into tangible spatial and material solutions.

An illustrative example of analogical concept formation is the conceptual lounge chair CarboLeaf, developed by a team of students from the Bachelor's programme in Engineering Design (Interior and Furniture Design) at the University of Forestry (Figure 1). The project was created during the intensive project-based learning module Project Week in collaboration with the industrial partner Carbon Touch in 2015. Inspired by the structural and formal characteristics of a natural leaf, the students translated biological principles into a coherent furniture concept through analogical reasoning.

The educational project subsequently evolved into an industrial product marketed under the commercial name Carbo Leaf by Carbon Touch. In 2018, the product received Third Prize and the Audience Award at the Technomebel International Exhibition. Beyond demonstrating the effectiveness of analogical thinking during concept formation, this example illustrates how project-based learning can successfully connect cognitive processes, creative exploration, academic education, and industrial innovation.

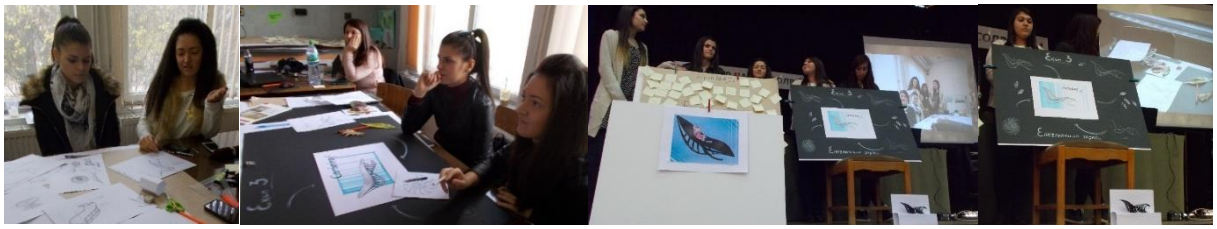


Figure 1: Student concept project CarboLeaf, developed during the Project Week module at the University of Forestry. Source: Authors' archive; product information based on Carbon Touch

This example demonstrates how analogical reasoning can be transformed from a cognitive mechanism into a practical pedagogical strategy, enabling students to convert abstract natural inspiration into innovative and market-oriented design concepts.

From an educational perspective, encouraging students to use analogical thinking can significantly enhance their ability to generate original design concepts. Analogies stimulate associative exploration, support visual imagination, and facilitate the discovery of unexpected relationships between different elements of the design problem. By engaging with diverse reference domains, students learn to interpret design challenges more creatively and to develop richer conceptual narratives for their projects.

Understanding the role of analogy in concept formation therefore provides valuable insight into the cognitive processes underlying design creativity. Integrating analogical methods into the conceptual stage of the design process can help students structure their ideas more effectively and develop more coherent design strategies. In this way, analogical thinking becomes an important methodological tool that supports both the creative and the pedagogical dimensions of conceptual design.

3. COGNITIVE MECHANISMS OF CONCEPTUAL THINKING IN DESIGN

Conceptual thinking in design is closely connected with a range of cognitive processes that enable designers to interpret problems, generate ideas, and construct meaningful relationships between abstract concepts and concrete design solutions. Among these processes, analogical reasoning plays a particularly important role, as it allows designers to transfer knowledge, structures, and relationships from one domain to another. Through such transfers, designers are able to reinterpret familiar patterns in new contexts and develop innovative conceptual frameworks for design.

One of the most influential theoretical explanations of analogical reasoning is provided by the Structure-Mapping Theory proposed by Dedre Gentner. According to this theory, analogy is not primarily based on superficial similarity between objects but on deeper relational correspondences between structures. Analogical reasoning involves aligning two systems in order to identify shared relational patterns and transferring knowledge from a familiar domain (the source) to a less familiar one (the target) (Gentner, 1983). In the context of design, this mechanism allows designers to interpret spatial, structural, or functional relationships by drawing parallels with other systems, such as natural structures, technological mechanisms, or cultural artefacts.

A complementary perspective on analogical reasoning is offered by Keith Holyoak and Paul Thagard, who describe analogy as a fundamental mechanism of creative thought. In their model, analogical reasoning involves the mapping of relationships between domains and the selective transfer of knowledge that can support problem solving and innovation (Holyoak & Thagard, 1995). The authors emphasize that analogies are particularly powerful in situations where problems are complex or insufficiently defined, which is characteristic of many design tasks. Through analogical thinking, designers can generate new interpretations of design problems and explore alternative conceptual directions.

The role of analogy as a central mechanism of human cognition is further explored by Douglas Hofstadter and Emmanuel Sander. In their work *Surfaces and Essences*, the authors argue that analogy is not merely a special type of reasoning but a fundamental process underlying human thought and perception. According to their view, everyday cognition is largely based on the ability to recognize patterns and relationships between different situations and to interpret new experiences through previously established conceptual structures (Hofstadter & Sander, 2013). This perspective suggests that analogical thinking is deeply embedded in the cognitive processes that support creativity and conceptualization in design.

The connection between analogy and creativity was also emphasized by Arthur Koestler in his theory of bisociation, which describes the creative act as the intersection of previously unrelated frames of reference. According to Koestler, creative insight emerges when two independent matrices of thought are brought together, producing a new conceptual configuration that did not previously exist (Koestler, 1964). In design practice, such bisociative processes often occur when designers combine ideas from different domains, leading to unexpected spatial or formal solutions.

Taken together, these theoretical perspectives highlight the central role of analogical reasoning in conceptual thinking and creative design processes. By enabling designers to establish connections between different domains of knowledge and experience, analogy supports the generation of innovative conceptual frameworks and enriches the interpretative possibilities of design problems. Within design education, encouraging students to engage in analogical thinking can therefore play an important role in developing their ability to construct coherent and meaningful design concepts.

Understanding the cognitive foundations of analogy provides an important theoretical basis for integrating analogical methods into the conceptual stage of the design process. Such methods can stimulate associative exploration, expand the range of conceptual possibilities, and support the development of more structured design strategies. In this way, analogical reasoning becomes not only a cognitive mechanism of creativity but also a methodological tool that can enhance the pedagogical effectiveness of design education.

4. COGNITIVE AND PEDAGOGICAL FOUNDATIONS OF CONCEPT FORMATION IN DESIGN EDUCATION

Recent empirical research on designer cognition provides important evidence for understanding how conceptual thinking develops during the design process. Rather than viewing design as a linear sequence of decisions, empirical studies demonstrate that designers continuously alternate between problem framing, idea generation, evaluation, and reformulation. This iterative cognitive activity is particularly evident during the conceptual stage, where designers construct and refine mental representations of the design problem before developing concrete solutions.

Comparative studies of novice and expert designers reveal substantial differences in the way conceptual problems are approached. Novice designers frequently concentrate on immediately producing formal solutions, often relying on obvious visual features or familiar precedents. Their design process is typically characterised by early fixation on a limited number of ideas and a relatively narrow exploration of alternative concepts. In contrast, experienced designers tend to postpone commitment to a specific solution while actively reframing the problem, exploring multiple conceptual alternatives, and establishing broader relationships between functional, spatial, and semantic aspects of the design task. Expert designers also demonstrate greater flexibility in shifting between abstract and concrete representations and make more extensive use of sketching, analogical reasoning, and reflective evaluation throughout the conceptual phase (Dinar et al., 2015). These findings suggest that conceptual capability is not an innate ability but a cognitive competence that can be systematically developed through educational interventions designed to support iterative exploration and reflective reasoning.

Among the cognitive mechanisms supporting conceptual thinking, analogical reasoning has received increasing empirical attention. While theoretical studies have long emphasized the importance of analogy in creative cognition, recent experimental research provides evidence explaining why analogical methods are particularly effective during concept formation.

Studies on design-by-analogy demonstrate that exposing students to multiple carefully selected analogical sources significantly increases both the quantity and diversity of generated design ideas. Presenting several analogies enables learners to identify higher-level structural principles rather than focusing on superficial similarities, thereby facilitating deeper conceptual transfer. However, the same studies indicate that excessive or irrelevant visual information may reduce the effectiveness of analogical reasoning by distracting attention from essential conceptual relationships (Song et al., 2018). These findings highlight the importance of carefully selecting pedagogical stimuli that encourage abstraction without overwhelming students with unnecessary visual complexity.

Recent cognitive research further explains this phenomenon by demonstrating that analogical reasoning promotes conceptual expansion through representational change. When designers establish meaningful relationships between distant conceptual domains, they frequently experience moments of cognitive restructuring that lead to new interpretations of the design problem. Such restructuring is often accompanied by insight experiences ("aha" moments), which reflect the successful reorganization of mental representations rather than the simple accumulation of ideas (Chesebrough et al., 2023). From an educational perspective, these findings suggest that analogical thinking should be regarded not merely as a creativity technique but as a pedagogical mechanism capable of expanding conceptual understanding and supporting the emergence of innovative design concepts.

The effectiveness of pedagogical approaches aimed at developing conceptual thinking depends not only on individual design methods but also on the educational environment in which these methods are applied. Project-based learning has increasingly been recognised as one of the most suitable educational contexts for developing higher-order cognitive skills because it engages students in authentic design problems requiring continuous inquiry, collaboration, reflection, and iterative problem solving.

A comprehensive review of project-based learning in higher education demonstrates that this educational approach contributes simultaneously to cognitive, behavioural, and affective learning outcomes. Beyond improving disciplinary knowledge, project-based learning enhances problem-solving abilities, teamwork, engagement, self-regulation, and reflective thinking, all of which are directly associated with successful concept formation (Guo et al., 2020). Authentic design projects encourage students to construct knowledge actively rather than reproduce existing solutions, creating favourable conditions for conceptual exploration and iterative refinement.

These conclusions correspond closely with previous investigations conducted within the Interior and Furniture Design programme at the University of Forestry, where intensive project-based learning modules have consistently demonstrated that collaborative design environments stimulate associative thinking, encourage the exploration of multiple conceptual alternatives, and strengthen students' ability to articulate coherent design concepts. Consequently, project-based learning should be understood not simply as a teaching strategy but as a cognitive environment that supports the interaction between creative exploration, analogical reasoning, reflection, and conceptual development throughout the design process.

The proposed cognitive-pedagogical framework presented in this paper builds upon a sequence of educational investigations conducted over the past fifteen years. These studies demonstrate that conceptual competence develops progressively through carefully structured pedagogical interventions that stimulate creative exploration, associative reasoning, and reflective practice.

The evolution of this pedagogical perspective has been supported by a series of educational studies conducted within the Interior and Furniture Design programme at the University of Forestry over the last fifteen years. These studies demonstrate a gradual transition from investigating individual creative methods toward the development of an integrated educational framework aimed at strengthening conceptual thinking throughout the design process.

The initial stage of this research focused on the role of design methods within design education. It was established that creative abilities should not be regarded solely as innate personal characteristics but as competences that can be systematically developed through appropriate methodological support. Design methods were identified as educational instruments that help students overcome psychological barriers, organize creative search, and transform accumulated knowledge into original design ideas (Raycheva & Angelova, 2010).

Subsequent investigations concentrated on methods stimulating idea generation and their educational application. The findings demonstrated that structured heuristic techniques significantly facilitate the generation of multiple design alternatives by encouraging visual thinking, free association, and divergent exploration. These methods proved particularly valuable during the early conceptual stage, where students often experience uncertainty and premature fixation on a single solution. Instead of directing students toward predetermined answers, the methods create favourable conditions for exploring a broad spectrum of conceptual possibilities (Angelova, 2011).

A further stage of the research examined analogy as one of the principal cognitive mechanisms supporting conceptual design. Analogical thinking enables students to transfer structural, functional, or semantic relationships from one domain to another, thus extending the range of possible interpretations of a design problem. Rather than functioning merely as a source of visual inspiration, analogy was found to facilitate abstraction, conceptual transformation, and the construction of coherent design narratives. Within educational practice, analogical reasoning proved especially effective for helping students move beyond literal interpretations toward more original conceptual solutions (Angelova, 2013).

Building upon these theoretical foundations, subsequent studies investigated pedagogical strategies capable of stimulating creative search during intensive design workshops. These studies demonstrated that the effectiveness of conceptual development depends not only on the methods employed but also on the organization of the educational environment. Carefully sequenced design tasks, teamwork, iterative discussions, rapid visualization, and continuous feedback were shown to accelerate conceptual exploration while encouraging students to postpone premature evaluation of their ideas. Such educational settings support divergent thinking and increase the probability of producing innovative design concepts (Angelova, 2014).

An important extension of this research addressed project-based learning as an educational environment for conceptual development. Long-term observations of intensive design modules revealed that students

frequently encounter their greatest difficulties during the conceptual phase of the design process rather than during technical development. They often tend to search immediately for formal solutions without constructing a sufficiently clear conceptual framework. Project-based learning creates authentic design situations in which concept formation becomes an explicit educational objective. Through collaborative work, interaction with external professionals, iterative presentations, and critical discussions, students gradually develop the ability to formulate, communicate, and defend coherent design concepts (Raycheva, Angelova & Vodenova, 2016).

The investigation of individual creativity methods was further expanded through the experimental application of the Method of Focal Objects in design education. The experiment demonstrated that associative combinations between unrelated objects effectively stimulate conceptual abstraction and non-standard thinking. By intentionally introducing unexpected characteristics into familiar design problems, students generate novel conceptual directions that would rarely emerge through conventional analytical reasoning alone. The method therefore represents a practical pedagogical instrument for strengthening associative thinking during the earliest stages of concept formation (Angelova, 2021/2022).

More recent studies shifted attention toward reflective learning as an integral component of conceptual development. The analysis of students' work diaries demonstrated that documenting the evolution of ideas enables students to become more conscious of their own conceptual processes. Reflection transforms concept formation from an intuitive activity into an explicit learning process, allowing students to analyse the development of their ideas, evaluate design decisions, and recognize relationships between initial inspiration and final design outcomes. Consequently, work diaries function not only as assessment tools but also as instruments supporting self-regulated conceptual learning (Angelova et al., 2023).

Finally, research on project-based teaching implemented in an online environment highlighted the influence of the educational context on conceptual thinking. Despite concerns regarding distance education, the study demonstrated that appropriately structured online collaborative environments may successfully support concept development by facilitating continuous communication, iterative feedback, visual information exchange, and collaborative reflection. These findings suggest that conceptual thinking depends less on the physical setting than on the quality of pedagogical organization and the availability of structured opportunities for interaction and idea development (Angelova, Vodenova & Raycheva, 2024).

Taken together, these studies outline a coherent pedagogical model in which conceptual thinking develops through the interaction of complementary educational components: systematic design methods, associative and analogical reasoning, structured creative search, project-based learning, heuristic creativity techniques, reflective practice, and collaborative learning environments. Rather than functioning as isolated teaching strategies, these approaches form an integrated methodological framework that progressively develops students' ability to construct, communicate, and refine coherent design concepts. This progression illustrates that concept formation should be understood not merely as one stage of the design process, but as a complex educational competence that can be intentionally cultivated through carefully designed pedagogical interventions.

The proposed Cognitive-Pedagogical Model synthesizes the theoretical and empirical perspectives discussed throughout the paper. Rather than considering concept formation as a single design stage, the model conceptualizes it as the result of continuous interaction between cognitive processes and educational interventions. Conceptual thinking develops through iterative cycles of problem framing, analogical reasoning, conceptual expansion, reflection, and collaborative project activity. Within this framework, pedagogical approaches are not regarded as isolated teaching techniques but as interconnected mechanisms that gradually strengthen students' ability to construct coherent and meaningful design concepts. Consequently, the model provides an integrated theoretical framework for understanding concept formation in interior and furniture design education and may serve as a basis for the future development of educational methodologies aimed at fostering higher levels of conceptual competence.

The relationships between the principal cognitive and pedagogical components of the proposed framework are summarized in Figure 2. The model integrates the theoretical perspectives of Cross, Lawson, Schön, Dorst, Gentner, Holyoak and Hofstadter with empirical findings from recent cognitive research and the authors' long-term pedagogical investigations.

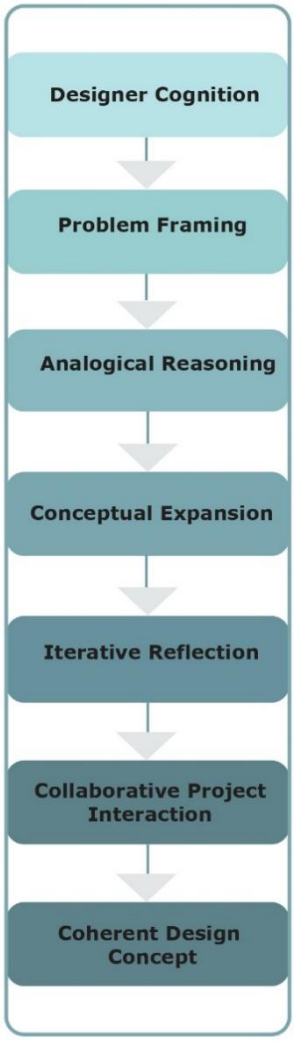


Figure 2: Proposed Integrated Cognitive-Pedagogical Model of Concept Formation in Design Education

5. CONCLUSIONS

This study has examined concept formation as a fundamental stage of the interior and furniture design process and as a central educational objective in contemporary design education. The theoretical analysis demonstrates that concept formation is not an isolated moment of idea generation but a dynamic cognitive process involving problem framing, analogical reasoning, abstraction, reflection, and iterative refinement. By integrating perspectives from design methodology, cognitive science, and creativity research, the paper highlights the importance of conceptual thinking as the mechanism that connects abstract interpretation with coherent design development. The review of pedagogical approaches further indicates that conceptual competence can be intentionally developed through appropriately structured educational environments that encourage exploration, experimentation, and reflective learning.

The principal contribution of this study is the proposed Integrated Cognitive-Pedagogical Model of Concept Formation, which synthesizes theoretical perspectives, empirical evidence from contemporary research on designer cognition, and the authors' long-term pedagogical investigations in interior and furniture design education. Unlike existing studies that examine cognitive mechanisms or educational methods separately, the proposed model establishes explicit relationships between designer cognition, analogical reasoning, conceptual expansion, reflective exploration, and project-based interaction. In doing so, it provides an integrated conceptual framework for understanding how conceptual thinking develops and how it may be systematically fostered within design education.

From a practical perspective, the proposed framework may support the design of educational methodologies aimed at strengthening conceptual design capability throughout the curriculum of interior and furniture design programmes. The model offers a theoretical basis for selecting and sequencing pedagogical approaches such

as analogical methods, heuristic creativity techniques, project-based learning, reflective practice, and collaborative design activities. It may also serve as a reference framework for curriculum development, studio teaching, assessment of conceptual competence, and the design of learning environments that encourage deeper conceptual exploration rather than premature formalization of design solutions.

Future research should focus on validating the proposed model through empirical studies involving students at different stages of design education and within diverse educational contexts. Experimental investigations may further examine the effectiveness of individual pedagogical strategies in supporting concept formation and compare different instructional approaches. Particular attention should also be given to the rapidly expanding role of artificial intelligence in conceptual design education. Future studies could investigate how AI-assisted ideation, intelligent design-support systems, and digital design studios influence conceptual thinking, analogical reasoning, and creative decision-making, thereby extending the proposed model to emerging forms of design education.

REFERENCES

Angelova, D. (2011). Methods for stimulating the creative process and their application in design education. In Proceedings of the First International Conference "Education, Science, Innovations" (pp. 98–106). Pernik, Bulgaria: European Polytechnical University. https://doi.org/10.13140/2.1.1587.1681

Angelova, D. (2013). Analogy as a basic technique in the process of creating new products. Innovation in Woodworking Industry and Engineering Design, 2(4), 151–156. https://doi.org/10.13140/2.1.3225.5686

Angelova, D. (2014a). Methods for stimulating the creative search. Innovation in Woodworking Industry and Engineering Design, 2(6), 102–107. https://doi.org/10.13140/RG.2.1.3785.4569

Angelova, D. (2014b). Tactics for stimulating the creative search in conducting intensive student modules (workshops). ATINER Conference Paper Series, No. IND2014-1142. Athens Institute for Education and Research. https://doi.org/10.13140/2.1.4076.3205

Angelova, D. (2021). Experimental application of the method of focal objects in design education. Innovation in Woodworking Industry and Engineering Design, 20(2), 83–88.

Angelova, D., Vodenova, P., Raycheva, R., & Tasheva, S. (2023). Students' work diaries: Visual impressions of a project-based learning module. Innovation in Woodworking Industry and Engineering Design, 24(2), 17–27.

Angelova, D., Vodenova, P., & Raycheva, R. (2024). Project-based teaching in the online medium: Advantages and disadvantages – Conclusions after an online study module for design students. Bulletin of the Transilvania University of Braşov. Series II: Forestry, Wood Industry, Agricultural Food Engineering, 17(66), 1. https://doi.org/10.31926/but.fwiafe.2024.17.66.1.4

Chesebrough, C., Chrysikou, E. G., Holyoak, K. J., Zhang, F., & Kounios, J. (2023). Conceptual expansion induced by analogical reasoning sparks "Aha" moments. Memory & Cognition. https://doi.org/10.3758/s13421-023-01461-5

Cropley, D. H., & Cropley, A. J. (2000). Fostering creativity in engineering undergraduates. High Ability Studies, 11(2), 207–219.

Cross, N. (2011). Design thinking: Understanding how designers think and work. Oxford: Berg.

Dash, S. P. (2021). An exploratory study on design process in architecture: Perspective of creativity. Creativity Studies, 14(2), 346–361. https://doi.org/10.3846/cs.2021.12989

Dinar, M., Shah, J. J., Cagan, J., Leifer, L., Linsey, J., Smith, S. M., & Vargas Hernandez, N. (2015). Empirical studies of designer thinking: Past, present, and future. Journal of Mechanical Design, 137(2), 021101. https://doi.org/10.1115/1.4029025

Dorst, K. (2011). The core of design thinking and its application. Design Studies, 32(6), 521–532.

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. Cognitive Science, 7(2), 155–170.

Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. International Journal of Educational Research, 102, 101586. https://doi.org/10.1016/j.ijer.2020.101586

Hofstadter, D., & Sander, E. (2013). Surfaces and essences: Analogy as the fuel and fire of thinking. New York: Basic Books.

Holyoak, K. J., & Thagard, P. (1995). Mental leaps: Analogy in creative thought. Cambridge, MA: MIT Press.

Koestler, A. (1964). The act of creation. London: Hutchinson.

Lawson, B. (2006). How designers think: The design process demystified (4th ed.). Oxford: Architectural Press.

Potur, A. A., & Barkul, Ö. (2009). Creative thinking in architectural design education. In Proceedings of the International Conference on Engineering and Product Design Education. pp. 113–125.

Raycheva, R., & Angelova, D. (2010). Design methods and design education. In Proceedings of the Third Scientific Conference "Innovations in Woodworking Industry and Engineering Design" (pp. 261–265). Sofia: University of Forestry Press. (In Bulgarian)

Raycheva, R., Angelova, D., & Vodenova, P. (2016). Project-based learning in engineering design in Bulgaria: Expectations, experiments and results. European Journal of Engineering Education, 42(6), 1–18. https://doi.org/10.1080/03043797.2016.1235140

Schön, D. A. (1983). The reflective practitioner: How professionals think in action. New York: Basic Books.

Song, H. I., Lopez, R., Fu, K., & Linsey, J. (2018). Characterizing the effects of multiple analogs and extraneous information for novice designers in design-by-analogy. Journal of Mechanical Design, 140(3), 031101. https://doi.org/10.1115/1.4038565

Poster session — Part 2 | Contribution 4

INFLUENCE OF RELATIVE HUMIDITY ON THE TYPE OF FITTING IN MORTISE AND TENON JOINTS

Nikola Mihajlovski, Elena Jevtoska, Gjorgi Gruevski

Ss. Cyril and Methodius University in Skopje, North Macedonia,
Faculty of Design and Technologies of Furniture and Interior-Skopje,
e-mails: mihajlovski@fdtme.ukim.edu.mk, jevtoska@fdtme.ukim.edu.mk, gruevski@fdtme.ukim.edu.mk

ABSTRACT

The quality of some products is particularly dependent on small tolerances in the joints. In furniture manufacturing, these are the mortise and tenon joints in chair constructions. The strength and durability of the chair construction depend on the fit and tolerances in the joint.

Dimensional changes in wood occur as a result of changes in relative humidity in the atmosphere. The moisture in the wood enters into equilibrium with the humidity in the air. For each percentage of humidity in the air, there is a corresponding moisture state in the wood.

The aim of this paper is to study the influence of changes in relative air humidity on the type of fit of the mortise and tenon joints. The aim is also to determine the dimensional changes of tenon and the machining accuracy class.

Details of chairs on which an oval mortise and tenon joint was made were measured. The details were made of beech wood (Fagus Silvatica) on conventional machines in a chair production plant. The average value of the measurements of the tenon thickness falls into the HT25 machining accuracy class. When changing the conditions in the production plant, the measured dimensions of the joints immediately after machining and after a few hours of delay are different. This leads to a change in the accuracy class and the type of fit.

Keywords: mortise and tenon joints, tolerances, accuracy class.

1. INTRODUCTION

The quality of some products is particularly dependent on small tolerance fields in the joints. In furniture production, these are the mortise and tenon joints in chair constructions. The strength and durability of the chair construction depend on the fit and tolerances in the joint. The influence of tolerances and the type of fit in mortise and tenon joints on the strengths has been investigated by several authors (Potrebic 1970, Skakic and Janicevic 2000, Smardzewski and Papruga 2004, Mackerle 2005, Gawronski 2006). In general, all authors state that the type of fit and the accuracy of processing of mortise and tenon joints have an impact on the strengths and thus on the durability of wooden chairs. They recommend an interference fit with an overlap of 0.1 to 0.2 mm.

Variations in the atmosphere's relative humidity cause dimensional changes in wood. Wood's moisture content and the air's humidity always balance each other out. According to

DIN 68100:2010-07, there is a corresponding moisture state in the wood for every percentage of air humidity. This water-saturation point of wood fibers is directly correlated with air relative humidity and varies depending on the type of wood. Wood exhibits anisotropy in three different directions because it is an anisotropic material, or more accurately, an orthotropic material. When designing a wood product, it is essential to understand the characteristics of a specific direction of wood grains as well as their mutual effect.

The aim of this paper is to study the influence of changes in the relative humidity of the air in the processing plant on the type of fit of the mortise and tenon joint. The aim is also to determine the dimensional changes of the tenon and the machining accuracy class.

2. EXPERIMANTAL METHOD

The measurement was performed in a chair manufacturing factory on chair parts that had an oval mortise and tenon joint. The parts were made of beech wood (Fagus Silvatica). The joint was made on conventional machines, a tenoning machine and an oscillating drill. The measurement was performed on 32 randomly selected parts. The dimensions of the joint are shown in Figure 1.

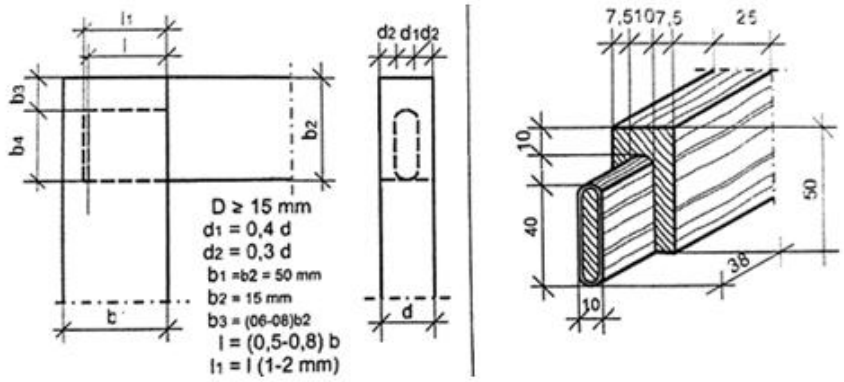


Figure 1: Dimensions of mortise and tenon joint

According to the DIN 68101:2012-02 standard, we use the common hole system for which we take the nominal hole dimension of 10mm. We measure only the thickness of the tenon for which tolerances and the type of fit in the joint are specified. The thickness of the tenon was measured in three places from which the average value was calculated as well as an indicator for each tenon separately. The calculation of the dimensional change of the wood caused by a change in humidity was according to the formula given in the DIN 68100:2010-07 standard:

$$\Delta M = (N \times \Delta w \times \beta v)/100 \text{ [mm]} \quad (1)$$

ΔM – change in the thickness of the tenon due to a change in the relative humidity in the air (mm)

N – nominal thickness of the tenon = 10 mm

Δw – change in the moisture content in the wood due to a change in the relative humidity in the air (%)

βv – volume shrinkage of the wood (%)

In addition to the thickness of the tenon, the following values were also measured: the moisture content of the wood after manufacturing, the angle of the wood grain and the relative humidity of the air in the measurement environment. The measurement of the dimension was performed with a caliper from the manufacturer "MIB" model 02026117 for which the manufacturer declares an accuracy of ± 0.03mm. The moisture content of the wood was measured with a contact moisture meter from the manufacturer "Nigos" model DVD240 with a declared accuracy of ±1%. The angle of extension of the wood grain was measured with a digital angle-meter from the manufacturer "Extol" model Premium with a declared accuracy of ±0.3°. The relative humidity of the air in the measurement environment was measured with a hygrometer from the manufacturer "Termocare" model KT908 with a declared accuracy of ±5%.

3. RESULTS AND DISCUSSION

The average value of the measurements of the manufactured tenons was 10.20 mm. According to the minimum and maximum measured values of the tenon thickness, the accuracy of the machine falls into the HT25 accuracy class (standard DIN 68100:2010-07). In this case, we have an overlap of 0.2 mm, i.e. a interference fit in the joint. Table 1 shows the values of the measurements of the tenon thickness and the dimensional changes after reaching equilibrium humidity.

Table 1: Values from tenon thickness measurement

No.	Variable	1 (mm)	2 (mm)	3 (mm)	d (mm)	α (°)	W (%)	Δw (%)	βv (%)	ΔM	d-ΔM
	1	2	3	4	5	6	7	8	9	10	11
1	x̄	**10.19**	**10.21**	**10.20**	**10.20**	**43.31**	**11.27**	**4.14**	**0.31**	**0.13**	**10.08**
2	σ	0.13	0.10	0.16	0.10	15.27	1.61	1.35	0.05	0.04	0.10
3	v	1.31	1.03	1.56	0.98	35.25	14.32	32.68	15.94	33.55	1.02
4	MIN	9.80	10.03	9.87	10.03	17.80	6.50	0.30	0.21	0.01	9.91
5	MAX	10.40	10.39	10.70	10.37	78.20	13.40	6.10	0.39	0.20	10.28

$\bar{x}$ – mean value, σ – standard deviation, v – coefficient of variation, 1,2,3 (mm) – measuring points on the tenon, d – tenon thickness (mm), α – angle of the wood grain at the tenon (°), W – moisture in the wood (%), Δw – change in moisture in the wood (%), βv – volume shrinkage of the tenon (%), ΔM – change in thickness while changing the tenon moisture (mm), d-ΔM – tenon thickness with dimensional change (mm)

At the time of measurement, the air in the facility had a relative humidity of RH=37%, while the average moisture content of the wood in the tested components was W=11.27%. Because wood is hygroscopic, it tends to adjust its moisture level until it reaches equilibrium with the surrounding environment. According to the DIN 68100:2010-07 standard, which specifies wood moisture content based on relative humidity and species, the measured moisture level in these parts corresponds to an ambient relative humidity of RH=59%. If the components are conditioned under the current plant conditions, they will eventually stabilize at a moisture content of W=8.21%. This reduction of 4.14% in moisture content will lead to shrinkage, resulting in a dimensional change of 0.13 mm in the tenon. The author (Thompson 2002) notes that wood typically takes around 48 hours to reach moisture equilibrium with the environment air humidity, with the most significant changes occurring within the first few hours. This effect is particularly noticeable in smaller wood components, such as those used in chair construction. Fluctuating conditions in a production environment can therefore lead to dimensional differences in joints when measured immediately after machining versus after a delay. In this example, once the parts are conditioned and the wood has shrunk, the tenon thickness would measure 10.08 mm (as indicated in column 11 of Table 1). At that point, joint fit could become transition fit. Based on the calculated range of tenon thickness after shrinkage, the required machining precision would fall within tolerance class HT40. Other researchers (Sydor et al. 2021) also discuss dimensional shifts in holes due to changes in wood moisture content caused by variations in relative humidity. Dimensional instability is most pronounced in the tangential direction of the wood grain (Forest Products Laboratory 2021), which commonly aligns with the grain orientation in tenons. This behavior is especially evident in highly hygroscopic wood species like beech (Wagenfuhr 2000), a material frequently used in chair manufacturing.

4. CONCLUSIONS

Based on the measurements and calculations carried out to assess how a change in relative air humidity affects the joint's type of fit, the following conclusions are justified:

- For an oval mortise-and-tenon joint with an interference fit, assuming an overlap of 0.2 mm and a processing accuracy level of class HT25, when the relative air humidity decreases for 22%, the tenon contracts in thickness by 0.13 mm. As the dimensions change, the fit shifts to a transition fit, and the processing accuracy falls to class HT40.
- Industrial facilities handling furniture components with interconnected mating dimensions must continuously control indoor temperature and relative humidity to align perfectly with the equilibrium moisture content of the wood.

5REFERENCES

DIN 68100:2010-07 – Tolerance system for wood working and wood processing – Concepts, series of tolerances, shrinkage and swelling

DIN 68101:2012-02- Fundamental deviations and tolerance zones for wood working and wood processing

Forest Products Laboratory. (2021). Wood handbook—wood as an engineering material. General Technical Report FPL-GTR-282. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 543 p.

Mackerle, J. (2005). Finite element analyses in wood research: A bibliography. Wood Science and Technology 39(7): 579–600

Potrebić, M. (1970). Joint tolerance as effecting factor on strength of mortise joint. Master thesis, Belgrade University, Faculty of Forestry. pp 105–107

Smardzewski, J., Papuga, T., 2004: "Stress distribution in angle joints of skeleton furniture, Electronic Journal of Polish Agricultural Universities 7(1)

Skakić, D., Janićijević, S. (2000). Effect of type of joint, machining precision, and type of fit on the strength of the joints in chairs. (Uticaj vrste spoja, tačnosti obrade i vida naleganja na čvrstoću spojeva stolica). Drvarski glasnik 9(35/36): 21–25

Gavronski, T. (2006). Rigidity-strength models and stress distribution in housed tenon joints subjected to torsion. Electronic Journal of Polish Agricultural Universities 9(4)

Sydor M., Majka J., Langová N. (2021). "Effective diameters of drilled holes in pinewood in response to changes in relative humidity," BioResources 16(3), 5407–5421.

Thompson R. (2002). Moisture Breathing Properties of Wood: Let's Get It Right! , CASJ Vol. 4, No. 6 (Series Il), November 2002

Wagenführ R. (2000). Holzatlas. Leipzig, Fachbuchverlag Lepzig: 707

Poster session — Part 2 | Contribution 5

INFLUENCE OF THE BEVEL ANGLE OF THE BANDSAW ON CUTTING RESISTANCE

Zoran Trposki[1], Vladimir Koljozov[1], Anastasija Temelkova[1], Ana Marija Stamenkoska[1], Damjan Stanojević[2], Monika Koljozova[1]

[1]Ss. Cyril and Methodius University in Skopje, Faculty of Design and Technologies of Furniture and Interior
e-mails: trposki@fdtme.ukim.edu.mk, koljozov@fdtme.ukim.edu.mk, temelkova@fdtme.ukim.edu.mk, stamenkoska@fdtme.ukim.edu.mk, koljozova@fdtme.ukim.edu.mk

[2]Academy of Technical and Educational Vocational Studies Niš – Vranje Department
e-mail: damjan.stanojevic@akademijanis.edu.rs

ABSTRACT

Cutting with bandsaw blades represents a well-established research area within wood machining. In this research, we focus on the impact moment, specifically the initial contact of the saw teeth with the wood surface up to the point when the full width of the blade penetrates the material. This distance is directly related exclusively to the width of the saw. It is the critical distance at which we must carefully penetrate the wood with lower feed speeds, in order to avoid high pressures on the back of the teeth. Increased pressures on the back of the teeth (while the saw body has not yet penetrated the wood surface) causes partial sinking of the saw, which results in a curvature of the cut at the onset of sawing. Many machine manufacturers solve this problem by partially tilting the saw blade. This adjustment reduces the pressure on the tooth back and stabilizes the cutting trajectory. This paper investigates the influence of the cutting angle on the cutting resistance at angles of 90° and 75°, thereby assessing the influence of the saw bevel on the cutting resistance. Three different feed rates were used: 3, 6 and 9 mmin-1, and four cutting heights: 20, 30, 40 and 50 mm. The research material was beech wood (*Fagus sylvatica* L.).

Keywords: bandsaw, cutting angle, wood.

1. INTRODUCTION

Bandsaw cutting has been extensively studied. This research focuses on a specific anomaly, which is the lateral blade deviation that occurs when the teeth first engage the wood at optimal feed speeds. The resulting curved cutting path often depends on blade width because the blade's back edge behaves much like a rudder. As a result, the blade typically returns to its intended cutting path only after traveling several blade widths (Figure 1).

Figure 1 illustrates the two adjacent cuts, positioned side by side to emphasize the curved initial path (lower part of the figure). The curved trajectory is clearly visible. In the upper part of the figure, under identical cutting conditions, it can be observed that the cut is straight. The reason for this difference is that the blade is tilted at an angle of 15°, resulting in a gradual entry of the blade into the wood. At the beginning of the cut, the active cutting length is small, reaching its maximum only after the blade has fully penetrated the wood (Figure 2b), unlike the situation shown in Figure 2a.

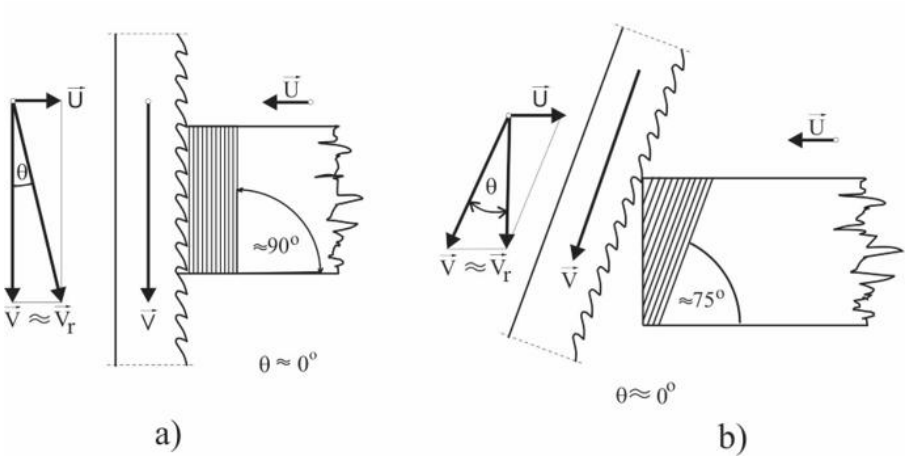


Figure 1: Curved initial cut caused by sudden impact forces acting on the back side of the teeth.



Figure 2: Initial tooth contact. a) conventional band saws; b) tilted band saws.

This arrangement allows cutting resistance to increase gradually, which stabilizes the blade and helps produce a straight cut without changing the feed speed set for the overall cutting process.

However, blade tilting also increases the active cutting length, raising an important question: does this adjustment lead to additional, undesirable costs?

2. AIM OF THE RESEARCH

Tilting the bandsaw blade increases the active cutting length. However, wood is anisotropic, and cutting resistance varies with the direction of the fibres. When fibres are cut at 90°, the ratio of cutting resistance for transverse, longitudinal, and tangential cutting ranges from 5:3:1 to 9:5:1. If the cutting edge severs the fibres at an angle other than 90°, lower resistance is generally expected. In this case, however, the increased active cutting length (l′) introduces an additional variable.

Accordingly, this research aims to determine how blade tilting affects cutting resistance and the resulting cutting trajectory.

3. PREVIOUS RESEARCH AND PRECONDITIONS

Many researchers have examined how different factors affect the productivity and quality of log bandsaw cutting. These factors include blade vibration, feed rate, cutting speed, cutting height, blade tension, and other operating parameters, as well as their effects on surface roughness, kerf width, cutting path, and the energy consumption of the main and auxiliary electric motors.

Among the most notable researchers, in addition to those listed in the References, who have studied log band saws, are: Thunell B.; Ulsou A.G.; Mote C.D.; Szymani R.; Wang J.; Mahalingam S.; Yurev Y.I.; Veselkov V.I.

Wood cutting is generally classified into three basic modes: tangential, longitudinal, and transverse. Depending on the wood species and anatomical structure, the cutting-resistance ratio for these modes ranges from 1:1.4:4.6 to 1:3:6.

In practice, wood fibres are usually cut through a combination of these modes. In conventional bandsaws, the cutting edge typically severs the fibres at a 90° angle, where cutting resistance is expected to be greatest.

As previously described, many manufacturers tilt the main machine frame at an angle between 15° and 20° to avoid the abrupt entry of the blade into the sawlog, which otherwise results in a curved initial cut.

There were two possible approaches for conducting this research:

1. Using an existing industrial machine with the required capability for tilting the main frame.

2. Constructing a model that enables the main frame to be tilted to different angles, specifically 15° from the vertical in the direction opposite to feed movement.

The second option was chosen because the laboratory at the Faculty of Design and Technologies of Furniture and Interior in Skopje already has a bandsaw with adjustable tilt angles, making it the most suitable research facility for this research (Figure 3).

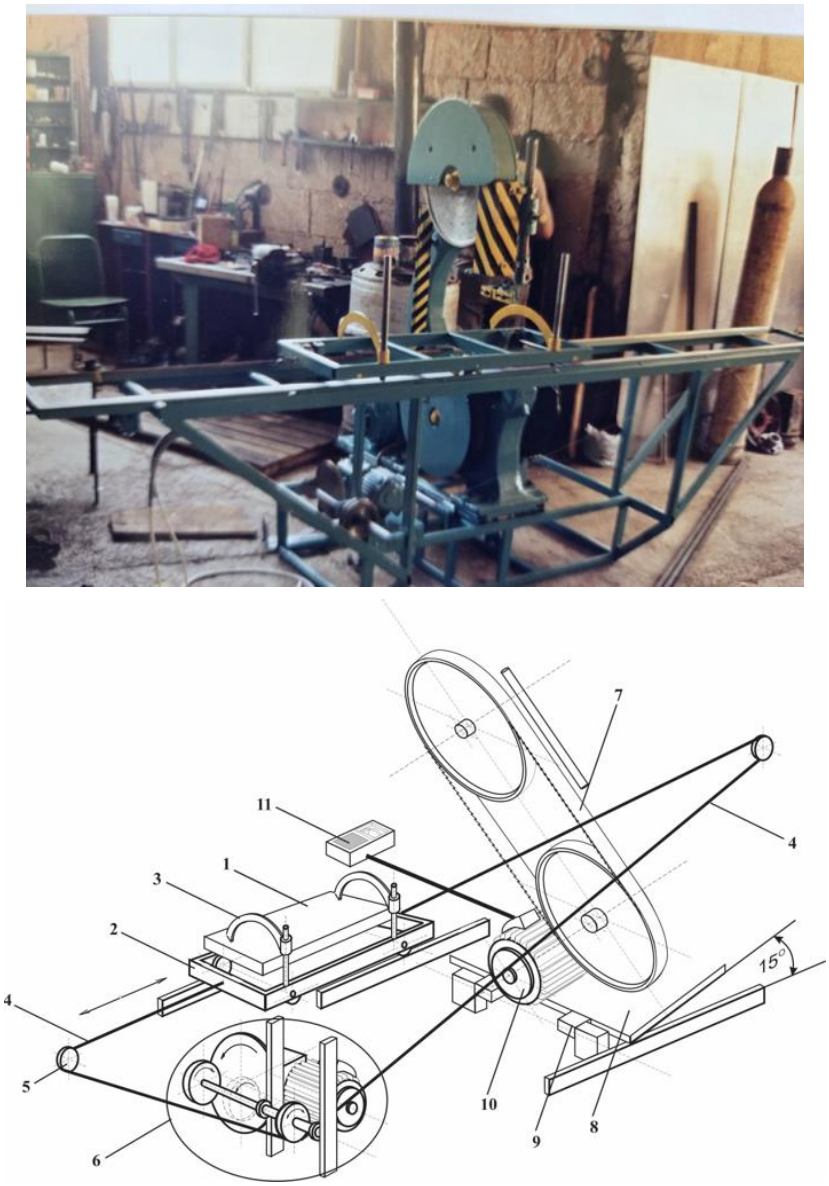


Figure 3: Laboratory experimental bandsaw with tilting capability up to 55° relative to the vertical. 1) specimen; 2) feed carriage; 3) clamping claws; 4) steel cable for carriage movement; 5) pulleys; 6) friction-drive feed mechanism; 7) band saw blade; 8) rotary base supporting the main machine; 9) shafts; 10) main electric motor (5 kW); 11) analog ammeter.

The electric motor has a power of 5 kW and a rotational speed of 980 min^{-1}, with an indirect belt transmission to the main wheel, providing a blade speed of 12 $m \cdot s^{-1}$. The blade has set teeth (NV), a width of 30 mm, a thickness of 0.6 mm, and a tooth height of 5 mm.

Based on the machine's capabilities, three feed rates were selected: U_1 = 3 $m \cdot min^{-1}$, U_2 = 6 $m \cdot min^{-1}$, and U_3 = 9 $m \cdot min^{-1}$.

The main frame was tilted 15° from the vertical, corresponding to the average angle used by various manufacturers.

The specimen thicknesses, which corresponded to the cutting heights, were h_1 = 20 mm, h_2 = 30 mm, h_3 = 40 mm, and h_4 = 50 mm.

Beech wood (*Fagus sylvatica* L.) was used because it is the most commercially utilized wood species in the Republic of North Macedonia.

4. RESEARCH METHODOLOGY

Three cutting trials were conducted on each specimen at fibre-cutting angles of 90° and 75°. This produced 18 trials for each specimen thickness (20, 30, 40, and 50 mm), for a total of 72 trials. During each trial, readings from the analog ammeter (Figure 3-11) were visually recorded. Because of the instrument's inertia, the measurements were considered reliable, with an error margin of up to 5%. No significant deviations were observed within any measurement group, as shown in Table 1.

5. RESULTS

The results show that, when wood fibres were cut at a 90° angle, the initial cutting path was curved for all feed speeds and extended approximately 20 cm from the front edge of the specimen. Both blade deflection and the length of the curved segment increased at higher feed speeds and decreased at lower feed speeds (Figure 1).

Electric-current measurements show that cutting resistance increased slightly as a result of the longer active cutting length. The cutting-length increase coefficient was 1.035 (Table 1).

Table 1: Measured values of electric current [A] for cutting heights of 20, 30, 40, and 50 mm and feed speeds of 3, 6, and 9 m·min⁻¹.

Count number	Feed rate [mmin^{-1}]	Fibre-cutting angle [^{o}]	Specimen thickness (h=20mm) Cutting lenght (l, l`) [mm]	Electric current [A]	Specimen thickness (h=30mm) Cutting lenght (l, l`) [mm]	Electric current [A]	Specimen thickness (h=40mm) Cutting lenght (l, l`) [mm]	Electric current [A]	Specimen thickness (h=50mm) Cutting lenght (l, l`) [mm]	Electric current [A]
1				1,00		1,15		1,25		1,55
2		90^o	l =20,00	1,00	l =30,00	1,15	l =40,00	1,30	l =50,00	1,60
3	U_1=3			1,00		1,15		1,25		1,50
4				1,05		1,20		1,45		1,80
5		75^o	l`=20,70	1,10	l`=31,05	1,30	l`=41,40	1,45	l`=51,75	1,75
6				1,15		1,25		1,45		1,85
7				1,10		1,20		1,80		2,25
8		90^o	l =20,00	1,10	l =30,00	1,20	l =40,00	1,85	l =50,00	2,15
9	U_2=6			1,10		1,20		1,85		2,20
10				1,15		1,30		1,95		2,30
11		75^o	l`=20,70	1,15	l`=31,05	1,30	l`=41,40	2,00	l`=51,75	2,30
12				1,15		1,30		2,05		2,35
13				1,20		1,50		2,05		2,60
14		90^o	l =20,00	1,20	l =30,00	1,45	l =40,00	2,15	l =50,00	2,60
15	U_3=9			1,20		1,40		2,10		2,60
16				1,25		1,50		2,40		2,95
17		75^o	l`=20,70	1,25	l`=31,05	1,60	l`=41,40	2,30	l`=51,75	3,05
18				1,25		1,55		2,35		3,00

Table 2: Mean values of electric current [A] for cutting heights of 20, 30, 40, and 50 mm and feed speeds of 3, 6, and 9 m·min⁻¹.

Count number	Feed rate [mmin^{-1}]	Fibre-cutting angle [º]	Specimen thickness (h=20mm) Cutting length (l, l`) [mm]	Electric currant [A]	Specimen thickness (h=30mm) Cutting length (l, l`) [mm]	Electric currant [A]	Specimen thickness (h=40mm) Cutting length (l, l`) [mm]	Electric currant [A]	Specimen thickness (h=50mm) Cutting length (l, l`) [mm]	Electric currant [A]
1	U_1=3	90º	l =20,00	1,00	l =30,00	1,15	l =40,00	1,25	l =50,00	1,55
2		75º	l`=20,70	1,10	l`=31,05	1,25	l`=41,40	1,45	l`=51,75	1,85
3	U_2=6	90º	l =20,00	1,10	l =30,00	1,20	l =40,00	1,85	l =50,00	2,20
4		75º	l`=20,70	1,15	l`=31,05	1,30	l`=41,40	2,05	l`=51,75	2,35
5	U_3=9	90º	l =20,00	1,20	l =30,00	1,40	l =40,00	2,10	l =50,00	2,60
6		75º	l`=20,70	1,25	l`=31,05	1,55	l`=41,40	2,35	l`=51,75	3,00

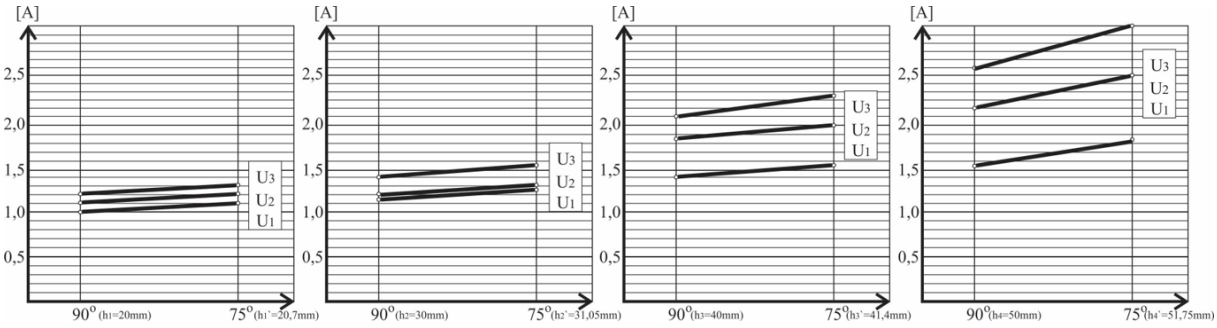


Figure 4: Graphical representation of the electric current values [A] at cutting heights of 20, 30, 40, and 50 mm and feed speeds of 3, 6, and 9 m·min⁻¹.

6. DISCUSSION

In conventional vertical and horizontal log bandsaws, the feed speed must be reduced to a minimum when the teeth first contact the wood and maintained until the full blade width enters the log. If the feed speed is too high during this initial stage, abrupt resistance forces acting on the back of the teeth can cause sudden excitation and blade bending.

To reduce this problem, many manufacturers design machines with the main frame tilted 15°–20° in the cutting direction. This arrangement allows cutting resistance to increase gradually even at higher feed speeds, improving the effective use of machine operating time.

In this research, measurements were carried out on the laboratory model of a vertical log bandsaw at the Faculty of Design and Technologies of Furniture and Interior in Skopje to assess how blade tilting affects cutting resistance. The cutting trajectory was also monitored during abrupt blade entry into the wood.

7. CONCLUSIONS

The measurements and graphical analysis support the following conclusions:

- At a 90° cutting angle, abrupt blade entry causes the cutting path to curve.
- At a 75° cutting angle, the cutting path remains straight, even with abrupt blade entry.
- Greater cutting height increases cutting resistance.
- Higher feed speed also increases cutting resistance.
- At a 75° cutting angle, the cutting-length increase coefficient is 1.035, indicating that the longer cutting length produces only a negligible increase in cutting resistance.

REFERENCES

Temelkova A. (2023). Impact of feed rate on roughness of the cut surface, during cutting dry spruce wood with a circular saw. Proceedings of the 6th International Scientific Conference „Wood Technology & Product Design Proceedings", Ohrid, 13th-15th September, North Macedonia, p. 180–186

Temelkova A. (2023). Impact of feed rate on roughness of the cut surface, during cutting dry beech wood with a circular saw. Proceedings of the 6th International Scientific Conference „Wood Technology & Product Design Proceedings”, Ohrid, 13th-15th September, North Macedonia, p. 134–140

Temelkova A., Trposki Z. (2023). Impact of feed rate on energy consumption during cutting dry beech wood with a circular saw. Proceedings of the 32nd International Conference on Wood Science and Technology – ICWST 2023 „Unleashing the Potential of Wood-Based Materials”, Zagreb, 7th–8th December, Croatia, p. 230

Temelkova A., Trposki Z. (2024). Impact of feed rate on roughness of the cut surface and energy consumption during cutting dry beech wood with a circular saw. Innovation in Woodworking Industry and Engineering Design, 2/2024 (26), p. 45–52

Trposki Z., Koljozov V., Rabadziski B., Zlateski G. (2013). Relationship between roughness of the surface being sawn and blade teeth wear and tear in log bandsaws. First International Scientific Conference „Wood Technology & Product Design", 16–18 May 2013, Ohrid, p. 310–318

Трпоски З. (1996). „Влијание на промена на кинематиката на режење кај лентовидни пили“, докторска дисертација, Шумарски факултет, Скопје

Р. Клинчаров, З. Трпоски, В. Кољозов. (2000). Теорија на режење на дрвото, Шумарски факултет, Скопје, 2000, 115 стр., CIP 630.8:674.023(075.8), ISBN 9989-43-146-9

Р. Клинчаров, З. Трпоски, В. Кољозов. (2000). Алат за механичка обработка на дрвото Шумарски факултет, Скопје, 2000, 110 р., CIP 630.8:674.05(075.8), ISBN 9989-43-147-7.

Р. Клинчаров, З. Трпоски, В. Кољозов. (2002). Машини за обработка на дрвото, Шумарски факултет, Скопје, 2002, 185 р., CIP 621.9-035.2(075.8) / 674.05(075.8), ISBN9989-9747-6-4.

Session 8A | Contribution 1

ALIGNING FACULTY AND STUDENT PERSPECTIVES ON DIGITAL LEARNING FORMATS: A CASE STUDY FROM THE UNIVERSITY OF FORESTRY, BULGARIA

Desislava Angelova, Tsvetan Stoykov, Vanina Tabakova, Adriana Yankova-Hristova, Denislav Lyubenov, Eli-Naya Konetsovska and Anna-Maria Sofianska

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Faculty of Forest Industry
e-mails: d.angelova@ltu.bg (D.A.), t.stoykov@ltu.bg (T.S.), v.tabakova@ltu.bg (V.T.), adriana.yankova@ltu.bg (A.Y.-H.), fn220119@ltu.bg (D.L), fn220072@ltu.bg (E.N.-K), fn220078@ltu.bg (A.-M.S.)

ABSTRACT

The ongoing digital transformation of higher education requires not only the adoption of new educational technologies but also closer alignment between institutional teaching practices and students' learning expectations. This study investigates the degree of convergence and divergence between faculty and student perceptions of digital learning formats within design education at the University of Forestry, Bulgaria.

The research adopts a quantitative comparative case study design based on a structured questionnaire administered to students enrolled in the Bachelor's programme *Engineering Design (Interior and Furniture Design)* and academic staff involved in teaching within the same programme. The analysis focuses on preferred learning formats, digital educational resources, and perceptions of the current educational model.

The findings reveal substantial agreement regarding the pedagogical principles that should continue to guide design education, including the importance of face-to-face teaching, project-based learning, and hybrid instructional approaches. At the same time, significant differences emerge concerning the intensity and forms of digital support, with students expressing stronger expectations for flexible, visually organised, and interactive learning resources than academic staff.

The study demonstrates that evaluating digital transformation solely through technological implementation provides an incomplete understanding of educational change. Instead, the findings highlight the importance of examining the alignment between institutional teaching practices and students' learning expectations as a prerequisite for evidence-informed curriculum development in design education.

Keywords: digital learning; design education; faculty perspectives; curriculum alignment.

1. INTRODUCTION

The rapid digital transformation of higher education has fundamentally changed not only the technological infrastructure of universities but also the expectations placed on teaching and learning. Contemporary students have access to an unprecedented variety of digital resources and learning environments, enabling them to acquire knowledge through multiple formal and informal channels. As a result, effective higher education increasingly depends on the ability of institutions to design learning experiences that correspond to students' cognitive characteristics, learning behaviours, and expectations rather than relying solely on the implementation of new educational technologies.

Successful digital transformation therefore requires more than the integration of learning management systems, multimedia resources, or online platforms. It also depends on the extent to which academic staff and students share similar perceptions of what constitutes an effective learning environment. When instructors and learners differ in their expectations regarding the organisation of educational content, the role of digital resources, or the balance between traditional and technology-enhanced instruction, even well-designed educational innovations may fail to achieve their intended outcomes. Understanding these similarities and differences has consequently become an important prerequisite for evidence-based curriculum development and informed pedagogical decision-making.

The need for such alignment is particularly significant in design education. Unlike many disciplines that rely primarily on theoretical instruction, design education combines conceptual thinking, visual communication, studio-based learning, project development, iterative problem solving, and intensive use of digital technologies. Learning is inherently interactive and requires continuous dialogue between theoretical knowledge, practical application, and creative experimentation. Consequently, the effectiveness of digital

learning formats depends not only on their technological capabilities but also on how successfully they support the specific cognitive and creative processes involved in design practice.

Current educational research increasingly advocates learner-centred approaches that combine the strengths of traditional teaching with the flexibility of digitally supported learning environments. Constructive alignment has long been recognised as a fundamental principle for designing effective higher education curricula (Biggs & Tang, 2007), while contemporary educational models emphasise that digital technologies should facilitate interaction, reflection, collaboration, and personalised learning rather than simply transferring conventional teaching into electronic environments (Laurillard, 2012). Similarly, connectivist perspectives highlight the growing importance of learners' ability to access, evaluate, and integrate knowledge from diverse digital sources (Siemens, 2005). Collectively, these theoretical perspectives suggest that curriculum development should be informed not only by technological possibilities but also by a thorough understanding of learners' expectations and educational experiences.

Within design education, previous studies have demonstrated the positive educational impact of multimedia learning, interactive instructional strategies, and hybrid learning environments on students' knowledge acquisition and interpretation. Research conducted by the authors within the same institutional research project confirmed that combining face-to-face instruction with multimedia resources and practical activities contributes to improved understanding, greater learner confidence, and more effective knowledge transfer in architectural visualisation and design education. Previous investigations also highlighted the growing importance of hybrid learning models and digital resources for supporting flexible and cognitively meaningful learning experiences.

Despite the growing body of research on digital learning and hybrid education, considerably less attention has been devoted to the degree of alignment between faculty perceptions and student expectations regarding digital learning formats. Most studies examine either students' experiences or instructors' attitudes independently, while comparatively few investigate both perspectives within the same educational context. As a result, limited empirical evidence exists concerning the extent to which academic staff accurately recognise students' preferences for digital learning environments and whether institutional teaching practices correspond to these expectations.

The present study addresses this research gap by analysing and comparing the perspectives of academic staff and students from the Faculty of Forest Industry at the University of Forestry, Bulgaria, regarding the implementation of digital learning formats in design education. Rather than evaluating a particular educational technology, the study examines the degree of convergence and divergence between the two groups concerning electronic learning materials, digital platforms, visual organisation of educational content, interactive learning tools, and blended learning approaches. By identifying areas of agreement as well as existing discrepancies, the research aims to provide empirical evidence that may support curriculum improvement and facilitate the development of learner-centred instructional strategies better aligned with the educational needs of contemporary design students.

Unlike previous studies that examine either students' or instructors' perspectives separately, the present study analyses both groups within the same institutional context. In doing so, it seeks to demonstrates that understanding the alignment between institutional teaching practices and students' learning expectations is a critical prerequisite for evaluating the effectiveness of digital transformation in design education.

2. RESEARCH METHODOLOGY

The present study employs a quantitative comparative research design aimed at examining the degree of alignment between faculty and student perceptions regarding the implementation of digital learning formats in higher education. Rather than evaluating the effectiveness of a particular educational technology, the research focuses on identifying similarities and differences between the two principal participants in the educational process—students and academic staff – and exploring how these perceptions may influence curriculum development and instructional decision-making.

The study represents one stage of a broader university-funded research project entitled *Exploring Opportunities for More Effective Acquisition and Interpretation of New Knowledge by Students Studying Design* (Contract No. NIS-B-1403/16.05.2025, University of Forestry, Sofia, Bulgaria). While previous analyses within the project considered the complete dataset collected from several Bulgarian universities, the

present investigation concentrates exclusively on respondents affiliated with the University of Forestry in order to provide a detailed institutional case study.

The analysed sample consists exclusively of respondents from the Faculty of Forest Industry at the University of Forestry, Sofia, Bulgaria. A total of 67 participants were included in the comparative analysis, comprising 37 students enrolled in the Bachelor's programme *Engineering Design (Interior and Furniture Design)* and 30 academic staff involved in teaching within the programme.

Both groups actively participate in the same educational environment, making them particularly suitable for investigating the degree of correspondence between instructional practices and student expectations regarding digital learning. By focusing on a single institution, the study minimises the influence of organisational differences that may exist between universities and allows a more direct comparison of faculty and student perspectives under identical educational conditions.

Data were collected using a structured anonymous online questionnaire developed specifically for the objectives of the institutional research project. The questionnaire consisted of 26 closed and semi-open questions, organised into several thematic categories:

- respondent profile;
- characteristics of the educational process;
- use of digital learning resources;
- preferred learning formats;
- organisation and presentation of educational content;
- attitudes toward digital learning tools;
- open recommendations for improving the educational process.

Most items employed multiple-choice or Likert-type response scales, allowing quantitative comparison between the two respondent groups.

Only responses submitted by students and academic staff from the University of Forestry were extracted from the complete dataset for the purposes of the present study.

The analysis is based primarily on descriptive and comparative statistical methods. Frequency distributions and percentage values were calculated for each survey item, followed by direct comparisons between student and faculty responses. Particular attention was paid to identifying areas of convergence and divergence concerning:

- preferred learning formats;
- perceived effectiveness of digital educational resources;
- visual organisation of learning materials;
- use of interactive educational tools;
- attitudes toward blended learning;
- expectations regarding the future development of digital education.

Rather than analysing each questionnaire item independently, the results are interpreted according to broader thematic categories that correspond to the principal dimensions of digital learning examined in the study.

Participation in the survey was voluntary and anonymous. Respondents were informed that the collected information would be used exclusively for scientific purposes within the framework of the university research project. All data were analysed in aggregated form, ensuring that no individual participant could be identified.

3. RESULTS AND DISCUSSION

3.1. OVERALL ALIGNMENT BETWEEN FACULTY AND STUDENT PERCEPTIONS

The comparative analysis of responses collected from students and academic staff at the University of Forestry indicates that both groups recognise the necessity of further digital transformation in higher education. However, despite this common understanding, noticeable differences emerge in their evaluation of current teaching practices, preferred learning formats, and expectations regarding the future development of digital learning environments.

Overall, academic staff demonstrate greater confidence in the ability of the existing educational model to respond to contemporary educational challenges, whereas students express a stronger demand for increased

flexibility, richer digital resources, and more interactive learning experiences. This finding suggests that the two groups share common educational goals but differ in their assessment of how successfully these goals are currently achieved.

The comparison also reveals that the differences are not uniformly distributed across all aspects of the educational process. In several areas—particularly the importance of practical learning, project-based activities, and the use of specialised software—faculty members and students demonstrate remarkably similar opinions. In contrast, substantially larger differences appear in issues related to the organisation of learning materials, the integration of digital resources into everyday teaching, and the perceived adequacy of existing instructional formats.

These observations indicate that the principal challenge is not the acceptance of digitalisation itself but rather the degree to which current pedagogical practices correspond to students' learning preferences. Consequently, the following analysis focuses on identifying the specific areas in which faculty and student perceptions converge and where significant discrepancies remain.

3.2. PERCEPTIONS OF THE CURRENT EDUCATIONAL MODEL

The first stage of the comparative analysis examined whether students and academic staff perceive the current educational model as sufficiently effective to address the challenges of contemporary higher education. Rather than focusing on individual survey items, the analysis was organised around three interrelated questions that reflect the core objective of the study: whether the existing educational process is perceived as effective, whether it provides sufficient flexibility, and whether it corresponds to the learning characteristics of contemporary students.

3.2.1. Is the current educational model perceived as sufficiently effective?

The responses reveal that both students and academic staff recognise the value of the existing educational model, while simultaneously acknowledging the need for its further development. Neither group questions the importance of traditional face-to-face teaching, particularly within design education, where direct interaction, studio work, and practical guidance remain essential components of the learning process.

However, the comparison indicates a noticeable difference in the overall evaluation of the current situation. Academic staff generally express greater confidence in the effectiveness of existing teaching practices, whereas students demonstrate a stronger tendency to identify areas requiring improvement. This difference does not reflect disagreement regarding educational objectives; rather, it suggests different perspectives arising from the distinct roles occupied by the two groups within the educational process. While lecturers primarily evaluate teaching from the perspective of curriculum implementation and pedagogical organisation, students assess its effectiveness through their own learning experience and their expectations concerning accessibility, flexibility, and engagement.

The results therefore suggest that the current educational model is perceived as functional by both groups but not yet fully optimised for the needs of contemporary learners.

3.2.2. Is the educational process sufficiently flexible?

Greater differences emerge when flexibility becomes the focus of comparison. Students consistently demonstrate stronger expectations for learning environments that allow easier access to educational resources, greater autonomy in organising the learning process, and more opportunities for combining classroom instruction with digital learning materials.

Academic staff also acknowledge the importance of introducing greater flexibility; however, their responses indicate a more cautious approach, reflecting concerns about preserving the practical, interactive, and studio-based nature of design education. For lecturers, flexibility appears to be understood primarily as a pedagogically controlled extension of traditional teaching, whereas students tend to associate flexibility with continuous access to learning resources, opportunities for self-paced learning, and increased use of digital educational tools.

These findings indicate that both groups support educational innovation but differ in their interpretation of how such flexibility should be implemented. This divergence represents one of the first significant areas of misalignment identified in the study.

3.2.3. Does the current educational model correspond to the characteristics of contemporary students?

The most pronounced differences appear in relation to the extent to which current teaching practices are considered compatible with the learning characteristics of today's students.

Students express a stronger perception that existing instructional approaches do not fully reflect their learning habits or the ways in which they access, process, and apply new knowledge. Their responses indicate expectations for greater use of visually structured educational content, digital learning resources, interactive activities, and opportunities for independent revision beyond scheduled classroom sessions.

Academic staff generally recognise these changing learning characteristics but evaluate the degree of institutional adaptation more positively. This difference suggests that lecturers tend to perceive the ongoing process of educational digitalisation as more advanced than students experience it in practice.

Nevertheless, an important point of convergence should also be emphasised. Both groups agree that future curriculum development should preserve the strengths of face-to-face education while integrating digital learning resources more systematically into everyday teaching. Rather than replacing traditional instruction, respondents from both groups support an educational model that combines direct interaction with flexible digital support.

Taken together, these findings indicate that the principal challenge identified by the study is not whether digitalisation should be pursued, but how it can be implemented in ways that better align institutional teaching practices with students' learning expectations.

3.3. PREFERRED LEARNING FORMATS

One of the central objectives of the study was to determine whether students and academic staff share similar views regarding the instructional formats that are most appropriate for contemporary design education. Since respondents were allowed to select multiple options, the results reflect the perceived educational value of each format rather than exclusive preferences (Table 1.).

Table 1: Comparison of preferred learning formats in design education

Learning format	Students (n = 36)	Faculty (n = 30)
Digital tools integrated into face-to-face teaching	83.3%	66.7%
Project-based learning	58.3%	63.3%
Hybrid learning	55.6%	50.0%
Independent learning supported by teacher-developed digital resources	30.6%	20.0%
Fully online learning	2.8%	0.0%

The comparison reveals a substantial degree of consensus between students and academic staff regarding the general direction of future curriculum development. Both groups identify digitally supported face-to-face teaching, project-based learning, and hybrid instruction as the three most appropriate educational formats for design education. This finding suggests that the debate is no longer centred on whether digital technologies should be incorporated into the educational process but rather on the extent and manner of their integration. Despite this overall agreement, several meaningful differences emerge.

The most pronounced discrepancy concerns the integration of digital tools into face-to-face teaching, which is supported by 83.3% of students compared with 66.7% of faculty members, representing a difference of 16.6 percentage points. This finding indicates that students expect digital technologies to become a routine component of classroom instruction rather than supplementary resources used only occasionally. Their responses suggest a preference for learning environments in which digital tools actively support visualisation, demonstration, interaction, and immediate access to educational content.

A second notable difference concerns independent learning supported by digital resources developed by instructors. Approximately one-third of students (30.6%) consider this format particularly valuable, whereas only one-fifth of academic staff (20.0%) identify it as a priority. Although the difference is smaller, it reflects

students' stronger expectations for flexible learning opportunities that extend beyond scheduled classroom activities and enable self-paced revision and knowledge consolidation.

In contrast, project-based learning receives similarly high levels of support from both groups. Interestingly, academic staff assign slightly greater importance to this instructional format (63.3%) than students (58.3%), confirming that lecturers continue to perceive authentic design projects as the core pedagogical approach within design education. This result also demonstrates that the increased interest in digital learning does not diminish the perceived importance of practical studio-based activities.

A comparable pattern is observed for hybrid learning, where both students (55.6%) and faculty (50.0%) express positive attitudes. The relatively small difference suggests that hybrid learning is viewed not as a replacement for traditional education but as an effective means of combining direct interaction with the flexibility offered by digital resources.

Finally, fully online learning receives almost no support from either group. Only one student selected this option, while none of the academic staff considered it an appropriate standalone format for design education. This finding clearly indicates that respondents distinguish between digitalisation and complete online delivery. Rather than replacing face-to-face teaching, both groups favour instructional models that preserve direct interaction while enriching it through carefully integrated digital technologies.

Overall, the findings demonstrate that the greatest divergence between faculty and student perspectives concerns the intensity of digital integration within conventional classroom teaching, whereas substantial agreement exists regarding the continued importance of project-based learning and hybrid educational models. These results provide strong empirical support for the central argument of the present study that successful curriculum development depends not only on introducing digital technologies but also on aligning institutional teaching practices with students' evolving learning expectations.

4. DIGITAL LEARNING RESOURCES AND LEARNING PRACTICES

The comparison of digital learning resources reveals a considerably more differentiated pattern than that observed for preferred learning formats (Figure 2). While both respondent groups acknowledge the educational value of digital resources, they assign different priorities to individual resource types, reflecting distinct perspectives on how digital technologies should support learning in design education.

Table 2: Comparison of faculty and student preferences regarding digital learning resources

Digital learning resource	Students (%) (n = 36)	Faculty (%) (n = 29)
Specialized software tools	83.3	75.9
Gamification elements	69.4	55.2
Video exercises	58.3	44.8
Online learning platforms (Moodle, Teams, Google Classroom, etc.)	55.6	62.1
Interactive tests and simulations	55.6	65.5
Digital textbooks	50.0	72.4
Video lectures	50.0	51.7

The strongest consensus is observed regarding the importance of specialised software tools. More than three-quarters of both students (83.3%) and academic staff (75.9%) identify discipline-specific software as one of the most valuable digital resources. This finding reflects the practice-oriented nature of design education, where digital technologies function as professional instruments for design development rather than merely as supplementary teaching aids.

The greatest divergence concerns digital textbooks. Whereas 72.4% of academic staff consider digital textbooks an important educational resource, only half of the students (50.0%) share this view, representing the largest difference observed within this group of variables (22.4 percentage points). This result suggests that lecturers continue to regard structured textual materials as a central component of learning, while students increasingly rely on alternative digital formats that provide more dynamic and visually oriented access to knowledge.

Students also demonstrate considerably stronger preferences for gamification elements (69.4% compared with 55.2%) and video exercises (58.3% compared with 44.8%). These findings indicate that learners value interactive and application-oriented educational resources that actively engage them in the learning process and support repeated practice outside scheduled classroom activities.

In contrast, academic staff assign slightly greater importance to online learning platforms and interactive assessment tools, suggesting a stronger emphasis on structured management of the educational process and continuous monitoring of student progress.

Interestingly, perceptions of video lectures remain almost identical between the two groups, indicating broad agreement regarding their educational value. This convergence suggests that both students and lecturers recognise video lectures as an effective supplementary resource, although neither group considers them sufficient as a standalone instructional format.

Overall, the findings indicate that the principal difference between faculty and student perspectives lies not in the acceptance of digital learning resources themselves, but in the preferred forms through which digital content is delivered. Students consistently favour more interactive, visually rich, and practice-oriented resources, whereas academic staff continue to attribute greater importance to structured instructional materials and institutional learning platforms.

5. AREAS OF CONVERGENCE AND DIVERGENCE

The comparative analysis reveals that faculty and student responses form a consistent pattern rather than a series of isolated opinions. Across the examined dimensions, three distinct relationships emerge: areas of strong convergence, areas of moderate divergence, and areas of significant divergence (Table 3).

The strongest convergence is observed in relation to the pedagogical foundations of design education. Both respondent groups consider face-to-face instruction, project-based learning, and the use of specialised design software to be indispensable elements of the educational process. Likewise, both groups reject fully online learning as an appropriate standalone instructional model for design education and express positive attitudes towards hybrid learning formats that combine classroom interaction with digital support.

Moderate divergence appears in relation to the integration of digital technologies into everyday teaching. Although both groups support the use of digital tools, students consistently favour a higher level of digital integration within classroom activities, whereas academic staff adopt a more balanced approach that combines technological innovation with established pedagogical practices.

The most pronounced divergence concerns the preferred characteristics of digital learning resources. Students demonstrate stronger preferences for visually rich, interactive, and practice-oriented resources, while lecturers assign greater importance to structured instructional materials and institutionally organised learning environments. These differences suggest that faculty and students evaluate digital resources from different educational perspectives rather than according to fundamentally different educational goals.

Overall, the observed patterns indicate that agreement is strongest at the level of educational principles, whereas divergence becomes more evident when considering the practical implementation of digitally supported learning.

Table 3: Summary of convergence and divergence between faculty and student perceptions

Dimension	Faculty	Students	Overall interpretation
Face-to-face teaching	High importance	High importance	Strong convergence
Hybrid learning	Positive	Positive	Strong convergence
Fully online learning	Low support	Low support	Strong convergence
Project-based learning	Very high importance	Very high importance	Strong convergence
Digital tools in classroom	High importance	Very high importance	Moderate divergence
Digital textbooks	Higher preference	Lower preference	Significant divergence
Video-based learning	Moderate preference	Higher preference	Significant divergence
Gamification	Moderate preference	Higher preference	Significant divergence
Flexible independent learning	Moderate preference	High preference	Significant divergence

6. KEY FINDINGS

The comparative analysis produced four principal empirical findings.

First, faculty members and students demonstrate a high level of agreement regarding the educational principles that should continue to guide design education. Traditional studio-based teaching, project-oriented learning, and direct interaction remain central components of the educational process despite the growing role of digital technologies.

Second, the greatest differences are associated with the expected intensity and forms of digital support rather than with the acceptance of digitalisation itself. Students consistently express greater interest in flexible and interactive learning opportunities, while academic staff place relatively greater emphasis on structured educational resources and organised instructional processes.

Third, the findings demonstrate that digital transformation is widely perceived as a process of educational enhancement rather than substitution. Respondents from both groups favour the integration of digital resources into existing teaching practices instead of replacing conventional forms of instruction.

Fourth, the comparison confirms that analysing faculty and student perspectives simultaneously provides insights that would remain difficult to identify if either group were studied independently. The observed similarities and differences therefore constitute an important empirical basis for understanding how digital transformation is experienced within a shared educational environment.

7. DISCUSSION: IMPLICATIONS FOR CURRICULUM DEVELOPMENT IN DESIGN EDUCATION

The empirical patterns identified in this study suggest that the central challenge facing digital transformation in design education is not technological adoption but educational coherence. The high level of agreement observed regarding the fundamental principles of design education indicates that faculty and students share a common understanding of what constitutes effective learning. Consequently, the differences identified in the study should not be interpreted as evidence of competing educational priorities.

Instead, the findings illustrate how the same educational objectives may generate different expectations depending on participants' roles within the educational process. Faculty members naturally evaluate digital learning through the perspectives of curriculum organisation, instructional quality, and academic standards, whereas students primarily evaluate it through accessibility, engagement, and support for independent learning. These perspectives are complementary rather than contradictory.

From this perspective, alignment should be understood as an ongoing pedagogical dialogue rather than as complete agreement between lecturers and students. The value of comparing both perspectives lies precisely in revealing those aspects of the educational process where institutional practices and learner expectations develop at different rates. Such information provides universities with an evidence-informed basis for reflecting on existing teaching practices and considering future improvements without assuming that either perspective should dominate curriculum development.

The results of the study have several implications for the future development of curricula in design education.

First, curriculum development should acknowledge that contemporary students increasingly expect learning resources to remain accessible beyond the classroom. Digital educational materials are perceived not merely as supplementary resources but as integral components of the learning process that facilitate revision, independent study, and the gradual development of practical competences.

Second, the findings highlight the importance of preserving the experiential character of design education. Although respondents strongly support the use of digital learning resources, neither students nor academic staff consider these technologies capable of replacing studio-based instruction, practical exercises, or direct communication with instructors. Instead, digital technologies are regarded as tools that enhance rather than substitute existing pedagogical practices.

Third, the observed differences between faculty and student perceptions suggest that curriculum revision should be informed by continuous dialogue between the principal participants in the educational process. Periodic evaluation of student expectations may provide valuable information for adapting instructional strategies while preserving the academic standards and pedagogical principles that define university education.

Taken together, these observations indicate that successful curriculum development depends not only on technological innovation but also on maintaining an appropriate balance between educational structure, pedagogical guidance, and learning flexibility.

The present findings are consistent with previous studies emphasising that effective digital transformation in higher education extends beyond the implementation of technological infrastructure. Biggs and Tang (2007) argue that meaningful educational improvement depends on constructive alignment between learning outcomes, teaching activities, and assessment. Similarly, Laurillard (2012) highlights that digital technologies should support interaction, dialogue, and adaptive learning rather than simply reproducing traditional teaching practices in electronic form.

The strong preference expressed by students for visually organised, flexible, and interactive learning resources also corresponds with research on multimedia learning, which demonstrates that appropriately designed digital materials can improve knowledge acquisition and cognitive engagement (Mayer, 2009; Clark & Mayer, 2016). Likewise, the continuing importance attributed to project-based learning confirms previous observations that authentic design projects remain central to developing design competences (Cross, 2011; Schön, 1983).

At the same time, the present study extends previous research conducted within the same institutional project. Earlier investigations primarily examined the educational effectiveness of multimedia learning and hybrid instructional approaches. In contrast, the current study shifts the focus towards the relationship between faculty and student perspectives, demonstrating that successful educational innovation depends not only on the quality of digital resources but also on the degree to which institutional teaching practices correspond to students' learning expectations.

Rather than providing definitive answers, the present findings raise several broader questions that deserve further discussion within higher education institutions.

The results suggest that the success of digital transformation cannot be evaluated solely through the implementation of new technologies or the availability of digital educational resources. Equally important is the extent to which these resources correspond to the learning behaviours and expectations of contemporary students. This raises the question of how universities can ensure that curriculum development remains responsive to the evolving characteristics of new generations of learners while preserving the educational values that define higher education.

The study also encourages reflection on current mechanisms for evaluating educational quality. Curriculum revision traditionally focuses on updating disciplinary knowledge and learning outcomes, whereas considerably less attention is often devoted to examining whether teaching methods continue to correspond to students' preferred ways of acquiring and applying knowledge. The findings suggest that systematic comparison of faculty and student perspectives may provide valuable evidence for supporting informed pedagogical decision-making.

Finally, the observed differences between lecturers and students should not be interpreted as evidence of conflicting educational priorities. On the contrary, both groups share common educational objectives while approaching them from different perspectives shaped by their respective roles within the educational process. Recognising these complementary perspectives may contribute to more informed discussions on curriculum development, digital transformation, and the future of design education.

The present study therefore does not seek to prescribe a specific model for educational change. Instead, it aims to encourage broader academic discussion regarding how universities can better understand and reconcile the perspectives of those who teach and those who learn. In this respect, alignment should be regarded not as a fixed outcome but as a continuous process of dialogue supporting evidence-informed improvement of higher education.

The present study should be interpreted in light of several limitations. The analysis was conducted within a single higher education institution and reflects the perceptions of students and academic staff from one academic environment. Consequently, the findings should be regarded as an institutional case study rather than as representative of higher education in general. Although the sample includes the majority of respondents directly involved in the analysed educational programme, its size remains relatively limited. This restricts the possibility of generalising the observed patterns to other universities or disciplinary contexts. Finally, the study is based on self-reported perceptions collected through a questionnaire and therefore reflects participants' views rather than direct measures of educational effectiveness.

8. CONCLUSIONS

The present study contributes to current research on digital transformation in higher education by examining faculty and student perspectives within the same institutional context. Rather than analysing either group independently, the research demonstrates how comparing the perceptions of both principal participants in the educational process provides a more comprehensive understanding of digitally supported learning.

The findings show that digital transformation in design education should not be evaluated solely through the implementation of technological solutions. Equally important is the degree to which institutional teaching practices correspond to students' learning expectations while preserving the pedagogical characteristics that define design education.

The study also demonstrates the value of institutional-level comparative analyses as a source of evidence for curriculum reflection and educational improvement. Although the investigation was conducted within a single university, the methodological approach may be applicable to other higher education institutions seeking to better understand the relationship between teaching practices and learner expectations during processes of educational digitalisation.

Finally, the research encourages further discussion on the role of faculty–student alignment as an important dimension of educational quality. Future investigations involving multiple institutions and disciplinary contexts could determine whether the patterns identified in the present study represent broader tendencies within contemporary higher education.

ACKNOWLEDGEMENTS

This research was funded by the Scientific Research Sector at the University of Forestry, Contract No. НИС-Б-1403/16.05.2025. The authors would like to thank the students and lecturers for their cooperation and participation in the survey.

REFERENCES

Angelova, D.; Stoykov, T.; Tabakova, V.; Lyubenov, D.; Konetsovska, E.-N.; Sofianska, A.-M. (2025). Exploring Opportunities for More Effective Acquisition and Interpretation of New Knowledge by Students in the Field of Architectural Visualization Through Multimedia Learning. Education Sciences, *15*, 1105. https://doi.org/10.3390/educsci15091105

Biggs, J.; Tang, C. (2007). Teaching for Quality Learning at University; 3rd ed.; Open University Press/McGraw-Hill Education: Maidenhead, UK

Clark, R.C.; Mayer, R.E. (2016). E-Learning and the Science of Instruction: Proven Guidelines for Consumers and Designers of Multimedia Learning; 4th ed.; Wiley: Hoboken, NJ, USA,

Cross, N. (2011). Design Thinking: Understanding How Designers Think and Work; Berg Publishers: Oxford, UK

Lawson, B. (2006). How Designers Think: The Design Process Demystified; 4th ed.; Architectural Press: Oxford, UK

Laurillard, D. (2012). Teaching as a Design Science: Building Pedagogical Patterns for Learning and Technology; Routledge: London, UK, https://doi.org/10.4324/9780203125083

Mayer, R.E. (2009). Multimedia Learning. 2nd ed.; Cambridge University Press: Cambridge, UK, https://doi.org/10.1017/CBO9780511811678

Schön, D.A. (1983). The Reflective Practitioner: How Professionals Think in Action; Basic Books: New York, NY, USA

Siemens, G. Connectivism. (2005). A Learning Theory for the Digital Age. International Journal of Instructional Technology and Distance Learning, 2(1), 3–10.

Henderson, C., Beach, A., & Finkelstein, N. (2011). Facilitating Change in Undergraduate STEM Instructional Practices. Journal of Research in Science Teaching, 48(8), 952–984.

Kuh, G.D. (2009). What Student Affairs Professionals Need to Know About Student Engagement. Journal of College Student Development, 50(6), 683–706.

Session 2 | Contribution 2

THE IMPACT OF ASH DIEBACK ON THE CHEMICAL AND MECHANICAL PROPERTIES OF WOOD: METHODOLOGICAL EXPERIENCES AND UNCERTAINTIES

Anett Sütő, Róbert Németh

University of Sopron, Bajcsy-Zs. u. 4., Sopron, Hungary,
e-mails: suto.anett@phd.uni-sopron.hu, nemeth.robert@uni-sopron.hu

ABSTRACT

Ash dieback, caused by *Hymenoscyphus fraxineus*, induces complex physiological and structural changes in infected trees, that can affect both the chemical and physical properties of wood. The aim of our research was to investigate these alterations, with a particular focus on the potential correlations between molecular-level modifications and mechanical characteristics.

One of the main aspects of the infrared spectroscopy applied during the study was high-resolution sampling, performed nearly on an annual ring basis. Based on the measurements conducted so far, the analysis of the spectra shows certain trends in the regions of hemicelluloses and extractives, which may indicate the sensitivity of these components during the infection process.

The chemical analyses were complemented by Brinell-Mörath hardness measurements, which were also performed on the narrow annual rings formed during the decline phase, in order to infer modifications in extractive content from changes in surface hardness. Based on the data, a certain degree of alteration can be detected, which is also influenced by measurement accuracy, tissue heterogeneity caused by the infection, and the varying response reactions of individual trees.

Keywords: ash dieback, *Hymenoscyphus fraxineus; Fraxinus excelsior*; FTIR spectroscopy; annual rings; Brinell-Mörath hardness.

1. INTRODUCTION

Ash dieback caused by *Hymenoscyphus fraxineus* has severely affected European ash (*Fraxinus excelsior* L.) populations throughout Europe over recent decades (Pautasso et al., 2013; Gross et al., 2014; Carroll & Boa, 2024). The disease may result in shoot and branch dieback, crown thinning, and a gradual decline in tree vitality; therefore, it is relevant not only from a forest protection perspective but also from the perspective of wood science.

Prolonged deterioration in tree condition may affect cambial activity and radial growth, which can be manifested in the narrowing of tree rings. In ring-porous species such as European ash, changes in tree-ring width may also modify the anatomical structure and, through this, influence the physical and mechanical properties of wood (Giagli et al., 2018; Klesse et al., 2021).

In addition to structural changes, the chemical properties of wood may also be altered. Fourier-transform infrared spectroscopy (FTIR) is suitable for investigating such changes, as it allows spectral differences associated with the major chemical components of wood to be detected (Faix, 1991; Pandey & Pitman, 2003; Tolvaj, 2024).

The aim of the present study was to investigate the anatomical, mechanical, and chemical changes occurring in the narrow tree rings of European ash samples showing substantial growth reduction. Tree-ring width and relative vessel area, Brinell–Mörath hardness, and radial variations in FTIR spectra were examined.

2. MATERIALS AND METHODS

2.1.WOOD MATERIAL AND SAMPLING

The study sites were carefully selected from monitored areas affected by ash dieback. For the study, 13 stem-disc samples of European ash (*Fraxinus excelsior* L.) were collected from the Németbánya 37/C site. Six of the 13 stem discs originated from different heights of the same trunk. These discs were cut at approximately 1 m vertical intervals, allowing radial changes to be compared at different positions within the same trunk.

In addition, six increment-core samples were collected at the Bakonyszücs 51/F site, which is also affected by ash dieback. At this site, increment cores were taken from older trees that appeared healthy at the time of sampling. Increment-core sampling allows the examinations to be repeated on the same trees at a later date and the resulting data to be compared over time. Such repeated sampling is not possible for trees from which stem discs are obtained after felling.

The samples included both specimens with relatively uniform tree-ring structure and specimens showing pronounced tree-ring narrowing in the outer part of the stem.

The characteristics measured in the narrow outer tree rings formed during recent years were compared with those determined in earlier, wider, and more uniform tree rings formed before the trees were affected by ash dieback.

2.2. MICROSCOPIC EXAMINATIONS

Microscopic sections were examined from six stem-disc samples, taken from the outermost narrow-ring zones, generally corresponding to the period of decline, and from inner wood formed in earlier years. Tree-ring width was measured, together with vessel diameters along a 1 mm segment of each tree ring. Vessel areas were calculated from the measured diameters, and the vessel area fraction was determined relative to the corresponding 1 mm tree-ring segment.

2.3. FTIR SPECTROSCOPIC MEASUREMENTS

Fourier-transform infrared spectroscopy (FTIR) was used to investigate the chemical characteristics of the wood. Measurements were performed using a JASCO FT/IR-6300 spectrometer.

Small specimens were cut manually from the increment cores using a cutting knife. Measurement positions were selected deliberately along the radial direction. Sampling was not performed according to an equally spaced geometric profile but was based on tree-ring structure and the growth history of the samples. In each sample, we aimed to include measurement points from the outermost tree rings formed in recent years, the inner part of the sapwood, the sapwood–heartwood boundary, and the heartwood.

The spectra were evaluated in the fingerprint region. During preprocessing, baseline correction and normalization were applied, followed by Kubelka–Munk transformation of the spectra.

The analysis focused on five selected absorption regions:

- 1170 cm^{-1}: a band primarily associated with hemicelluloses;
- 1270 cm^{-1}: a band associated with guaiacyl lignin;
- 1510 cm^{-1}: a band associated with the aromatic lignin skeleton;
- 1657 cm^{-1}: a region also associated with carbonyl-containing compounds and certain extractive-related components;
- 1740 cm^{-1}: a band associated with acetyl and carbonyl groups of hemicelluloses and with certain ester bonds.

Interpretation of the spectral bands was based on assignments commonly used in FTIR studies of wood (Faix, 1991; Pandey & Pitman, 2003; Tolvaj, 2024). Because individual absorption regions may contain contributions from several chemical structures, the bands were not regarded as markers specific to a single component.

The aim of the analysis was to determine whether consistent or partially consistent FTIR spectral differences could be observed among wood regions with different growth histories.

2.4. BRINELL–MÖRATH HARDNESS TESTING

Brinell–Mörath hardness measurements were performed using an Instron 5985 universal testing machine (Instron Corporation, Norwood, Massachusetts, USA) on the transverse surfaces of the samples. The load was increased uniformly to 490.33 N over 15 s, maintained at this level for 30 s, and then removed over 15 s in accordance with the MSZ 6786/11-1982 standard. Brinell–Mörath hardness was calculated from the measured indentation depth using the relationship specified in MSZ 6786-11:1982.

Measurements were performed on specimens prepared from the stem discs, proceeding from the bark towards the inner wood. For each sample, measurements were made in the outermost narrow tree rings wherever possible, and comparative measurements were also performed in earlier, wider, and more uniform tree rings.

3. RESULTS

3.1. TREE-RING WIDTH

For the paired tree-ring analysis, six of the eight sampled trees were selected because they showed a clear and pronounced narrowing of the most recently formed outer tree rings. From each selected tree, one narrow outer tree ring was compared with an earlier, wider tree ring from the same stem-disc sample. In all six sample pairs examined, the outer narrow tree ring was narrower than the earlier, wider tree ring from the same specimen (Figure 1).

The mean width of the narrow tree rings was 1046.9 ± 548.6 µm, whereas the mean width of the wider tree rings was 4609.5 ± 1652.2 µm. Across the six paired comparisons, the narrow tree rings were, on average, only 27.7% as wide as their corresponding wider tree rings. The largest difference was observed in the sample taken from the affected wood, in which the outer tree ring was 610 µm wide, compared with 6791 µm for the corresponding inner tree ring. Thus, the width of the outer tree ring was reduced by more than 90% compared with that of the inner tree ring. In several samples, the wider tree ring was 4–11 times wider than the corresponding narrow tree ring.



Figure 1: Samples showing tree-ring narrowing.

3.2. VESSEL AREA FRACTION

The relative cross-sectional vessel area was greater in the narrow tree ring than in the wider tree ring from the same specimen in all six sample pairs. The mean vessel area fraction was 30.3 ± 11.0% in the narrow tree rings and 8.3 ± 1.8% in the wider tree rings. (Figure 2, Figure 3)

The mean difference between paired samples was 22.0 ± 12.4 percentage points, with individual differences ranging from 5.1 to 39.4 percentage points. The largest difference occurred in Sample 12, where the vessel area fraction was 45.3% in the narrow tree ring and 5.9% in the wider tree ring.

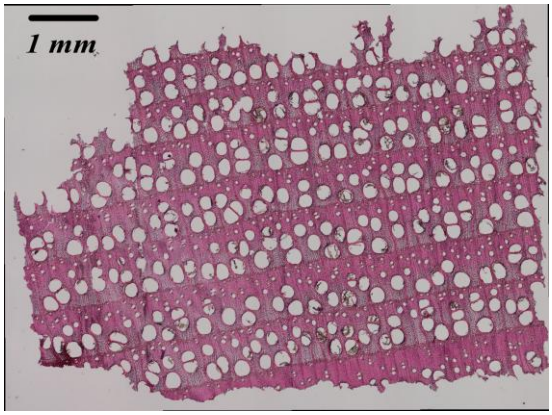


Figure 2: Microscopic images of the sections with narrow annual rings.

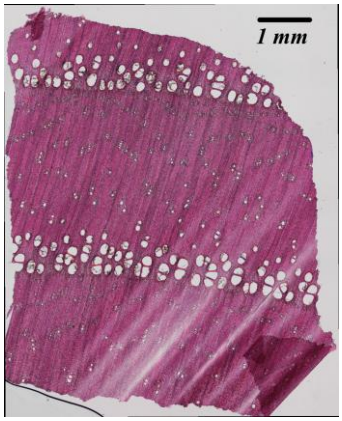


Figure 3: Microscopic images of the sections with wider annual rings.

3.3. BRINELL–MÖRATH HARDNESS

Brinell–Mörath hardness was generally lower in wood regions containing narrow tree rings. The largest observed difference reached 46% compared with the earlier grown wood containing wider tree rings.

In contrast, the sample with a uniform tree-ring structure showed a more even radial hardness profile, with no comparable decrease in hardness in that section of the wood that was formed by the affected tree.

Stem discs taken at different heights from the same trunk showed similar radial hardness profiles in several cases. Lower hardness values occurred in the outer narrow tree rings, and reduced hardness was also observed in an earlier zone containing similarly narrowed tree rings.

3.4. FTIR SPECTRAL CHANGES

The degree of radial variation in the FTIR spectra differed among samples.

The largest changes occurred primarily in spectral regions also associated with hemicelluloses, carbonyl-containing components, and certain extractive-related compounds. The band around 1170 cm^{-1} showed one of the greatest within-sample variations, while considerable variation was also observed around 1657 cm^{-1}. (Figure 4, Figure 5)

The lignin-related bands around 1270 and 1510 cm^{-1} were generally more stable and showed no clear relationship with tree-ring narrowing.

The spectral profile of the sample with a relatively uniform tree-ring structure generally showed less radial variation than those of samples characterized by substantial growth reduction.



Figure 4: Increment core sample from a declining tree

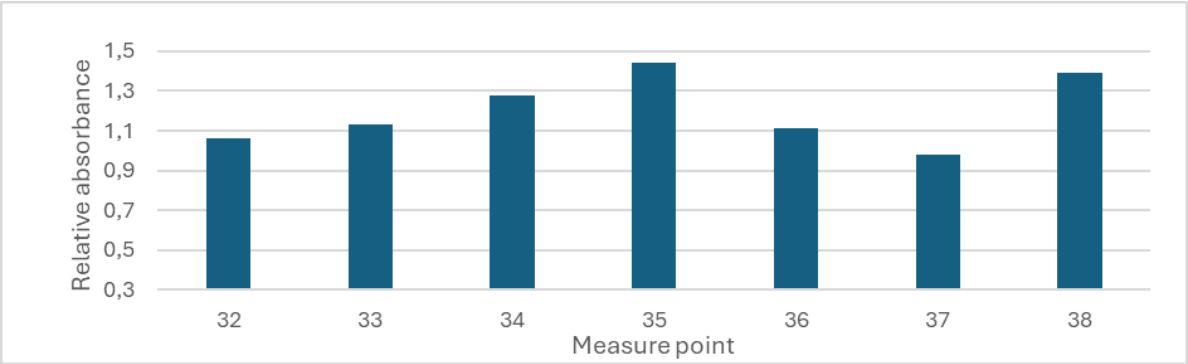


Figure 5: Data for a typical sample, 1170 Wavenumber (cm-1) at the measuring points on Figure 3.

4. DISCUSSION

4.1. ANATOMICAL CONSEQUENCES OF TREE-RING NARROWING

One of the most consistent findings of the study was the relationship between tree-ring narrowing and an increase in relative vessel area. In all samples examined, a greater vessel area fraction was associated with the narrower tree ring.

This is consistent with the ring-porous anatomical structure of European ash. Earlywood contains large-diameter vessels, whereas latewood is richer in more densely structured tissues. Consequently, pronounced tree-ring narrowing may result in earlywood vessels occupying a larger proportion of the entire tree ring while the relative proportion of latewood decreases (Klesse et al., 2021).

The higher vessel area fraction observed in the narrow tree rings indicates a substantial shift in anatomical structure compared with the wider tree rings. This phenomenon is driven by the physiological processes taking place within the living tree.

4.2. RELATIONSHIP BETWEEN ANATOMICAL STRUCTURE AND HARDNESS

The microscopic and hardness measurements showed complementary patterns. Wood regions with narrow tree rings and a higher relative vessel area generally exhibited lower Brinell–Mörath hardness.

A greater vessel area is associated with a smaller proportion of dense tissue (less supporting cell wall) and a reduced relative proportion of latewood. This contribute to changes in wood density and mechanical resistance, consistent with the reported relationship between tree-ring width and wood density in European ash (Giagli et al., 2018).

The similar radial hardness profiles observed in stem discs taken at different heights from the same trunk are particularly noteworthy. In addition to the outer narrow-ring zones, reduced hardness was also measured in an earlier section containing narrowed tree rings, suggesting that the phenomenon was not restricted to a single local measurement position.

Nevertheless, hardness may also be influenced by density, local tissue structure, extractive content, and the natural heterogeneity of wood. The present results therefore indicate an association between anatomical structure and hardness but do not, by themselves, demonstrate a direct causal relationship.

4.3. FTIR SPECTRAL CHANGES AND CHEMICAL BACKGROUND

The FTIR measurements indicated that structural and mechanical changes may also be accompanied by variation in the chemical characteristics of the wood.

The greatest differences occurred mainly in spectral regions associated with hemicelluloses, carbonyl-containing compounds, and certain extractive-related components, whereas lignin-related bands were generally more stable.

Based on the present results, however, it cannot be concluded that the chemical differences detected by FTIR directly caused the reduction in hardness. It is more likely that the anatomical, mechanical, and chemical changes represent parallel manifestations of the same prolonged deterioration in tree condition.

4.4. INTEGRATED INTERPRETATION OF THE RESULTS AND LIMITATIONS

Taken together, the different analytical approaches indicate that several properties of wood regions characterized by narrowed tree rings may change in parallel. The clearest relationship observed in the present study was between changes in tree-ring anatomy and reduced hardness, while FTIR analysis additionally indicated variation at the molecular level.

Some samples with a relatively uniform tree-ring structure provided an important basis for comparison. They did not show the pronounced narrowing of outer tree rings observed in the other samples, and their radial hardness profile remained more uniform. This suggests that the observed differences may not be explained solely by general environmental factors affecting all sampled trees in the same manner.

Nevertheless, tree-ring narrowing alone cannot be regarded as a specific marker of *H. fraxineus* infection. Radial growth may also be influenced by climatic and site-related factors (Giagli et al., 2018). In addition, fungi other than *H. fraxineus* may occur in weakened ash trees and may contribute to their decline (Kowalski et al., 2017; Langer, 2017; Linaldeddu et al., 2022).

Because of the exploratory nature of the study and the limited sample size, caution is required when generalizing the observed relationships. Future studies using larger sample sets, more precise spatial alignment of anatomical, mechanical, and spectroscopic measurement points, and direct measurements of wood density and chemical composition could help clarify the relationships among these changes.

Project no. 2025-2.1.1-EKÖP-2025-00002 has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the EKÖP-25-3-I funding scheme.

NATIONAL RESEARCH, DEVELOPMENT AND INNOVATION OFFICE HUNGARY

PROGRAM FINANCED FROM THE NRDI FUND

REFERENCES

Carroll, D., & Boa, E. (2024). Ash dieback: From Asia to Europe. Plant Pathology, 73(4), 741–759. doi: 10.1111/ppa.13859

Faix, O. (1991). Classification of lignins from different botanical origins by FT-IR spectroscopy. Holzforschung, 45(S1), 21–28. doi: 10.1515/hfsg.1991.45.s1.21

Giagli, K., Baar, J., Fajstavr, M., Gryc, V., & Vavrčík, H. (2018). Tree-ring width and variation of wood density in Fraxinus excelsior L. and Quercus robur L. growing in floodplain forests. BioResources, 13(1), 804–819. doi: 10.15376/biores.13.1.804-819

Gross, A., Holdenrieder, O., Pautasso, M., Queloz, V., & Sieber, T. N. (2014). Hymenoscyphus pseudoalbidus, the causal agent of European ash dieback. Molecular Plant Pathology, 15(1), 5–21. doi: 10.1111/mpp.12073

Klesse, S., von Arx, G., Gossner, M. M., Hug, C., Rigling, A., & Queloz, V. (2021). Amplifying feedback loop between growth and wood anatomical characteristics of Fraxinus excelsior explains size-related susceptibility to ash dieback. Tree Physiology, 41(5), 683–696. doi: 10.1093/treephys/tpaa091

Kowalski, T., Bilański, P., & Kraj, W. (2017). Pathogenicity of fungi associated with ash dieback towards Fraxinus excelsior. Plant Pathology, 66(8), 1228–1238. doi: 10.1111/ppa.12667

Langer, G. (2017). Collar rots in forests of northwest Germany affected by ash dieback. Baltic Forestry, 23(1), 4–19.

Linaldeddu, B. T., Bregant, C., Montecchio, L., Brglez, A., Piškur, B., & Ogris, N. (2022). First report of Diplodia fraxini and Diplodia subglobosa causing canker and dieback of Fraxinus excelsior in Slovenia. Plant Disease, 106(1), 26–29. doi: 10.1094/PDIS-06-21-1204-SC

Magyar Szabványügyi Hivatal. (1982). MSZ 6786-11:1982. Faanyagvizsgálatok. Keménység meghatározása [Wood testing. Determination of hardness]. Budapest, Hungary.

Pandey, K. K., & Pitman, A. J. (2003). FTIR studies of the changes in wood chemistry following decay by brown-rot and white-rot fungi. International Biodeterioration & Biodegradation, 52(3), 151–160. doi: 10.1016/S0964-8305(03)00052-0

Pautasso, M., Aas, G., Queloz, V., & Holdenrieder, O. (2013). European ash (Fraxinus excelsior) dieback—A conservation biology challenge. Biological Conservation, 158, 37–49. doi: 10.1016/j.biocon.2012.08.026

Tolvaj, L. (2024). Optical properties of wood: Measurement methods and result evaluations. Springer Cham. doi: 10.1007/978-3-031-46906-0

Session 2 | Contribution 3

INFLUENCE OF SITE CONDITIONS AND STAND COMPOSITION ON THE WOOD PROPERTIES OF *ROBINIA PSEUDOACACIA* AND *QUERCUS CERRIS* IN HUNGARY

Róbert Németh[1], James Kudjo Govina[2], Fath Alrhman A. A. Younis[3], Mátyás Báder[1], Miklós Bak[1], Anett Sütő[1], Tamás Hofmann[4], Szabolcs Komán[1]

[1]University of Sopron, Faculty of Wood Engineering and Creative Industries, Bajcsy-Zs. u. 4., 9400 Sopron, Hungary
[2]CSIR-Forestry Research Institute of Ghana, Kumasi, Ghana
[3]Faculty of Forest Sciences and Technology, University of Gezira, Wad Madani, P.O. Box 20, Sudan
[4]University of Sopron, Faculty of Forestry, Institute of Environmental Protection and Nature Conservation, Bajcsy-Zs. u. 4., 9400 Sopron, Hungary

ABSTRACT

Climate change increases the need for drought-tolerant tree species that yield wood of predictable quality. Black locust (*Robinia pseudoacacia* L.) and Turkey oak (*Quercus cerris* L.) are relevant hardwood resources in Hungary. This synthesis integrates five studies on wood formed under contrasting Hungarian sites and stand types. In black locust, site and stand conditions significantly affected anatomy, density, dimensional stability, mechanical performance, extractives and colour. Poor-growth mixed stands maintained wide rings and showed high total content of extractive, polyphenol and antioxidant levels, whereas poor-growth pure stands had the highest mean density, bending strength and compression strength among growth-condition groups. At county level, Győr-Moson-Sopron showed the highest mean bending and compression strengths. In Turkey oak, soil quality and especially stand composition affected fibre characteristics and ring width; mixed stands produced longer fibres and thicker walls, while site type significantly influenced colour and pure stands generally produced more uniform appearance. The results demonstrate that site and stand effects are property-specific rather than uniformly favourable. Linking ecological site conditions with end-use requirements can therefore improve climate-adaptive management and targeted utilization of these hardwoods.

Keywords: Black locust; Turkey oak; site quality; stand composition; wood properties

1. INTRODUCTION

Climate change modifies temperature and precipitation regimes and increases drought stress, thereby affecting cambial activity, radial growth and wood formation. Forest adaptation should therefore be evaluated not only through survival and volume production, but also through the anatomical, physical, mechanical, chemical and aesthetic quality of the resulting timber (Nicolescu et al. 2020, Younis et al. 2025).

Wood properties integrate processes at several scales. Fibre and vessel dimensions, annual-ring structure, density, extractives and heartwood formation respond to genotype, age and environmental conditions; these changes influence strength, dimensional stability, durability and appearance (Adamopoulos and Voulgaridis 2002, Vek et al. 2020). Consequently, a site favourable for growth does not necessarily maximize every technological property.

In black locust, heartwood extractives and phenolic compounds are particularly important because they contribute to colour and natural durability (Latorraca et al. 2011, Vek et al. 2020). Recent Hungarian work has shown that their quantity, antioxidant capacity and relationships with CIELAB colour also vary among sites and stand conditions (Younis et al. 2026).

Black locust is a major plantation hardwood in Hungary, valued for rapid growth, drought tolerance, high density and natural durability (Nicolescu et al. 2018). Studies across five Hungarian counties demonstrated significant environmental variation in fibre and vessel characteristics, ring width, density, dimensional change and mechanical properties (Younis et al. 2025, Németh et al. 2026).

Turkey oak is a native, drought-tolerant oak with substantial Hungarian resources but lower utilization than the noble oaks. Its future value depends on understanding how site and stand structure affect wood quality. In western Hungary, soil quality and stand composition influenced ring width and fibre characteristics, while a broader study found significant site effects on colour and colour uniformity (Govina et al. 2023, Németh et al. 2025). Together, these datasets permit a multi-property assessment of how growing environment is recorded in wood structure and translated into performance and appearance.

The objective was to synthesize the effects of site quality and stand composition on black locust and Turkey oak wood in Hungary, with emphasis on anatomy and growth, black-locust physical, mechanical and

chemical properties, and Turkey-oak colour, and to discuss implications for climate-adaptive forestry and timber utilization.

2. EXPERIMENTAL METHODS

STUDY DESIGN AND GROWING-CONDITION CLASSES

Five coordinated Hungarian studies were integrated (Table 1). All compared wood formed under contrasting site qualities and/or stand compositions, allowing environmental effects to be considered across several property groups. Black locust originated from Bács-Kiskun, Szabolcs-Szatmár-Bereg, Vas, Baranya and Győr-Moson-Sopron counties. Eleven sites represented three classes: good-growth pure stands (GGC), poor-growth pure stands (PGC) and poor-growth mixed stands (MPGC). **The physical**-mechanical and chemical-colour studies used 22 logs; tree ages were 30–47 years (Younis et al. 2025, Németh et al. 2026, Younis et al. 2026). Long-term (1982–2023) climate data showed marked regional contrasts: Bács-Kiskun was the warmest and driest sampled region (11.5 °C; 585.1 mm annual precipitation), whereas Baranya had the highest precipitation (739.2 mm) (Németh et al. 2026).

Turkey oak anatomy was studied at four Vas County locations combining good/poor soils with pure/mixed broadleaved stands. The colour study used a wider Hungarian sampling and four site types: poor-growth mixed, poor-growth pure, good-growth mixed and good-growth pure stands (Govina et al. 2023, Németh et al. 2025).

Table 1. Overview of the datasets integrated in the present synthesis.

Species / study	Spatial coverage	Site / stand classes	Main properties	Source
Black locust – anatomy	5 counties, 11 sites	GGC; PGC; MPGC	FL, FW, FWT, LD, VL, VW, RW	Younis et al. (2025)
Black locust – chemistry/colour	5 counties, 11 sites	GGC; PGC; MPGC	Ash, MWE, CYE, TEC, TPC, FRAP, L*, a*, b*	Younis et al. (2026)
Black locust – physical/mechanical	5 counties	GGC; PGC; MPGC	D12, BD, shrinkage, swelling, MOR, MOE, CS	Németh et al. (2026)
Turkey oak – anatomy	Vas County, 4 locations	Good/poor soil × pure/mixed stand	Fibres, vessels, ring width, sapwood/heartwood	Govina et al. (2023)
Turkey oak – colour	5 Hungarian regions	Poor/good × pure/mixed stand	CIELAB colour and homogeneity	Németh et al. (2025)

***GGC= good growth condition; PGC= poor growth condition; MPGC= poor growth mixed stand. FL= fiber length; FW= fiber width; FWT= fiber wall thickness; LD= lumen diameter; VL= vessel length; VW= vessel width; RW= ring width; MWE= methanol water extraction; CYE= cyclohexane-ethanol extraction; TEC= total extractives content; TPC= total polyphenol content; FRAP= antioxidant capacity; L*= lightness; a*= redness; b*= yellowness; D12= density at 12% moisture content; BD= basic density; MOR= modulus of rupture; MOE= modulus of elasticity; CS= compressive strength parallel to the grain.*

ANATOMICAL AND GROWTH MEASUREMENTS

For black locust, 4-cm in thickness, discs were taken at breast height and bark-to-bark strips were used to determine fiber length (FL) and width (FW), fiber-wall thickness (FWT), lumen diameter (LD), vessel length (VL) and width (VW), and annual-ring width (RW) (Younis et al. 2025).

For Turkey oak, macerated sapwood and heartwood were used for fibre and vessel measurements; ring width and sapwood-heartwood proportions were measured on sanded, scanned pith-to-bark strips. ANOVA and post-hoc tests evaluated soil and stand effects (Govina et al. 2023).

PHYSICAL AND MECHANICAL TESTING OF BLACK LOCUST

Black locust clear heartwood specimens were kiln dried and tested for density, radial, tangential, longitudinal and volumetric shrinkage and swelling according to ISO 13061 procedures; 347 specimens were used for physical tests (Németh et al. 2026).

Static bending and compression parallel to grain provided modulus of elasticity (MOE), modulus of rupture (MOR) and compressive strength (CS); county and growth-condition effects were tested at $p < 0.05$ (Németh et al. 2026).

CHEMICAL COMPOSITION AND COLOUR OF BLACK LOCUST

Black locust heartwood particles from breast-height discs were analysed for ash, methanol-water extractives (MWE), cyclohexane-ethanol extractives (CYE), total extractives (TEC), total polyphenols (TPC) and ferric reducing antioxidant power (FRAP) (Younis et al. 2026).

Colour was measured on conditioned transverse surfaces in CIELAB coordinates under D65 illumination, with 30 replicates per location. Pearson correlations tested relationships between extractives and colour (Younis et al. 2026).

COLOUR MEASUREMENT OF TURKEY OAK

Turkey oak colour was measured after kiln drying and surface preparation using CIELAB coordinates. After excluding obvious discoloration/artefacts, 1502 sapwood and 1389 heartwood points were analysed by ANOVA and Fisher's LSD test ($p < 0.05$) (Németh et al. 2025).

The analysis compared sapwood and heartwood, growing-site types and within-tree colour variability, with particular attention to lightness (L*).

3. RESULTS AND DISCUSSION

BLACK LOCUST: ANATOMICAL VARIABILITY AND RADIAL GROWTH

Black locust anatomy differed significantly among counties for FL, FW, FWT, VW and RW; LD and VL were more stable. Bács-Kiskun generally showed the lowest values, while Szabolcs-Szatmár-Bereg and Vas included many of the highest (Younis et al. 2025).

Growth-condition effects were also property-specific. Mean FL was 1.12 mm (GGC), 1.06 mm (PGC) and 1.04 mm (MPGC), while RW was 3.68 mm in both GGC and MPGC but only 2.70 mm in PGC. FL, FW, FWT, VW and RW differed significantly among conditions (Younis et al. 2025). Thus, MPGC partly compensated for reduced radial growth.

The comparison indicates that poor site quality alone does not determine anatomical response; stand composition can modify how site limitations are expressed.

BLACK LOCUST: DENSITY AND DIMENSIONAL STABILITY

Physical properties likewise varied by region and growth condition. Bács-Kiskun had the highest reported density at 12% moisture content (~0.84 g cm^{-3}), whereas PGC had the highest mean density among growth-condition groups (~0.81 g cm^{-3}) (Németh et al. 2026).

Bács-Kiskun also showed the lowest mean radial, tangential and volumetric shrinkage (4.13, 4.78 and 9.31%) and low swelling, whereas Vas had the highest shrinkage values. County effects were significant for almost all shrinkage and swelling variables (Németh et al. 2026).

MPGC specimens had the greatest linear and volumetric shrinkage. Hence, favourable anatomical traits in mixed stands did not necessarily imply better dimensional stability.

BLACK LOCUST: MECHANICAL PERFORMANCE

Mechanical properties showed strong county effects (Table 2; Fig. 1). Overall means were ~125 MPa MOR, 12.67 GPa MOE and 67 MPa CS. Bács-Kiskun had the highest MOE (13.33 GPa), while Győr-Moson-Sopron had the highest MOR (146 MPa) and CS (~73 MPa) (Németh et al. 2026).

Table 2. Mechanical properties of black locust by county (mean ± SD), adapted from Németh et al. (2026).

County	MOR (MPa)	MOE (GPa)	CS (MPa)
Szabolcs-Szatmár-Bereg	122.0 ± 13.1	12.81 ± 2.66	62.8 ± 6.20
Bács-Kiskun	112.2 ± 20.7	13.33 ± 3.18	68.0 ± 8.26
Győr-Moson-Sopron	146.0 ± 28.6	12.37 ± 2.36	73.1 ± 11.10
Baranya	122.0 ± 24.3	11.43 ± 2.46	67.9 ± 4.31
Vas	124.6 ± 16.3	13.32 ± 2.64	60.6 ± 6.87

***MOR= modulus of rupture; MOE= modulus of elasticity; CS= compressive strength parallel to the grain*

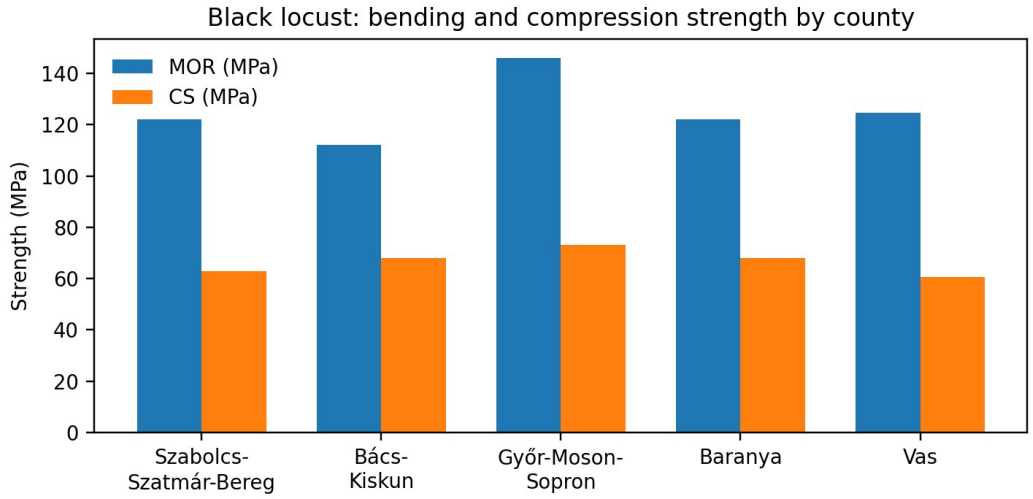


Figure 1. County-level variation in black locust modulus of rupture (MOR) and compression strength parallel to grain (CS), redrawn from Németh et al. (2026).

Among growth conditions, MPGC had the highest MOE (13.32 GPa), while PGC had the highest MOR (131 MPa) and CS (71.90 MPa). MOE and CS differed significantly, but MOR did not. No single growth class therefore maximized all mechanical properties (Németh et al. 2026).

BLACK LOCUST: CHEMICAL COMPOSITION AND COLOUR

Chemical composition also varied significantly (Table 3; Fig. 2). Vas had the highest MWE (11.8%), TEC (13.4%), TPC (36.0 mg GAE g−1) and FRAP (17.8 mg AA g−1), whereas Baranya had the lowest MWE, TEC, TPC and FRAP (Younis et al. 2026).

Table 3. Selected chemical and colour properties of black locust by county, adapted from Younis et al. (2026).

County	MWE (%)	TEC (%)	TPC (mg GAE/g dw)	FRAP (mg AA/g dw)	L*
Győr-Moson-Sopron	9.35	10.9	28.4	14.7	59.4
Bács-Kiskun	7.69	11.1	24.4	11.1	56.8
Baranya	5.04	7.37	15.1	6.03	56.2
Szabolcs-Szatmár-Bereg	7.37	9.61	25.2	11.5	57.6
Vas	11.8	13.4	36.0	17.8	62.0

***CYE= cyclohexane-ethanol extraction; TEC= total extractives content; TPC= total polyphenol content; FRAP= antioxidant capacity; L*= lightness*

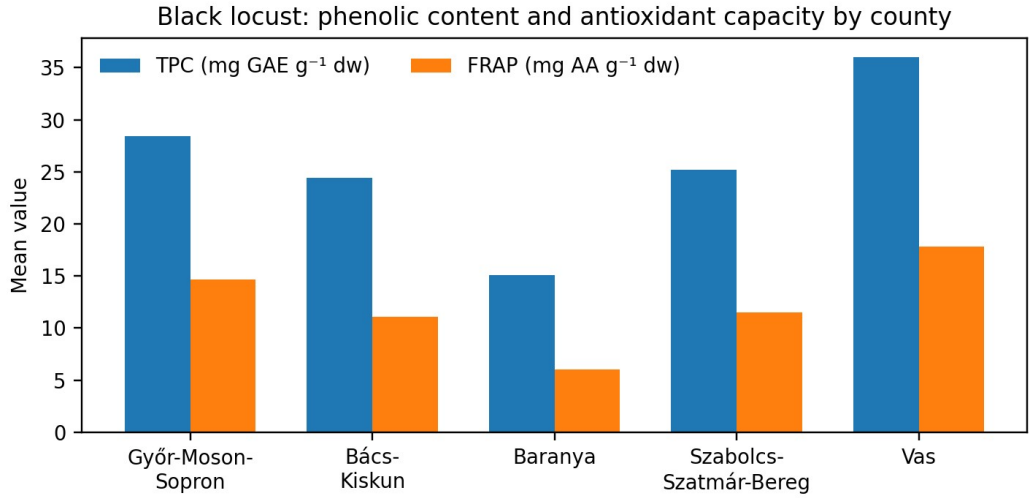


Figure 2. Total polyphenol content (TPC) and ferric reducing antioxidant power (FRAP) of black locust wood by county, redrawn from Younis et al. (2026).

MPGC wood likewise had the highest MWE, TEC, TPC and FRAP and the lowest ash content. These chemical patterns broadly paralleled the favourable anatomical response of MPGC wood, but not its dimensional stability (Younis et al. 2026).
Colour varied among counties and conditions: mean L* ranged from 56.2 (Baranya) to 62.0 (Vas). MPGC had the highest L* (62.0), while PGC was darkest (56.15) (Younis et al. 2026).
Chemical-colour relationships were selective (Table 4). MWE and TPC correlated positively with L* (r = 0.55 and 0.48), whereas CYE correlated negatively with L* and b* and positively with a*. TEC was not significantly correlated with colour (Younis et al. 2026).

Table 4. Significant Pearson correlations between chemical fractions and CIELAB coordinates in black locust, from Younis et al. (2026).

Relationship	r	p	Interpretation
MWE vs L*	0.55	<0.01	positive
TPC vs L*	0.48	<0.05	positive
CYE vs L*	−0.52	<0.05	negative
CYE vs a*	0.47	<0.05	positive
CYE vs b*	−0.59	0.01	negative

TURKEY OAK: EFFECTS ON FIBRE CHARACTERISTICS AND GROWTH

Turkey oak responded to both soil quality and stand composition. Fibre length ranged from ~800 to 1306 µm and double-wall thickness from 11.73 to 18.51 µm. Mean fibre length and wall thickness were higher on poor than good soils in the investigated material (Govina et al. 2023).
Stand composition had the clearer effect (Fig. 3): mixed stands averaged 1273.6 µm fibre length and 17.29 µm double-wall thickness, compared with 975.89 µm and 12.92 µm in pure stands; fibre diameter was also larger in mixed stands (Govina et al. 2023).

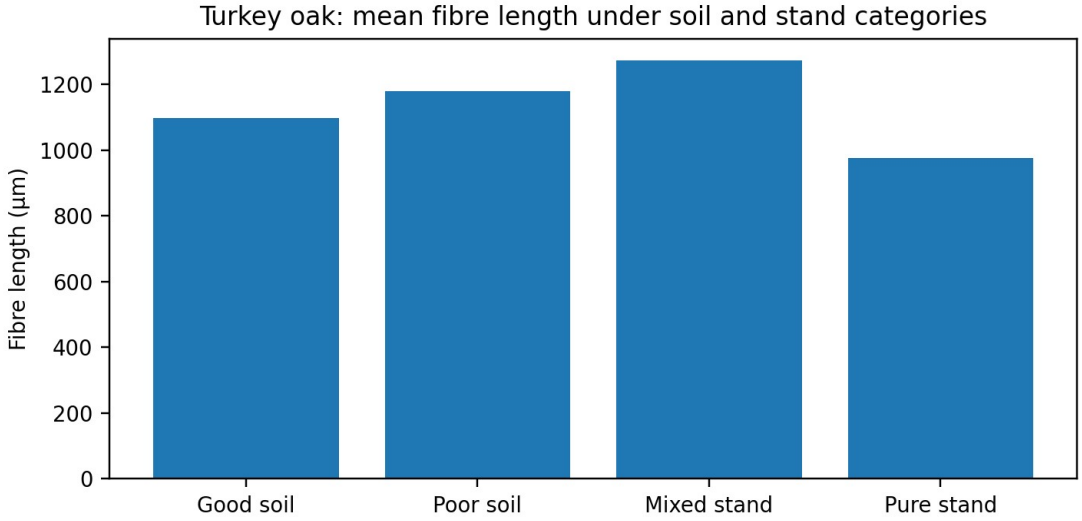


Figure 3. Mean Turkey oak fibre length under soil-quality and stand-composition categories, redrawn from Govina et al. (2023). Error bars are omitted because the four categories combine two different grouping factors.

Heartwood represented ~67–82% of stem diameter. Ring width declined from juvenile wood (about 2400–3300 µm) through heartwood (1600–2500 µm) to sapwood (1000–1600 µm), and both soil quality and stand composition significantly affected ring width (Govina et al. 2023).

TURKEY OAK: COLOUR AND VISUAL UNIFORMITY

Turkey oak sapwood was significantly lighter and more yellowish-white than heartwood. The relative difference in a* was 28.8%, whereas mean b* differed by only ~3% (Németh et al. 2025).
Growing-site type affected colour particularly strongly for L*, indicating that lightness is sensitive to the combined effects of site quality and stand composition (Németh et al. 2025).

Within-tree colour variation was generally modest; most coefficients of variation were below 10%, although a* reached 17.6%. Pure stands generally produced more uniform colour than mixed stands (Németh et al. 2025).

SITE EFFECTS ARE EXPRESSED DIFFERENTLY ACROSS WOOD-QUALITY TRAITS

Across both species, environmental effects were measurable but not unidirectional. In black locust, GGC and MPGC supported wide rings and favourable anatomical development, yet PGC produced the highest mean density, MOR and CS among growth classes; MPGC also showed the greatest shrinkage. Thus, growth rate, anatomy, density, dimensional stability and strength should not be treated as interchangeable indicators of quality (Younis et al. 2025, Németh et al. 2026).

This decoupling is consistent with the hierarchical nature of wood: ring width records radial increment, fibre dimensions reflect cell differentiation, density integrates wall material and tissue proportions, and mechanical behaviour additionally depends on structural organization. End-use requirements must therefore define which response is considered favourable.

Regional results reinforce this conclusion. The warm, dry Bács-Kiskun sites produced narrow rings and relatively low anatomical dimensions but high density, the highest MOE and low dimensional change, whereas Győr-Moson-Sopron produced the highest MOR and CS (Németh et al. 2026).

Chemical variation adds a further dimension: MPGC combined wide rings and favourable anatomical traits with the highest MWE, TPC and antioxidant capacity, but not with the best dimensional stability (Younis et al. 2026).

The positive associations of MWE and TPC with L*, and the contrasting correlations of CYE with all CIELAB coordinates, also show that visual appearance cannot be inferred simply from total extractive content (Younis et al. 2026).

STAND COMPOSITION CAN PARTLY OFFSET UNFAVOURABLE SITE CONDITIONS

Stand composition modified site effects in both species. MPGC black locust maintained ring widths comparable with GGC, and mixed Turkey oak stands produced markedly longer fibres and thicker walls than pure stands (Younis et al. 2025, Govina et al. 2023).

Such responses may reflect differences in competition and resource partitioning, but the present datasets do not support a universal advantage of mixtures. MPGC black locust had greater shrinkage, and pure Turkey oak stands tended to show more uniform colour (Németh et al. 2025, Németh et al. 2026).

For climate-adaptive silviculture, this means that stand composition should be selected together with the intended timber use rather than from ecological performance alone.

FROM ANATOMY TO UTILIZATION

Integrating anatomy with technological measurements links wood formation to utilization. Fibre and vessel traits affect the structural framework and permeability of hardwoods, while density is related to strength but does not explain every regional difference observed in black locust.

The black locust results support demanding applications while demonstrating useful regional combinations: Győr-Moson-Sopron material had particularly high bending and compression strength, whereas Bács-Kiskun combined high stiffness and density with relatively low dimensional change (Németh et al. 2026).

For Turkey oak, the available studies document anatomy and appearance rather than direct mechanical performance. Longer fibres and thicker walls in mixed stands may be technologically favourable, but strength cannot be inferred without testing. Conversely, the greater colour uniformity of pure stands may benefit visible furniture and interior products (Govina et al. 2023, Németh et al. 2025).

IMPLICATIONS UNDER CLIMATE CHANGE

Both species are relevant to Central European forestry under increasing drought stress, but adaptation should include timber quality as well as survival and growth. The present studies show substantial utilization potential across contrasting Hungarian conditions, accompanied by meaningful site-related variation.

Linking ecological site classification with wood-quality information could therefore improve species choice, stand design and allocation of harvested timber to higher-value uses.

The synthesis is limited by non-identical experimental designs and incomplete property overlap between species. Direct numerical comparison is therefore inappropriate; the value of the combined analysis lies in identifying recurring environmental controls and property-specific trade-offs.

CONCLUSIONS

Site quality and stand composition significantly affected wood formation and quality in both *Robinia pseudoacacia* and *Quercus cerris* in Hungary, from anatomy and ring width to technological and aesthetic properties.

In black locust, GGC and MPGC generally favoured anatomical development and ring width, MPGC had the highest extractive/polyphenol/antioxidant levels, while PGC showed the highest mean density, MOR and CS among growth classes. Győr-Moson-Sopron had the highest mean MOR and CS, whereas Bács-Kiskun combined high stiffness and density with relatively low dimensional change.

In Turkey oak, mixed stands produced longer fibres and thicker walls, while site type significantly influenced colour and pure stands generally produced more uniform appearance.

Neither good sites nor mixed stands maximize every wood-quality attribute. Climate-adaptive management should therefore match site and stand composition to intended end-use properties and integrate forestry decisions with wood-quality information.

REFERENCES

Adamopoulos, S.; Voulgaridis, E. (2002). Within-tree variation in growth rate and cell dimensions in the wood of black locust (*Robinia pseudoacacia*). IAWA Journal, 23, 191–200.

Govina, J.K.; Németh, R.; Bak, M.; Báder, M. (2023). Effect of variable growth conditions on selected anatomical properties of Hungarian Turkey oak wood. Bulletin of the Transilvania University of Braşov, Series II: Forestry • Wood Industry • Agricultural Food Engineering, 16(65), Special Issue.

Latorraca, J.V.; Dünisch, O.; Koch, G. (2011). Chemical composition and natural durability of juvenile and mature heartwood of Robinia pseudoacacia L. Anais da Academia Brasileira de Ciências, 83, 1059–1068. https://doi.org/10.1590/s0001-37652011005000016

Nicolescu, V.N.; Hernea, C.; Bakti, B.; Keserű, Z.; Antal, B.; Rédei, K. (2018). Black locust (*Robinia pseudoacacia* L.) as a multi-purpose tree species in Hungary and Romania: a review. Journal of Forestry Research, 29, 1449–1463. https://doi.org/10.1007/s11676-018-0626-5

Nicolescu, V.N.; Rédei, K.; Mason, W.L.; et al. (2020). Ecology, growth and management of black locust (*Robinia pseudoacacia* L.), a non-native species integrated into European forests. Journal of Forestry Research, 31, 1081–1101. https://doi.org/10.1007/s11676-020-01116-8

Németh, R.; Báder, M.; Younis, F.A.A.A. (2026). Selected physical and mechanical properties of wood of *Robinia pseudoacacia* L. across Hungarian counties. Forests, 17, 1119. https://doi.org/10.3390/f17091119

Németh, R.; Tolvaj, L.; Báder, M. (2025). Color variations of Turkey oak (*Quercus cerris* L.) wood from different types of growing sites. Forests, 16, 1681. https://doi.org/10.3390/f16111681

Vek, V.; Poljanšek, I.; Oven, P. (2020). Variability in content of hydrophilic extractives and individual phenolic compounds in black locust stem. European Journal of Wood and Wood Products, 78, 501–511. https://doi.org/10.1007/s00107-020-01523-y

Younis, F.A.A.A.; Báder, M.; Bak, M.; Németh, R. (2025). Site variability in fibers, vessels, and ring width of *Robinia pseudoacacia* L. wood: a case study in Hungary. Forests, 16, 807. https://doi.org/10.3390/f16050807

Younis, F.A.A.A.; Hofmann, T.; Németh, R. (2026). Site variability in chemical compositions and color parameters of black locust (*Robinia pseudoacacia* L.) wood. European Journal of Wood and Wood Products, 84, 24. https://doi.org/10.1007/s00107-026-02377-6

Plenary session | Contribution 1

EVALUATE FLAMMABILITY OF WOOD BY MULTIPLE SCALE TESTS

Prof. Dr Qiang Xu

School of Mechanical Engineering, Nanjing University of Science and Technology, China
e-mail: xuqiang@njust.edu.cn

ABSTRACT

Understanding wood flammability is essential for accurately assessing fire hazards in wooden structures, guiding the selection of low-flammability species, and designing effective fire-retardant treatments. This will help to quantify its intrinsic tendency to ignite, sustain combustion, and release heat when exposed to a heat source, and to reduce fire risks associated with wood use. Evaluating the flammability of wood requires a comprehensive approach that spans multiple scales, from micro scale test, to bench scale, then to real-scale fire scenarios test. This presentation will present the results of experimental measurements on wood flammability at different scales, from Microscale Combustion Calorimetry ASTM D7309, bench scale cone calorimetry ISO 5660, and room scale test ISO 9705. These results provide the fundamental data on ignition time, heat release rate, mass loss under controlled radiant heat fluxes, flame spread behavior, flashover potential, smoke production, and structural integrity loss. These would be contribute to building codes, material selection, and fire safety engineering, ultimately reducing the risk of wood-related fire accidents as key reference.

Keywords: flammability, wood, different scales, heat release rate.

Plenary session | Contribution 2

MECHANICAL AND HYGROSCOPIC PROPERTIES OF CASTANEA SATIVA WOOD ORIGINATED FROM HOLY MOUNTAIN OF GREECE

Georgios Ntalos, Andromachi Mitani, Dimitrios Koutsianitis, Konstantinos Ninikas, Paulos Ntalos, Kassiani Theodorakou

[1]Department of Forestry, Wood Sciences & Design, University of Thessaly, Greece,
e-mails: gntalos@uth.gr, amitani@uth.gr, kninikas@uth.gr
[2]Department of Forestry and Natural Environment Management, Agricultural University of Athens
e-mail: dkoutsianitis@aua.gr

ABSTRACT

The physical and mechanical features of the mature wood of Castanea sativa have been characterized in detail. Appropriate wood species have been selected from the wood sector literature over the years. We focused on a wood species which has contributed significantly and durably throughout Europe in terms of economic and cultural significance for the individual countries of Europe. Athos chestnut wood samples were described using a 0.62 g/cm^3 density value at an average equilibrium moisture content of 9.2 % and an oven-dry density of 0.57 g/cm^3. Tangential shrinkage of 6.6% and radial of 3.8% . The determined mean modulus of rupture is 108 N/mm^2 and the static modulus of elasticity of the data set is 10,360 N/mm^2. Janka hardness value for chestnut heartwood was 41.1 N/mm^2 side and 48 N/mm2 face, while the compression strength parallel to grain was 39.5 N/mm^2. Moisture content at 65% relative humidity and 20 °C was 11.5%, while the fiber saturation point was 20.8%.

Keywords: Castanea sativa, mechanical properties, hydroscopic properties.

Plenary session | Contribution 3

AUXETICS, FROM WOOD AND FOR FURNITURE

Prof. Jerzy Smardzewski

Poznań University of Life Sciences, Faculty of Forestry and Wood Technology, Department of Furniture Design
e-mail: jsmardzewski@up.poznan.pl

ABSTRACT

The objective of this lecture is to illustrate the capacity to transform natural wood and its composites into an active, smart structural material with a negative Poisson's ratio that is, a material with auxetic properties. Consequently, the development of smart wooden components that exhibit auxetic mechanical behavior has become a viable prospect. These components have been engineered to respond to environmental factors such as humidity, temperature, and external stresses, thereby demonstrating adaptability. This innovation paves the way for the integration of a novel category of passively intelligent biological materials within the domain of furniture design, thereby unveiling considerable prospects for implementation in the realm of adaptive architecture. Furthermore, the utilization of auxetics in various structural applications will be examined, including their application as joints in wooden structures, thin-walled structures with synclastic properties, and in the context of responsive cores in honeycomb panels. Examples of the use of auxetics in the design of reactive mattresses and seats for upholstered furniture will be illustrated. Furniture incorporating auxetics can indeed represent an intriguing offering that meets the needs of consumers seeking smart solutions for ready-to-assemble (RTA) furniture or mass-customized upholstered furniture tailored to users' individual biomechanical preferences.

Keywords: auxetics, wood, composites, panels, firniture, customer.

Plenary session | Contribution 4

QUO VADIS WOOD TECHNOLOGY?

Prof. Tomasz Krystofiak

Poznan University of Life Sciences, Department of Wood Science and Thermal Techniques, Laboratory of Gluing and Finishing of Surface, Poland
e-mail: tomasz.krystofiak@up.poznan.pl

ABSTRACT

In the light of dynamic climate change, the raw materials crisis and the digital transformation, the timber industry is at a turning point. This presentation attempts to address the question of the sector’s future in the context of the synergy between science and economic practice WSEEP (the Wood-Science-Economy-Ecology-Practice initiative). The main focus of the discussion is the evolution of wood surface finishing and gluing processes. The transition from traditional methods to low-carbon and energy-efficient technologies, such as UV-cured systems will be presented. In the era of the circular economy (CE), a key challenge is the development of modern functional materials which, on the one hand, will increase the durability of products and, on the other, will allow for their safe disposal or recycling. The presentation will also address the issue of digitalisation – from the automation of production lines to the use of artificial intelligence in optimising raw material consumption. The speaker will emphasise that the future of wood technology lies not only in new machinery, but above all in an innovative approach to wood as a strategic raw material, which, in the spirit of Industry 5.0, must combine high efficiency with care for human well-being and the natural environment. Emphasis will be placed on international cooperation and staff training. Using examples of initiatives undertaken in Poland, the role of international projects, dual training and applied PhD programmes will be presented as a bridge linking academic research into wood with the practical needs of wood technology.

Keywords: wood technology, WSEEP, UV system, circular economy, Industry 5.0, sustainability.

Plenary session | Contribution 5

ECODESIGN AND FURNITURE: CHALLENGES AND OPPORTUNITIES FOR THE EUROPEAN FURNITURE INDUSTRY

Vassil Jivkov

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Chairman of the Board of Bulgarian Branch Chamber of Woodworking and Furniture Industry; Member of the Board, European Furniture Industries Confederation
e-mail: v.jivkov@ltu.bg

ABSTRACT

The transition towards a circular economy and the implementation of the Ecodesign for Sustainable Products Regulation (ESPR) are expected to significantly influence the development of the European furniture industry. The sector is characterised by a large number of small and micro-enterprises, a high diversity of products, materials and manufacturing technologies, and strong competition from imported products. At the same time, Europe has established competitive advantages in furniture design, quality, engineering, and high-value-added production.

This keynote paper discusses the main challenges and opportunities associated with implementing ecodesign principles in furniture, with particular emphasis on materials, furniture structures, and joining solutions. Extending product lifetime through reliability, maintenance and repair, improving material efficiency, and designing for effective end-of-life treatment are considered among the key priorities for future furniture development. However, individual circularity strategies should not be assessed in isolation. Increased recycled content, easy disassembly or the use of mono-material solutions do not necessarily result in more sustainable products if they compromise structural performance, durability, safety or functionality.

Particular attention is therefore given to the relationship between material selection, structural design, joint performance, disassembly and reassembly capability, repairability and recyclability. The paper argues that ecodesign requirements should be performance-oriented rather than prescriptive and should reflect the functional and structural diversity of furniture products. The role of modularity, detachable joints and priority components is discussed in relation to emerging European approaches and standards for furniture circularity.

The transition towards ecodesign represents a considerable technical and administrative challenge for European furniture manufacturers, particularly SMEs. At the same time, it creates opportunities for innovation in materials, furniture structures, joining systems, product lifetime extension, repair, upgrading and new circular business models. In this context, engineering design can become a key competitive advantage for the European furniture industry.

Keywords: ecodesign, furniture, circular economy, furniture structures, materials, detachable joints, durability, repairability, disassembly, recyclability.

Session 1 | Contribution 1

POTENTIAL OF WOOD IN THE ENERGY BALANCE OF BULGARIA

Tsvetelina Simeonova-Zarkin[1], Kalin Simeonov[2]

[1] University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mail: tsvete.simeonova@gmail.com

[2] Ecotechproduct Ltd
e-mail: kalin@ecotechproduct.com

ABSTRACT

Wood is a renewable source of energy and can have a significant potential in the energy balance of this country. It is widely used for energy production as fire wood, but also in form of pellets, briquettes and waste wood from sawmill industry and furniture production, Altogether the amount of waste wood from these two industries is about 60 - 75 percent and more from the volume of round wood used. Used furniture and home furnishings, wood from demolished wooden constructions including windows, doors and floorings, are also a cheap and available energy source. Practically all the wood coming out from the forests soon or later can be used for energy production.

The legislation of the Europe Union promotes the use of wood for energy production as a fuel with a neutral carbon impact. The plants and the technologies used have a high efficiency and without any negative effect towards environment and nature. In contrary, in Bulgaria the existing procedures are such ones, that the society is becoming a not positive opinion against the use of wood as energy source with a negative influence on the environment in the residential areas and on the nature.

Summarized is the existing legislative framework in the European Union and practical aspects of burning wood for energy production, thermal and electrical. Recommendations are given for improving the praxes in Bulgaria.

Keywords: Wood as energy source, neutral carbon impact, technical and technological aspect of burning wood.

Session 2 | Contribution 1

SURFACE LEVEL EFFECTS OF FOREST FIRE ON NORWAY SPRUCE AND SCOTS PINE WOOD: INSIGHTS FROM MICROINDENTATION

Sauradipta Ganguly, Luka Albreht, Miha Humar, Jaka Levanič, Veikko Möttönen, Erkki Verkasalo, Marko Petrič

Production Systems, Natural Resources Institute Finland, Joensuu, Yliopistokatu 6B, FI-80100, Finland
e-mails: sauradipta.ganguly@luke.fi, veikko.mottonen@luke.fi, erkki.verkasalo@luke.fi
University of Ljubljana, Biotechnical Faculty, Jamnikarjeva 101, 1000 Ljubljana, Slovenia
e-mails: luka.albreht@bf.uni-lj.si, miha.humar@bf.uni-lj.si, jaka levanič@bf.uni-lj.si, marko.petric@bf.uni-lj.si

ABSTRACT

Forest fires increasingly affect boreal and temperate forests, generating large volumes of fire-damaged wood with uncertain material performance and limited utilisation. While the macroscopic mechanical properties of such wood have been investigated, less attention has been paid to the microscale mechanical behaviour and associated chemical alterations of wood cell walls. This study examines the micromechanical changes on the surfaces of fire-affected Norway spruce (*Picea abies* (L.) H. Karst.) and Scots pine (*Pinus sylvestris* L.) wood in comparison with reference material. Microindentation testing was applied to earlywood and latewood regions of wood from fire-affected trees and control samples, to assess indentation hardness (HIT) and indentation modulus (EIT). In general, wood from affected trees exhibited moderate but apparently systematic surface mechanical changes at the microscale, with increased variability compared to reference samples. Fire-affected wood generally exhibited lower stiffness, as indicated by reduced indentation modulus (EIT), whereas hardness responses were less consistent and showed increased variability. These changes were more clearly expressed in the case of spruce wood. In parallel, Fourier Transform Infrared spectroscopy was used to assess potential changes in major cell wall components and to support the microindentation results. It was demonstrated that localised fire exposure affects the surface micromechanical response of wood, which can be attributed to thermally induced chemical and physical changes in wood exposed to fire. These findings should be considered when evaluating the suitability of fire-damaged wood for further utilisation.

Keywords: forest fire, fire-damaged wood, microindentation, FTIR spectroscopy, Norway spruce, Scots pine.

Session 2 | Contribution 4

IMPREGNATION OF BEECH WOOD (FAGUS SYLVATICA L.) WITH CORN OIL: A COMPREHENSIVE EVALUATION OF HYGROSCOPIC BEHAVIOR, SURFACE PROPERTIES, AND ARTIFICIAL WEATHERING

Maria Papakonstantinou[1], Andromachi Mitani[1,*], Dimitrios Koutsianitis[2], Constantina Mitani[1], and Kassiani Theodorakou[1]

[1] Department of Forestry, Wood Sciences & Design, University of Thessaly, Greece,
e-mails: marpapakonst@uth.gr, amitani@uth.gr
[2] Department of Forestry and natural Environment, Agricultural University of Athens
e-mail: dkoutsian@for.auth.gr
* Corresponding author: amitani@uth.gr

ABSTRACT

Beech (*Fagus sylvatica* L.) is a widely used hardwood species whose limited natural durability and dimensional instability under moisture restrict its outdoor applications. This study investigated the effect of vacuum impregnation with corn oil (*Zea mays* L.), a low-cost and underexplored vegetable oil, on the surface and hygroscopic properties of beech wood. Specimens were impregnated for 30 or 60 min and characterized, together with non-impregnated controls, for weight percentage gain (WPG), dimensional change, FTIR spectra, color, hardness, surface roughness, and contact angle, before and after accelerated artificial weathering in a Xenon chamber; hygroscopic behavior was further assessed through water absorption and dimensional swelling during 24 h of water immersion. FTIR analysis confirmed effective oil penetration into the wood structure through characteristic triglyceride absorption bands. Impregnation resulted in high oil uptake (WPG > 45%) at both durations without inducing substantial dimensional change and significantly increased the contact angle and reduced water absorption (by 65%–66%) and radial and tangential swelling relative to the controls ($p < 0.05$), while surface hardness remained unaffected ($p = 0.263$). Color difference (ΔE^*) after artificial weathering was significantly higher in impregnated specimens than in the controls ($p < 0.001$), reflecting the natural yellowish hue of the oil rather than material degradation. Overall, corn oil impregnation, applied for as little as 30 min, improved the hydrophobicity and dimensional stability of beech wood without compromising its hardness, supporting its potential as a sustainable, bio-based wood modification medium.

Keywords: *Fagus sylvatica* L.; corn oil; vacuum impregnation; wood modification; hygroscopic properties; artificial weathering; contact angle

Session 2 | Contribution 5

FUNCTIONALIZED NANOCELLULOSE AS A MODIFIER OF UREA-FORMALDEHYDE RESIN FOR PARTICLEBOARD PRODUCTION

Jakub Kawalerczyk

Faculty of Forestry and Wood Technology, Poznan University of Life Sciences
e-mail: jakub.kawalerczyk@up.poznan.pl

ABSTRACT

Nanocellulose is a highly attractive renewable nanomaterial due to its high specific surface area, excellent mechanical performance, biodegradability, and abundance of reactive hydroxyl groups. These unique characteristics make it particularly suitable for chemical functionalization, enabling the development of tailored materials for advanced industrial applications. At the same time, growing environmental concerns and increasing sustainability requirements have intensified the search for bio-based additives for formaldehyde-based adhesives, including urea-formaldehyde (UF) resins, which remain the most widely used binding agents in particleboard production. In this study, functionalized nanocellulose was investigated as a bio-based modifier of UF resin. Various functionalization strategies were employed, including modification with 3-aminopropyltriethoxysilane, methylene diphenyl diisocyanate, lysine, and ethylenediamine, as well as acetylation using acetic anhydride, sulfonation, and phosphorylation. The effects of these modifications on selected functional properties of UF resin were evaluated to determine the relationship between nanocellulose surface chemistry and adhesive performance. Particleboards manufactured using modified UF resins were subsequently characterized in terms of internal bond strength, modulus of elasticity, bending strength, thickness swelling, water absorption, and formaldehyde content. The obtained results demonstrated that the type of functionalization significantly influenced both resin behavior and board performance, indicating the potential of tailored nanocellulose modifications to enhance the properties of UF-bonded wood-based composites. In addition, the applied functionalization methods were compared in terms of procedural complexity, processing requirements, and the need for specialized equipment. Such an assessment provides valuable insight into the feasibility of industrial implementation and identifies the most promising approaches.

Keywords: nanocellulose, functionalization, particleboard, urea-formaldehyde adhesive.

Session 3 | Contribution 1

LINKING TREE PHYSIOLOGY, GROWTH, AND BIODIVERSITY: LONG-TERM ECOLOGICAL RESEARCH FROM THE PETROHAN FOREST SITE (BULGARIA)

Svetoslav Anev, Sonya Damyanova, Toma Tonchev, Violeta Dimitrova, Pavel Pavlov, Stoyka Ruseva, Teodor Nedelin, Georgi Kadinov

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: svetoslav.anev@ltu.bg, sdamyanova@ltu.bg, ttonchev@ltu.bg, vilydi@ltu.bg, toniruseva@ltu.bg, nedelin@ltu.bg, pavelppj@ltu.bg, gkadinov@ltu.bg

ABSTRACT

Long-term ecological research is crucial for understanding forest ecosystem responses to environmental variability and global change. This study offers an integrated assessment of tree physiology, growth, and biodiversity based on multi-annual observations from the 'Petrohan' forest site (Bulgaria), part of the Long-Term Ecological Research (LTER) network. Tree physiological performance was assessed using gas exchange measurements, leaf area index, and chlorophyll content, providing insights into interannual variability in photosynthetic activity. Forest productivity was measured through repeated assessments of diameter and height increments, while litterfall dynamics were quantified using litter traps as indicators of carbon allocation and nutrient cycling. These data were supplemented by continuous meteorological observations from an automated weather station and evaluations of atmospheric deposition. Biodiversity monitoring included surveys of flying insects, understory vegetation, and fungal communities, facilitating a comprehensive evaluation of ecosystem complexity. The integration of multi-scale and multi-parameter datasets reveals significant linkages between climatic drivers, physiological responses, and the structural and functional attributes of the forest ecosystem. The findings underscore the importance of coordinated long-term monitoring to detect trends, enhance ecosystem understanding, and support sustainable forest management under changing environmental conditions.

Keywords: LTER forest site, physiology, growth, biodiversity, carbon allocation, nutrient cycling.

Session 3 | Contribution 3

THE POTENTIAL OF BULGARIAN BEECH FORESTS AS A SUSTAINABLE SOURCE OF TIMBER FOR THE FURNITURE INDUSTRY

Metodi Atanasov

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mail: metodi.atanasov@ltu.bg

ABSTRACT

European beech (Fagus sylvatica L.) is one of the most widespread and economically important tree species in Bulgaria, covering approximately 600 000 ha of forest area. In addition to providing essential ecosystem services, beech forests represent an important renewable resource. Their sustainable management requires a comprehensive understanding of their distribution, site conditions, stand structure, productivity, and current management practices. Bulgarian beech forests have considerable potential to serve as a sustainable source of wood raw material for the furniture industry. During the last fourteen years, the utilization of beech timber in Bulgaria has shown a continuous downward trend. At the beginning of the period, the average annual harvest amounted to approximately 1.03 million m³, whereas by 2024–2025 it had declined to 0.65 million m³, representing a 46% decrease. Timber harvesting is characterized by an unsatisfactory assortment structure, with industrial roundwood accounting for only 18% of the total harvested volume, while large-diameter roundwood represents merely 14%. The actual harvest from Bulgarian beech forests during the study period reached only about 70% of the volume planned in forest management plans. The majority of harvested beech timber is used as fuelwood, limiting opportunities for higher value-added wood processing. This practice is inconsistent with the production objectives established for beech forests, the principles of the cascade use of wood, and the concept of long-term carbon storage in harvested wood products. The forest management sector removes, on average, approximately 8.8 million tonnes of CO_2 equivalent annually, making a substantial contribution to Bulgaria's climate objectives. These findings highlight the need to increase the utilization of high-quality beech timber in the furniture industry while reducing the proportion of timber consumed as fuelwood.

Keywords: European beech, sustainable forest management, timber, cascade use of wood, furniture industry.

Session 3 | Contribution 4

MICROBIAL AND ENZYMATIC ACTIVITY DURING THE PRODUCTION AND APPLICATION OF MULTI-COMPONENT ORGANO-MINERAL AMENDMENTS DERIVED FROM PLANT RESIDUES: EFFECTS ON THE GROWTH OF TOMATO SEEDLINGS

Boyka Malcheva, Gergana Mladenova, Milena Yordanova, Bilyana Grigorova-Pesheva, Alexandrina Kostadinova-Slaveva

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: boika.malcheva@gmail.com, g.mladenova@ltu.bg, yordanova_m@yahoo.com, grigorovabilyana.b@gmail.com, algkbg@gmail.com

ABSTRACT

Six multi-component compost variants were developed from plant residues, including vegetable and fruit wastes, wood sawdust, cereals, and essential oil crops, with additives: molasses, microbial fertilizer, mineral amendment, and extracts from essential oil crops. These were classified as innovative compost-based organo-mineral amendments (COMA). Microbiological parameters (total microbial count, non-spore-forming bacteria (dominant fraction), bacilli, lactobacilli, actinomycetes, molds, microbial biomass) and enzymatic activities (cellulase, catalase, urease, dehydrogenase) were highest in the variant composed of mixed vegetable wastes (tomatoes, lettuce, potato and cucumber peels), maize stalks, and ground sunflower, with all additives and soil as a starter. This trend was maintained during application; however, microbial abundance alone was not an independent factor determining biometric parameters. Application was carried out in tomato cultivation using two approaches: peat–compost mixtures (1:1 and 1:3) and irrigation with COMA extracts. Irrigation mainly stimulated aboveground growth of tomato seedlings. The strongest positive effect was observed in the variant composed of zucchini, maize (dry leaves), fresh and dry weeds, fresh grass, green apples, and fresh weeds, with starter (old compost and soil) applied in layers; additive: microbial fertilizer. Root system development in some variants remained less pronounced than the control. In most cases, increasing the proportion of COMA in the peat substrate to 1:3 led to improved aboveground biomass, larger leaf area, and better stem formation. The best biometric performance was recorded at this ratio for a variant containing maize husks, ground sunflower, fresh grass, and fresh and dry residues of essential oil crops (basil, oregano), with microbial fertilizer and mineral amendment. Statistical analysis showed that compost functional activity depends not only on physicochemical conditions but also on microbial community structure. COMA created more favorable conditions for actinomycetes, while extracts exerted a stronger stimulating effect on the more mobile bacterial fraction.

Keywords: organo-mineral amendments, soil microorganisms, enzymes, compost extracts, tomato.

Session 3 | Contribution 5

SOIL RESOURCE MANAGEMENT THROUGH GIS, OPEN SPATIAL DATA AND ARTIFICIAL INTELLIGENCE

Galin Milchev, Elena Tsvetkova, Radoslav Miltchev

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
Technical University, Sofia, Bulgaria
e-mails: gmilchev@ltu.bg, etsvetkova@ltu.bg, rmiltchev@tu-sofia.bg

ABSTRACT

Rapidly developing information and communication technologies (ICT), remote sensing techniques and artificial intelligence provide new opportunities for monitoring, analysis and sustainable management of natural resources. With climate change, soil degradation and more effective greening activities, the use of digital technologies is becoming an important tool to support decision-making processes in ecosystem management. The study examines the application of ICT and AI in resource management by analyzing active soil acidity in the area of Radomir municipality. Field surveys of soil pH at two depths (0-10 and 10-20 cm) were conducted, for which digital thematic maps were prepared using GIS, which can identify areas with different soil properties. The results were compared with those from the global soil database SoilGrids, which offers predictions of soil pH obtained with machine learning models. The possibility of using open spatial data in soil resource monitoring and management is assessed. The potential of satellite data and artificial intelligence methods for analyzing spatial and temporal changes in soil properties and the impact on vegetation status is additionally examined. The expected results can be used in planning and optimizing measures for sustainable soil management, selecting appropriate species for afforestation, assessing the risk of unsuccessful sapling capture, as well as in the development of digital systems for monitoring and sustainable ecosystem management. The study shows how digital technologies can increase the efficiency of soil resource management and support sustainable management practices.

Keywords: ICT, soil acidity, monitoring processes.

Session 4 | Contribution 1

QUANTIFYING YIELD EFFICIENCY IN SAWMILLING USING REAL AND SIMULATED DATA

Ana Marija Stamenkoska, Goran Zlateski, Anastasija Temelkova, Branko Rabadziski

Ss. Cyril and Methodius University in Skopje, Faculty of Design and Technologies of Furniture and Interior
e-mails: stamenkoska@fdtme.ukim.edu.mk, zlateski@fdtme.ukim.edu.mk, temelkova@fdtme.ukim.edu.mk, rabadziski@fdtme.ukim.edu.mk

ABSTRACT

Rational sawmilling represents an important indicator of the efficiency of sawing processes. The performance of sawmilling operations is determined by a set of parameters, including the anatomical characteristics of the raw material and the efficient utilization of primary and secondary machinery. During log breakdown, a key indicator of raw material utilization is the achievement of maximum quantitative yield from sawlogs, also known as the recovery rate. This parameter is directly related to the economic efficiency of sawmilling operations. The primary objective in processing logs into sawn products is to obtain the highest possible proportion of usable products while minimizing the share of wood residues. The concept of maximum quantitative yield can be interpreted as a geometric problem involving the optimal coverage of a circular cross-section by inscribed rectangular elements, representing the cross-sections of sawn products such as boards, planks, and beams. This theoretical problem can be addressed through mathematical models or computer-based simulation tools that replicate the log breakdown process and enable prediction of potential recovery rate. However, the actual values of yield obtained under real production conditions differ from those derived through simulation. These discrepancies arise due to technological constraints, including machine parameters (e.g., kerf width), as well as the presence of anatomical irregularities in the logs. Such irregularities cannot be fully captured in simulation models and consequently reduce the achievable quantitative yield. This paper presents a comparative analysis of results obtained from the sawing of black pine (Pinus nigra) logs under industrial operating conditions and results derived from simulated calculations of quantitative yield for the same logs. The findings indicate the need for greater integration of simulation tools and computer-based approaches in the sawmilling industry to improve the prediction and optimization of the recovery rate.

Keywords: efficiency, log breakdown, log geometry, pine, simulations, yield.

Session 4 | Contribution 3

INFLUENCE OF TEMPERATURE ON THE BEARINGS LOAD ON A CIRCULAR SAW MILL

Georgi Kovatchev, Valentin Atanasov

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria,
Faculty of Forest Industry, Department of Woodworking Machines
e-mail: g_kovachev@ltu.bg, vatanasov_2000@ltu.bg

ABSTRACT

The influence of temperature on the magnitude of vibrations of the cutting mechanism in a circular saw mill is presented in the study. During operation, vibro acceleration was measured using specialized measuring equipment described in the methodology.Measurements are made at four points in the radial direction. Two of them are located near the cutting tool (A_x and A_y) of the machine and the other two (B_x and B_y) near the belt pulley.The results of the experiment are presented graphically.The experiments were carried out with rotation frequencies of 1014 min^{-1}. During the experiments, beechwoods were cut. The study is aimed at improving the reliability and efficiency of a machine as well as to ensure the accuracy and quality of products.

Keywords: circular saw mill, cutting mechanism, vibrations.

Session 4 | Contribution 4

EXPERIMENTAL DETERMINATION OF CUTTING FORCE FOR THE DESIGN OF HEAVY-DUTY CIRCULAR SAW SHAFTS

Valentin Atanasov, Georgi Kovatchev

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Department of Woodworking Machines
e-mail: vatanasov_2000@ltu.bg, g_kovachev@ltu.bg

ABSTRACT

The paper presents results from experimental investigations of the force during the cutting of a hardwood species – beech (*Fagus sylvatica* L.), performed using a heavy-duty circular sawing machine – Kallion Konepaja Oy (Finland). The study was carried out in the production workshop of Pentop Ltd., Varshets, Bulgaria. The results were obtained under unfavourable operating conditions of the machine – feed speed vf above 60 $m \cdot min^{-1}$ and cutting height ae above 240 mm. By measuring the power consumption of the electric motor driving the cutting mechanism during both loaded and idle operation, the cutting power was determined, and from it the average cutting force was calculated. The obtained maximum values exceed 400 N. The results of the study can be applied in the strength and stiffness design of shafts of heavy-duty circular sawing machines.

Keywords: circular sawing machine, beech (*Fagus sylvatica* L.), wood cutting, cutting force, cutting power.

Session 4 | Contribution 5

EXPERIMENTAL STUDY ON THE INFLUENCE OF WORKPIECE MATERIAL AND CUTTING PARAMETERS ON NOISE EMISSION DURING CNC WOOD MACHINING

Pavlin Vitchev, Rosen Lozanov

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: p_vitchev@ltu.bg, rosenlozanov2@gmail.com

ABSTRACT

This study presents an experimental investigation of sound pressure level variations during longitudinal peripheral milling of different wood and wood-based materials. The influence of key machining parameters, including spindle speed (n), feed rate (V_f), and depth of cut (h), on the A-weighted sound pressure level measured at the operator's position was systematically examined. The experiments were conducted on a CNC machining center using a solid carbide end mill with positive helical flute geometry. The materials investigated included oak wood (*Quercus* spp.), Scots pine wood (*Pinus sylvestris* L.), and medium-density fiberboard (MDF).

The experimental results demonstrated a significant influence of both material type and machining parameters on noise generation during the milling process. The measured A-weighted sound pressure levels ranged from 76 to 84 dB(A) for oak wood, from 81 to 86 dB(A) for Scots pine wood, and from 77 to 81 dB(A) for MDF. The experimental data analysis enabled the identification of characteristic relationships between noise emission, cutting conditions, and material properties. Graphical models describing the influence of individual machining parameters on sound pressure level were developed for each investigated material. The findings contribute to a better understanding of noise generation mechanisms in CNC wood machining and provide a basis for the optimization of cutting parameters to reduce occupational noise exposure and enhance workplace safety in the woodworking industry.

Keywords: noise emission, sound pressure level, CNC machining, wood machining, milling, oak wood, Scots pine, medium-density fiberboard (MDF), cutting parameters, feed rate, spindle speed, occupational noise.

Session 5 | Contribution 1

MECHANISMS OF SURFACE IRREGULARITY FORMATION IN CNC MILLING OF SOLID WOOD

Lukáš Adamčík, Richard Kminiak, Adrián Banski

Department of Woodworking, Faculty of Wood Sciences and Technology, Technical University in Zvolen
e-mails: lukas.adamcik@tuzvo.sk, richard.kminiak@tuzvo.sk, banski@tuzvo.sk

ABSTRACT

This study presents an experimental investigation of sound pressure level variations during longitudinal peripheral milling of different wood and wood-based materials. The influence of key machining parameters, including spindle speed (*n*), feed rate (*Vf*), and depth of cut (*h*), on the A-weighted sound pressure level measured at the operator's position was systematically examined. The experiments were conducted on a CNC machining center using a solid carbide end mill with positive helical flute geometry. The materials investigated included oak wood (*Quercus* spp.), Scots pine wood (*Pinus sylvestris* L.), and medium-density fiberboard (MDF).

The experimental results demonstrated a significant influence of both material type and machining parameters on noise generation during the milling process. The measured A-weighted sound pressure levels ranged from 76 to 84 dB(A) for oak wood, from 81 to 86 dB(A) for Scots pine wood, and from 77 to 81 dB(A) for MDF. The experimental data analysis enabled the identification of characteristic relationships between noise emission, cutting conditions, and material properties. Graphical models describing the influence of individual machining parameters on sound pressure level were developed for each investigated material. The findings contribute to a better understanding of noise generation mechanisms in CNC wood machining and provide a basis for the optimization of cutting parameters to reduce occupational noise exposure and enhance workplace safety in the woodworking industry.

Keywords: noise emission, sound pressure level, CNC machining, wood machining, milling, oak wood, Scots pine, medium-density fiberboard (MDF), cutting parameters, feed rate, spindle speed, occupational noise.

Session 5 | Contribution 2

STUDY OF SURFACE QUALITY DURING CO2 LASER CUTTING OF BEECH PLYWOOD

Engindzhan Halim[1], Lukáš Adamčík[2], Zhivko Gochev[1]

[1]University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Department of Woodworking Machines, Faculty of Forest Industry
[2]Department of Woodworking, Faculty of Wood Sciences and Technology, Technical University in Zvolen, Slovakia
e-mails: e_halim@ltu.bg, zhivkog@ltu.bg, lukas.adamcik@tuzvo.sk

ABSTRACT

Surface quality is an important criterion in CO2 laser cutting of wood-based materials, as it is influenced by the combined effects of the processing parameters and the material's heterogeneous structure. Although previous studies have investigated the influence of CO2 laser processing conditions on the cut quality and surface characteristics of solid wood and wood-based materials, comparatively less attention has been devoted to the combined and nonlinear effects of focal point position (*ΔF*), feed speed (*vf*), and laser power (*P*) on the surface roughness of beech plywood (*Fagus sylvatica* L.).
This article investigates the influence of the focal point position relative to the material surface (*ΔF*), the feed rate (*vf*), and the laser beam power (*P*) on the surface quality of beech plywood (*Fagus sylvatica* L.). The experiments were conducted on a CO2 laser machine, model AEON MIRA 9, at three levels of laser power (*P* = 30 W, 60 W, 90 W), varying feed rates (*vf* = 70 mm.s^{-1}, 80 mm.s^{-1}, 90 mm.s^{-1}), and the position of the focal point relative to the surface (*ΔF* = -2 mm, 0 mm, 2 mm). Surface quality was evaluated using the roughness parameters *Ra*, *Rz*, *Rp*, and *Rv*, and the influence of the machining factors was assessed through analysis of variance and regression analysis. For *Ra*, a statistically significant second-order regression model was obtained, explaining 80.6% of the experimental variation in the parameter.
The results of the study showed that the focal point position (*ΔF*) has the strongest influence on the Ra parameter, exhibiting significant linear and quadratic effects, as well as a significant interaction with laser power (*P*). Increasing the feed rate (*vf*) within the studied range led to lower values of Ra, while the effect of laser power (*P*) was predominantly nonlinear and depended on the position of the focal point (*ΔF*). The results indicate that the surface quality of beech plywood (*Fagus sylvatica* L.) cut with a CO2 laser is determined by the combined and nonlinear effects of the processing parameters, which underscores the need for simultaneous optimization of the focal point position (*ΔF*) and laser power (*P*).

Keywords: CO2 laser cutting, surface irregularities, beech plywood, kerf depth, digital microscope .

Session 5 | Contribution 3

INTERACTION OF A PULSED CUBR VAPOR LASER WITH DIFFERENT WOOD SPECIES

Nikolai Minkovski, Nikolai Bardarov

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: nminkovski@abv.bg, niki_bardarov@abv.bg

ABSTRACT

The interaction of a pulsed copper bromide (CuBr) vapor laser with wavelengths λ=510 and 578 nm with several wood species with different densities and different water content in the wood was studied. The three main wood cuts were processed – transverse, radial and tangential. Attention is focused on the changes in the surface and texture of the wood. The experiments were carried out at different laser intensities, different marking speeds on the wood surface, at different laser repetition rates. A microscopic analysis of the laser-treated surface was carried out.

Keywords: laser, wood, moisture content, texture, processing direction.

Session 5 | Contribution 4

INFLUENCE OF TEMPERATURE ON THE MECHANICAL PROPERTIES OF SPRUCE WOOD

Nikolai Bardarov[1], Olena Pinchevskaya[2], Daniel Madzharov[1]

[1] University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: niki_bardarov@abv.bg, Daniel_madzharov@abv.bg
[2]National University of Life and Environmental Sciences of Ukraine
e-mail: opinchewska@gmail.com

ABSTRACT

Frozen wood undergoes significant changes in its mechanical properties, usually showing higher brittleness. Extreme temperatures change the structure of the wood and the interaction of molecules. This leads to different behavior under mechanical load and different values of mechanical properties. The work examines the influence of different temperatures on the mechanical properties of spruce wood. The bending strength and the longitudinal compressive strength of the fibers were studied. These properties were studied at two degrees of water content (8% and 30%) and five degrees of temperature (-40°C, -20°C, 0°C, 20°C, 50°C). An analysis of the failure surface was made for varying wood parameters.

Keywords: wood, moisture content, temperature, mechanical properties, spruce.

Session 5 | Contribution 5

BEARING LOADING DURING LONGITUDINAL MILLING OF SPECIMENS FROM KOTO

Georgi Kovatchev

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Faculty of Forest Industry, Department of Woodworking Machines
e-mail: g_kovachev@ltu.bg

ABSTRACT

Technological factors have a significant influence over bearing loading of the cutting mechanism in a woodworking spindle moulder machine. The rotation frequency used for the experiments was 6000 min^{-1} as it is one of the most commonly used in practice for milling machines. Measurements were made at four points in the radial direction. Two of them are located in the upper bearing units and the other two are in the lower bearing units. A universal woodworking spindle moulder machine with a lower position of the working shaft is used for the experiment. This type of machine continues to be very widespread. During the research, the focus was on some technological factors such as feed speed of the processed material. Within the experiment koto (*Pterygota macrocarpa*) test samples were milled.

Key words: Woodworking spindle moulder machine, vibration speed, bearings.

Session 6A | Contribution 1

ENERGY RECOVERY AND RETURN TO THE GROUND OF WOOD BIOMASS

Anelie Petrissans, Jerome Remy, Ria Aniza, Che-An Lin, Bernhard Zeller, Corentin Didier, Mathieu Petrissans

Université de Lorraine, INRAE, LERMAB, F88000, Epinal, France
e-mail: Anelie.Petrissans@univ-lorraine.fr
INRAE, BEF, F-54000 Nancy, France
e-mail: Bernhard.Zeller@inrae.fr
ENGIE Solutions, Epinal, France
e-mail: Corentin.Didier@engie.com

ABSTRACT

This study proposes an integrated approach to sustainable forest biomass valorization by linking bioenergy performance with mineral recycling and soil restoration. In the context of climate change mitigation and energy decarbonization, wood biomass represents a strategic renewable resource. However, biomass harvesting and combustion lead to significant exports of mineral nutrients from forest ecosystems, potentially affecting long-term soil fertility and ecosystem resilience. Our work addresses this challenge through a circular bioeconomy framework combining energy optimization, ash characterization, and ecosystem modeling. The project brings together two academic teams LERMaB and BEF-INRAE, and a n industrial compagly, ENGIE Solutions. The aim is to evaluate local lignocellulosic biomasses from the Grand Est region. Thermochemical analyses assess theoretical higher heating value, exergy efficiency, combustibility indices, and ash composition for different hardwood, softwood, and mixed biomass feedstocks and will be compared to industrially recorded HHV Using physicochemical and mineralogical data, BEF-INRAE will model the return of major nutrients (Ca, Mg, K, and P) to forest soils and simulate their impacts on soil pH, cation exchange capacity, and organic matter mineralization under different soil conditions. By integrating experimental data, industrial practices, and ecosystem simulations, the project aims to develop indicators and decision-support tools for sustainable biomass management. The project ultimately seeks to reconcile renewable energy production, nutrient recycling, soil fertility preservation, and environmental safety, thereby contributing to carbon neutrality and the development of a circular forest bioeconomy.

Keywords: Forest biomass, Bioenergy, Wood ash recycling, Circular bioeconomy, Soil fertility, Exergy analysis.

Session 6A | Contribution 2

BIOMASS DISTRICT HEATING NETWORKS AND ENERGY OPTIMIZATION OF PUBLIC BUILDINGS: FEEDBACK FROM A LOCAL AUTHORITY

Hugo Mark, Sami Kriouche, Mathieu Pétrissans, Anélie Pétrissans

Université de Lorraine, INRAE, LERMAB, F88000, Epinal, France,
e-mail: hugo.mark5@etu.univ-lorraine.fr

ABSTRACT

As part of its energy transition strategy, the Urban Community of Épinal implemented several projects aimed at replacing fossil fuels with biomass-based solutions and improving the energy efficiency of public buildings. This study presents feedback from two complementary operations: the replacement of an oil-fired boiler with a wood pellet boiler and the creation of a small biomass district heating network. The first project concerned a school and municipal housing units previously heated by a 42 kW oil boiler. Following a technical and economic assessment, a KWB Easyfire 2 wood pellet boiler was selected. During commissioning, excessive energy consumption was observed due to improper heating curve settings. Optimizing this regulation system reduced the average network supply temperature by 2.9°C, leading to lower energy consumption while improving thermal comfort. The second project involved modernizing the biomass boiler plant of a town hall and connecting the nearby fire station (SDIS) through a district heating network equipped with a heat-exchanger substation. Two KWB Multifire 2 biomass boilers fueled by wood chips were installed. This solution promotes the use of a local renewable resource and enabled an estimated 74% reduction in CO_2 emissions, decreasing from 24 tCO_2/year to 6.2 tCO_2/year. These projects highlight the relevance of biomass district heating networks as an effective decarbonization solution for rural public buildings.

Keywords: District heating network, Biomass energy, Wood chips, Decarbonization, Biomass boiler plant, Energy efficiency.

Session 6A | Contribution 3

GEOGRAPHIC INFORMATION SYSTEM FOR BIOENERGY PRODUCTION IN BULGARIA

Adelina Ivanova, Boriana Delijska

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mail: aivanova@ltu.bg, delijska@gmail.com

ABSTRACT

Geographic Information Systems (GIS) are increasingly used across various sectors of the national economy in recent years due to their advantages over traditional information systems. They offer much broader possibilities for statistics, analysis, and visualization of attribute and geospatial data. The obtained results are significantly richer, more visual, and, respectively, more effective in supporting decision-making of the studied economic entities. This study is motivated by the lack of GIS for bioenergy production (including bioelectricity and biofuels) in Bulgaria. The objectives, scope, architecture, and functionality of such GIS are considered. It is implemented using QGIS platform and including data for bioenergy producing firms for the period 2022–2024. The analysis was conducted on the base of thematic maps and diagrams illustrating territorial distribution, production types and capacities, human resources, and sustainability indices. The results indicate that, with few exceptions, the sector is dominated by small firms with low production capacity and comparatively low sustainability indices.

Keywords: geographic information system, index of sustainability, bioenergy, geospatial data, statistical analysis.

Session 6A | Contribution 4

GREEN EFFICIENCY OF WOOD WASTE VALORISATION ALTERNATIVES: EVIDENCE FROM THE MALMQUIST–LUENBERGER PRODUCTIVITY INDEX

Nikolay Neykov[1], Mariana Sedliačiková[2], Petar Antov[3], Maria Osvaldová[4], Vesela Dimchova[5], Viktoria Dudeva[6]

[1]University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Faculty of Ecology and Landscape Architecture;
e-mail: nneykov@ltu.bg
[2]Technical University in Zvolen, Slovakia, Faculty of Wood Sciences and Technology
e-mail: sedliacikova@is.tuzvo.sk
[3]University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Faculty of Forest Industry
e-mail: p.antov@ltu.bg
[4]Technical University in Zvolen, Slovakia, Faculty of Wood Sciences and Technology
e-mail: xosvaldova@is.tuzvo.sk
[5]University of Forestry, Bulgaria, Faculty of Forestry
e-mail: veselaivanoff@gmail.com
[6]University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Faculty of Forest Industry;
e-mail: v.dudeva@ltu.bg

ABSTRACT

The utilization of wood waste is a key component of sustainable resource management in the wood-processing and furniture manufacturing industries. In the era of the bioeconomy, maintaining profitability increasingly depends on the implementation of effective circular economy practices. This research work aimed to apply Data Envelopment Analysis (DEA) framework incorporating Directional Distance Functions (DDF) to benchmark the efficiency of wood waste utilization across 21 European Union countries called Decision Making Units (DMU) over the period 2014–2022. The efficiency is defined as green efficiency, reflecting the ability to increase desirable outputs while reducing undesirable outputs associated with environmental impact. Furthermore, the improvement of the green efficiency over time is measured through Malmquist-Luenberger Productivity Index. The DDF model was applied under both variable and constant returns to scale assumptions.

Keywords: bioeconomy, wood waste, circular economy, DEA, DDF, Malmquist–Luenberger, efficiency.

Session 6A | Contribution 5

CIRCULAR ECONOMY IN MATERIAL ECODESIGN: BRICK PRODUCTION FROM MINE WASTE

Aleksandrina Kostadinova-Slaveva[1], Ekaterina Todorova[2], Nikolay Neykov[3]

[1]University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Department of Ecology, Protection and Remediation of the Environment,
[2]Center of competence: Clean technologies for a sustainable environment – water, waste, energy for a circular economy, Sofia, Bulgaria
[3]University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Department of Alternative Tourism

e-mails: aslaveva@ltu.bg, etodorova@ltu.bg, nneykov@ltu.bg

ABSTRACT

The construction materials industry increasingly faces difficulties in securing high-quality raw materials for ceramic products such as bricks. In Bulgaria, natural clay resources are limited, while growing demand for building materials and the transition toward a circular economy require alternative raw materials. This study examines the potential for utilizing accumulated mining waste from the Pernik coal basin as a substitute for natural clay in brick production. Laboratory analyses including X-ray diffraction (XRD), chemical composition, and grain-size distribution were conducted to determine the mineralogical and technological properties of the material. The results show that the mining waste contains significant clay minerals, with kaolinite reaching up to 30% and a plasticity index of 22.3, confirming its suitability for ceramic production. Techno-ecological-economic analysis indicates that up to 60% of conventional clay raw materials can be replaced without compromising product quality. The economic evaluation demonstrates positive Net Present Values for all analyzed production capacities. The results confirm the potential of mining waste as a secondary raw material supporting circular economy practices.

Keywords: circular economy, material eco-design, mining waste, utilization, bricks.

Session 6A | Contribution 6

CLIMATE ROADMAPS AS A MEANS OF INTRODUCING A CIRCULAR ECONOMY IN BULGARIAN MUNICIPALITIES: EXPERIENCE FROM THE MUNICIPALITY OF SANDANSKI

Emil Kitchoukov, Nikolay Neykov, Georgi Kadinov, Alexandrina Kostadinova-Slaveva

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: ekitchoukov@yahoo.com, nneykov@ltu.bg, aslaveva@ltu.bg

ABSTRACT

This paper presents the development and implementation of a Climate Road Map for the municipality of Sandanski, Bulgaria, within the framework of the international ILCA (Innovation Laboratories for Climate Actions) project. Based on in-depth analysis of the local economy and interviews, three priority areas were identified: circular economy, water resources management and urban mobility. Through active stakeholder engagement, targeted surveys and workshops, the project outlined actionable initiatives including educational campaigns, promoting waste recycling, measures to optimise water resource management and improvements in urban mobility. Applying a structured assessment approach, stakeholders jointly selected a set of actions for introducing a circular economy, climate change adaptation and synergistic effects achivment. The results obtained highlight the importance of stakeholder dialogue, knowledge exchange and systematic evaluation for the successful introduction of the circular economy at the local level. The lessons learned from Sandanski's experience provide valuable guidance for accelerating climate innovation and multiplying good practices for introducing a circular economy in other Bulgarian municipalities and regions.

Keywords: Climate roadmap, Sandanski municipality, Stakeholder involvement, Climate innovation Circular economy.

Poster session — Part 1 | Contribution 1

REVISITING CLIMATE NORMALS: EVIDENCE OF A REGIME SHIFT AND ITS LINK TO FOREST FIRE ACTIVITY IN SOUTHWESTERN BULGARIA

Antonia Goleva

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mail: agoleva@ltu.bg

ABSTRACT

The present study aims to assess whether the transition between the climate normals 1961–1990 and 1991–2020 reflects a statistically significant change in the climatic regime in Southwestern Bulgaria and to examine the relationship between this change and the climatic conditions associated with the occurrence of forest fires. The analysis is based on temperature and precipitation data from two meteorological stations with contrasting characteristics—Sandanski (lowland) and Musala (high-mountain)—for the period 1961–2024, as well as on forest fire data from the Sandanski region for the period 2000–2025. Trend analysis methods (Mann–Kendall and Sen's slope), the De Martonne aridity index, and change-point detection methods (CUSUM and Pettitt test) were applied. The results reveal a clear and statistically significant shift in the temperature regime around 1997 at both stations. For summer temperatures, an earlier transition is observed in Sandanski, around 1989. The comparison between the climate normals 1961–1990 and 1991–2020 indicates an increase in mean annual temperature of approximately 0.8°C, with the most pronounced warming occurring during summer (+1.6°C). Precipitation exhibits weaker and spatially variable changes, with no statistically significant shift detected in summer precipitation. The De Martonne index reveals different sensitivity depending on elevation, with a tendency toward drier conditions observed at Musala. The analysis of forest fires indicates a strong positive relationship between summer temperatures and fire activity, while precipitation and aridity show a weaker influence. The results suggest that the contemporary climate normal reflects a real change in the climatic regime, which has direct implications for wildfire risk in the region.

Keywords: climate change, climate normals, Pettitt test, CUSUM, De Martonne index, wildfire risk.

Poster session — Part 1 | Contribution 2

ECONOMICS, ORGANIZATION AND MANAGEMENT OF THE FOREST INDUSTRY UNDER INCREASING RISK OF FOREST FIRES

Todor Stoyanov[1], Nikolay Neykov[2]

[1]Forest Research Institute – Bulgarian Academy of Sciences
e-mail: toti13@abv.bg
[2]University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria,
e-mail: nkneykov@gmail.com

ABSTRACT

The forest industry in Europe, particularly in Southeastern Europe, is undergoing a profound transformation driven by climate change, increasing risk of forest fires, digitalization, and the requirements of the circular bioeconomy. This study examines the interaction among economic mechanisms, organizational structures, and management practices as key factors for enhancing the sector's sustainability and competitiveness. The main objective is to develop an integrated conceptual model that combines economic resource assessment, optimization of organizational processes, and implementation of adaptive management solutions. The methodological approach includes cost-benefit analysis, ecosystem services assessment, institutional analysis, and a comparative review of good practices from EU Member States. Special emphasis is placed on the role of innovation – digital technologies (GIS, remote sensing, drones), intelligent risk management systems, and new business models in the forest industry. The results show that integrating economic, organizational, and management approaches leads to significant improvement in resource use efficiency, reduction of losses from natural risks, and increased added value in the forest sector. The proposed model supports the transition from reactive to proactive management based on data and predictive analytics. In conclusion, the study offers practical guidelines for policies and management solutions aimed at building a sustainable, innovative, and competitive forest industry aligned with European strategic priorities.

Keywords: forest industry, economy, organization, management, innovation, sustainability, bioeconomy.

Poster session — Part 1 | Contribution 3

SPATIAL DISTRIBUTION OF PHYSICAL CHARACTERISTICS IN DOUGLAS FIR (PSEUDOTSUGA MENZIESII MIRB.) STEMS CONTAINING COMPRESSION WOOD

Martina Todorova[1], Tatiana Vilkovská[2]

[1]University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mail: martinatodorova@ltu.bg
[2]Technical University of Zvolen, Slovakia
e-mail: tatiana.vilkovska@tuzvo.sk

ABSTRACT

The presence of reaction wood, specifically compression wood in softwoods, significantly alters the physical and structural performance of timber. This research focuses on the specific characteristics of Douglas fir (*Pseudotsuga menziesii* Mirb.) wood containing substantial amounts of unilateral compression wood. Comparative analysis shows that the presence of this tissue leads to higher standard density values and influences the overall hygroscopic behavior of the stem. Notably, the study observes that tangential shrinkage and swelling values are minimized in sections with a high proportion of compression wood, attributed to the modified cell wall structure and increased latewood ratio. The findings also address the phenomenon of longitudinal shrinkage, which deviates from normal wood behavior, highlighting the technical importance of identifying reaction wood for precision woodworking and structural applications.

Keywords: compression wood, moisture content, density, shrinkage, swelling, Douglas fir.

Poster session — Part 1 | Contribution 4

INVESTIGATION OF PRESSURE LOSSES IN ELBOWS USED IN PNEUMATIC CONVEYING SYSTEMS FOR WOOD PARTICLES

Petar Nikolov, Pavlin Vitchev

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Department of Woodworking Machinery
e-mail: petarn@ltu.bg, p_vitchev@ltu.bg

ABSTRACT

The present study investigates the pressure characteristics of elbows used in pneumatic conveying systems with pipeline diameters of 150 mm and 200 mm for the transport of wood particles generated during machining operations. The research combines numerical simulations and experimental measurements to evaluate the influence of elbow configuration on pressure losses and local flow resistance. The obtained results indicate that the pressure losses (ΔP) across a single elbow vary from 14.05 to 25.5 Pa, whereas for two consecutively connected S-shaped elbows arranged in the same plane, the losses range from 16.7 to 27.5 Pa, depending on the dynamic pressure (PD). The local resistance coefficient (ξ), determined on the basis of the numerical and experimental data, varies from 0.19 to 0.21 for a single elbow and from 0.21 to 0.24 for the S-shaped elbow configuration. Furthermore, graphical relationships illustrating the influence of dynamic pressure on pressure losses and local resistance coefficients are established and analyzed. The obtained results contribute to a better understanding of the aerodynamic behaviour of elbows in pneumatic conveying systems and may serve as a basis for their design and optimization.

Keywords: pneumatic conveying systems, wood particles, dynamic pressure, pressure losses, local resistance coefficient.

Poster session — Part 1 | Contribution 5

UPHOLSTERED FURNITURE FRAME CONSTRUCTION IN THE CONTEXT OF DESIGN FOR DISASSEMBLY (DFD): STRENGTH AND DEFORMATION BEHAVIOR OF CORNER JOINTS USING LAMELLO INVIS MX2 CONNECTORS

Desislava Hristodorova

University of Forestry, e -mail: d.hristodorova@ltu.bg

ABSTRACT

The present study investigates the applicability of contemporary demountable joint systems in the construction of upholstered furniture within the framework of circular economy principles and Design for Disassembly (DfD). The objective is to evaluate the strength and deformation behavior of end and intermediate corner joints incorporating two *Lamello „Invis Mx2*“ demountable connectors, using birch plywood members with a cross-sectional dimension of 50×21 mm. The study examines the effect of the centre-to-centre spacing (c-c) between the demountable connectors on the maximum bending moments and rotational stiffness coefficients of the experimentally tested joints subjected to bending loading.

The results demonstrate that the centre-to-centre spacing (c–c) exerts a significant influence on both the strength characteristics and deformation behavior of the investigated joints. The findings indicate considerable potential for the application of this type of demountable joint in frame structures used in the construction of upholstered furniture carcasses. However, the comparatively low values of the maximum bending moment ($M_{\max,\text{bend.}}$) and the rotational stiffness coefficient (c_i) limit their applicability in structural members subjected to high service loads. Accordingly, their use is recommended primarily for secondary structural members, where the imposed mechanical demands are comparatively moderate.

Keywords: Design for Disassembly, Detachable joints, Maximum Bending Moments, Stiffness Coefficients, Upholstery Furniture

Poster session — Part 1 | Contribution 6

IMPORT TRENDS IN THE EU MARKET FOR WOODEN TRANSPORT PACKAGING PRIOR TO THE IMPLEMENTATION OF REGULATION (EU) 2025/40

Slavica Petrović

University of Belgrade – Faculty of Forestry
e-mail: slavica.petrovic@sfb.bg.ac.rs

ABSTRACT

Regulation (EU) 2025/40 stipulates that, as of 1 January 2030, all packaging placed on the market must be recyclable. Owing to its characteristics, wooden packaging largely meets this requirement, indicating the potential for continued growth in EU imports. The subject of this study is wooden transport packaging, while the main objective is to analyze the EU market with a focus on identifying the largest importers and the key supplying countries within the EU. Particular attention is given to EU countries that have recorded significant growth in imports during the observed period. The results show that EU countries are the dominant suppliers of their own market for wooden transport packaging, while imports from non-EU countries remain significantly lower. However, during the observed period, certain countries recorded substantial growth in imports from non-EU countries. Bulgaria is a notable example. In 2025, it became the fourth largest importer of wooden transport packaging from non-EU countries, with imports of €9.4 million. The study is based on data obtained from the Eurostat database (Section 44, tariff code 44151010) and covers the period 2010-2025. The market analysis was further complemented by simple regression models. The results indicate a growing supply of wooden transport packaging to the EU market and, under the influence of the new regulation, this trend is expected to continue.

Keywords: packaging, wood, EU, import, non-EU countries.

Poster session — Part 1 | Contribution 7

IMPACT OF OPERATING TEMPERATURE ON THE HEAT BALANCE AND EFFICIENCY OF PITS WHEN STEAMING UNFROZEN LOGS

Nencho Deliiski, Dimitar Angelski, Pavlin Vitchev, Krasimira Atanasova

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: deliiski@netbg.com, d.angelski@gmail.com, p_vitchev@abv.bg, k_atanasova@ltu.bg

ABSTRACT

An approach for computing the heat balance and heat efficiency of concrete pits when steaming unfrozen logs intended for production of peeled veneer has been presented. With the help of our personal non-stationary model, the heating times of beech logs with a diameter of 0.4 m, initial temperature of 10° C, and moisture content of 0.4, 0.6, and 0.8 $kg \cdot kg^{-1}$ were determined at operating temperature of the steaming medium in the pit equal to 70, 80 and 90° C. Using the determined logs' heating times and our own stationary model of the heat balance of concrete pits when steaming logs, the change in the total energy required to carry out the entire steaming process and that required for each of the individual components of the heat balance were calculated. Computations were conducted for a concrete pit with overall dimensions 7.4 x 2.8 x 2.5 m, working volume of 20 m^3, and a degree of filling with logs 45, 60, and 75%, It was found that the increase in the operating temperature from 70 to 90° C at maximum possible loading level of 75% causes an increase in the energy consumption of the pit from 103.4 to 127.0 $kWh \cdot m^{-3}$ and a decrease in the heat efficiency of the pit from 39.1 to 38.9%.

Keywords: logs, steaming, pits, operating temperature, heat balance, heat efficiency.

Poster session 1 | Contribution 8

A METHOD FOR EVALUATING THE HOMOGENIZATION OF WET SAWN TIMBER COLORATION DURING AUTOCLAVE STEAMING

Nencho Deliiski[1], Ladislav Dzurenda[2], Dimitar Angelski[1], Pavlin Vitchev[1], Krasimira Atanasova[1]

[1]University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: deliiski@netbg.com, p_vitchev@abv.bg, d.angelski@gmail.com, k_atanasova@ltu.bg
[2]Technical University in Zvolen, Zvolen, Slovakia
e-mail: dzurenda.ladislav@gmail.com

ABSTRACT

A method is presented for computing the temperature-time parameters of autoclave steaming modes of wet sawn timber, which ensure good homogeneity of coloring throughout the entire volume of the steamed timber. With the help of own non-stationary model and a new integral temperature-time quantitative indicator of the homogeneity of desired wood coloration, the parameters of all 4 stages of steaming mode of beech sawn timber with thickness of 80 mm, initial temperature of 10° C, and moisture content of 0.4, 0.6, and 0.8 $kg \cdot kg^{-1}$ were determined at maximum operating temperature in the autoclave of 123° C. This mode ensures the achievement of values from 1.6·106 to 1.7·106 K·s of the integral temperature-time areas Sw in all characteristic points of the volume of steamed timber with the specified characteristics, which corresponds to the achievement of a homogeneous red brown color of the wood. The deviation between Sw on the surface and in the center of the steamed timber is within 4.8%, which makes it practically impossible to visually distinguish the nuances of coloring of the different layers of timber. The suggested method can be applied to compute the temperature-time parameters of autoclave steaming modes of frozen and non-frozen wood materials with different characteristics to any desired homogeneous coloring.

Keywords: sawn timber, moisture content, autoclave steaming, coloration, homogenization.

Session 6B | Invited lecture

ENGINEERED WOOD PRODUCTS FOR MODERN AND SUSTAINABLE CONSTRUCTION IN THE UK AND WESTERN EUROPE

Mila Duncheva[1], Marius-Catalin Barbu[2], Eugenia Mariana Tudor[2]

[1]Stora Enso Wood Products, Building Solutions, United Kingdom
[2]Salzburg University of Applied Sciences (FH Salzburg), Department Design and Green Engineering, Campus Kuchl, Markt 136a, 5431 Kuchl, Austria
e-mails: mila.duncheva@storaenso.com, marius.barbu@fh-salzburg.ac.at, eugenia.tudor@fh-salzburg.ac.at

ABSTRACT

Engineered wood products are changing not only the materials used in construction, but also the processes through which buildings are designed, manufactured and assembled. Mass timber systems use products including cross-laminated timber, glue-laminated timber and laminated veneer lumber to create prefabricated structural components for walls, floors, roofs, stairs, beams and columns. Their successful use, however, depends on the integration of material knowledge, engineering design, manufacturing constraints, logistics and construction planning.

Drawing on practical experience from the United Kingdom and Western Europe, this presentation examines the technical decisions that influence the feasibility and performance of mass timber buildings. It considers the selection of appropriate structural systems and spans; the relationship between solid and ribbed floor solutions; coordination of connections and building services; fire-resistance strategies; moisture-resilient detailing; transportation constraints; and the sequencing, protection and installation of prefabricated elements. The role of design for manufacture and assembly, building information modelling and digital installation tools is discussed as part of a coordinated approach to project delivery.

The presentation positions these technical questions within the wider forest-to-frame value chain. Responsible sourcing, product traceability, biodiversity-conscious forest management, material efficiency and end-of-life planning are considered alongside structural and construction performance. This demonstrates that sustainable construction cannot be assessed solely at product level, but must connect forestry, manufacturing, design, delivery, use and potential reuse.

Contributions from Central and Eastern European specialists will complement the UK and Western European perspective by addressing regional knowledge, resources, production capabilities and implementation conditions. The session will identify areas where research, industrial practice and international knowledge exchange can support the responsible development of mass timber construction across Europe.

Keywords: engineered wood products, mass timber, CLT, DfMA, fire safety, moisture management, prefabrication, European construction.

Session 6B | Contribution 2

DEMONSTRATING VERSATILE FIBRE-BASED VALUE CHAINS FROM BIOMASS GROWN ON MARGINAL LANDS

Stergios Adamopoulos, Percy Alao

Department of Forest Biomaterials and Technology, Swedish University of Agricultural Sciences, Uppsala, Sweden

stergios.adamopoulos@slu.se

ABSTRACT

The utilisation of lignocellulosic biomass from marginal and degraded lands represents a promising pathway for developing sustainable material systems while reducing pressure on conventional forest resources. However, the translation of heterogeneous fibre feedstocks into high-performance industrial products remains constrained by variability in fibre morphology, composition, and processability. This paper presents a comparative evaluation of fibre-based materials derived from multiple non-conventional biomass sources, targeting applications in insulation and bio-based construction elements. Fibre fractions obtained from herbaceous and woody feedstocks were processed using mechanical and thermo-mechanical routes and subsequently integrated into non-woven structures and cementitious matrices. Material performance was assessed across scales, from laboratory characterisation to pilot-scale prototyping. Results demonstrate that fibre length distribution, surface chemistry, and extractive content are critical parameters governing both processing behaviour and final material properties. In non-woven insulation systems, short lignocellulosic fibres enabled scalable panel production, achieving thermal conductivities as low as 0.037 W/(m·k) and sound absorption coefficients up to 0.8. However, excessive fines content led to increased dust formation, compromised structural integrity, and difficulty in reaching target densities. In cementitious applications, lignocellulosic particles from woody biomass were successfully incorporated into mineral matrices, demonstrating potential for lightweight bio-based construction materials, although optimisation of fibre-cement compatibility and water balance remains necessary due to the influence of extractives and hygroscopic behaviour. Across all material systems, the results highlight a consistent trade-off between processability and performance, driven by intrinsic fibre characteristics and their interaction with industrial processing routes. Despite this variability, the studied feedstocks demonstrate significant potential to substitute fossil-based or resource-intensive materials in multiple sectors. Overall, these findings provide new insights into the structure-property-process relationships of lignocellulosic fibres from marginal biomass, underlining their potential for scalable, circular, and bio-based material solutions.

Session 6B | Contribution 2

EXPERIMENTAL VALIDATION OF COMPUTATIONAL METHODS USED IN TIMBER STRUCTURAL DESIGN THROUGH DESTRUCTIVE TESTING OF FULL-SCALE TIMBER FRAMES

Miltiadis Pappas[1], Georgios Ntalos[1], Andromachi Mitani[1], Dimitrios Koutsianitis[2], Konstantinos Ninikas[1], Paulos Ntalos[1]

[1]Department of Forestry, Wood Sciences & Design, University of Thessaly, Greece
e-mails: mipappas@uth.gr, gntalos@uth.gr, amitani@uth.gr, kninikas@uth.gr, pntalos@uth.gr
[2]Department of Forestry and natural Environment, Agricultural University of Athens
e-mail: dkoutsian@for.auth.gr

ABSTRACT

This study examines the correlation between the experimentally determined load-bearing capacity of timber frames and the values predicted by finite element method (FEM) simulations and Eurocode 5 design provisions. Full-scale timber frames were fabricated from solid sawn black pine (Pinus nigra) lumber, with geometric configurations representative of those typical in real-world timber construction. A series of destructive tests was conducted under compression, double bending, and shear loading conditions — stress states that represent the primary loading mechanisms governing the structural design of timber members and assemblies. Complementary numerical models were developed using Autodesk Robot Structural Analysis, and analytical calculations were carried out in compliance with Eurocode 5. Cross-comparison of experimental, numerical, and code-predicted results enabled a systematic evaluation of the consistency between the three approaches, and provided insight into the practical implications of the simplifying assumptions inherent in current timber design methodologies.

Session 6B | Contribution 3

EFFECT OF DENSITY ON THE PROPERTIES OF BIOCOMPOSITE BOARDS FROM WOOD FIBRES AND WHEAT BRAN

Viktor Savov, Maria Angelova, Georgi Ivanov

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: victor_savov@ltu.bg, Georgi_Ivanov@ltu.bg

ABSTRACT

This study investigates the effect of target density on the properties of biocomposite boards produced from wood fibres and wheat bran. Wheat bran is an agricultural by-product rich in polysaccharides and proteins, which may contribute to the formation of bio-based composites when combined with lignocellulosic fibres. Laboratory boards will be manufactured at different density levels under controlled pressing conditions. The influence of density on key properties such as bending strength, modulus of elasticity, internal bond strength, water absorption and thickness swelling will be analysed. The research aims to identify the relationship between board compaction, structure formation and performance, and to determine density ranges that provide a favourable balance between mechanical properties and dimensional stability. The results will contribute to the development of ecological biocomposite boards based on wood fibres and agro-industrial residues.

Keywords: biocomposite boards, wood fibres, wheat bran, density, mechanical properties, dimensional stability.

Session 6B | Contribution 4

LOW-TEMPERATURE PLASMA TREATMENT AS A SUSTAINABLE APPROACH FOR ELIMINATION OF HEAVY METALS CONTAMINATION EFFECTS

Plamena Marinova[1,2], Milena Yordanova[1], Vera Petrova[1], Alexsandrina Kostadinova[1], Iliana Apostolova[1], Evgenia Benova[2], Yovanna Todorova[2,3], Ludmila Čechová[4], Sanja Živković[5]

[1]University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria

[2]Clean & Circle Center of Competence, Sofia University, Sofia, Bulgaria

[3]Central European Institute of Technology (CEITEC), Brno University of Technology, Brno, Czech Republic

[4]Faculty of Biology, Sofia University 'St. Kliment Ohridski', Sofia, Bulgaria

[5]VINČA Institute of Nuclear Sciences – National Institute of the Republic of Serbia, University of Belgrade, Belgrade, Serbia

ABSTRACT

Promising and extensively studied applications of modern plasma technologies are aimed at achieving a cleaner environment. They are focused on the efforts against pathogens, heavy metals, microplastics, pesticides, PFAS, pharmaceuticals and many other organic and inorganic polutants in various medium such as water, soil, wastewater, sediments and sludge. Contamination of soil and underground water with heavy metals is one of the biggest threats to the environment. Heavy metals are known to be a stress inducing agent in plants and inhibit the growth of plants significantly. They decrease activity of the photosynthetic apparatus and generally diverse disturbances of the entire metabolism.

Low-temperature plasma treatment of water positive effect on plant growth has been confirmed in many studies, however, little is known about the specific effect on plants uptake of nutrients and heavy metals. The reactive species generated by plasma – such as hydroxyl radicals, hydrogen peroxide, nitrite and nitrite ions and ozone, can break down recalcitrant organic pollutants. Plasma treatment also can be implemented as a new approach to heavy metals mitigation. Plasma treatment can convert toxic dissolved metal ions into stable oxides and to alter their bioavailability so plants absorb significantly less. In this work, low-temperature plasma is used to treat water contaminated with metals from mining activities and the effect on the physicochemical properties of the water is analyzed. Treated waters were used for cultivation in hydroponic systems of *Lactuca Sativa* to investigate the effect of plasma treatment on the accumulation of heavy metals in plants.

To investigate and evaluate the presence and accumulation of heavy metals and other pollutants in plants Laser Induced Breakdown Spectroscopy (LIBS) is used. LIBS is a cutting-edge analytical technique applicable for analysis of plants and soil. Recent advancements in the LIBS technology have enabled its use for mapping heavy metal distribution in plants.

Keywords: plasma, wastewater, agriculture, laser-induced breakdown spectroscopy.

Session 6B | Contribution 5

INVESTIGATION OF STRENGTH PROPERTIES OF WOOD PLASTIC COMPOSITE FOR EXTERIOR FLOORING TYPE DECKING

Vladimir Mihailov

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mail: vladko86mihailov@gmail.com

ABSTRACT

One of the areas of wood waste processing is the use in the production of wood-polymer composites (WPC). In the last 10 years wood-polymer products, have a significant role due their wide range of applications and qualities of this material. The WPC does not rot, is not damaged by insects and fungi, and does not contain harmful binders. WPC are water-resistant, which makes them a good material for manufacturing decking. Therefore, the decking board must have certain mechanical qualities – the WPC boards are going to be exploited under the influence of moisture, UV radiation and with a certain load. The wood composite products are often not precisely uniform in their composition, sometimes they contain voids, their surface (particularly unbrushed) often contains more plastic compared to the "bulk" material. This article investigates the strength properties of the wood filler–reinforced polymer composites, which have gained attention among the researchers and in the market in woody applications. After the carried out experiment, the results are analyzed and graphically presented.

Keywords: wood polymer composite, strength properties, decking boards, moisture, UV radiation.

Session 6C | Contribution 1

VARIATION OF THE PHYSICAL PROPERTIES IN THE VOLUME OF THE STEM IN DOUGLAS FIR (PSEUDOTSUGA MENZIESII MIRB.)

Martina Todorova[1], Tatiana Vilkovská[2]

[1]University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mail: martinatodorova@ltu.bg
[2]Technical University of Zvolen, Slovakia
e-mail: tatiana.vilkovska@tuzvo.sk

ABSTRACT

Douglas fir (*Pseudotsuga menziesii* Mirb.) is a major coniferous species for the woodworking industry and is recognized as one of the most significant introduced species in European dendroflora. In Bulgaria, plantations have been established primarily to assess its adaptability and growth rates. However, comprehensive studies on its wood properties remain limited. This research investigates trees harvested from the highest and lowest altitudes within a specific plantation. The study focuses on key physical properties, including green moisture content, density, shrinkage, and swelling. The objective is to determine the variation of these properties based on the location of the specimens within the stem, altitude, and geographic orientation. Furthermore, the study analyzes the anisotropy of shrinkage and swelling along with the specific environmental factors influencing these processes.

Keywords: wood, moisture content, density, shrinkage, swelling, Douglas fir.

Session 6C | Contribution 2

AGING OF WATERBORNE WOOD COATINGS EXPOSED TO NATURAL CLIMATE CONDITIONS

Krasimira Atanasova[1], Tomasz Krystofiak[2], Dimitar Angelski[1], Barbara Lis[2], Dobriyan Dobriyanov[1]

[1]University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: k_atanasova@ltu.bg, d.angelski@ltu,bg, d.dobriyanov@ltu.bg

[2]Poznan University of Life Sciences, Department of Wood Science and Thermal Techniques, Wojska Polskiego 28, 60-627 Poznan, Poland.
e-mails: tomasz.krystofiak@up.poznan.pl, barbara.lis@up.poznan.pl

ABSTRACT

In the context of the transition to sustainable models and technologies, waterborne wood coatings are increasingly being used and knowledge of their properties is becoming essential. The presented article investigates moisture absorption and changes in the roughness and hydrophobicity of wood surfaces treated with waterborne coatings and exposed to natural weathering conditions. The following lacquer products were used: a nano-based acrylic varnish, a nano-based white acrylic paint, and a bio-based coloured varnish. The coating systems were applied to wood from Larch (*Larix spp.*), Meranti (*Shorea spp.*), Canadian oak (*Quercus rubra*), and Spruce (*Picea abies*). The coatings were exposed for 5 years in conditions of a moderate continental climate in a dusty urban environment. The results obtained are presented in tabular and graphical form.

Keywords: coating, roughness, wettability, aging, nano-based acrylic lacquer product, bio-based lacquer product.

Session 6C | Contribution 3

PROPERTIES OF HARD WAX OIL COATINGS ON VENEERED SURFACES

Dobriyan Dobriyanov[1], Dimitar Angelski[1], Tomasz Krystofiak[2], Barbara Lis[2], Krasimira Atanasova[1], Stefan Petrov[1]

[1]University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: d.dobriyanov@ltu.bg, d.angelski@ltu,bg, k_atanasova@ltu.bg, st.petrov03@gmail.com

[2]Poznan University of Life Sciences, Department of Wood Science and Thermal Techniques, Wojska Polskiego 28, 60-627 Poznan, Poland
e-mails: tomasz.krystofiak@up.poznan.pl, barbara.lis@up.poznan.pl

ABSTRACT

Hard wax oil coatings are increasingly regarded as a sustainable alternative to conventional synthetic wood finishing systems in furniture manufacturing. This study investigates the surface properties of two-layer hard wax oil coatings applied to specimens veneered with zebrano (*Microberlinia* spp.), ash (*Fraxinus* spp.), birch (*Betula* spp.), rosewood (*Dalbergia* spp.), and maple (Acer spp.). Changes in colour, gloss, and roughness were evaluated before coating application and after each coating layer. The results were statistically analysed and presented in tabular and graphical form.

Keywords: hard wax oil, veneered surfaces, colour; gloss, roughness, properties.

Session 6C | Contribution 4

PRODUCTION AND PROPERTIES OF BIOCOMPOSITE MATERIALS FROM HEMP SHIVES AND LIGNOSULFONATE

Georgi Ivanov, Konstantin Vasilev, Viktor Savov

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: Georgi_Ivanov@ltu.bg, victor_savov@ltu.bg

ABSTRACT

The study focuses on the production and characterization of bio-based composite materials from hemp shives and lignosulfonate as a renewable binder. Hemp shives are an abundant agricultural by-product with low density, porous structure and potential for application in lightweight panels and insulation-type materials. Lignosulfonates, as industrial lignin-derived products, offer opportunities for reducing the dependence on conventional synthetic binders and for improving the environmental profile of composite materials. Experimental panels will be produced under laboratory conditions at different material ratios and pressing regimes. The main physical and mechanical properties, including density, bending strength, modulus of elasticity, water absorption and thickness swelling, will be evaluated. The expected results will provide information on the potential of hemp shives and lignosulfonate for the development of sustainable biocomposite materials suitable for applications in furniture, interior elements and building-related products.

Keywords: hemp shive, lignosulfonate, biocomposites, bio-based binder, physical and mechanical properties.

Session 6C | Contribution 5

CASCADE USE OF WOOD WASTE IN MEDIUM-DENSITY FIBERBOARD PRODUCTION: RECYCLING, ADHESIVE SYSTEMS AND CIRCULAR ECONOMY PERSPECTIVES

Viktoria Dudeva, Georgi Ivanov

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: v.dudeva@ltu.bg, Georgi_Ivanov@ltu.bg

ABSTRACT

The paper examines the cascade use of wood waste as a strategy for obtaining eco-friendly biocomposite materials within the framework of the circular economy. Wood residues generated during primary and secondary processing are often underutilized despite their potential as a valuable secondary raw material. The study discusses technological approaches for transforming these residues into composite products with improved environmental performance and extended material life cycles. Special attention is given to the selection, preparation and classification of wood waste fractions, their combination with suitable binders or functional additives, and the evaluation of the resulting material properties. The proposed approach aims to reduce waste generation, support resource efficiency and contribute to the development of sustainable wood-based products. The results are expected to outline practical opportunities for integrating cascade utilization concepts into the production of biocomposite materials for furniture, interior and construction-related applications.

Keywords: wood waste, cascade use, circular economy, biocomposite materials, resource efficiency.

Session 6C | Contribution 6

MECHANICAL PROPERTIES OF THREE-LAYER FURNITURE PANELS WITH PARTICLEBOARD CUTTING WASTE CORE

Krasimira Atanasova, Dimitar Angelski, Vanesa Angelova

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: k_atanasova@ltu.bg, d.angelski@ltu.bg, angelova438@gmail.com

ABSTRACT

The utilization of cutting residues from laminated particleboards as a core in multilayer furniture elements represents a sustainable approach to reducing the increasing volume of waste generated in furniture manufacturing. The obtained materials are characterized by good appearance, sufficiently high mechanical properties, and pronounced anisotropy. The appropriate arrangement scheme of the core details and the use of a one-component polyurethane adhesive lead to a reduction in anisotropy. In the present study, regression models were developed to describe the influence of the core detail width and the amount of used adhesive on the modulus of elasticity and the bending strength of HPL-laminated three-layer furniture panels. The amount of adhesive was varied between 100 and 200 $g.m^{-2}$, while the width of the core details ranged from 16 to 30 mm. Both models were represented by second-order polynomials with correlation coefficients of 0.995 and 0.999. The following were established: a linear inversely proportional relationship between the width of the core details and the modulus of elasticity, and a linear directly proportional relationship between the bending strength and the amount of adhesive used. The presented graphic solutions of the models allow for an easy selection of the required width of the core details when producing three-layer panels with previously known mechanical characteristics.

Keywords: particleboard cutting waste, polyurethane adhesive, HPL lamination, modulus of elasticity, bending strength, regression modelling.

Session 7A | Contribution 2

DEVELOPMENT OF A CRITERIA SYSTEM FOR ASSESSING MODULARITY IN CABINET FURNITURE

Vassil Jivkov, Polina Yunchova-Kolova, Boryana Petrova

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: v_jivkov@ltu.bg, polina.yunchova-kolova@ltu, b.petrova@ltu.bg

ABSTRACT

Modularity has become a central concept in the design and development of cabinet furniture systems, as it supports product variety, customization, efficient manufacturing, and improved lifecycle performance. Despite its widespread application, the term “modularity” is often interpreted inconsistently, typically reduced to isolated characteristics such as standardized dimensions, uniform components, or detachable joints. This lack of conceptual clarity limits the ability to evaluate and compare furniture systems systematically. The aim of this study is to develop a structured system of criteria for assessing modularity in cabinet furniture. The proposed criteria are summarized from available literature on cabinet and sectional furniture design, modular furniture systems, functional modularity, mass customization, evaluation of modular design, design for disassembly and reassembly, and sustainable product development. As a result, eight areas characterizing modularity and sustainable design were identified: coordination of dimensions and systems; structural modularity and module independence; compatibility of interfaces and connection systems; assembly/disassembly/reassembly; functional modularity; configuration variability; user-oriented adaptability; and manufacturing efficiency, logistics, and sustainability. These areas cover 36 individual criteria. An evaluation methodology is proposed in which each criterion is rated on a 5-point scale from 0 to 4. The total score is converted into a modularity index with a maximum possible score of 144 points. The proposed methodology enables a balanced, comprehensive comparison of cabinet systems and supports both the evaluation of existing products and the development of new modular furniture concepts.

Keywords: cabinet furniture, modularity, modular design, assessment criteria.

Session 7A | Contribution 4

COMPARATIVE ANALYSIS OF TRADITIONAL 3D METHODS AND NERF IN FURNITURE VISUALIZATION

Radoslav Miltchev[1], Galin Milchev[2], Mihail Zagorski[1]

[1]Technical University, Sofia, Bulgaria
e-mail: rmiltchev@tu-sofia.bg, mzagorski@tu-sofia.bg
[2]University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mail: gmilchev@ltu.bg

ABSTRACT

The traditional furniture visualization processes used to create 3D scans, polygonal models, textures and renders are very controlled, accurate and precise but they require a lot of time and expertise. The use of NeRF allows photorealistic 3D representations to be generated directly from images, without much manual processing and with considerably higher speed. This study investigates the options for furniture visualization with a comparative analysis between conventional 3D techniques and Neural Radiance Fields (NeRF). With the increasing demands of realism and productivity in product design and digital representation, the correct choice of visualization technology becomes a crucial factor. The object of the study is a real visitor chair, which is represented in three different ways: representing three-dimensional modelling and rendering in AutoCAD; 3D scanning, taking its geometry and texture; and reconstructing it with NeRF from several images. The findings indicate that a high photorealism level can be attained through NeRF, in addition to the generation of new views with less modeling effort. 3D scanning, modeling with polygons, texturing and rendering contribute to an impressive geometric accuracy, topology control, and easy fitting into manufacturing and CAD environment. This makes them expertly suited for engineering applications requiring measurable precision and optimization of models. NeRF can quickly produce photorealistic visualizations from images including complicated light interactions. Though the method suffers from limited editing and geometric interpretability, it is potentially very efficient, flexible and automated. The analysis indicates that there is no one-size-fits-all solution and that each case has both advantages and drawbacks. NeRF is proving to be a useful tool for visualising and marketing. Nevertheless, traditional tools still have a role in the design and engineering processes.

Keywords: NeRF, 3D Modeling, Artificial Intelligence (AI), CAD.

Session 7A | Contribution 6

SUSTAINABLE TIMBER CONSTRUCTION AND PREFABRICATION FOR A LOW-CARBON BUILDING

Gauthier Colloch, Flavien Bouquet, Mathieu Pétrissans, Anélie Pétrissans

Université de Lorraine, INRAE, LERMAB, F88000, Epinal, France
e-mail: gauthier.colloch8@etu.univ-lorraine.fr

ABSTRACT

This paper presents the design and prefabrication process of a future school complex in France, developed within the "New Generation School Plan" (PENG). The project illustrates how timber construction and bio-based materials can contribute to low-carbon architecture while meeting contemporary requirements for energy performance, occupant comfort, and environmental integration. The school complex combines nursery and elementary facilities, shared educational spaces, landscaped outdoor areas, and pedagogical gardens within an environmentally conscious urban framework. Designed according to RE2020 environmental standards, the project emphasizes passive building principles, reduced energy consumption, summer thermal comfort, and the extensive use of locally sourced bio-based materials. Timber structures and prefabricated wood-frame systems play a central role in minimizing the project's carbon footprint while ensuring high thermal and acoustic performance. The contribution of LE BRAS Frères, a French company specialized in timber structures, heritage restoration, and sustainable construction, focused on the prefabrication of structural timber elements in controlled workshop conditions. The use of local Vosges spruce, wood fiber insulation, prefabricated roof cassettes, and optimized airtightness solutions demonstrates the potential of industrialized timber construction for sustainable public buildings. Prefabrication improved assembly precision, reduced material waste, shortened on-site construction time, and limited environmental disturbance. Beyond technical performance, the project highlights the importance of integrating sustainability, circular resource management, and construction quality into educational infrastructure. This case study demonstrates how modern timber construction methods can support the ecological transition while creating healthy, durable, and energy-efficient learning environments adapted to future climate challenges.

Keywords: Timber construction, Sustainable building, Prefabrication, Bio-based materials, Low-carbon architecture, RE2020 environmental design.

Session 7B | Contribution 1

THE FORMAL LOGIC OF THE TRADITIONAL MACEDONIAN HOUSE: STRUCTURE, GEOMETRY, AND EXPRESSION

Branko Temelkovski, Vladimir Karanakov, Elena Jevtoska

Faculty of Design and Technologies of Furniture and Interior – Skopje, Ss. Cyril and Methodius University in Skopje, North Macedonia

e-mails: temelkovski@fdtme.ukim.edu.mk, karanakov@fdtme.ukim.edu.mk, jevtoska@fdtme.ukim.edu.mk

ABSTRACT

This paper examines the traditional Macedonian house through a formal approach, aiming to define its architectural logic as a coherent system based on geometric abstraction, modularity, and structural expression. Methodologically, the research is grounded in formal and morphological analysis across multiple dimensions. The modular arshin system is understood as a generative principle of spatial organization, while the dichotomy between the massive stone ground floor and the light wooden superstructure is interpreted as a volumetric and structural strategy. The timber-frame (bondruk) system is examined as a means of dematerializing wall mass and as a mechanism for establishing fluid boundaries between interior and exterior space. The analysis further explores the relationship between part and whole as a unified architectural syntax. The paper ultimately seeks to establish this architecture as an abstract and universal formal model with relevance to contemporary architectural theory.

Keywords: traditional architecture, formal analysis, modularity, structural expression, geometric abstraction.

Session 7B | Contribution 2

IMAGE RECOGNITION IN INTERIOR DESIGN PRACTICE

Stela Borisova Tasheva

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mail: stasheva@ltu.bg

ABSTRACT

The study examines the transformative role of image recognition technologies within contemporary interior design workflows. By leveraging advanced computer vision algorithms, practitioners can automate the identification of furniture styles, materials, and spatial dimensions from digital imagery. The author evaluates how these tools streamline the procurement process and enhance the accuracy of trend analysis in professional practice. Furthermore, it discusses the integration of artificial intelligence in bridgeing the gap between conceptual compositions&visuals and technical specifications. Ultimately, the research suggests that image recognition serves as a critical catalyst for increasing operational efficiency and fostering innovation in design visualization.

Keywords: Image recognition, AI tools, interior design, composition, architecture, design theory.

Session 7B | Contribution 5

THE ROLE OF NEW TECHNOLOGIES IN SUPPORTING INDEPENDENT LIVING AMONG OLDER ADULTS: CHALLENGES AND OPPORTUNITIES IN BULGARIA

Maria Kitchoukova

Vocational High School of Design „Elisaveta Vazova"
e-mail: mkitchoukova@yahoo.com

ABSTRACT

Population aging represents a significant social and economic challenge, with Bulgaria being among the countries with a high proportion of older adults. In this context, supporting independent living has emerged as a key priority for improving quality of life and social inclusion. This article analyzes the role of new technologies—such as smart home systems, remote health monitoring, and assistive devices—as a means of enhancing the autonomy, safety, and long-term independence of older people within their living environment. Particular attention is paid to the interaction between technologies and the residential environment, as well as to the need to adapt living spaces to the needs of an aging population. The specific characteristics of the older population in Bulgaria are also examined, including challenges related to digital literacy, access to services, and uneven infrastructure development. The paper concludes by outlining the main opportunities and limitations associated with the implementation of technological solutions to support independent living in Bulgaria.

Keywords: population ageing, independent living, smart homes, assistive technologies.

Session 7B | Contribution 6

PERFORMANCE REQUIREMENTS FOR SURFACES OF SPECIALIZED VETERINARY EQUIPMENT: RESISTANCE TO MECHANICAL DAMAGE AND CHEMICAL CLEANING

Yoanna Fikincheva, Vassil Jivkov

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: fikincheva@ltu.bg, v_jivkov@ltu.bg

ABSTRACT

Specialized veterinary equipment is exposed to a combination of intensive mechanical wear and frequent cleaning and disinfection with chemically active agents. These operating conditions impose specific requirements on the surface materials used in veterinary practice, particularly regarding scratch, impact, and chemical resistance, cleanability, and long-term hygienic performance. This study examines the performance requirements for such surfaces, focusing on the balance between durability and effective decontamination. The research is based on a targeted survey of veterinary practitioners, aimed at identifying the most common types of surface degradation, the cleaning and disinfection protocols most frequently used, and the practical limitations of currently used materials. The results provide a basis for defining key criteria for material selection and for future evaluation of surfaces intended for specialized veterinary equipment.

Keywords: veterinary equipment, surface materials, mechanical wear, chemical resistance, cleanability, disinfection protocols, material selection.

Session 7B | Contribution 7

DESIGN AND ARCHITECTURE FESTIVALS AS LABORATORIES FOR TEMPORARY ARCHITECTURE: MATERIAL INNOVATION AND SPATIAL EXPERIMENTATION

Ralitsa Dikanska

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mail: ralitsa.dikanska@ltu.bg

ABSTRACT

Design and architecture festivals have evolved into complex spatial phenomena that temporarily transform urban environments. Beyond their cultural role, these events generate a distinct category of build environment defined by experimentation, material innovation, and impermanence. Despite growing scholarly attention to both festival urbanism and experimental pavilion architecture, these two bodies of literature remain largely disconnected – and the Balkan context is almost entirely absent from peer-reviewed research. This paper examines design and architecture festivals as laboratories for architectural and material experimentation, focusing on the constructive strategies employed in temporary structures and the mechanisms by which knowledge generated in the festival context transfers into permanent practice. The research operates across two scales: at the micro level, it investigates individual installations and pavilions – their material composition, constructive logic, and post-event lifecycle; at the macro level, it explores how temporary festival architecture mediates the relationship between built environment, public space, and urban identity. The study adopts a comparative case study approach, drawing on international examples – including the Serpentine Pavilion series (London), Milan Design Week, and Dutch Design Week – alongside examples from the Balkan context. Key questions include: What materials and constructive systems are tested in the festival context, and what role does wood and bio-based material experimentation play? Who appropriates the results, and through what mechanisms does knowledge enter permanent practice? What role does documentation play in preserving the legacy of ephemeral structures? The findings contribute a structured framework for understanding festivals as sites of material and spatial innovation, with particular attention to circular economy principles. The research identifies a documentation gap in the Balkan region, where festivals demonstrate cultural impact but lack systematic material legacy frameworks – a gap representing both a research opportunity and a practical challenge for the regional industry. The expected results are situated within architectural theory and design research.

Keywords: design festivals, temporary architecture, material innovation, circular economy, ephemeral pavilions, festival legacy.

Poster session — Part 2 | Contribution 1

INFLUENCE OF MOISTURE CONTENT ON THE BENDING STRENGTH AND MODULUS OF ELASTICITY OF BEECH AND SPRUCE WOOD

Galina Kutova

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mail: galina.saykova@gmail.com

ABSTRACT

The present study evaluates the influence of moisture content on the modulus of rupture (MOR) and modulus of elasticity (MOE) in static bending of beech (*Fagus sylvatica* L.) and spruce (*Picea abies* (L.) H. Karst.) wood. The experimental study was conducted on small clear specimens of solid wood at four target moisture content levels – 8, 12, 18, and 25%, testing 30 specimens for each combination of wood species and target moisture content (total number $n = 240$).

The specimens were conditioned under controlled conditions, followed by three-point static bending tests. For each specimen, the actual moisture content (ISO 13061-1:2014), density (ISO 13061-2:2014), MOR (ISO 13061-3:2014), and MOE (ISO 13061-4:2014) were determined.

A statistical analysis was performed using descriptive statistics, two-way analysis of variance (Two-Way ANOVA), and regression modeling. The interaction between wood species and moisture content was also evaluated. The results confirm the hypothesis that an increase in moisture content leads to a statistically significant decrease in MOR and MOE, with absolute values being higher for beech wood, while the relative percentage reduction of the parameters upon wetting is similar for both wood species.

Keywords: beech wood, spruce wood, moisture content, MOR, MOE, static bending, strength, modulus of elasticity, density.

Poster session — Part 2 | Contribution 2

EFFECT OF HOMOGENIZATION PRESSURE ON THE VISCOSITY OF MICROFIBRILLAR CELLULOSE

Stoyko Petrin, Ivaylo Gavrilov, Petya Mileva-Petrova, Ivo Valchev

University of Chemical Technology and Metallurgy, 8 "St. Kl. Ohridski" bul., 1756 Sofia, Bulgaria
e-mails: stpetrin@uctm.edu, ivoval@uctm.edu, mileva.71@abv.bg, ivoval@uctm.edu

ABSTRACT

High-pressure homogenization is a mechanical method for producing microfibrillated cellulose. Homogenization pressure is a critical parameter to obteined microfibrillated cellulose. Increasing the pressure and the number of cycles significantly increase the degree of fibrillation and obteined higher viscosity. The aim of the present study is to investigate the influence of the number of homogenization cycles and pressure on the production of microfibrillated cellulose from low degree of polymerization cellulose. The cellulose used in this study was previously depolymerized by acid hydrolysis in order to reduce the degree of polarization (under 500 DP). The laboratory experiments are caried out at different homogenization pressures with varying the number of homogenization cycles in a laboratory Homodenizator GEA Xstream 2000. The combined effects of homogenization pressure and processing cycles on the viscosity of the obteined microfibrillated cellulose is investigated. The results show that at high pressures, the viscosity of microfibrillated cellulose increase very fast and only two cycles are requaredq while very low homogenization pressure does not affect the viscosity.

Keywords: homogenization, microfibrillated cellulose, degree of polymerization.

Poster session — Part 2 | Contribution 3

PROFILE AS A FACTOR THAT INFLUENCES ON AIR PERMEABILITY RESISTANCE

Elena Jevtoska, Gjorgi Gruevski, Nikola Mihajlovski, Branko Temelkovski

Ss. Cyril and Methodius University in Skopje, Faculty of Design and Technologies of Furniture and Interior-Skopje, Republic of North Macedonia

e-mails: jevtoska@fdtme.ukim.edu.mk, gruevski@fdtme.ukim.edu.mk, mihajlovski@fdtme.ukim.edu.mk, temelkovski@fdtme.ukim.edu.mk

ABSTRACT

The window as a product is a complex composition of different materials and parts. The different parts of the window are the basic structural elements, filling elements, fittings, additional accessories. The basic structural elements of the window are the supporting frame or casement and the window sash, which can be made of different materials and different dimensions of the profile. Frequently, manufacturers of PVC profiles, dedicated to the production of windows, produce different profiles with different thicknesses in order to achieve better quality. This paper will focus on the PVC profiles which the windows are made of, as a factor that affects air permeability. For the research, different PVC window profiles with different thicknesses and from different manufacturers were used, and the same identical hardware with the same number of locks, as well as the same glass package, was used on all windows. The measurement of air permeability will be made in accordance with EN 1026:2016 Windows and doors – Air permeability – Test method, as well as the determination of classes in accordance with EN 12207:2016 Windows and doors – Air permeability – Classification.

Keywords: windows, PVC profiles, air permeability, construction carpentry.

Poster session — Part 2 | Contribution 6

INTEGRATION OF LEAN AND CIRCULAR ECONOMY IN THE FURNITURE INDUSTRY

Ivana Antovska, Mira Stankevikj Shumanska

Ss. Cyril and Methodius University, Skopje, Republic of North Macedonia, Faculty of Design and Technologies of Furniture and Interior
e-mails: antovska@fdtme.ukim.edu.mk, stankevik@fdtme.ukim.mk

ABSTRACT

European furniture industry producing 25 to 28% of the worlds furniture, represent a very important segment of Europe's economy. This sector is currently transitioning towards a circular economy, facing a variety of regulatory, economic and environmental challenges. Implementing this economy system is for enhance resource efficiency and prolong product lifespans. Furniture manufacturers have managed to increase their competitiveness, primarily through improving quality, optimizing production processes and material-selection, but in the last period also to understanding consumer perceptions and fostering consumer engagement in circular practices. Lean methodology focuses on optimizing processes, reducing costs and increasing quality by identifying and eliminating activities that do not add value to the product or service. It is a systematic approach to eliminating waste in a manufacturing process to create more value for the customer and also jointly shifting the mindset and behavior among those involved in the production process, not just enforcing rules. The integration of these two methodologies represents an important strategic approach for improving sustainability, operational efficiency, and competitiveness in furniture manufacturing enterprises.

Keywords: Lean production, furniture manufacturing, circular economy.

Poster session — Part 2 | Contribution 7

INFLUENCE OF THE OUTER INTERMEDIATE LAYER OF TURKEY OAK (QUERCUS CERRIS L.) ON THE PHYSICO-MECHANICAL PROPERTIES OF FIVE-LAYER PARTICLEBOARDS

Rosen Grigorov

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mail: rosengrigorov@ltu.bg

ABSTRACT

The production of particleboards is influenced by multiple technological factors affecting both product quality and economic efficiency. Medium-density boards are typically manufactured from softwood species due to their favorable compaction behavior and mechanical performance, while the incorporation of hardwood species is generally limited by their lower technological suitability.

This study investigates the effect of incorporating turkey oak (*Quercus cerris* L.) particles into the outer intermediate layer, as well as the influence of adhesive content, on the physico-mechanical properties of five-layer particleboards.

Three levels of turkey oak content in the outer intermediate layer were applied: 20%, 30%, and 40%. The adhesive content was set at 12% in the face layers, while in the outer intermediate layer it varied at 8%, 7%, and 6%, with 8% in the inner intermediate layer. The panels were manufactured under laboratory conditions with a target density of 640 $kg \cdot m^{-3}$, pressing temperature of 180°C, pressure of 2.3 MPa, and pressing time of 20 s/mm.

The results indicate that increasing the proportion of turkey oak in the outer intermediate layer improves mechanical performance at an adhesive content of 8%. However, reducing adhesive content to 6% leads to deterioration of performance, with some panels failing to meet interior-use requirements according to relevant standards.

Session 8A | Contribution 2

FROM THEORY TO DIGITAL PRACTICE: DESIGN, IMPLEMENTATION AND EVALUATION OF ELECTRONIC LEARNING GUIDES IN DESIGN EDUCATION

Desislava Angelova, Tsvetan Stoykov, Vanina Tabakova, Adriana Yankova-Hristova, Denislav Lyubenov, Eli-Naya Konetsovska and Anna-Maria Sofianska

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Faculty of Forest Industry
e-mails: d.angelova@ltu.bg (D.A.), t.stoykov@ltu.bg (T.S.), v.tabakova@ltu.bg (V.T.), adriana.yankova@ltu.bg (A.Y.-H.), fn220119@ltu.bg (D.L), fn220072@ltu.bg (E.N.-K), fn220078@ltu.bg (A.-M.S.)

ABSTRACT

Design education encompasses disciplines with substantially different learning objectives, cognitive processes, and instructional methods, creating a need for flexible digital learning models that can be adapted across diverse educational contexts.

This study investigates the applicability of a shared pedagogical framework for electronic learning guides implemented in two contrasting studio-based design courses within the Engineering Design (Interior and Furniture Design) programme at the University of Forestry, Bulgaria. The first guide supported Visual Art Methods and Techniques for Interior Design, while the second, Fundamentals of Computer Visualisation, supported the course Animation and Virtual Reality. Although the two disciplines differ considerably in learning activities and instructional media, both guides were developed according to the same instructional principles.

Students evaluated the learning guides through structured questionnaires examining usability, support for independent learning, development of practical competences, engagement, and overall educational value. The findings demonstrate consistently positive evaluations across both educational contexts, suggesting that the effectiveness of electronic learning guides depends primarily on coherent pedagogical design rather than on the specific instructional medium.

The study demonstrates the applicability of a shared pedagogical framework for integrating electronic learning resources across complementary domains of studio-based design education.

Keywords: design education, electronic learning guides, multimedia learning, digital transformation.

Session 8A | Contribution 3

BRIDGING THE GAP BETWEEN TRADITIONAL TEACHING MODELS AND CONTEMPORARY LEARNING HABITS IN DESIGN STUDENTS: A CONCEPTUAL AND EMPIRICAL PERSPECTIVE

Desislava Angelova, Tsvetan Stoykov, Vanina Tabakova, Adriana Yankova-Hristova, Denislav Lyubenov, Eli-Naya Konetsovska and Anna-Maria Sofianska

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Faculty of Forest Industry
e-mails: d.angelova@ltu.bg (D.A.), t.stoykov@ltu.bg (T.S.), v.tabakova@ltu.bg (V.T.), adriana.yankova@ltu.bg (A.Y.-H.), fn220119@ltu.bg (D.L), fn220072@ltu.bg (E.N.-K), fn220078@ltu.bg (A.-M.S.)

ABSTRACT

Digital transformation has expanded the ways in which students access, organise, and engage with learning, while studio-based design education continues to depend on experiential, project-based, and dialogic forms of teaching. The resulting challenge is not simply how to introduce digital technologies, but how to respond to contemporary learning requirements without weakening the established pedagogical strengths of studio education.

This study addresses this challenge through an empirically informed conceptual synthesis of two complementary investigations conducted in design education at the University of Forestry, Bulgaria. The first examined faculty and student perspectives on teaching formats and digital learning practices, while the second explored students' evaluations of digitally supported learning resources implemented in two contrasting design-learning contexts. The combined findings indicate a continuing value placed on direct interaction and project-based learning alongside requirements for flexible access, structured learning resources, continuity of support, and opportunities for independent learning.

Based on these findings, the study proposes a Conceptual Model of Pedagogical Reorganisation, in which Alignment coordinates the Established Pedagogical Core and Contemporary Learning Requirements through five interrelated principles: Preservation, Reorganisation, Extension, Integration, and Contextual Adaptation. The resulting Integrated Learning Continuum conceptualises studio teaching, learning resources, independent practice, revision, and feedback as interconnected components of an iterative learning process. The model shifts the analytical focus from technological adoption and delivery modes towards the organisation of pedagogical relationships, providing a framework for preserving what is educationally essential while reconsidering how learning is supported, connected, and sustained.

Keywords: design education, teaching models, learning habits, digital generation, higher education.

Session 8A | Contribution 4

TRANSFORMATION OF THE ACADEMIC ENVIRONMENT THROUGH ARTIFICIAL INTELLIGENCE: AN EMPIRICAL STUDY AMONG STUDENTS AND FACULTY

Melina Neykova, Galin Milchev, Viktor Savov

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mails: mneykova@ltu.bg, gmilchev@ltu.bg, victor_savov@ltu.bg

ABSTRACT

The rapid development of information technologies and the accelerated integration of artificial intelligence (AI) have transformed the academic environment, underscoring the urgent need to reassess traditional educational models in higher education. The study presents an empirical analysis of the perceptions and extent of AI adoption among students and faculty members at the University of Forestry, Sofia. The research is closely linked to the university's specific profile, which trains specialists in the fields of forestry and natural resources management. As AI is increasingly recognized as a critical tool for the precise analysis of ecosystems and biodiversity monitoring in these fields, its integration into the educational process is essential to prepare future professionals for the technological demands of the industry. The study involved 286 students (approximately 54%) and 74 faculty members. The methodology encompasses a two-stage survey approach and a cross-analysis to identify correlations between the attitudes of faculty members and students. The data reveal a high level of technological engagement as most respondents regularly use information and communication technologies in their academic activities, while great part of them are already using AI platforms for specific university-related tasks. There are notable differences in the perception of AI, with students demonstrating higher levels of use, particularly for learning support purposes, while faculty members exhibit a more cautious approach, often influenced by concerns regarding academic integrity and ethical implications. The findings of the research highlight important aspects of the inevitable AI-driven transformation in education, where AI serves as a key factor of innovation, offering advantages such as personalized learning, optimization of research processes, and enhanced administrative efficiency, while simultaneously posing challenges associated with academic integrity, algorithmic bias, diminished critical thinking, misinformation, and data privacy. The study contributes to a deeper understanding of the ongoing AI transformation in higher education, by highlighting the need to adopt a strategy for the responsible and effective integration of AI that supports innovation in the educational process and prepares the academic community for the digital demands of the future.

Keywords: Higher Education, Artificial Intelligence (AI), Information and Communication Technologies (ICT), AI Transformation.

Session 8A | Contribution 5

THE IMPORTANCE OF A MULTIDISCIPLINARY APPROACH IN THE DESIGN OF RETAIL SPACES

Carmella Lombardi

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
e-mail: c.lombardi@ltu.bg

ABSTRACT

This article examines the importance of a multidisciplinary approach in the design of contemporary retail spaces as complex environments shaped by spatial, visual, psychological and technological factors. The introduction outlines the necessity of a multidisciplinary collaboration when designing contemporary retail spaces. Based on the literature review, the article explores the interaction between interior design, branding, consumer behavior, sales strategies, digital technologies and user experience in the process of retail space design. The empirical part includes a review of contemporary retail practices and selected case studies illustrating how different disciplines contribute to the creation of coherent and effective retail environments. In conclusion, the article formulates the need for a holistic and multidisciplinary methodology in retail space design and outlines possible directions for future research and design practice.

Keywords: retail spaces, multidisciplinary design, consumer experience, branding, interior design, retail design.

Session 8B | Contribution 1

INNOVATION ACTIVITY OF THE FOREST INDUSTRY IN BULGARIA FOR THE PERIOD 2018–2022

Vesela Dimchova, Nikolay Neykov, Radostina Popova-Terziyska

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria, Faculty of Forestry,
e-mails: vesselaivanoff@gmail.com, nneykov@ltu.bg, rpopova@ltu.bg

ABSTRACT

The modern global economy is characterized by rapid development and intensified competition, which requires continuous improvements in production, management, and supply chains. Enterprises can address these challenges through the active implementation of innovations to enhance efficiency and competitiveness. The Bulgarian forest industry is striving to catch up with European markets through investments and innovation-driven strategies. The intensity of these processes is a key factor for improving market positioning. There is a strong need for up-to-date research in this field in order to reflect current trends. The main objective is to analyze innovation processes in the Bulgarian forest industry and to formulate recommendations for their improvement.

Keywords: innovation, competitiveness, forest industry, entrepreneurship.

Session 8B | Contribution 2

INDUSTRY 4.0 IN THE WOODWORKING AND FURNITURE INDUSTRY: TECHNOLOGICAL SOLUTIONS, APPLICATIONS AND FUTURE TRENDS

Aleksandar Doichinov

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria

ABSTRACT

The paper presents an overview of Industry 4.0 technologies and their application in the woodworking and furniture industry. It discusses cyber-physical production systems, industrial Internet of Things, sensors, data acquisition, cloud platforms, artificial intelligence, robotics, digital twins and integrated production planning. Applications in process monitoring, quality control, predictive maintenance, material optimisation, traceability and flexible manufacturing are considered, together with the organisational, technological and human-resource barriers to implementation. Future trends are outlined in the context of increasingly connected, data-driven and sustainable production systems.

Keywords: Industry 4.0, woodworking, furniture industry, digitalisation, automation, artificial intelligence.