WOOD 4 sustainability

*p*rocessing *c*onstruction

*p*roduct *d*esign

2024

Wood 4 Sustainability

Processing, Construction, Products and Design

2024

Főszerkesztő: Dr. Csiha Csilla

Wood 4 Sustainability

Processing, Construction, Products and Design

2024

SOPRONI EGYETEM KIADÓ

SOPRON, 2024

Közreadó a Soproni Egyetem Faipari Mérnöki és Kreatívipari Kara

Felelős kiadó: Prof. Dr. Fábián Attila

a Soproni Egyetem rektora

Főszerkesztő

Dr. Csiha Csilla Mária

Szerkesztők

Prof. Dr. Kósa Balázs, Prof. Dr. Magoss Endre, Dr. habil. Németh László

Lektorok

Gerencsér Kinga Címzetes Egyetei Tanár, Szabadhegyi Viktor Címzetes Egyetemi Docens, Prof. Dr. Alpár Tibor, Prof. Emeritus Tolvaj László, Prof. Dr. Markó Balázs

Technikai szerkesztő

Mucsi Zsuzsanna

ISBN 978-963-334-541-2 (pdf)

DOI: https://doi.org/10.35511/978-963-334-541-2

Tartalom

95 / 95-103

Finite element analysis of furniture structures made from underutilized wood species

Zsófia Benedek-Csányi[a], **József Garab**[a]

[a] University of Sopron, Faculty of Wood Sciences and Creative Industries, H-9400 Sopron, Bajcsy-Zsilinszky u. 4.
Email: benedek-csanyizs12@student.uni-sopron.hu garab.jozsef@uni-sopron.hu

DOI: https://doi.org/10.35511/978-963-334-541-2-10

ABSTRACT
This numerical study investigates the structural performance of Norway spruce (*Picea abies*), a traditional softwood, and grey poplar (*Populus x canescens*), an underutilized hardwood species in Hungary, within a kitchen furniture system. Finite element analysis was conducted under static loading conditions, assuming linear elasticity, to compare the two materials. The results indicate that the structural behavior of furniture made from Norway spruce and grey poplar is approximately equivalent, demonstrating the potential of grey poplar as an alternative material in furniture applications. This work also highlights the scarcity of mechanical property data for grey poplar, emphasizing the need for comprehensive mechanical characterization as a basis for further numerical investigations.

Keywords: underutilized wood species, grey poplar, furniture, numerical simulation, mechanical properties, Industry, innovation and infrastructure

1. Introduction

Wood species most commonly used in Hungary for furniture production include beech (*Fagus sylvatica*), maple (*Acer spp.*), walnut (*Juglans regia*), Norway spruce (*Picea abies*), Scots pine (*Pinus* sylvestris), common oak (*Quercus robur*), and ash (*Fraxinus excelsior*). The growing area of pine family, as well as other climate-sensitive and significant tree species, is expected to decrease – this holds for beech and sessile oak (*Quercus petraea*) too. Due to nature conservation and growing area considerations, the area of hybrid poplar plantations is also declining (Fodor & Mertl, 2023). This phenomenon will be a long-term challenge for the domestic wood industry, which shall be handled. Therefore, using the underutilized hardwood species in the wood industry plays a significant role in the future. Furniture industry is one potential area of utilisation, where coniferous wood could be replaced with the underutilized wood species. Some of such wood species in Hungary are hornbeam (*Carpinus betulus*), Turkey oak (*Quercus cerris*) and grey poplar (*Populus x canescens*). Grey poplar offers significant potential from both ecological and economic perspectives, but their utilization remains largely unexploited (Ábri, Honfy, et al., 2024; Ábri, Keserű, et al., 2024; Komán et al., 2023).

In order to examine the underutilized wood species for furniture application a first step could be applying numerical simulation in engineering analysis to investigate the performance of those materials. The purpose of the simulation model is to predict the behavior of the original system and support the decision-making. In the classical sense, simulation is typically placed in the middle or towards the end of the design process. In modern practice, however, it can be utilized at any stage of the process. It can serve as continuous monitoring within a development process (Németh, 2023). With the application of numerical simulations (e.g. finite element analysis), the mechanical behaviour of furniture could be simulated without building the same furniture and apply the same loads. Therefore a digital representation of the furniture with different materials can predict piece of the response of the structure to the loads.

The finite element analysis (FEA) is a proven methodology for the analysis of wooden furniture. Detailed bibliographies focusing on FEA applied to wood, also touching analysis of wooden furniture and interiour structures are given in the works of Tankut et al. and Mackerle (Tankut et al., 2014; Mackerle, 2005). The design principles, the current design practice of furniture and other end-user wood products, the application of principles and systematic product development and engineering design of furniture are discussed in the fundamental work by Csanády et al. (Csanády et al., 2019). When analysing wooden furniture, several aspects of behaviour can be in focus: sitting area deflection, backsupport deformation, foot support movement, wooden joints (Chen & Wu, 2018; Mustafa Hilmi Colakoglu, 2012; Gustafsson, 1995; Yu et al., 2024; Simek & Sebera, 2010; Bas et al., 2024). Previous studies analysed widely used wood-based materials. The main objective of our study is to investigate the response to mechanical loading of a set of furniture made of a Hungarian underutilized wood species, the grey poplar.

2. Material and method

The 3D CAD model of the pieces of furniture under study was designed by Autodesk Inventor 2024 (Autodesk, 2024). The computational model for the finite element method was built using Ansys software package (licensed product is Ansys® Academic Research Mechanical, Release 15).

Figure 1. Designed kitchen furniture. Lower and upper parts

Static structural analysis was performed in the Workbench module. The imported geometry was cleaned in the built in DesignModeler software. The fillet of the edges were removed in order to have better mesh structure. Orthotropic material models were created for the wooden parts, therefore local coordinate systems were applied according to the anatomical directions of the wood. Table 1 summarizes the material properties taken from the literature. The worktop of the lower part was modelled with oak wood in both cases. Depending on the case, Norway spruce or grey poplar was assigned as the material of the shelves and side boards. Because the full set of the orthotropic elastic constants of grey poplar were not found, existing data for Hungarian poplar (Szalai, 2001) were used. High density fibreboard (HDF) was assigned to the back panel. The lower part stands on legs made of polypropylene (PP). Both the upper and lower parts have a vertical plane of symmetry; therefore, for saving computing time, half of the parts is modelled, as shown in Figure 2. Furthermore, Figure 2 demonstrates the applied orientation of the anatomical main directions of the wood of the boards, which were applied as local coordinate systems. At this stage of the study the doors and the kickboard were not taken as part of the model. The details of the furniture joints were not modeled either. Instead, the contacts between the elements were set as bonded contact. The shelf was not contacted to the back wall; it was only edgewise bonded to the side of the cabinet. In case of wooden parts quadratic Hex20 finite elements, in case of the plastic foot, quadratic Tet10 finite elements were applied. The total number of nodes were approximately 118000 pcs and 104200 pcs for the lower and upper part respectively. The generated mesh on both parts of the furniture is presented on the Figure 3. The applied forces were defined based on the weight of household items. The lower and upper parts were constrained to resemble the installation methods used for the furniture (Figure 4.). The lower part was supported at the legs (*Dx = 0 mm*) and fixed to the wall at the edge of the worktop (D_x, D_y, D_z = 0 mm). In case of the upper part, fixed support (D_x, D_y, D_z = 0 mm) was applied at the top 100 mm of the edge face of the side board and displacement constraint (*Dx = 0 mm*) was applied at the bottom edge of the side board.

Table 1. The material properties used in finite element analysis

Material	Density	E_L	E_R	E_T	G_{RT}	G_{TL}	G_{LR}	v_{LR}	v_{LT}	v_{RT}
Norway Spruce (Szalai, 2001)	0.37	9 900	730	410	32	500	720	0.44	0.56	0.57
Hungarian poplar (Szalai, 2001)	0.38	9 700	700	410	720	670	110	0.32	0.39	0.70
Oak (Tippner et al., 2022)	0.74	14 669	656	910	127	2015	1900	0.037	0.028	0.326
HDF (ABH System, n.d.)	0.9	3000	--	--	--	--	--	0.3	--	--
PP (Ashby, 2021)	0.91	1600	--	--	--	--	--	0.45	--	--

Density – density of the beech wood [g/cm^3];E_L, E_R, E_T – normal moduli of elasticity [MPa]; G_{RT}, G_{TL}, G_{LR} – shear moduli of elasticity [MPa]; v_{LR}, v_{LT}, v_{RT} – Poisson's ratios [-]; in case of isotropic materials the modulus of elasticity and the Poisson's ratio was given into E_L and v_{LR} columns respectively

4. Results and discussion

The total deformation for the lower and upper part of the kitchen furniture is presented in Figure 5 and 6 according to the two wood species. With both wood species, the deformations are very similar, no significal difference is apparent. In case of the lower part, the highest deformation is at the shelf, becase the shelf is not tied to the backwall in the model. In case of the upper part, the furniture made of poplar wood performed slightly better. Comparing the normal stresses in the Y direction in the structures, Figure 7 and 8 demonstrate the influence of the wood species. The stress locations and the magnitude of the stresses are comparable in case of the lower part of the furniture. It should be noted, that the elastic constants applied for Norway spruce are in matching range with that of Hungarian poplar in our study. However, it is clear from scientific literature, that spruce wood of higher stiffness is also avaiable (Hörig, 1933; Keunecke et al., 2008), therefore the deformation and stress values could be less, when stiffer spruce material is applied. Because of the horizontal elements of the furniture, the normal stresses in the X directions are also analyzed (Figure 9). The normal stresses in the X directions are higher in case of the furnitre where the used material is Hungarian poplar.

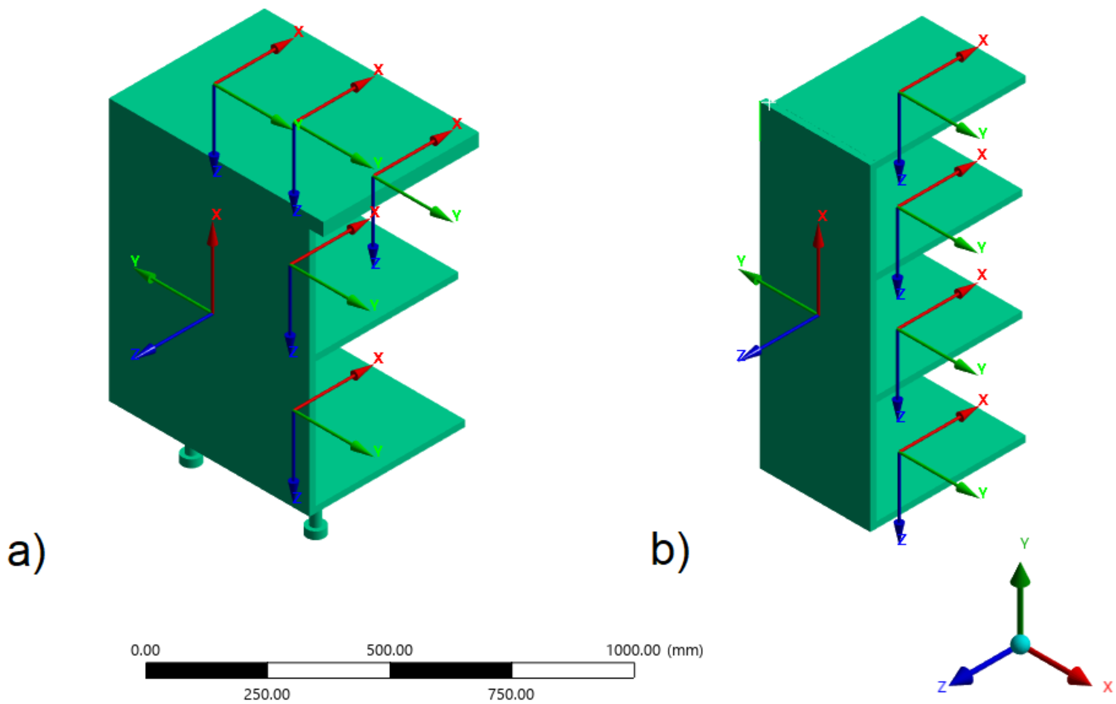

Figure 2. Geometrical models with the local coordinate systems of the wooden boards according to the anatomical main directions. (Local X = longitudinal, Local Y = radial, Local Z = tangential), a) lower part, b) upper part

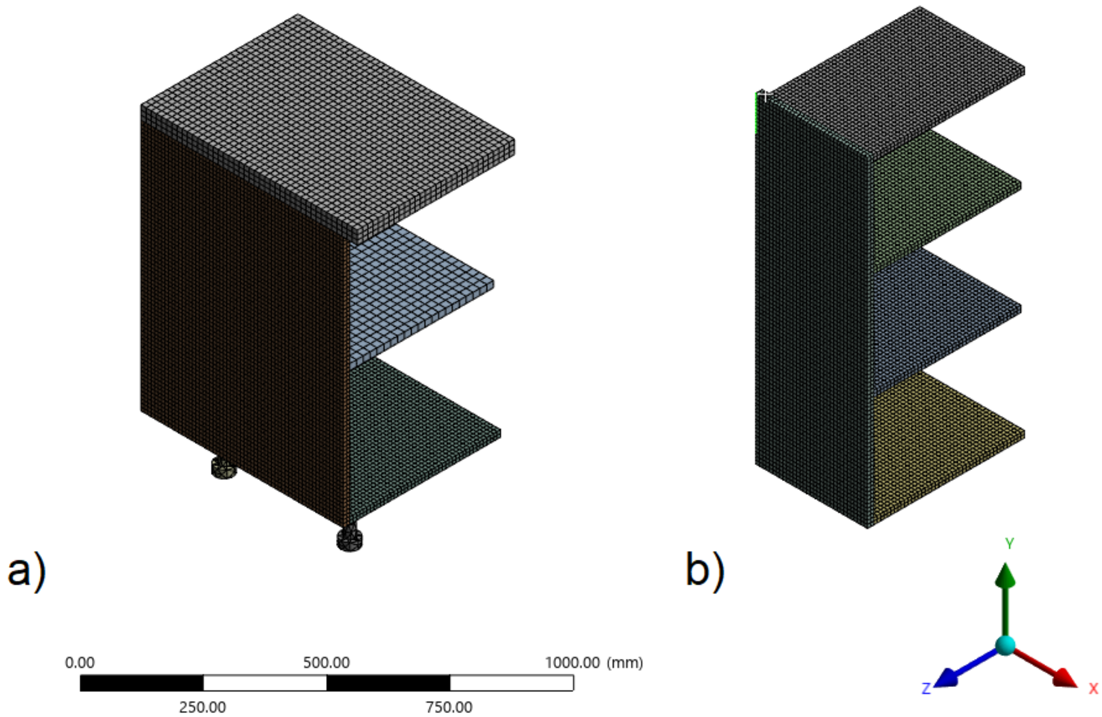

Figure 3. FE models with mesh, a) lower part, b) upper part

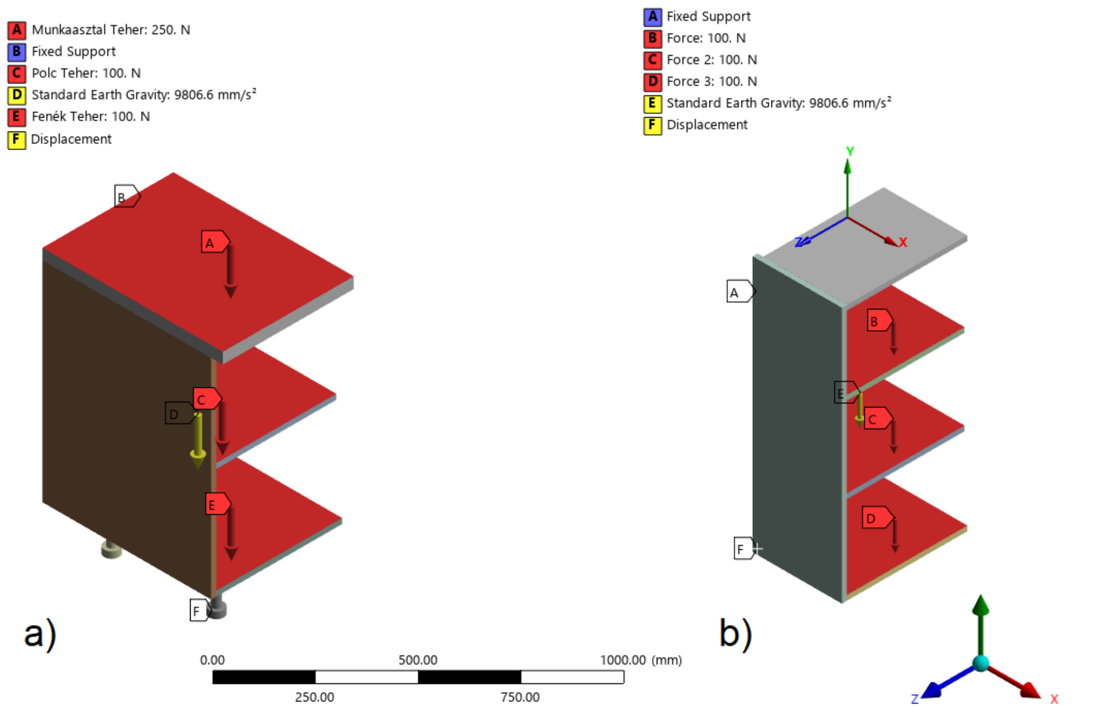

Figure 4. FE models with loads and boundary conditions, a) lower part, b) upper part

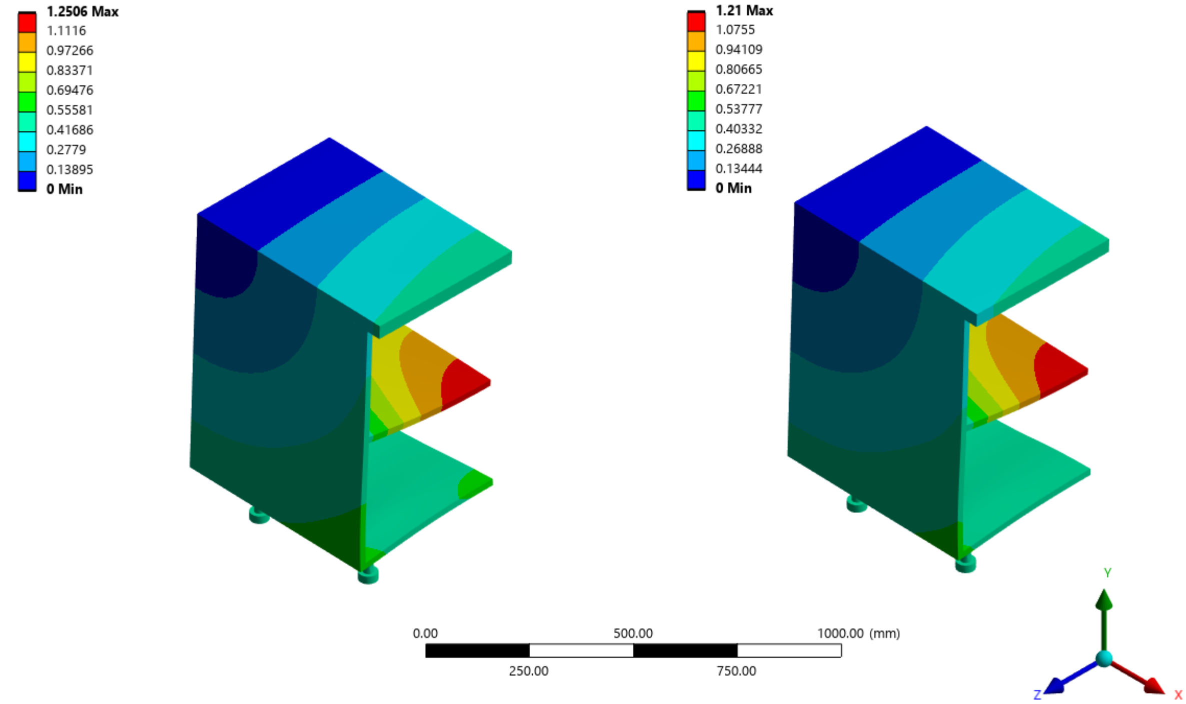

Figure 5. Total deformation of the lower part of the kitchen furniture, a) material is Norway spruce, b) material is Hungarian poplar

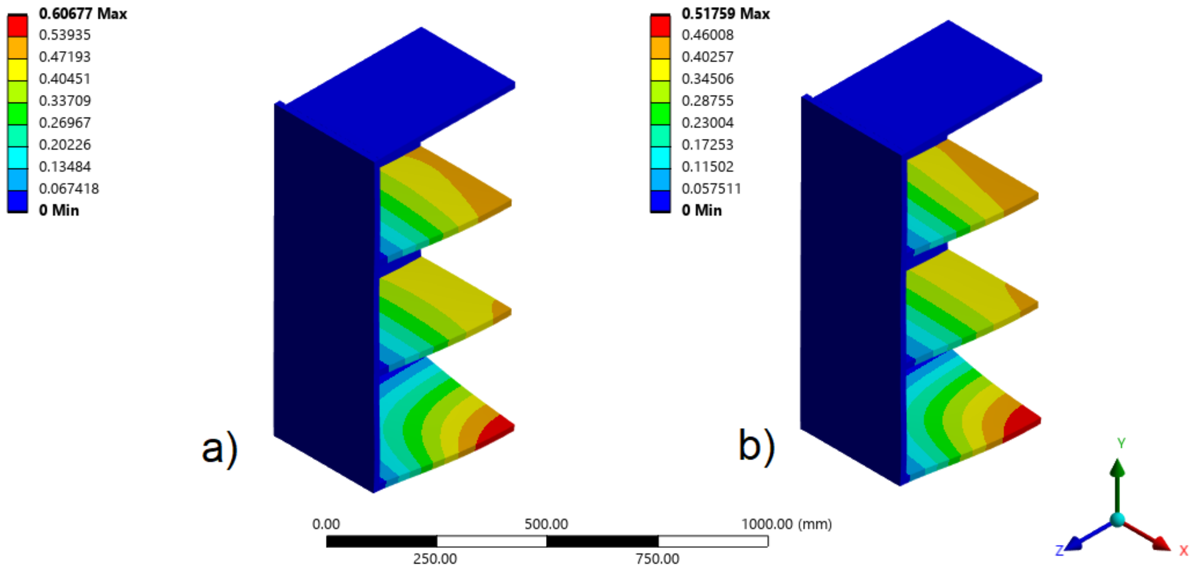

Figure 6. Total deformation of the upper part of the kitchen furniture, a) material is Norway spruce, b) material is Hungarian poplar

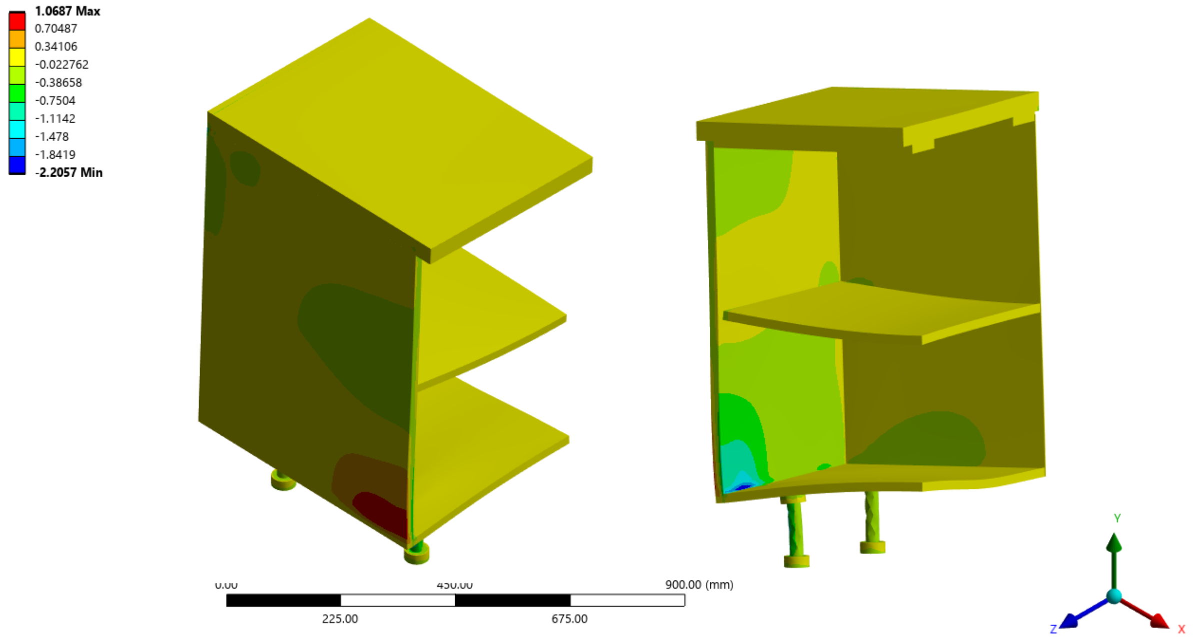

Figure 7. Normal stress in the global Y direction of the side panel made from Norway spruce

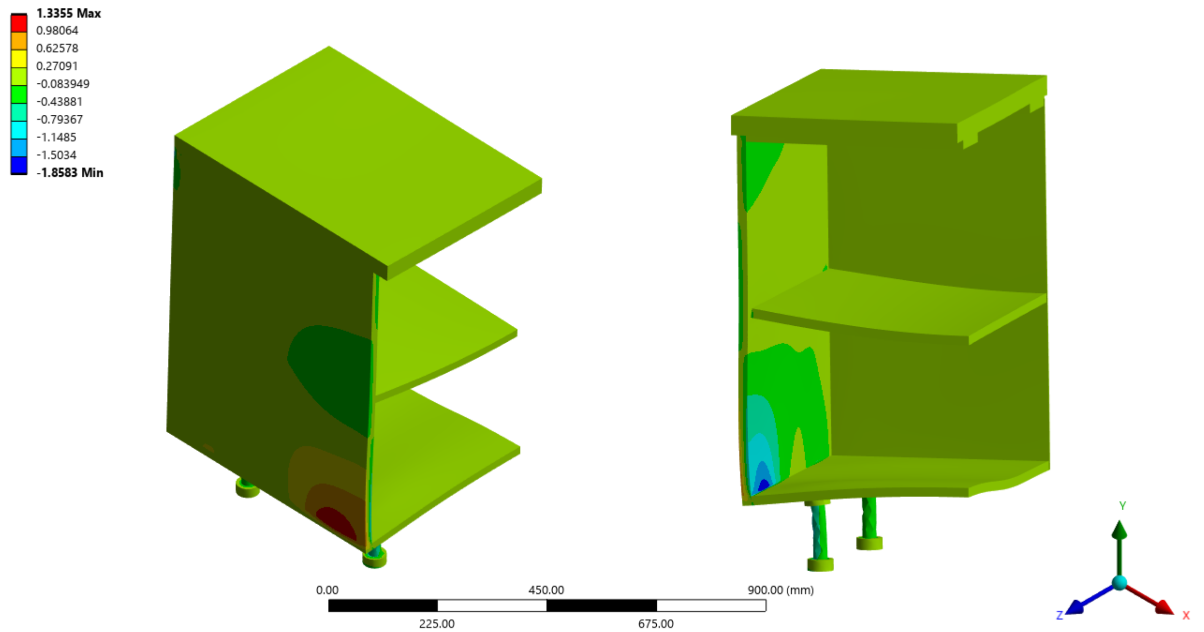

Figure 8. Normal stress in the global Y direction of the side panel made from Hungarian poplar

5. Conclusions

In this study we employed numerical simulation to compare the performance of two materials (Norway spruce, a traditional softwood, and grey poplar, an underutilized hardwood species in Hungary) in a set of kitchen furniture system. Using a static structural simulation under the assumption of linear elasticity, the analysis revealed that both materials performed comparably in the modeled structure. The findings highlight the value of numerical investigations as a powerful tool for gaining insights into material behavior, particularly for underutilized hardwood species like grey poplar. However, the limited availability of orthotropic elastic constants for grey poplar underscores the need for a thorough mechanical characterization of this species to support further research and applications. Future studies should extend this work by investigating the non-linear behavior of the materials, the interactions at joint contacts, and the dynamic response of the furniture under various loading conditions. Additionally, experimental testing of physical prototypes, following established experimental methodologies, would be essential to validate and complement the numerical results.

Author statements

Zsófia Benedek-Csányi – investigation, methodology, software, writing.
József Garab – conceptualization, methodology, software, writing, review and editing.

Funding information

This article was made in frame of the project TKP2021-NKTA-43 which 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 TKP2021-NKTA funding scheme.

References

ABH System. *HDF anyagtulajdonságok*. https://www.abh-system.hu/termekek_butorkeszitoknek/hdf-lapok/natur_hdf_lapok_3-4-5-6_mm

Ábri, T., Honfy, V. & Rédei, K., 2024. Simplified volume equations for grey poplar (Populus canescens Smith.) standing trees. *Acta Agraria Debreceniensis*, (1): 27–31. https://doi.org/10.34101/actaagrar/1/13858

Ábri, T., Keserű, Z., Honfy, V., Borovics, A. & Rédei, K., 2024. Stand structural analyses of grey poplar (Populus canescens) stands focused on the expected volume in Hungary. *Journal of Forest Science*, 70(10): 539–544. https://doi.org/10.17221/53/2024-JFS

Ashby, M., 2021. *Material property data for engineering materials*. Cambridge. https://www.ansys.com/content/dam/amp/2021/august/webpage-requests/education-resources-dam-upload-batch-2/material-property-data-for-eng-materials-BOKENGEN21.pdf

Bas, S., Denes, L. & Csiha, C., 2024. Mechanical Properties of Furniture Joints Using Loose Tenons and Connectors. *Forests*, 15(2). https://doi.org/10.3390/f15020343

Chen, Y. & Wu, Z., 2018. Study on structure optimization design of modified wood furniture tenon structure based on the finite element analysis of ANSYS. In *Journal of Intelligent and Fuzzy Systems*. https://doi.org/10.3233/JIFS-169385

Csanády, E., Kovács, Z., Magoss, E. & Ratnasingam, J., 2019. *Optimum Design and Manufacture of Wood Products*. https://doi.org/10.1007/978-3-030-16688-5

Fodor, F. & Mertl, T., 2023. A közönséges gyertyán (Carpinus betulus L.) jelenlegi helyzete és potenciálja az erdészetben és faiparban. *Erdészettudományi Közlemények*, 13(1). https://doi.org/10.17164/EK.2023.03

Gustafsson, S.I., 1995. Furniture design by use of the finite element method. *Holz als Roh- und Werkstoff*, 53(4). https://doi.org/10.1007/s001070050084

Hörig, H., 1933. Zur Elastizität des Fichtenholzes. *Zeitschrift für Technische Physik*, 12: 369–379.

Keunecke, D., Hering, S. & Niemz, P. 2008. Three-dimensional elastic behaviour of common yew and Norway spruce. *Wood Science and Technology*, 42(8). https://doi.org/10.1007/s00226-008-0192-7

Komán, S., Németh, R. & Báder, M., 2023. An Overview of the Current Situation of European Poplar Cultures with a Main Focus on Hungary. *Applied Sciences* (Switzerland), 13(23). https://doi.org/10.3390/app132312922

Mackerle, J., 2005. Finite element analyses in wood research: a bibliography. *Wood Science and Technology*, 39(7). https://doi.org/10.1007/s00226-005-0026-9

Mustafa Hilmi Colakoglu., 2012. Finite element analysis of wooden chair strength in free drop. International *Journal of the Physical Sciences*, 7(7). https://doi.org/10.5897/IJPS11.1229

Németh, G.,2023. *Termékszimuláció I.* (Product simulation I.). Előadás (Lecture notes).

Simek, M. & Sebera, V. 2010. *Traditional furniture joinery from the point of view of advanced technologies*. In Proceedings of the international convention of society of wood science and technology and United Nations economic commission for Europe—Timber Committee, Geneva, Switzerland. 11–14.

Szalai, J., 2001. *A faszerkezetek méretezését és gyártását befolyásoló sajátosságok*. Wittmann Gy. szerk.) Mérnöki faszerkezetek II., Mezőgazdasági Szaktudás Kiadó, Budapest: 143–258.

Tankut, N., Tankut, A.N. & Zor, M., 2014. Finite Element Analysis of Wood Materials. *Drvna industrija*, 65(2). https://doi.org/10.5552/drind.2014.1254

Tippner, J., Milch, J., Sebera, V. & Brabec, M., 2022. Elasto-plastic material model of oak at two moisture content levels. *Holzforschung*, 76(10). https://doi.org/10.1515/hf-2022-0008

Yu, R.Z., Liu, Y., Konukcu, A.C. & Hu, W.G., 2024. A method of simulating seat load for numerical analysis of wood chair structure. *Wood Res*, 69: 432–444. https://doi.org/10.37763/wr.1336-4561/69.3.432444