

Structural suitability of oak and spruce in highly loaded bed design

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Abstract

This study investigates the feasibility of using spruce and oak for a bed frame designed for all users, including those with higher body mass. Based on Slovak anthropometric data, optimal bed dimensions were established (2,400 mm L × 1,410 mm W × 660 mm H) for a design load of 250 kg. The structural performance of the side frame components was assessed using finite element analysis (FEA). Components made of spruce (C30) and oak (D50), with a cross-section of 200 mm × 20 mm, were subjected to the specified load. Simulation results were evaluated against a maximum permissible deflection of 7.2 mm. The oak component exhibited a maximum stress of 18.5 MPa and a deflection of 7.2 mm, satisfying both strength and deflection requirements. In contrast, while meeting the stress requirement with a maximum stress of 11.7 MPa, the spruce component exhibited a deflection of 8.4 mm, exceeding the limit. Therefore, only oak was deemed suitable for the bed frame's structural components. This research validates oak's potential as a sustainable alternative to metal in general-purpose furniture.

Key words: strength design; wood strength classes; sustainability; furniture design; inclusive design

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1. Introduction

Global obesity presents significant challenges for general-purpose furniture design, particularly in providing adequate support and comfort for all users. Current literature (e.g., Geary & Collins 2012; Dockrell & Hurley 2021) reveals that a substantial proportion of individuals with obesity experience difficulties with standard sleeping furniture and chairs due to insufficient structural capacity of the furniture. This underscores the critical need for human-centered design (HCD) approaches that address the diverse needs and preferences of all end-users, including those with obesity (Kuys et al. 2021).

While specialized bariatric furniture – particularly beds – addresses the needs of heavier users through reinforced structures and enlarged dimensions, these designs predominantly rely on metal for load-bearing components (Wignall 2008; Kramer-Jackman & Kramer 2010). Although wood may occasionally serve decorative purposes, its viability as a structural material in bariatric beds remains underexplored. In contrast, standard beds

with slightly increased load capacity offer a less stigmatizing alternative by maintaining conventional aesthetics. This approach ensures safety and comfort for users with increased body mass, while avoiding overt labeling and promoting inclusivity and dignity. By normalizing accessibility without singling out individuals based on weight, such designs align with broader efforts to reduce social stigma associated with everyday furniture use (Steinfeld & Maisel 2012).

Simultaneously, the furniture industry is facing increasing pressure to enhance its environmental sustainability (Ševčíková & Knošková 2021). Wood is a highly viable and ecologically beneficial alternative to petroleum-based plastics, metals, and heavily chemically treated wood composites (Bello-Bravo & Lutomia 2022). As a renewable resource, certified wood offers a potentially negative carbon footprint. Its inherent recyclability also reduces waste, aligning with essential principles for minimizing a product's life-cycle environmental impact (Jayalath et al. 2024; Yang & Vezzoli 2024). The scientific literature demonstrates that sustainable practices can

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be economically viable, offering cost-effective solutions for durable and accessible furniture (Maharlika 2022; Wieruszewski et al. 2023).

A clear gap exists in the application of wood as a primary structural material in high-load applications like bed frames. This is driven by the established need for inclusive furniture design for individuals with obesity and the imperative for sustainable material choices. This approach places greater demands on both the quality of wood materials and the methods used for their assessment, particularly in the context of solid furniture manufactured from hardwood species. Additionally, it raises concerns regarding occupational health and safety during the procurement of these materials (Suchomel & Gejdoš 2010; Gejdoš et al. 2019). Despite the availability of insights into sustainable timber design, including advanced timber technologies and connections for enhanced structural integrity (Dickson & Parker 2014), the specific application of these to the structural demands of bariatric beds, notably their side rails, has yet to be comprehensively explored.

Therefore, this study investigates the feasibility of using wood as a primary structural material in bed frames, focusing on the design and structural performance of the wooden side rails. By integrating sustainable material selection, ergonomic design, and human-centered principles, this research proposes a pathway for creating functional, environmentally responsible, and inclusive furniture that addresses the specific needs of users with higher body mass while contributing to a broader shift towards sustainable practices in the furniture industry.

2. Design criteria for beds designed for bariatric users

2.1. Characteristics of beds designed for bariatric users

In Europe, platform beds feature a base that directly supports the mattress, eliminating the need for a box spring. This base, or foundation, provides stability and secures the mattress. While some bases are solid, others use sprung slats to provide flexibility. The side frame members are the primary structural components, bearing the majority of user weight. The European standard EN 1725 (2023) establishes minimum safety, strength,

and durability requirements for adult beds in both domestic and non-domestic environments, encompassing all components. However, the testing procedures are based on a simulated user weight of up to 110 kg. Research suggests that this load capacity may be insufficient. Réh et al. (2019), analysing the Slovak population, propose a minimum design load of 150 kg. Similarly, Gallagher et al. (2004) recommend weight limits for standard single beds ranging from 159 to 227 kg, with widths ranging from 86 to 91 cm. Individuals who exceed these limits, or those with a high BMI, may require bariatric beds. Studies indicate that a BMI greater than 55 or a weight greater than 147 kg requires a bariatric bed due to its enhanced capacity and specialized features (Bakewell 2007). Furthermore, Wiggermann et al. (2017) found that patients with a BMI greater than 35 kg m² lack sufficient space to turn comfortably in a standard bed.

Gherzi et al. (2018) note that recent advances in medical-bed technology introduce new features and functions designed to meet specific patient requirements. These innovations—together with evolving design concepts and manufacturing processes—suggest that the load capacity and usable area of beds commonly supplied to hospitals should also be re-evaluated.

2.2. Determining weight limit and dimensions of beds designed for bariatric users

Hitka et al. (2022) collected data on body mass and height from bariatric patients in Slovakia via healthcare facilities between 2020 and 2023. The descriptive statistics for these data—including average body mass, height, BMI, and other parameters—are presented in Table 1.

To effectively accommodate users of varying heights, the dimensions of the bed's lying surface can be established by referencing average male height, which generally accounts for the height difference between men and women. Equation 1 calculates the length of the lying surface (L_p) by factoring in average male stature (TV_m), standard deviation (s_x), and a comfort factor (K_p) that varies depending on the bed's location in the room.

$$L_p = TV_m + 2s_x + K_p \quad [1]$$

The width of the lying area (B_p) was determined using Equation 2. This ensures that the bed width provides

Table 1. Descriptive statistics of the Slovakian bariatric population in 2020–2024.

Parameter	n	A. Mean	Median	Min.	Max.	Percentiles					Std. Dev.
						1	5	50	95	99	
Body weight (kg)	319	142.61	138.00	93.00	242.00	97.50	102.00	138.00	193.00	214.00	27.50
Body height (cm)	319	170.92	170.00	150.00	199.00	150.00	155.00	170.00	183.00	196.00	9.20
BMI (kg m ²)	319	48.80	47.17	33.12	89.74	38.56	47.18	59.49	65.61	76.37	7.86
Waist circumference (cm)	319	136.43	135.00	100.00	188.00	109.00	113.00	135.00	169.00	181.00	16.87
Hip circumference (cm)	319	146.47	145.00	108.00	192.00	113.00	123.00	145.00	176.00	186.00	15.28
Waist width (cm)	319	43.46	42.99	31.84	59.87	34.71	35.98	42.99	53.82	57.64	5.32
Hip width (cm)	319	46.64	47.18	34.39	61.14	35.98	39.17	46.17	56.05	59.23	4.87

enough space for a bariatric user to turn comfortably in both directions without requiring lateral body repositioning (Prokopec 1998).

$$B_p = 2 \cdot (BW_m + 2s_x) + 0.25 [2 \cdot (BW_m + 2s_x)] \quad [2]$$

Equation 2 includes the maximum body width BW_m (“Hip width” parameter from Table 1), with a 25% increase to facilitate unrestricted turning during sleep. The height of the lying surface was calculated based on the average height of a man and adjusted to accommodate standing egress for individuals with bariatric needs. Table 2 summarizes the results of these calculations.

Table 2. Recommended bed dimensions accommodating bariatric users, by room type (Hitka et al. 2022).

Bed dimensions	Room type	Proposed value (cm)
Length (L_p)	Smaller room space	220
	Middle room space	230
	Large room space	240
Width (B_p)	For all room types	141
Height (h_p)	For all room types	66

The values in Table 2 ensure comfortable use and easy repositioning for most users. While specifically determined for bariatric individuals, these dimensions offer a generous size that comfortably accommodates the general population.

Bariatric user needs include not only their body dimensions but also, crucially, their weight, which often far exceeds that of the standard population. Figure 1 illustrates a typical wooden platform bed frame design, featuring basic dimensions and structural components.

2.3. Methodology for strength assessment of bed components

An essential stage in the bed design process involves assessing the strength of its components in relation to the expected load imposed by a bariatric individual. It is crucial to note that the side rails typically bear the highest load. While the load on connections between bed components – particularly those joining the side frame members to the headboard and footboard – cannot be overlooked, this study primarily focuses on the strength and deformation properties of the side frame member itself, rather than the strength analysis of the joints (Réh et al. 2019).

Critical values in the stress-strain state of the side frame member (side rail) occur when the bariatric person is sitting in the middle section of the side rail. When a bariatric person sits on the bed as described above, the load from their weight is transferred through the mattress and lamellae to the side rail. This means that the resultant force acts eccentrically on the side rail, causing both vertical and lateral deformation.

A prerequisite for the reliable and safe use of the bed under the considered load is compliance with the strength and deformation conditions defined by the limit states. In general, the following strength conditions must be met when evaluating bed components:

$$S_d \leq R_d \quad [3]$$

where S_d is the design value of the action effect (the internal force, stresses, etc.), caused by the considered

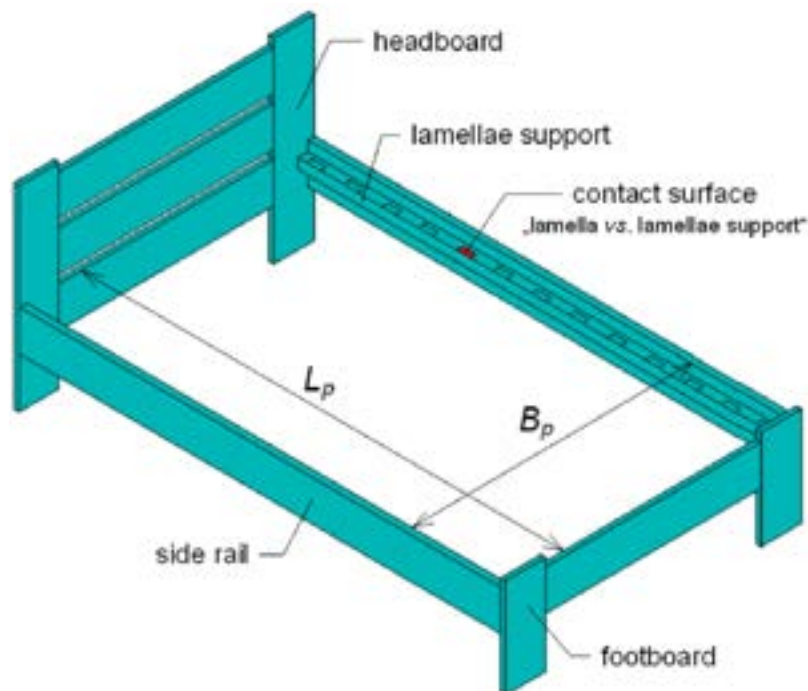


Fig. 1. Typical design of a wooden platform bed frame.

load, and R_d is the design value of the resistance (i.e. load-carrying capacity) (Hitka et al. 2018; Ranasinghe 2021).

Design resistance values for a given material are defined as:

$$f_d = k_{mod} \frac{f_k}{\gamma_M} \quad [4]$$

where f_k is the characteristic strength value for a given wood material, k_{mod} is the modification factor accounting for the loading process and moisture, and γ_M is the partial factor for the material property.

In addition to the strength limits, the side frame rails must also meet the deformation requirements. The requirement for admissible deformation of the bed frame member is met if the maximum deflection caused by the load is less than $L_0/333$ (L_0 – length of frame member).

As mentioned above, the assumed load acting on the side rail causes its vertical and lateral deformation, resulting in a specific stress state in the side rail.

3. Computational model of the bed frame

The strength and deformation analysis of the bed's side rail was investigated using the finite element method. Numerical simulations and calculation procedures were performed using the engineering simulation software ANSYS 2023 R2 (Ansys Inc., Canonsburg, PA, USA) (2023). The 3D calculation model of the bed structure is shown in Figure 1, and the bed dimensions are presented in Table 3.

Since the bed structure is symmetrical regarding the XY plane, a symmetric half-model was employed to optimize computational efficiency while considering the bed structure, loading conditions, and study objectives (Fig. 2a). Symmetry conditions are applied to the computational finite element model.

Table 3. Bed dimensions for strength and deformation analysis.

Parameter	Value			
Length, L_p (mm)	2,400			
Width, B_p (mm)	1,400			
Height of cross-section – side rail, h_{bsr} (mm)	200	250	300	
Thickness of cross-section – side rail, t_{bsr} (mm)	20	25	30	35
Width of cross-section – lamellae support, b_0 (mm)	50			
Height of cross-section – lamellae support, h_0 (mm)	40			
Height position of the lamellae support, h_{op} (mm)	$\langle 10 + h_0; h_{bsr} - 10 \rangle$			
Weight of a bariatric user, m_b (kg)	250			

Two wood types – spruce (C30) and oak (D50) – were selected for the bed frame model. The corresponding material properties are detailed in Table 4.

Table 4. Material properties of wooden materials used in FEM modelling (Niemz et al. 2023).

Physical properties		Spruce C30	Oak D50
Young's modulus (GPa)	E_L	10.00	13.00
	E_T	0.45	0.92
	E_R	0.80	1.58
Shear modulus (GPa)	G_{LR}	0.60	1.15
	G_{LT}	0.65	0.80
	G_{RT}	0.04	0.40
Poisson's ratio (–)	μ_{LR}	0.041	0.044
	μ_{LT}	0.033	0.027
	μ_{RT}	0.350	0.330

In the context of structural timber, classifications such as “Spruce C30” and “Oak D50” denote the material's strength class, as defined by European standards (EN 338 2016). Specifically, the prefix “C” (e.g., in C30) designates coniferous wood (softwoods) like spruce, pine, or fir, while “D” (e.g., in D50) refers to deciduous wood (hardwoods) such as oak, beech, or maple. The numerical value accompanying these letters, ‘30’ or ‘50’, quantifies the characteristic bending strength of the timber in Newtons per square millimetre (N/mm²).

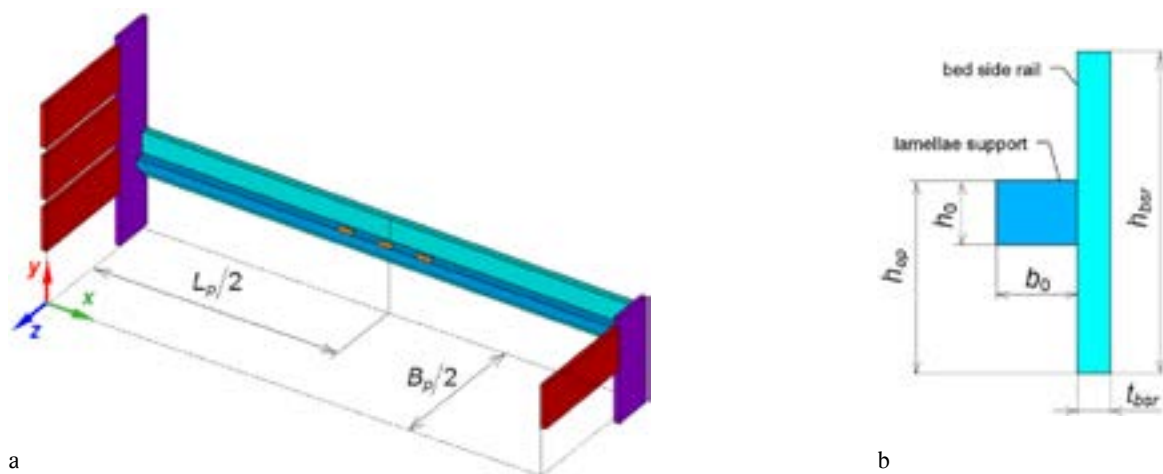


Fig. 2. A half computational model of the bed: a – assignment of physical properties to components (Tables 4 and 7); b – cross-section dimensions of the side rail showing the position of the lamellae support.

The material properties listed in Table 4 were assigned to the bed components in the calculation model (Fig. 2a, Table 5 – considering the coordinate axes of the calculation model). This assignment accounted for the orthotropic properties of the examined woods and the wood fibre orientation related to the real-world structure.

Table 5. Assigning mechanical properties to the analyzed bed components according to the coordinate system in the ANSYS model.

Mechanical properties	①		②		③	④
	E_L	E_x	E_y	E_z	E_x	E_x
Young's modulus (GPa)	E_T	E_y	E_z	E_y	E_z	E_z
	E_R	E_z	E_x	E_x	E_y	E_y
Shear modulus (GPa)	G_{LR}	G_{xz}	G_{xy}	G_{yz}	G_{xy}	G_{xy}
	G_{LT}	G_{xy}	G_{yz}	G_{yz}	G_{xz}	G_{xz}
	G_{RT}	G_{yz}	G_{xz}	G_{xy}	G_{yz}	G_{yz}
Poisson's ratio (–)	μ_{LR}	μ_{xz}	μ_{xy}	μ_{yz}	μ_{xy}	μ_{xy}
	μ_{LT}	μ_{xy}	μ_{yz}	μ_{yz}	μ_{xz}	μ_{xz}
	μ_{RT}	μ_{yz}	μ_{xz}	μ_{xy}	μ_{yz}	μ_{yz}

L – longitudinal, *T* – tangential, *R* – radial

The strength properties of both types of wood are determined by their assumed properties in the standard (EN 338 2016), i.e. spruce (C30) and oak (D50), and these are shown in Table 6.

Table 6. Strength properties for the considered types of wooden materials EN 338 (2016).

Strength characteristics		Strength properties (MPa)	
		Spruce C30	Oak D50
Characteristic strength values	bending	$f_{m,k}$	30.0
	tensile	$f_{t,0,k}$	19.0
		$f_{t,90,k}$	0.4
	compression	$f_{c,0,k}$	24.0
		$f_{c,90,k}$	2.7
	shear	$f_{v,k}$	4.0
The corresponding design values of resistance (determined by Eq. 4)	bending	$f_{m,d}$	18.0
	tensile	$f_{t,0,d}$	11.7
		$f_{t,90,d}$	0.2
	compression	$f_{c,0,d}$	14.8
		$f_{c,90,d}$	1.7
	shear	$f_{v,d}$	2.5

The effect of the bariatric person's weight, acting on the side of the bed, is not a concentrated force, but due to the mattress and the slats, it is distributed over the surface. In the calculation model, the side rail is loaded by pressure on the three contact surfaces on the lamellae support (Fig. 2a), while the resulting loading effect corresponds to the weight of a bariatric user.

4. Results

The data presented in Figures 3–5 characterize the structural response of the oak wood bed frame model subjected to a 250 kg load, specifically displaying the vertical deflection

(u_y , Fig. 3), lateral deflection (u_z , Fig. 4), and tensile stress (s_x , Fig. 5). The model has a side rail height (h_{bsr}) of 200 mm, a thickness (t_{bsr}) of 20 mm, and a lamella support position (h_{op}) of 50 mm. Figure 3 illustrates greater vertical deflection (u_y) in the central section of the rail, where the deformation is most significant. The maximum vertical deflection is 0.0062 m, or 6.2 mm.

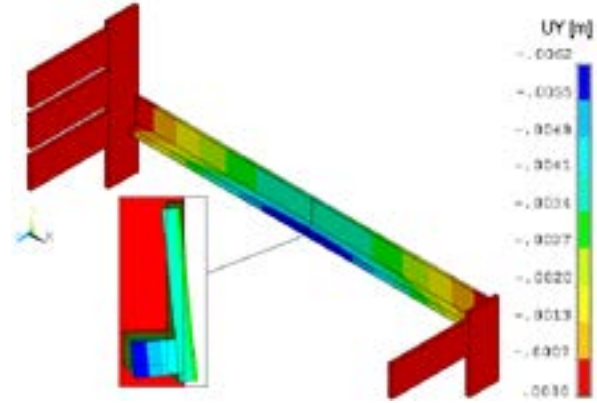


Fig. 3. Vertical deflection u_y of the side rail (oak wood) ($h_{bsr} = 200$ mm; $t_{bsr} = 20$ mm; $h_{op} = 50$ mm; $m_b = 250$ kg).

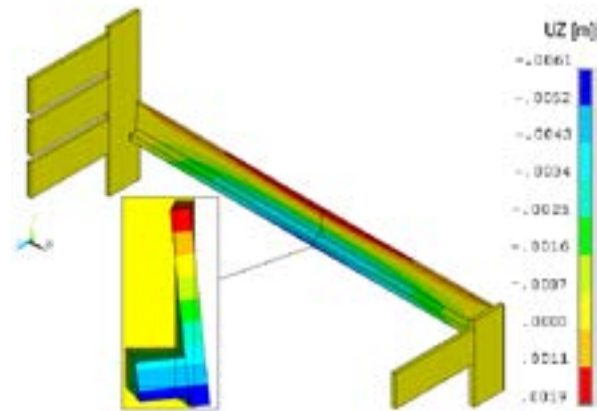


Fig. 4. Lateral deflection u_z of the side rail (oak wood) ($h_{bsr} = 200$ mm; $t_{bsr} = 20$ mm; $h_{op} = 50$ mm; $m_b = 250$ kg).

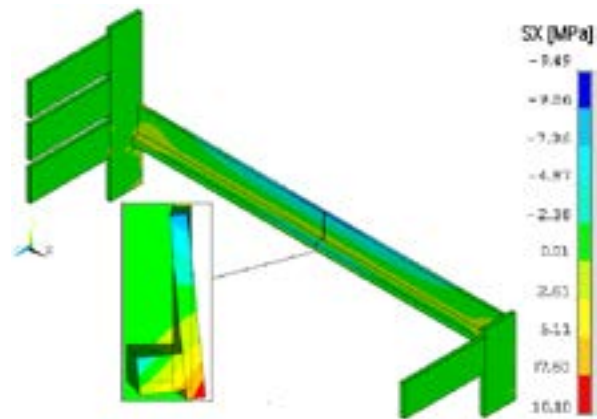


Fig. 5. Tensile stress s_x of the oak wood side rail ($h_{bsr} = 200$ mm; $t_{bsr} = 20$ mm; $h_{op} = 50$ mm; $m_b = 250$ kg).

The maximum lateral deflection is 0.0061 m, or 6.1 mm, as shown in Figure 4.

Figure 5 shows the tensile stress (s_x) distribution within the oak wood side rail. The highest tensile stress is concentrated at the base of the rail where it connects to the supporting leg, reaching a maximum value of 17.60 MPa. This area of high stress is visible in the zoomed-in inset of the image.

The dimensions of the cross-section of the side rail (height – h_{bsr} and thickness – t_{bsr}) have a crucial influence on its vertical deflection. The dependence of the

vertical deflection of the oakwood side rail on the thickness of t_{bsr} for different heights of h_{bsr} is shown in Fig. 6a. The inherent differences in the physical properties of wood types, exemplified by oak and spruce wood, have a significant effect on the vertical deflection of the side rail (Fig. 6b).

The influence of the height position of the lamella support (h_{op}) significantly affects the lateral deflection of the side rail analyzed (Fig. 7 – oak). The value of the lateral deflection of the side rail (Fig. 8) is also influenced by the type of wood (oak, spruce) used.

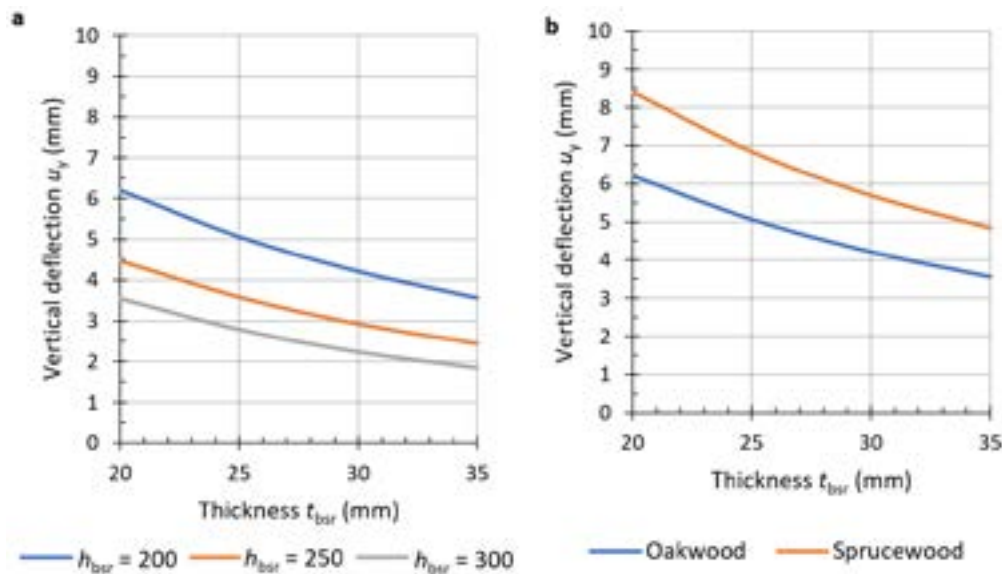


Fig. 6. Vertical deflection u_y of the side rail ($h_{op} = 50$ mm; $m_p = 250$ kg): a – effect of thickness (t_{bsr}) side rail (oak wood) – for different heights (h_{bsr}); b – effect of different types of wood (oak and spruce).

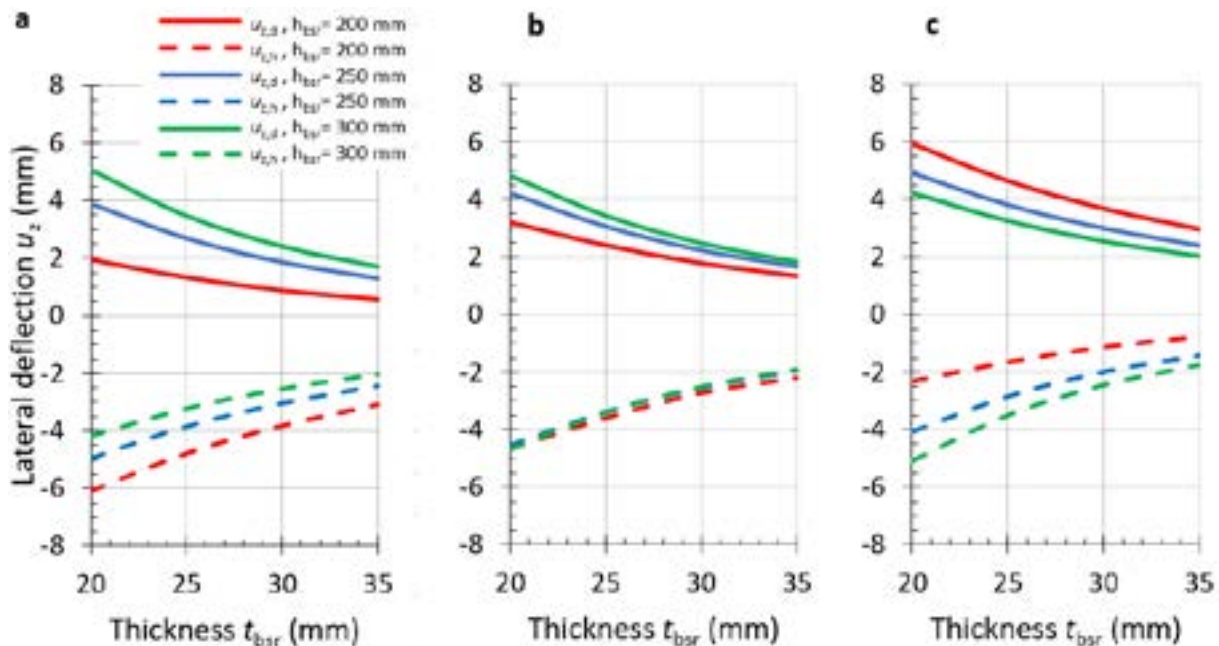


Fig. 7. Lateral deflection u_z of the side rail (oak wood) ($m_p = 250$ kg): a – the lowest position of h_{op} , b – the center position of h_{op} , c – the highest position of h_{op} .

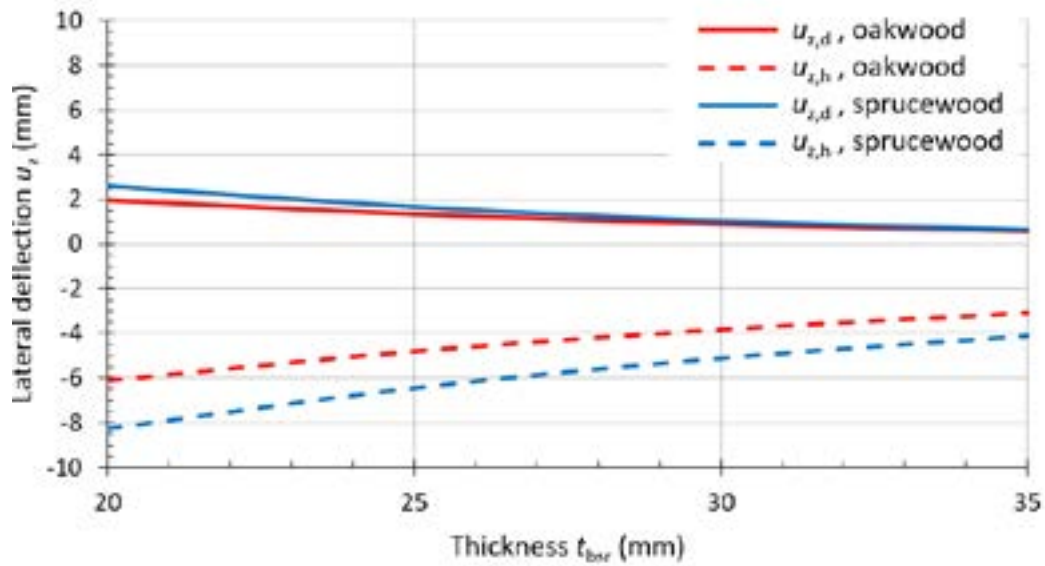


Fig. 8. Lateral deflection u_z of the side rail (oak and spruce wood) ($h_{op} = 50$ mm – the lowest position, $h_{bsr} = 200$ mm; $m_b = 250$ kg).

In addition to strength and deformation analyses, the study investigated the influence of the lamella support position on vertical deflection (u_y , Fig. 9a), lateral deflection (u_z , Fig. 9b), and tensile stress (s_x , Fig. 10). As shown in Fig. 9a, the variation in the lamella support position had a negligible effect on the vertical deflection of the side rail. However, the impact on lateral deflection was significant (Fig. 9b). Specifically, when the lamella support was in the lowest position, the edge of the support experienced an outward push, which could potentially cause the central lamellae to dislodge. Conversely, when the support was placed higher on the side rail, the upper

part of the frame member, and consequently the edge of the support, deflected inwards. This inward deformation effectively prevents the lamellae from falling out.

The height position of the lamellae support h_{op} also has a significant influence on the tensile stress values in the side of the bed. If the lamellae support position is in the upper part of the side rail ($h_{op} > h_{bsr}/2$), a specific decrease in tensile stress occurs.

The maximum values of the deflections of the side rail (length: $L_0 = 2,400$ mm) were calculated for the smallest cross-sectional dimensions considered $h_{bsr} = 200$ mm; $t_{bsr} = 20$ mm, and for $h_{op} = 50$ mm.

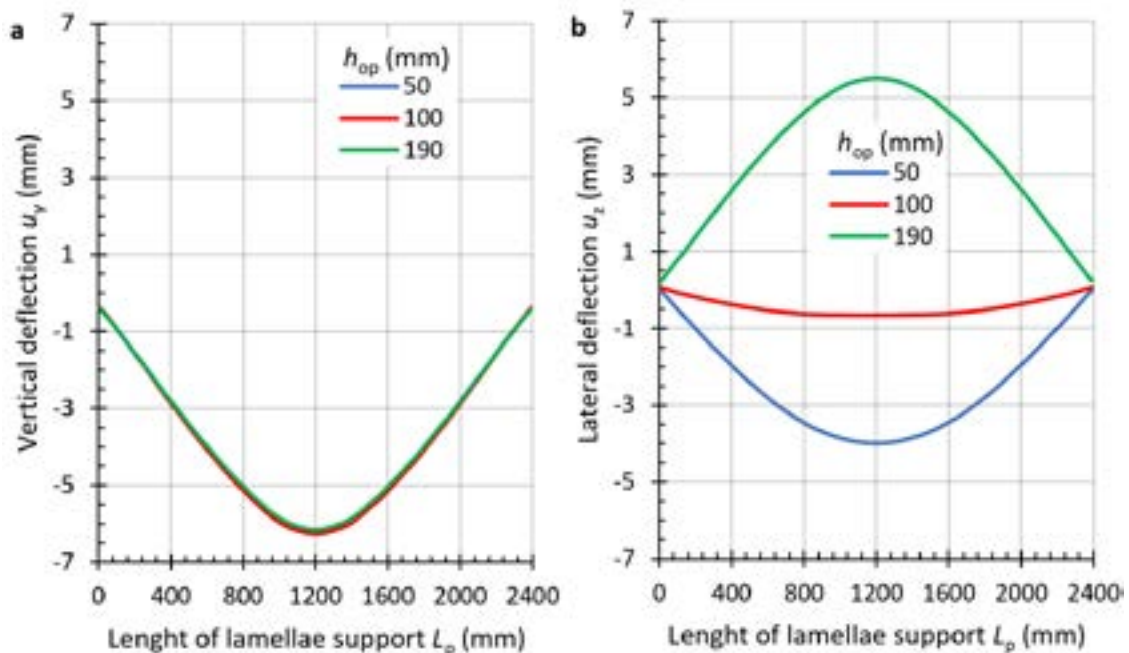


Fig. 9. Vertical deflection u_y of the side rail (oak wood) ($h_{bsr} = 200$ mm; $m_b = 250$ kg): a – vertical deflection, b – lateral deflection.

The vertical deflection u_y for spruce and oak wood, along the side of the bed, is shown in Fig. 11a. The maximum value of vertical deflection is $u_y = 6.2$ mm for oak and $u_y = 8.4$ mm for spruce.

Lateral deflection $u_{z,d}$ for spruce and oak wood, along the length of the lamellae support, is shown in Fig. 11b. The maximum value of lateral deflection is $u_{z,d} = 3.9$ mm for oak and $u_{z,d} = 5.3$ mm for spruce.

5. Discussion

The finite-element analysis (FEA) confirmed that oak can satisfy the deflection limits imposed on highly-loaded bed frames, whereas spruce does not. The spruce side rail (200 mm × 20 mm) showed a deflection of 8.4 mm under a 250 kg vertical load, exceeding the permissible maximum of 7.2 mm. In contrast, oak wood remained within the allowable deflection (6.2 mm).

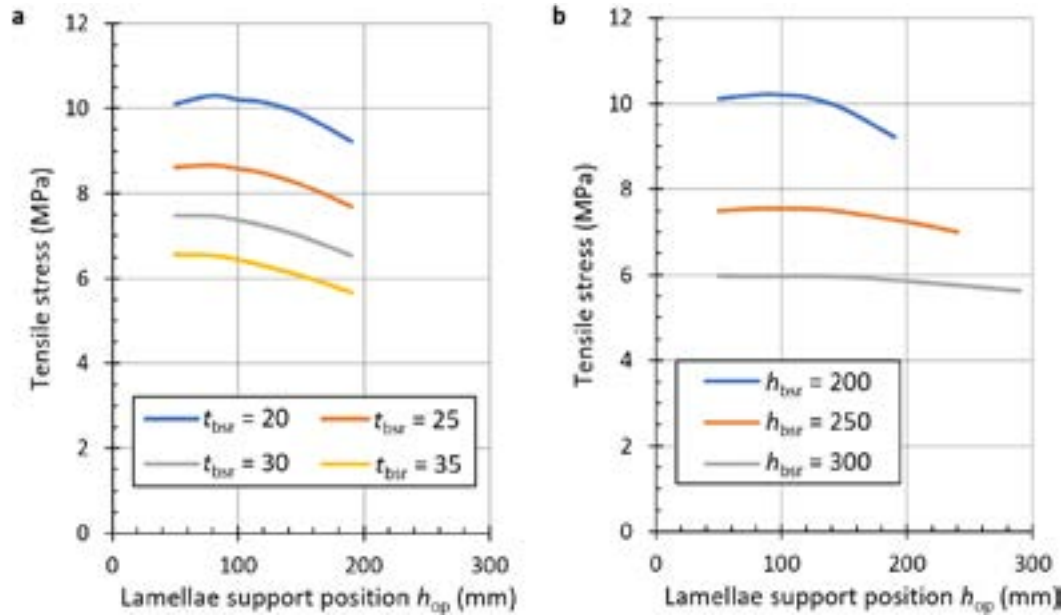


Fig. 10. Dependence of tensile stress s_x in the side rail (oak) ($m_b = 250$ kg): a – width of the section of the side of the bed side rail (t_{bsr}), b – height of the side rail (h_{bsr}).

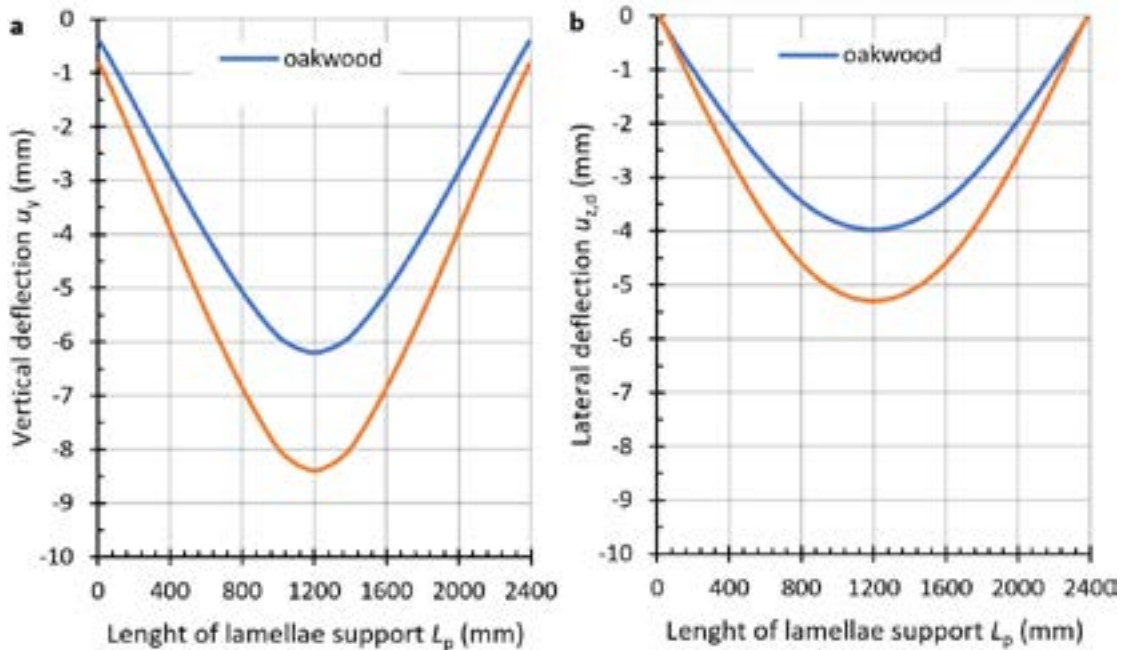


Fig. 11. Vertical (a) and lateral (b) deflection along the bed length ($h_{op} = 50$ mm, $h_{bsr} = 200$ mm, $m_b = 250$ kg): a – vertical deflection, b – lateral deflection.

These results underline the decisive influence of wood-specific mechanical properties on the performance of bed frames. The modulus of elasticity (MOE) of mature *Quercus* spp. (oak) is roughly three times that of *Pinus* spp. (pine) – MOE $\approx$ 13 GPa for oak versus $\approx$ 5 GPa for pine (Bartolucci et al. 2020). Consequently, oak exhibits a higher modulus of rupture (MOR) and lower elastic strain for a given load, delivering the stiffness required to limit deflection. Oak's higher density ($\approx$ 0.70 g cm⁻³) further contributes to its superior load-bearing capacity and reduced deflection under the 200–250 kg design loads typical for bariatric beds.

The analysis demonstrated that the side rail's dimensions – height (h_{bsr}) and thickness (t_{bsr}) – are crucial for controlling deflection and stress. Increasing these dimensions significantly reduces vertical deflection, consistent with fundamental engineering principles where a larger moment of inertia enhances bending resistance (Gere & Timoshenko 1997). Similarly, tensile stress (s_x) is highly dependent on cross-sectional geometry; increasing h_{bsr} and t_{bsr} decreases stress concentration. The highest tensile stress (17.60 MPa for oak) was observed at the base of the rail where it connects to the supporting leg (Figure 5), identifying a critical point that may require reinforcement or careful joint design to prevent failure.

The position of the lamella support (h_{op}) was found to have a negligible effect on vertical deflection but a significant effect on lateral deflection. As illustrated in Figure 9b, a lower support position results in outward lateral deflection, risking lamellae dislodgement. Conversely, placing the support higher on the side rail causes inward deflection, which effectively prevents lamellae from falling out. This is a key design insight for enhancing structural stability and safety. Furthermore, a higher support position ($h_{op} > h_{bsr}/2$) leads to a specific decrease in tensile stress, reinforcing the dual benefit of this design feature (Grekin 2006).

The side-by-side comparison of oak and spruce (Figure 11) conclusively demonstrates oakwood's superior performance. For identical dimensions and load, spruce exhibited significantly greater vertical and lateral deflections (8.4 mm vs. 6.2 mm vertical; 5.3 mm vs. 3.9 mm lateral). These results align with the literature, which reports that mature *Quercus* spp. (oak) typically has a modulus of rupture (MOR) and modulus of elasticity (MOE) 2–3 times higher than *Pinus* spp. (pine) (Bartolucci et al. 2020). While engineered wood products (e.g., laminated veneer lumber, LVL) can enhance spruce's performance, solid oak provides the necessary balance of mechanical performance and cost-effectiveness for the structural components of universally designed beds.

6. Conclusion

As noted in the Introduction, the prevalence of obesity has risen significantly worldwide. As obesity becomes a growing social challenge, a multidisciplinary approach, including engineering-level interventions, is needed. Manufacturers must adapt everyday consumer goods to meet these changed needs. One such area requiring adaptation is wooden furniture. This study examines the influence of material properties of two wood types – oak and spruce, commonly used in Europe – on the strength and deformation of the side frame members of the bed base. We performed computational analyses to determine the stress-strain state of the side frame member with various cross-sectional heights (h_{bsr}) and thicknesses (t_{bsr}). Additionally, we investigated how the position of the lamellae support (h_{op}) affects the vertical (u_y) and lateral (u_z) deflection, as well as the tensile stress (s_x) in the side rail. This analysis considers two essential requirements: the maximum allowable tensile stress (also known as the 'corresponding design value of resistance') for C30 spruce ($f_{t,0,d} = 11.7$ MPa) and D50 oak ($f_{t,0,d} = 18.5$ MPa), and the maximum allowable deflection of the side frame member ($u_{y,allow} = 7.2$ mm).

This study yielded the following key findings:

1. Simulations of a 250 kg load on the specified side rail dimensions (2,400 mm length, 200 mm $\times$ 20 mm cross-section, 50 mm support position) revealed that only oak wood (D50) met both the maximum allowable tensile stress and deflection limits. While spruce (C30) met the tensile stress criterion (11.7 MPa), its excessive vertical deflection (8.4 mm) exceeded the allowed limit (7.2 mm), indicating a possible risk of instability and compromised user safety.
2. Within the analyzed dimensions and loading conditions, oak wood (D50) demonstrated suitability for bariatric side rails, exhibiting superior strength and compliance with deflection requirements. Although spruce wood (C30) possesses adequate tensile strength, its excessive bending under load renders it unsuitable in its current dimensions. The side rail cross-sectional dimensions must be modified to meet strength and deflection criteria, enabling the use of spruce wood.

The study results emphasize the importance of considering both strength and deformation properties in bed frame design, particularly when accommodating loads from seated bariatric users, which can lead to vertical and lateral deformation. Furthermore, the findings demonstrate that while wood is a viable material for "universally designed" beds, carefully selecting wood species and making appropriate design modifications are essential to ensure the structural integrity, safety, and functionality of general-purpose furniture.

Study limitations

The findings of this study should be interpreted considering the following limitations. First, the investigation was restricted to two solid wood species (oak and spruce); therefore, the generalizability of the results to other materials, such as wood-based composites, is limited. Second, the analysis focused on component-level structural integrity (side rails) and did not account for the critical effects of joints or connections, which can significantly impact the overall performance and durability of the assembly. Third, the study's conclusions are based solely on numerical simulations. Without physical prototyping and testing, the results remain uncorroborated by empirical data, and the model's fidelity to real-world conditions is not experimentally confirmed.

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