The Effect of Body Mass on Designing the Structural Elements of Wooden Chairs

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This study aimed to evaluate the effect of increased body mass of users on the structural loading of wooden chair elements following the changes in anthropometric parameters in the adult population of the Slovak Republic. Moreover, the functional parts of a wooden chair most affected by the weight gain of an adult population were defined. The strength analysis of the tested chair was conducted using the program ANSYS. In the software environment, the 3D volume model taking into consideration orthotropic properties of wood was created. The structural elements of chairs for the current adult population are designed for the weight of 110 kg. The results suggest that the weight necessary for designing the structural elements of chairs must be 150 kg (130 kg + 15%). Comfort, physical health, well-being, performance, and security can be increased by designing such a device and equipment meeting the needs of the human body in a long-term viewpoint. It is suggested to create the standard taking into account men with a weight of up to 150 kg. Based on the results of the strength analyses, a chair load with a user's weight of 150 kg will require a change in the dimensions of the side rails and the cross-section of the legs. The new knowledge gained is helpful for a better design of chair wooden elements taking into account the anisotropic (directional) structure of natural wood.

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INTRODUCTION

Automation, robotization, and chemical or biological treatment during production can increase productivity in the workplace, but these methods can increase the demand for natural resources. Thus, the environment is affected, and carbon dioxide emissions are produced. The carbon footprint of a product or activity is defined as the total amount of greenhouse gases generated during production and product lifecycle. Because producers try to minimise it, renewable materials such as wood must be used to the maximum extent.

Wood is a unique material utilised everywhere, in all spheres of life. Among the materials used in furniture manufacture (wood, plastics, metal, glass), its carbon footprint is the lowest one (Sandak *et al.* 2019). Considering its workability, sustainability, and practical utilisation, wood is an attractive material that is preferred in the furniture manufacturing industry.

The ergonomic standards in designing the living space must be adapted to reflect increases in the body dimensions and weight of a population. When designing strength characteristics of wooden chairs, the European standard EN 1335-1 (2020) is used. To date, the effect of anthropometric measurements on individual structural elements of wooden chairs has been taken into account only in the case of adolescent population in schools or in terms of minimising health problems (Van Niekerk *et al.* 2016).

The issue of designing the structural elements of wooden chairs is extensively described in previous studies (Fenety *et al.* 2000; Norman *et al.* 2004). Most of the studies are focused on the correct sitting posture and health problems resulting from it (Carayon and Smith 2000; Robertson *et al.* 2013). Muscular-skeleton pain and aches, headache, *etc*. are especially discussed (Kuster *et al.* 2018; Bontrup *et al.* 2019). Designing the furniture should correspond with anthropometric data of the main user population (Macedo *et al.* 2014). In an effort to adapt sizes of the everyday objects to the sizes of final users, designers and constructors draw on the results from the actual anthropometric research, *e.g.*, body height, weight, and BMI index (Body Mass Index) when designing and dimensioning an interior or objects (Andersson and Ortengren 1974; Spryropoulos *et al.* 2007). The changes in BMI in the past decades have been confirmed by several works (Stevens *et al.* 2012; Gomula *et al.* 2015). In many developed countries, trends in an increase in body height are slowing down, even though the weight gain is still in progress (Cardoso and Padez 2008; Lu *et al.* 2015). A secular trend can be considered an indicator of health, welfare, improved nutrition, and healthcare (Schell and Knutsen 2002; Komlos 2003). Besides health and nutrition, the growth reflects hygiene (Fogel 1986). A secular trend can be observed worldwide. It results from the changes in lifestyle, improved healthcare, miscegenation, and psychosocial changes (Schell 1986; Bogin 1999). It is similar all around the world, with the differences only in its speed and timing (Morgan 2000). The measurements are aimed at the specific points on upper and lower limbs, head, trunk, and the body mass index (BMI), used to evaluate the adequacy of body weight to height (Chen *et al.* 2016). It is a very effective and simple measurement (Hajdarevic *et al.* 2016). Moreover, in many countries of central Europe, there are studies dealing with the issue of an increase in body dimensions of an adult population as well as a secular trend (Zellner *et al.* 2004; Bodenhorn 2010). Weight gain of a population in many countries is due to many factors associated mainly with improved living standards, reflecting the nutrition and lifestyle (Tanner 1992; Eaton *et al.* 2012). An increase in height can be explained as an impact of the changes in civilization development. The height of children and teenagers is a good sign of this trend (Vignerová *et al.* 2006). Anthropometric data corresponding with the human body morphology, its size, structure, form, and composition elucidate the quality of life of a specific population (Widyanti *et al.* 2015). The values of biological characteristics of the human body depend upon endogenous and exogenous factors, the effect of the environment, and social and economic factors (Havari and Peracchi 2017). The nutrition of the specific population is affected by the socio-economic variables (Komlos and Lauderdale 2009); a higher *per capita* income results in more available, higher quality food. Known in the literature is the secular trend in human body mass (Kelly *et al.* 2008). Regular and high-quality nutrition is an important factor supporting normal growth and development. Individual differences result from genetic variation and from the nutrition and economic situation during growth. To account for changes in population weight, the database must be updated regularly.

Human health is affected, to a great extent, by the furniture available to sit on. The wrong material or poor ergonomics can cause tiredness, fatigue, allergy, risk of somatic mutation, or latent infection (Neykov *et al.* 2020). Wooden seating furniture is characterized by a large variability of dimensions and mechanical properties (Branowski *et al.* 2020). In this paper, the focus is only on chairs with standard construction. The construction of the chair must be stable for everyday use and especially when sitting down and getting out of it. Adequate stability must be ensured also when sitting on some part of the furniture including armrests. The furniture must not tip over, become damaged, or cause a user injury (Bonenberg *et al.* 2018). Once the chair is properly adjusted for the weight, its resistance to tipover is greater. The user's weight affects the structural elements directly due to mechanical load. The user's weight is an effect of mechanical load depending upon the way the furniture is used by the final user, *i.e.*, it depends on the interaction between the user and the furniture. The standards associated with designing the furniture to sit on and its components allow for a maximum weight of 110 kg. Due to rapid weight gain of the users, a higher weight limit should be debated. The joints and individual elements of the furniture are affected by the user's weight. The seating board is loaded with area load applying to the planar area of the structural element. The bending moment can be reduced by appropriate dimensions of the seat cross-section, whereby the seat size as width and depth must be designed to provide adequate space for the user. The armrest is loaded with the user's upper limbs. When designing the correct dimensions of cross-section as well as the length, the bending moment of the structural element can be eliminated. Considering the low weight of the user's upper limbs, the armrest load can be considered irrelevant. The bending load occurs in the case of loading the rails of the furniture to sit on them. The legs are deformed due to stress loading. When vertical force corresponding with the weight gain of a user increases, the legs of chairs bend or deflect. Deflection can be eliminated by designing the correct cross-section dimensions reflecting the increased weight of the users. Considering the cross-section dimensions of legs corresponding with the joint size and leg length, the buckling loading can be considered irrelevant. The authors including Kasal (2006), Kasal *et al.* (2016), Hu *et al.* (2019), Hajdarevic *et al.* (2020), Chen *et al.* (2022), and Güray *et al.* (2022) have dealt with the issue of optimising the furniture design using finite element methods (FEM).

The process of change is an inevitable part of the development of human society. It is a natural state of its development and existence. Technological development and social changes are parts of the process. The economy is one of the basic factors affecting technological development and social changes. The development of the population in all areas can be considered a further source of changes, from the population growth in some parts of the Earth to the technology advances and cultural development. In relation to social changes, the technological standards emerge and adapt. Ecological factors, lack of physical activities, constant watching TV, and bad eating habits can result in an increase in BMI very early (Deheeger *et al.* 1997). In all developed counties, changes in healthcare, social system, education, and food availability occur (Schmidhuber and Traill 2005). The percentage of people suffering from being overweight is growing annually. Overweight or obesity results from a long-term energy imbalance between calories consumed and calories expended due to lifestyle with not adequate sports activities. As this trend is global, the attention paid to the furniture items affected by the weight gain is in high demand.

Designing the furniture must correspond with the dimensions and weight not only of the current population but also of the coming generations. Structural elements of chairs determined for the current generation in the Slovak Republic are designed for a weight of 110 kg. All areas of human life are affected by technological development as a part of social changes. Anthropometric and ergonomic requirements are essential in relation to the shape and size of consumer goods. Human comfort, health, wellbeing, performance, and safety can be improved by designing such a device and equipment, which will meet the needs of the human body for a long time. Work and personal spaces and equipment used by people, which are in compliance with the anthropometric and biomechanical characteristics of the users, are some of the important conditions (Langova *et al.* 2021). Optimising the sitting posture and especially the construction of main components of chairs must correspond with the anthropometric parameters of the current generation (Tunay and Melemez 2008). Anthropometric and ergonomic requirements are also linked with health protection and work safety.

This study aimed to evaluate the effect of increased body mass of users on the structural loading of wooden chairs elements following the changes in anthropometric parameters in the adult population of the Slovak Republic. The new knowledge gained is helpful for a better design of chair wooden elements taking into account the anisotropic (directional) structure of natural wood.

EXPERIMENTAL

An increase in the load of the chair changes the tension of the individual furniture components, which requires the changes in the design dimensions of the chair components. The main aim of the expected construction changes associated with the weight gain of the users must be a decrease in values of mechanical stress and strain in chair components to the values accepted by the standards and avoid chair damage. The mechanical stresses in the chair components can be reduced by suitable changes in the cross-sectional dimensions of components. However, the dimensions of the chair seat such as width and depth must be designed to provide sufficient space for a comfortable seating for a user.

Regarding strength assessment, the chair structure must be resistant to the loads specified in the standards STN EN 1335 (2020), STN EN 1728 (2013), and STN EN 338 (2010). The load capacity analysis of the wooden chair structure for new considered loads is performed according to these standards.

In general, the design and the assessment of reliability of wood structural components in ultimate limit state means that each component has to satisfy the following condition,

$$S_d \leq R_d \tag{1}$$

where S_d represents the design value of the actions (internal forces, stresses, *etc*.) and R_d is corresponding design value of resistance (*i.e.*, load-carrying capacity) of the wooden structural component.

The design value of corresponding strength of wood material is defined by Eq. 2,

$$f_d = k_{\text{mod}} \frac{f_k}{\gamma_M} \tag{2}$$

where f_k is the characteristic value of strength, k_{mod} is modification factor taking into account the loading process and moisture, and γM is the partial factor for material property.

The strength analysis of the tested chair was conducted using the program ANSYS. In the software environment, the 3D volume model taking into consideration orthotropic properties of wood was created. The material used to make the chair was oak. The physical properties of oak for chair model (Fig. 1) load simulations, which are used in the computational finite element model, are given in Table 1.

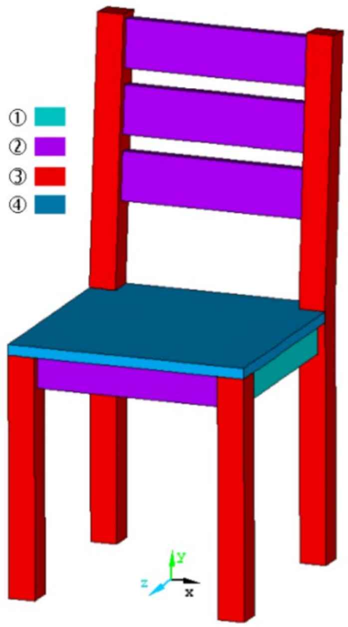


Fig. 1. Chair model

In terms of the direction of the oak fibers, the configuration of the individual chair components with respect to the global coordinate system of the computational model is different. The assignment of the axes (longitudinal, radial, tangential) of the local coordinate system of the individual components to the axes (x, y, z) of the global coordinate system of the computational model are given in Table 1. The strength properties of the chair made of oak material are shown in Table 2.

Table 1. Mechanical Properties of Oak (STN EN 338), (Wood Handbook, 2010) and their Assignment to Chair Components

Basic Mechanical Properties "Oak"			Mechanical Properties of Chair Components			
			①	②	③	④
Young's Modulus (GPa)	E_L =	13.0	E_z	E_x	E_y	E_x
	E_T =	0.99	E_y	E_y	E_x	E_z
	E_R =	2.19	E_x	E_z	E_z	E_y
Shear Modulus (GPa)	G_{LR} =	1.32	G_{zx}	G_{zx}	G_{yz}	G_{xy}
	G_{LT} =	0.78	G_{yz}	G_{xy}	G_{xy}	G_{zx}
	G_{RT} =	0.40	G_{xy}	G_{yz}	G_{zx}	G_{yz}
Poisson's Ratio (-)	μ_{LR} =	0.044	μ_{zx}	μ_{zx}	μ_{yz}	μ_{xy}
	μ_{LT} =	0.027	μ_{yz}	μ_{xy}	μ_{xy}	μ_{zx}
	μ_{RT} =	0.33	μ_{xy}	μ_{yz}	μ_{zx}	μ_{yz}
L - longitudinal, *T* - tangential, *R* - radial						

Table 2. Strength Properties of Chair Material – Oak (Source: Khestl and Mec 2013)

Load		Characteristic Value of Strength		Corresponding Design Value of Resistance	
Tensile	‖	$f_{t,0,k}$ =	108.0 MPa	$f_{t,0,d}$ =	41.54 MPa
	⊥	$f_{t,90,k}$ =	3.3 MPa	$f_{t,90,d}$ =	1.27 MPa
Compression	‖	$f_{c,0,k}$ =	42.0 MPa	$f_{c,0,d}$ =	16.15 MPa
	⊥	$f_{c,90,k}$ =	11.5 MPa	$f_{c,90,d}$ =	4.42 MPa

The characteristic values of the strength (Khestl and Mec 2013) and the design values of the chair material resistance (*i.e.*, oak) are given in Table 2 (for k_{mod} = 0.5).

The meaning of the strength values (oak) given in Table 2 is following: $f_{t,0}$ ($f_{c,0}$) - tensile (compressive) strength in the fiber longitudinal direction, $f_{t,90}$ ($f_{c,90}$) - tensile (compressive) strength in the fiber perpendicular direction.

To the strength verification of chair structure for the ultimate limit state, the computational model is created and corresponding simulations for considered loads are performed. When creating a computational simulation model, the wood inhomogeneity and mutual configuration of components, from which the chair is made, must be taken into account. The configuration of the chair structural components and assignment of orthotropic properties of oak are shown in Table 1.

The simulation computational model of the chair was created using the ANSYS code based on finite element method (Fig. 2b) is used.

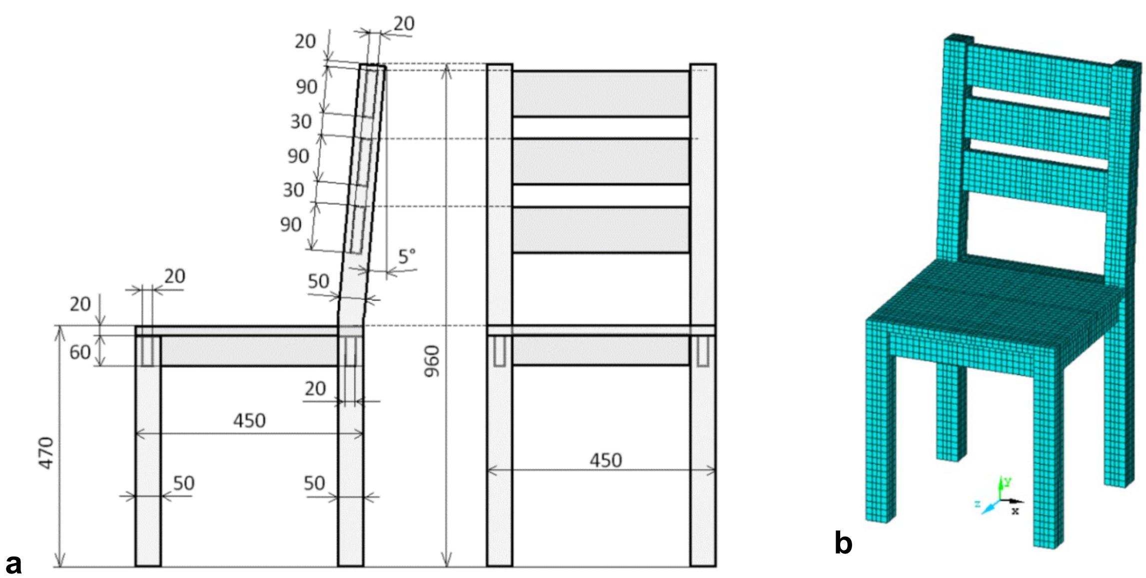
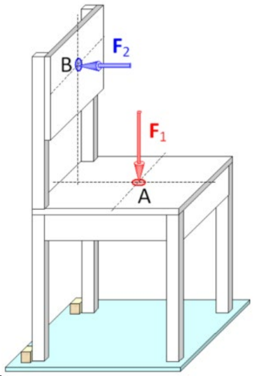
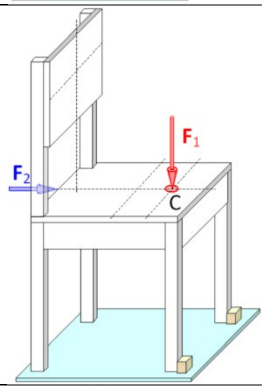
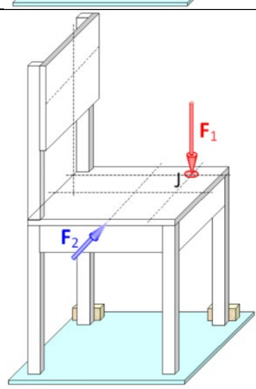
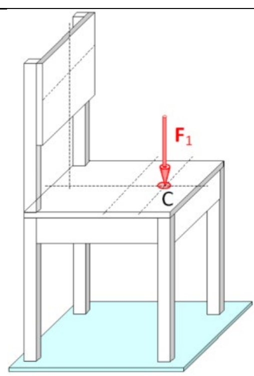


Fig. 2. Chair model (a - dimensions of chair; b - finite element model)

In accordance with standards STN EN 1335 (2020) and STN EN 1728 (2013), the chair loading cases are specified in Table 3, and for these load cases the computational simulations are performed. The stress and strain states that occur in the chair components as a result of the considered loads must fulfill the conditions given in Eq. 1.

Table 3. Specified Load Cases of Chair According to STN EN 1335 (2020) and STN EN 1728 (2013)

	**Loading case LC-01:** *Seat and back static load test* **Loading point A -** the vertical force F_1 is acting at the center point A of the seat. **Loading point B -** the force F_2 is acting perpendicularly at the point on the centreline of the back rest, 300 mm above loading point A. The stops of the back legs prevent movement.
	**Loading case LC-02:** *Leg forward static load test* **Loading point C -** the vertical force F_1 is acting at the center axis of the seat 100 mm from the structure of the front of seat edge on that line. The horizontal force F_2 acts forward in the direction of the axis of seat symmetry. The movement is prevented by stops against the front legs.
	**Loading case LC-03:** *Leg sideways static load test* **Loading point J -** the vertical force F_1 is acting at the position across the seat but not more than 150 mm from the unloaded seat edge and longitudinal position 100 mm from the front of seat edge is considered in this analysis. The horizontal force F_2 acts forward in the direction of the axis of seat symmetry. The movement is prevented by stops on the right-side legs.
	**Loading case LC-04:** *Seat static load* **Loading point C -** the vertical force F_1 is acting at the center axis of the seat at the position 100 mm from the front of seat edge.

In order to gather data on the body mass, national institutions were contacted and the public sources were analysed. The sample consisting of 71,816 male participants aged 18 to 70 was analysed to evaluate the development in the body mass of the Slovak population in the years 1993 to 2017. The sample was provided by the Public Health Authority of the Slovak Republic. The analysis was carried out in individual years over the studied period. The third degree polynomial was used to describe the trend in body mass.

RESULTS AND DISCUSSION

Secular Trend

The development of an average body weight of male population over the years 1993 to 2017 is presented in Fig. 3. There was an annual increase in body weight of 0.167 kg. From 1993 to 1997, there was a weight gain to the value 83 kg. Until the year 2005 it remained the same. After 2005, there was a fluctuation in the average male body weight. The lowest average value of body weight was measured in the year 1993; it was 80.5 kg. The highest average value of body weight was measured in the year 2015; it was 85.5 kg.

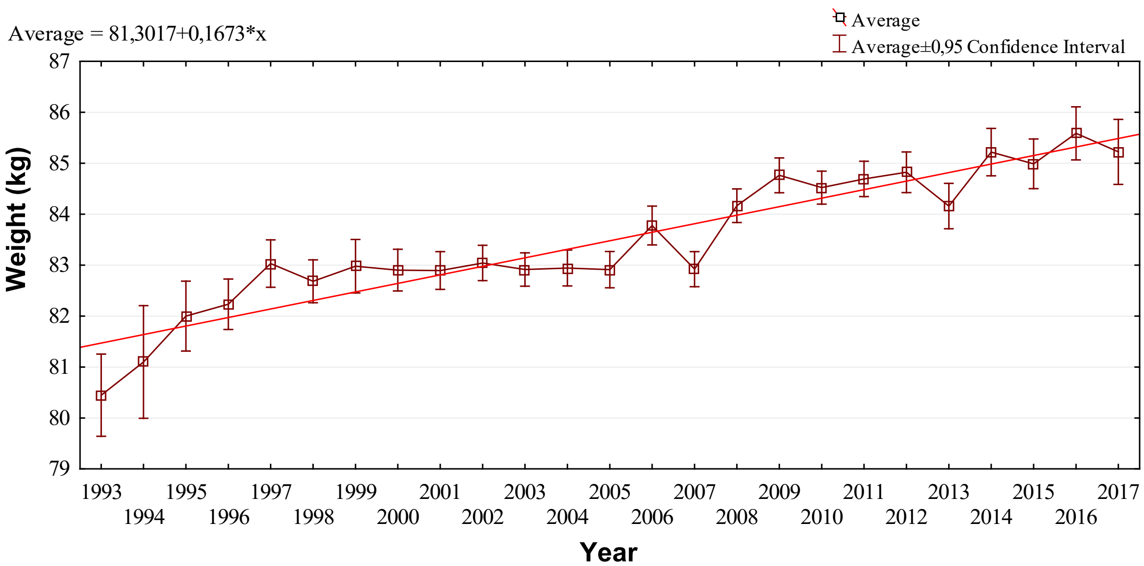
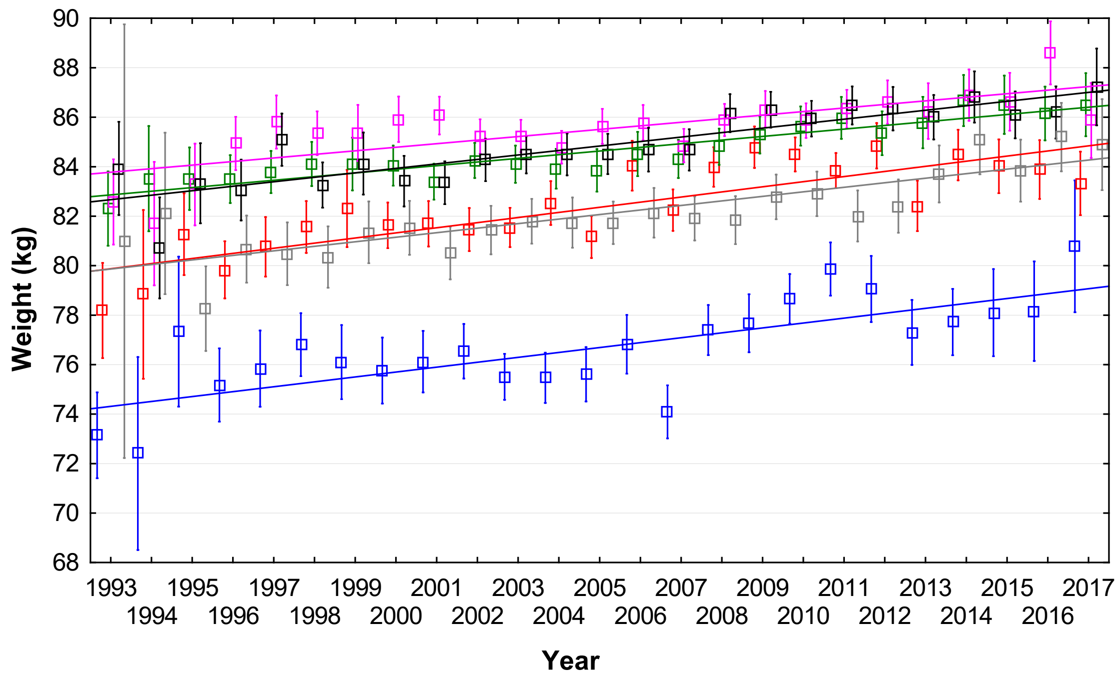


Fig. 3. Development of the body weight of male population in 1993 to 2017 (sampling unit of 1,079 men aged 18 to 25)

In terms of the age groups, the changes in body weight of male population in the years 1993 to 2017 are shown in Fig. 4. A significant difference was identified in the case of the youngest age group (18 to 25 years). The average values were much lower than in other groups. In this age group, an annual increase in body weight by 0.198 kg was observed. The most significant increase in the body of all investigated age groups was observed in the case of group 3 (26 to 35 years). There is an annual increase by 0.207 kg. Following the data of the Public Health Authority of the Slovak Republic and other available sources (Ministry of Health of the Slovak Republic 2017; Public Health Authority of the Slovak Republic 2020; Statistical Office of the Slovak Republic 2021), there were approximately 113,000 men with a body weight of more than 110 kg, where approximately 11% had a weight of more than 130 kg in Slovakia in the year 2017 (Fig. 5).



Age under 20, average = 74,1238+0,198*x
Age under 30, average = 79,6769+0,207*x
Age under 40, average = 82,7199+0,1477*x
Age under 50, average = 83,6393+0,1443*x
Age under 60, average = 82,496+0,1807*x
Age under 70, average = 79,6899+0,1834*x

Fig. 4. Development of the body weight of male population in the years 1993 to 2017 according to the age groups (sampling unit of 295,261 men aged 18+)

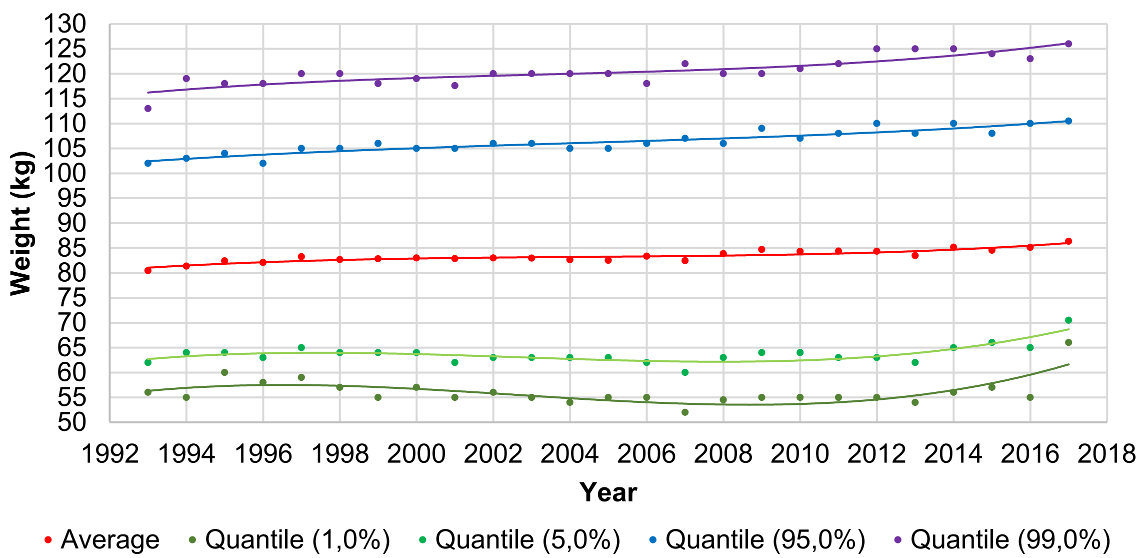


Fig. 5. Development of the average body weight and percentiles for men from 1993 to 2017 (Source: Hitka *et al.* 2018)

The situation in other European countries is very similar. Therefore, the weight of 110 kg mentioned in actual standards for testing the chairs (EN 12520 (2017) and EN 1728 (2013)) cannot be considered adequate. Following the analysis of the weight of the Slovak (partially also European) men, it is necessary to establish the standard for testing the chairs taking into account men with a weight of up to 150 kg.

Strength Analysis of the Wooden Chair

The numerical simulations on the chair model (Fig. 6) using the finite element method for the considered load cases (Table 3) were performed, and stress-strain states were determined. In accordance with global coordinate system, the results of mechanical stresses were obtained and then transformed into fiber directions for individual groups of chair components. The strength resistance of the chair for loading by user weights of 110 kg and 150 kg can be assessed.

The results of stress-strain states for the user's weight of 150 kg are presented in Figs. 6 through 13. To compare the results of mechanical stresses that arise in the chair components under the action of considered load cases (Table 3) for users with a weight of 150 kg and 110 kg, the results of mechanical stresses for a user with a weight of 110 kg are also given in Figs. 7, 9, 11, and 13, and they are displayed by bold numbers.

The computational simulations of the chair load exceeded the allowed strength values in some groups of chair components, as shown in Table 2. Exceeding the limit values of strength was also found for a user's weight of 110 kg. These critical stress states occurred mainly in the side rails of the chair, in the legs, and in the seating plate. When the chair is loaded with a user's weight of 150 kg, the mechanical stresses acquire values that differ more greatly from the limit values. Values of mechanical stresses that are outside the limit values are highlighted in bold numbers in the tables. Based on the results of the strength analyses, a chair load with a user's weight of 150 kg will require a change in the dimensions of the side rails and the cross-section of the legs.

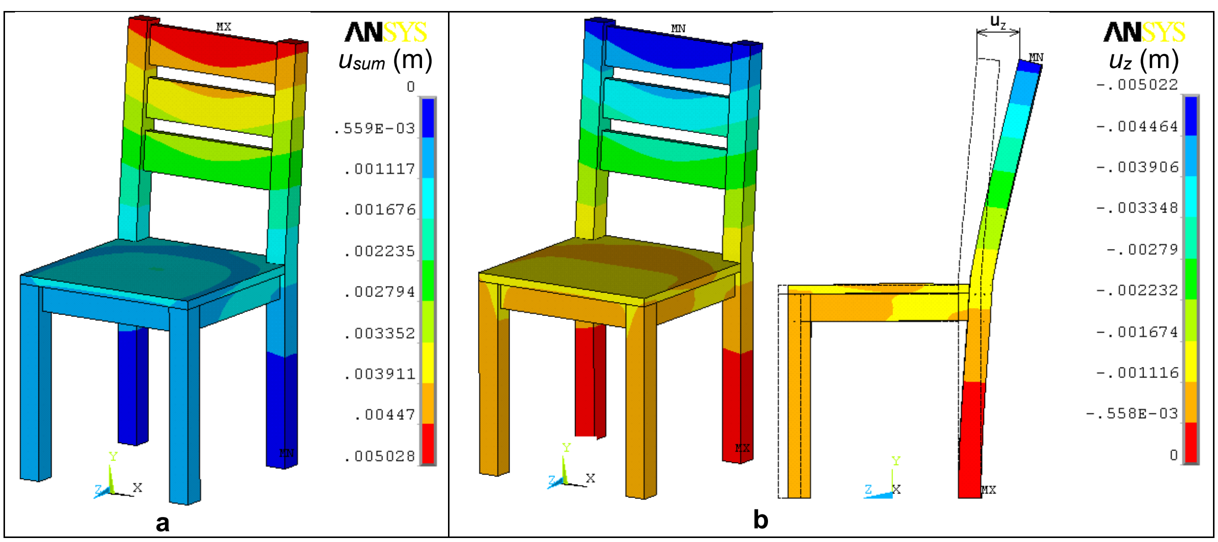
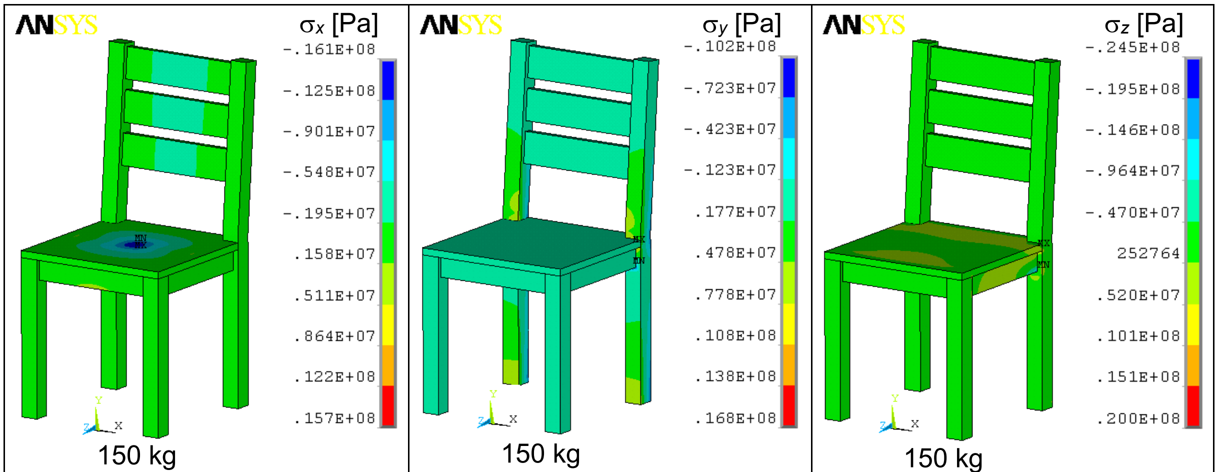


Fig. 6. Total chair deformation u_{sum} (a) and deformation u_z in z direction; (b) (user´s weight is 150 kg; loading case LC-01)



Tensile/Compressive Stresses in Relation to the Fiber Directions (MPa)											
User´s Weight		110 kg				150 kg				Limit stresses	
Direction of fibers		Group of components with the same fiber orientation				Group of components with the same fiber orientation					
		①	②	③	④	①	②	③	④		
Longitudinal	min	**-17.9**	-2.7	-8.1	-11.8	**-24.5**	-3.6	-11.1	-16.1	$f_{c,0,d}$ =	-16.2
	max	14.6	2.7	12.3	11.5	20.0	3.7	16.9	15.7	$f_{t,0,d}$ =	41.5
Tangential	min	-1.5	-0.6	-1.6	-2.1	-2.0	-0.8	-2.2	-2.9	$f_{c,90,d}$ =	-4.4
	max	0.9	0.4	**1.7**	**4.5**	1.2	0.5	**2.3**	**6.2**	$f_{t,90,d}$ =	1.3
Radial	min	-1.2	-0.4	**-4.6**	-3.8	-1.7	-0.6	**-6.2**	**-5.1**	$f_{c,90,d}$ =	-4.4
	max	0.5	0.3	**5.0**	**4.3**	0.7	0.4	**6.8**	**5.9**	$f_{t,90,d}$ =	1.3

Fig. 7. Tensile/compressive stresses in the chair components - loading case LC-01

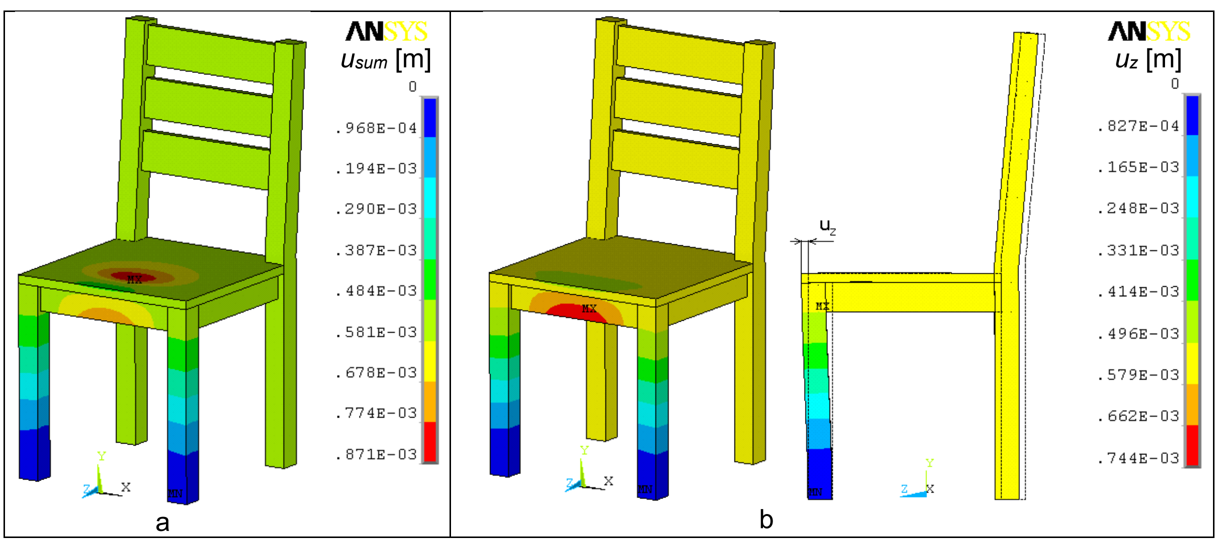
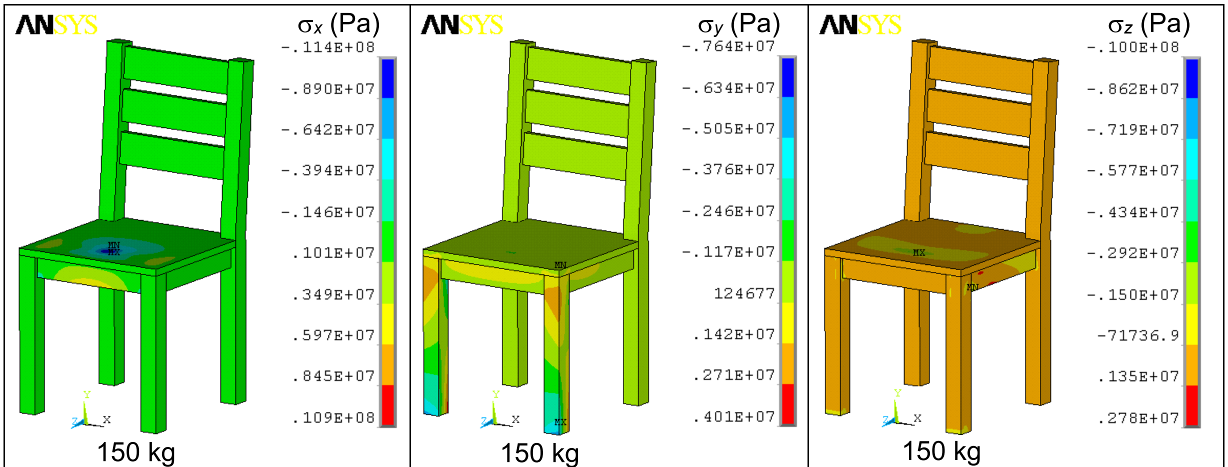


Fig. 8. Total chair deformation u_{sum} (a) and deformation u_z in z direction (b) (user´s weigth is 150 kg; loading case LC-02)



Tensile/Compressive Stresses in Relation to the Fiber Directions (MPa)											
User´s Weight		110 kg				150 kg				Limit stresses	
Direction of fibers		Group of components with the same fiber orientation				Group of components with the same fiber orientation					
		①	②	③	④	①	②	③	④		
Longitudinal	min	-7.3	-3.7	-5.6	-8.3	-10.0	-5.0	-7.6	-11.4	$f_{c,0,d}$ =	-16.2
	max	2.0	3.8	2.9	8.0	2.8	5.2	4.0	10.9	$f_{t,0,d}$ =	41.5
Tangential	min	**-5.6**	-1.2	-0.7	-2.2	**-7.6**	-1.7	-1.0	-3.0	$f_{c,90,d}$ =	-4.4
	max	**2.9**	0.5	0.9	**2.0**	**4.0**	0.8	1.2	**2.8**	$f_{t,90,d}$ =	1.3
Radial	min	**-8.4**	-0.8	-1.7	-1.5	**-11.4**	-1.1	-2.4	-2.1	$f_{c,90,d}$ =	-4.4
	max	**8.0**	0.2	0.7	0.8	**10.9**	0.3	1.0	1.1	$f_{t,90,d}$ =	1.3

Fig. 9. Tensile/compressive stresses in the chair components - loading case LC-02

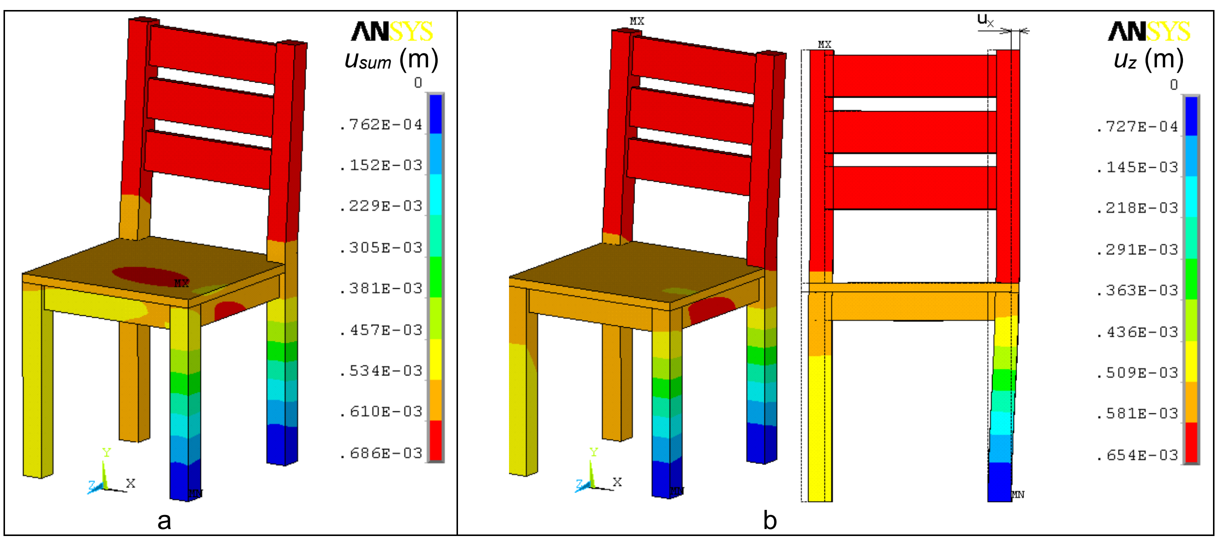
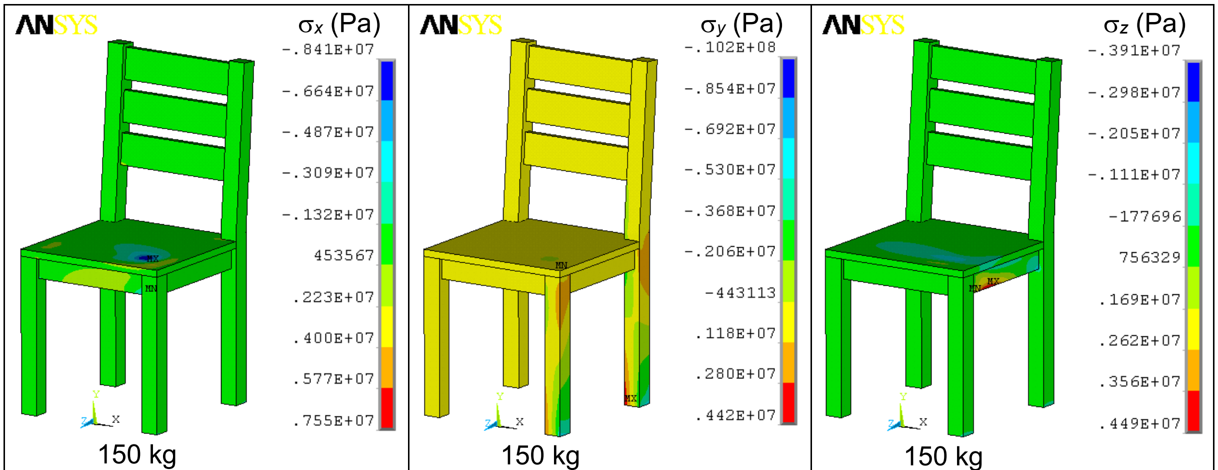


Fig. 10. Total chair deformation u_{sum} (a) and deformation u_z in z direction (b) (user´s weight is 150 kg; loading case LC-03)



Tensile/Compressive Stresses in Relation to the Fiber Directions (MPa)											
User´s Weight		110 kg				150 kg				Limit stresses	
Direction of fibers		Group of components with the same fiber orientation				Group of components with the same fiber orientation					
		①	②	③	④	①	②	③	④		
Longitudinal	min	-2.9	-6.1	-7.4	-6.0	-3.9	-8.4	-10.2	-8.2	$f_{c,0,d}$ =	-16.2
	max	3.3	1.6	3.2	5.5	4.5	2.3	4.4	7.6	$f_{t,0,d}$ =	41.5
Tangential	min	-2.0	-0.9	-1.6	-1.3	-2.8	-1.2	-2.2	-1.8	$f_{c,90,d}$ =	-4.4
	max	0.9	0.4	0.5	1.1	**1.3**	0.6	0.7	**1.5**	$f_{t,90,d}$ =	1.3
Radial	min	-1.0	-0.7	-1.4	-2.2	-1.4	-0.9	-2.0	-3.0	$f_{c,90,d}$ =	-4.4
	max	0.6	0.1	0.8	1.2	0.8	0.2	1.1	**1.6**	$f_{t,90,d}$ =	1.3

Fig. 11. Tensile/compressive stresses in the chair components - loading case LC-03

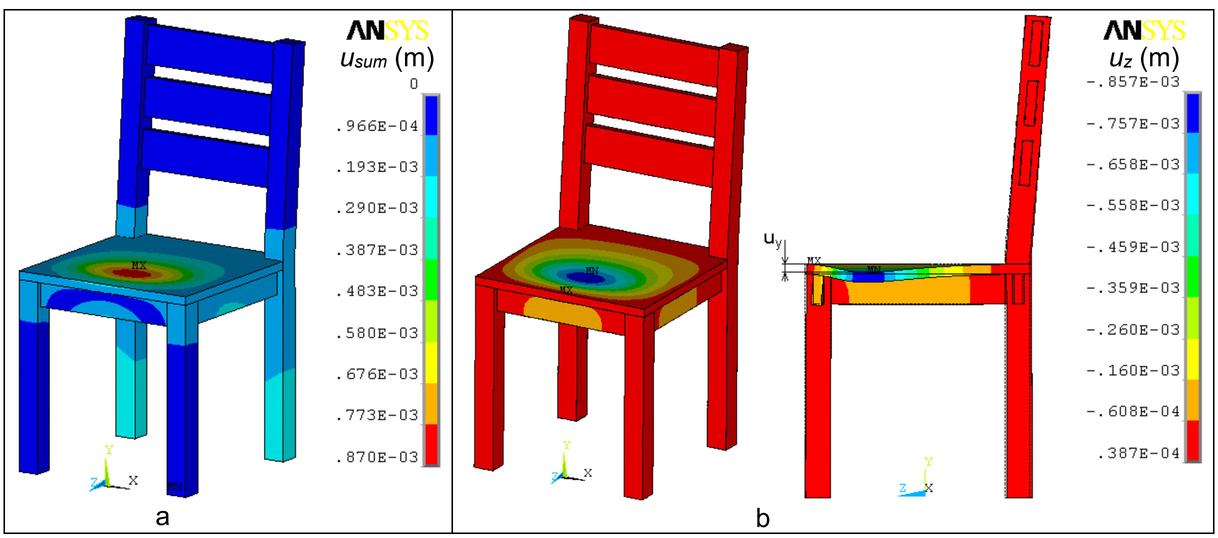
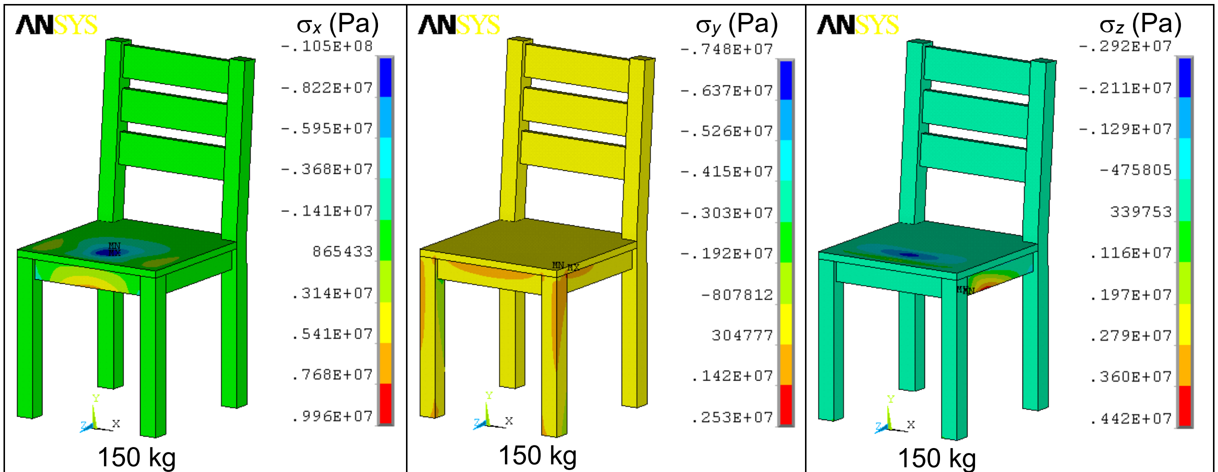


Fig. 12. Total chair deformation u_{sum} (a) and deformation u_z in z direction (b) (user´s weigth is 150 kg; loading case LC-04)



Tensile/Compressive Stresses in Relation to the Fiber Directions (MPa)											
User´s Weight		110 kg				150 kg				Limit stresses	
Direction of fibers		Group of components with the same fiber orientation				Group of components with the same fiber orientation					
		①	②	③	④	①	②	③	④		
Longitudinal	min	-2.1	-0.4	-5.5	-7.7	-2.9	-0.6	-7.5	-10.5	$f_{c,0,d}$ =	-16.2
	max	3.2	4.6	1.8	7.3	4.4	6.3	2.5	10.0	$f_{t,0,d}$ =	41.5
Tangential	min	-1.3	-1.4	-0.8	-1.7	-1.8	-2.0	-1.2	-2.3	$f_{c,90,d}$ =	-4.4
	max	1.0	0.6	1.2	**1.5**	**1.4**	0.8	**1.7**	**2.1**	$f_{t,90,d}$ =	1.3
Radial	min	-0.8	-0.9	-1.0	-1.4	-1.1	-1.3	-1.4	-1.9	$f_{c,90,d}$ =	-4.4
	max	0.5	0.2	1.2	1.0	0.7	0.3	**1.6**	**1.4**	$f_{t,90,d}$ =	1.3

Fig. 13. Tensile/compressive stresses in the chair components - loading case LC-04

When designing the parameters of furniture for workplaces, but also households, it is necessary to take into account the physical parameters of future human generations. The design of furniture of all types must correspond to the anthropometric dimensions and weight not only of the current population but also of the future one. Anthropometric and ergonomic needs are essential in many ways, especially in terms of shape, size, and quality of furniture and materials used. The importance of anthropometric parameters when designing especially dimensions of chairs has been confirmed by an analysis of the anthropometric data of an adult population in seven countries (Ran *et al.* 2017). Chair design should include actual trends in development of an adult population, and a secular trend and should be applied in manufacturing. Kureli *et al.* (2020) evaluated the strength of designed chairs in comparison with industrially manufactured chairs. The result was that the designed chairs were better adapted to the higher load.

The existence of a secular trend as a global phenomenon is confirmed by the results of the research studies conducted abroad. The results of an anthropometric research carried out in the Czech Republic by Kovařík (2009) show that there has been a significant increase in body dimensions (especially body weight and height) in the Czech population, similarly to the Slovak one. There is an interesting finding mentioned by Kovařík (2009) that there is no correlation between an increase in weight and height. Weight gain of the Czech population is faster than an increase in height, especially in the case of men. Social status and education are some of the important factors affecting an increase in population, due to lifestyle differences such as living standard, better-quality nutrition, and sports activities.

In general, strength analysis of wooden chairs in the case of different types of loading has not been mentioned in the literature very often. Similar research was conducted with rattan chairs, but only the effect of the way of rattan weaving on the load-carrying capacity was investigated (Gu *et al.* 2016).

Kuskun *et al.* (2018) verified the strength elements of chairs manufactured from beech (*Fagus sylvatica*). The chairs constructed with any size of tenons could meet the light-duty service (domestic usage), except for the chairs constructed with 30 by 30 mm tenons. The chairs constructed with 50 by 50 mm tenons could meet the heavy-duty service, whereas the chairs constructed with 30 by 50 mm tenons could meet the medium-duty service.

A strength analysis of wooden chair frame was carried out by the authors of the study (Hajdarevic and Busuladzic 2015). The results indicated that the chair side frame becomes stiffer as the position of the stretcher is lowered and/or the stretcher cross section is increased. The results revealed that stiffness of joints in a frame had a considerable impact on the structure deflection. A satisfactory agreement was found between the numerical results and the results obtained by direct stiffness method. Other critical parts in chair frame emerge in the analysis with increased weight loading.

Chairs are designed for the current adult population weighing 110 kg as the load-carrying capacity. Following the analyses of the selected anthropometric parameters, it was determined that the load-carrying capacity of chairs must be designed for users weighing over 150 kg. Following the weight analysis of men in Slovakia and other European countries and in addition to improving the existing standards aimed at testing chairs, it is necessary to develop new standards for people weighing over 150 kg. Furniture of all types must be designed with respect to anthropometric proportions, especially weight and height, and not only for the current population, but also for the future population. It is suitable to produce chairs for the normal population (normal weight being up to 110 kg) and higher weight population (higher weight being up to 150 kg) (Hitka *et al.* 2018).

However, well-designed ergonomic parameters of chairs do not imply a positive sense of comfort for users (Maradei-Garcia *et al.* 2017). The sampling unit of women aged 20 to 45 with BMI 20 to 30 kg/m^2 participated in the survey. The sense of comfort or discomfort cannot be unequivocally defined, although there are parameters that can be measured (de Looze *et al.* 2003).

Modification of wooden chair designs considering the weight of the users will ask for further research on the effect of the sitting posture on the health, sense of comfort, durability, and safety as well as on the effect of various construction methods and materials.

Cleaner production is a concept that means practical application of a sustainable development strategy. Therefore, individual stages of a cleaner production can be defined as an effort to reduce waste and carbon footprint. It is a continual and systematic application of an environmental pollution-control strategy focused on processes, products, and services. The aim of it is to increase effectiveness and to reduce the risks for a human and subsequently for the environment.

The secular trend causing with an increase of structural loading of chair elements is an important reason to design wooden chairs with consideration of the directional structure of wood. This can support cleaner production by decreasing material usage.

CONCLUSIONS

1. The average values of body weight were much lower than in other groups. In this age group, an annual increase in body weight by 0.198 kg was observed. The most significant increase in the body of all investigated age groups was observed in the case of group 3 (26 to 35 years). There is an annual increase by 0.207 kg.
2. Based on the obtained results, the permitted strength values were exceeded for some groups of chair components. Exceeding the strength limits was found for a user weight of 110 kg. These critical stress states occurred mainly in the side rails of the chair, in the legs, and the seat plate. If the chair is loaded with the user's weight of 150 kg, the mechanical stress acquires values that differ significantly from the limit values. Following the analyses, the need to design the structural chair element for a weight of 150 kg (130 kg plus 15%) can be seen. It is suggested to establish the standard taking into account people with the weight of up to 150 kg.
3. Based on the results of the strength analyses, a chair load with a user's weight of 150 kg will require a change in the dimensions of the side rails and the cross-section of the legs.
4. The aim of the production is to increase the effectiveness and to eliminate the risk for humans and the environment. The secular trend causing with an increase of structural loading of chair elements is an important reason to design wooden chairs with consideration of the directional structure of wood. This can support cleaner production by decreasing material usage. Individual stages of a cleaner production can be defined as an effort to reduce waste and carbon footprint.

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